DE GRUYTER

Peet van Biljon

INNOVATION FOR VALUE AND MISSION

AN INTRODUCTION TO INNOVATION MANAGEMENT AND POLICY

Foreword by
Vice Admiral US Navy (Ret) David A Dunaway

BUSINESS & ECONOMICS

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Advance Praise for *Innovation for Value and Mission: An Introduction to Innovation Management and Policy*

Innovation is essential for organizations to create sustainable success and requires the integration of many different talents and capabilities across the enterprise. This book provides a rich overview of the total landscape all innovators must address, presenting the most important tools and how they connect. It discusses the underlying principles for each, so you can determine how to implement them in your organization, and includes excellent references for additional learning. *Innovation for Value and Mission* is an excellent resource for both teachers and practitioners of innovation and would have made my own leadership in innovation much easier!

–Wayne Delker, Chief Innovation Officer (ret.), The Clorox Company

With all the environmental and social challenges facing us, we literally need innovation to save the world. To do that, we need more practitioners and policymakers who don't only know how to innovate, but also understand innovation in its wider economic and social context. *Innovation for Value and Mission* uniquely connects the world of private-sector innovation with the world of innovation policymaking. It's a rigorous but accessible introduction to innovation for university students. And it’s also a great reference that all innovation practitioners and policymakers should have on their bookshelves.

–Magnus Penker, *Wall Street Journal* & *USA Today* bestselling author; innovation and green-transformation thought leader; CEO, Innovation360

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This book is dedicated to all current and future innovators who want to use innovation to make the world a better place for everyone.

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Preface and Acknowledgments

The purpose of this book is to help you on your innovation journey, whether you are just starting out or taking it to the next stage. It is primarily aimed at postgraduate students who need an accessible, but sufficiently rigorous, introduction to the discipline of innovation within its larger economic, technological, and public-policy context. The book should also find a place on the desks of innovation practitioners who already have deep experience in some areas of the innovation discipline, but would like to expand their horizons to learn about other areas. It is intended as a reference on most innovation topics, presenting prominent methods and frameworks, while citing major sources to further consult on those topics. (I also wrote it with the intention of using it as a handy reference for my personal use!)

Most works on the management and practice of innovation do not cover innovation policy, nor its wider economic context. Most works on innovation policy do not cover how entrepreneurs actually create and innovate, or how innovation is managed at the organization level. I believe that those who desire to make innovation policy need to understand how firms innovate, and that private-sector innovators should be more aware of the potential of their innovations to solve big economic and societal challenges. System-wide transformations, such as we need for sustainability, can hardly be brought about by a single firm. I therefore wrote this book to bridge the gap between the worlds of policy and practice. And at the topic level, the goal is to reveal the interconnections between multiple topic areas, just like any innovation itself is an interconnection of many elements.

Three important threads are pursued and come up repeatedly. These are value, mission, and uncertainty. Innovation should always have a purpose, which is to create *value* – for customers, the organization, and society at large – and, for the public sector, to fulfill a *mission*. However, what makes innovation especially challenging is that it is done under a high degree of *uncertainty*, which necessitates different managing methods and financing models than any other endeavor.

The book starts at a high level with an introduction to innovation, how technological progress works, and how innovation drives economic growth, which together form an essential foundation for the discussion of innovation policy in the latter part of the book. In the middle, the discussion dives deeper into how innovation is conducted in organizations and teams, and how it is managed at different levels. Special attention is given to open innovation, business model innovation, and Lean Startup techniques. Where applicable, references are made to innovation within the context of public-sector organizations.

The private financing of innovation, with a focus on venture capital, is introduced, followed by a discussion of the public financing of innovation. At this point, the discussion ascends again to a higher level, with an introduction to innovation at the national level. The book concludes with an introduction to innovation policy

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tools, a description of major policy inflections over the years, and recent appeals for major directional changes to innovation policy.

No chapter is the last word on any innovation topic. For each topic, I have attempted to provide an entry point to innovation at the firm level and the national level respectfully, as well as to help start or accelerate the reader's innovation journey. For this purpose, the reader is introduced to the relevant terminology, models, and frameworks on innovation management and policy. Once you know what something is called, and where it fits in, it is fairly easy to do further research on your own.

In my experience there is a big divide between the academic treatment of innovation and the popular business writings on innovation. In this work, I have attempted to make the academic writings on innovation – particularly on technology, economic growth, and national innovation and policy – more accessible to practitioners, while at the same time explaining the practice and management of innovation in fairly rigorous terms to students. I have been mindful of the risk that straddling these two worlds might make this book too academic for practitioners and perhaps not academic enough for professors, but this is a risk that I was willing to take for the greater benefit of connecting these two worlds.

The book focuses mostly on the United States, for two main reasons: First, it is necessary to focus and limit the scope. In covering such a breadth of topics, it is not feasible to provide international comparisons as well though several other countries have admirable innovation policies that the United States might learn from. Second is the sheer magnitude of U.S. investment in R&D and innovation over the post-World War II decades, which has been highly consequential and contributed most of the critical technologies that are powering our current era of industrial development.

While I provided brief examples where relevant, I have avoided so-called best-practices cases, even though I am well aware of their popularity. The promise of following others' practices is that we will also enjoy their performance, but that is seldom true. Case studies of how actual companies or agencies perform innovation are highly perishable, as organizations constantly change how they do things and previously successful organizations stumble, invalidating much-vaunted cases.[i] There is also the *halo effect*, a cognitive bias which makes us want to copy everything an admirable organization does, even though those practices may have had nothing to do with its success. Therefore, students and practitioners interested in the latest and greatest examples of how successful organizations perform some aspects of innovation are better off sourcing such cases themselves. (This is best done as and when needed – at least the cases will be fresh then.) The business media is a

i An excellent analysis by McKinsey, "What happened to the world's 'greatest' companies?" (Bradley 2017), of how companies profiled in three best-selling business books fared over the longer run proves this point.

never-ending source of such content, as well as business subscription services specializing in how-to innovation resources and templates.

It is my conviction that the best solution for any given organization and situation is always devised by considering the full context of that organization, its problems and goals, and then applying the innovation principles and best available expertise to the particular innovation challenge to come up with a tailored solution. I have accordingly set out to equip readers by introducing concepts and terms, providing frameworks, and including references on each innovation topic covered. Citations are used throughout the text. None of these is the last word on any of these subjects but should be seen as an entry point instead. Therefore, each chapter provides a pathway for those who want to dive deeper, by listing important references and data sources as applicable. Ample cross-references between chapters are provided, as many topics are interlinked.

The reader does not need to read the book from start to finish but should feel free to move around between subjects. Indeed, one of the hardest parts of writing this book was to determine the order in which to introduce subjects and concepts. With innovation, so many elements are interrelated that it is a great challenge to present them in a linear order. For the most part, each chapter is written as an essay that can mostly stand on its own. An overview of book chapters provided below will help the reader navigate the book.

All the processes, techniques, and frameworks presented here are suitable for direct application to sustainability-oriented innovations, which goals are identified in terms of environmental value, or the completion of a particular sustainability mission. It is indeed important that we channel our innovation abilities to meet the major sustainability challenges of our time. This book was initially going to have one chapter dedicated to sustainability-oriented innovation, but it soon became three, and kept on growing. Eventually, the publisher and I agreed that given the importance and scope of the topic, sustainability-oriented innovation was best kept aside for a later work that could be fully dedicated to it. I am doing ongoing research and advisory work in this new but fast-expanding field, and will have more to contribute on the sustainability challenge when the time is right.

In closing, I firmly believe that one can only ever be a student of innovation, and never a master of this discipline that is too complex and everchanging to ever comprehend fully. We all need to stay curious and keep learning. I am happy to help others on their journey of learning and discovery, even as I continue my own. Teaching innovation at the McCourt School of Public Policy at Georgetown University for the last few years has been a great experience. I would like to thank all my graduate students for the enriching conversations we have had in class, and everything I have learned from them about public-sector innovation all over the world.

I owe much to my fellow innovation travelers and would like to acknowledge all of them here. In particular, I would like to thank my former colleagues at McKinsey for the many learning experiences while serving clients on innovation challenges and growing the innovation practice there. In particular, I would like to extend my appreciation to Marc de Jong, my mentor in the practice. I learned much about public-sector innovation from Billy Mae and benefited from his experience of how government bureaucracies operate. I would also like to acknowledge a few of my current fellow practitioners: Navin Kunde for sharing his extensive experience with open innovation; Magnus Penker for his inspiring ideas on the transformative power of innovation; George Hemingway for his thoughts on innovation management and strategy; and Geoff Orazem for his insight on the difference in risk tolerance between the private and public sectors. Last, but not least, I am indebted to Mårten Leijon for taking the time to read draft chapters and providing very thoughtful feedback. Of course, any errors of omission or commission in the book are mine alone.

Dear reader, I wish you well on your innovation journey and hope this book will help you see the world in a new way. Bon voyage!

Foreword

I am blessed to have served our great country for 34 years as a naval aviator and to have retired at the rank of Vice Admiral. After graduating from the Naval Academy, I served as an operational strike fighter pilot, a test pilot, a program manager, an engineer, and I commanded four different organizations. My ultimate assignment was as the commander of the Naval Air Systems Command (NAVAIR) where we designed, developed, verified, validated and sustained all things Naval Aviation. While it may sound strange that NAVAIR's $40b annual budget is inadequate to buy all of the capability necessary to protect our national interests, it is true. The key to past and continued success of the US Navy is how well we innovate within the confines of constrained resources and ever-changing threats. I was told by many of my mentors that my success in the Navy was founded in my ability to innovate.

Sadly, the bureaucratic inertia within the U.S. Government and DOD impedes the pace of innovation. When I retired, it was clear that commercial technology development and innovation was outpacing DOD technology development and innovation in many areas. I have dedicated my post-Navy career to finding commercial or hybrid commercial/defense technologies that can be rapidly inserted into the DOD system to speed up the assimilation of state-of-the-art technology. Using commercially developed technology as a fuel to reinvigorate DOD innovation is a clear priority for DOD, as is helping commercial companies navigate the bureaucracy, which by itself requires some innovation. I currently sit on multiple boards and am involved on the ground level or as a co-founder of multiple startups focused on technology and innovation.

In my quest since 2015 to insert innovation into DOD I have run across many incredibly accomplished entrepreneurs and innovators. One of them asked me if I'd be interested in reading a new book on innovation and providing the author feedback on his efforts. Thus my introduction to Peet van Biljon and his book, *Innovation for Value and Mission*. Having read literally hundreds of titles over my life as an executive, I have become quite skeptical of the regurgitated processes, procedures, buzz words, techniques and gimmicks of many improvement books. I was quite pleasantly surprised when I read through Peet's work and found that he was not prescribing a cookbook approach to innovation. On the contrary, he systematically and articulately describes the history of innovation, its successes, failures, implementation techniques, public policy implications, private business implementation and management techniques. Instead of being prescriptive, he describes the toolset along with the pros and cons of those tools so the innovator has a clearer perspective.

My perspective on innovation has evolved over the years and is founded in decades of success and failures. While there are fundamental tenets to successful innovation, every single case is unique and there is never a checklist for innovation. If painting by the numbers created masterpieces, we could all be world-renowned

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artists. In my experience, the fundamentals of innovation require the following characteristics:

- Innovation must elate the customer and create mission success with a viable business strategy and technical competence. The three-legged stool of mission, business, and technology must balance.
- Customers rarely have a vision of innovation but know it when they get there. To that end, closing the loop, failing rapidly, iterating quickly and having the end user closely connected to the process is essential to success.
- For every innovator, there are 10 status-quo advocates who resist the change. Innovators have to be perseverant and managers of innovators need to walk the line between disciplined process and unstructured iteration, while protecting innovators. Unconstrained, innovators can diverge. Too much discipline, and they fail to succeed.
- Bureaucracy is the opposite of innovation. Leaders must create enclaves and protect innovation within bureaucracy.

As I read through Peet's book, I realized he was providing a map to success. His vision resonates precisely with my vision and, in fact, advanced my thinking significantly. His innovation is creating a map and guide for anyone with the curiosity and drive to innovate. From a parent looking to make diaper changing easier to a startup tech CEO in Silicon Valley trying to change the world, this book provides a frame of reference that can be uniquely applied to any situation. In a world where 9 out of 10 individuals hate change, the status quo is viewed as the easiest way, bureaucracies resist change and unconscious bias thwarts good ideas, the innovator needs all the tools and information he or she can find. *Innovation for Mission and Value* is a fantastic reference for those who can always see a better way. Thank you, Peet.

David A. Dunaway
VADM (ret.), USN

Overview of the Book Chapters

Chapter 1 introduces the discipline of innovation and traces its development over recent decades. The special nature of innovation at the intersection of other disciplines is explained. Introductory comments are made on the broader context of innovation with its contribution to economic growth and public welfare, and the respective roles played by the public and private sectors.

Chapters 2 and 3 provide the societal and national context of technological and economic progress, by introducing key innovation and economic concepts. These form a foundation for understanding the objectives and major choices of innovation policy that will follow later in the book:

- Chapter 2 explains the process of technological innovation and how diffusion leads to productivity growth. Key economic concepts needed to understand the linkages between technological innovation, productivity, and economic growth are introduced. The idea of long technological cycles is discussed, with specific reference to industrial revolutions.
- Chapter 3 introduces economic growth theory and explains the main theories that link innovation to economic growth. It aims to provide an understanding of how different schools of thought on economic growth have developed and how each school informs innovation policy choices.

Chapters 4 through 6 explain how innovation is conducted within and beyond organizational borders, along with the typical challenges that need to be met. Specific attention is given to three major extensions of the innovation discipline: open innovation, business model innovation, and the Lean Startup:

- Chapter 4 explains how human creativity works, where insights come from, and how people can best organize to be productive at innovation. Some popular innovation and creativity techniques, as well as the design-thinking approach, are introduced. Common organizational challenges to innovation are discussed, including the constant tension between efficiency and innovation.
- Chapter 5 covers open innovation, in recognition of the reality that no modern organization can effectively innovate entirely within its own boundaries. Different models for open innovation and design considerations are reviewed, as well as open innovation in government.
- Chapter 6 introduces two innovation game changers from the last two decades: business model innovation and its public-sector version, mission-model innovation; as well as the Lean Startup method for innovating under conditions of high uncertainty.

Chapters 7 and 8 are dedicated to the management of innovation, and how it is managed and steered at various levels within an organization. Some important areas of

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innovation management are selected for more in-depth discussion and an explanation of relevant complexities and tradeoffs:

- Chapter 7 offers brief perspectives on key areas of innovation management such as strategic fit, governance, stages, metrics, and the Innovation Management System. The *Innovation Management Map*, which shows how the different layers of innovation management and strategy fit together, is introduced. Particular challenges of managing innovation in government are discussed.
- Chapter 8 continues the discussion of innovation management with an introduction to innovation portfolio management, project selection, and innovation project management. The popular Stage-Gate® model and the major U.S. Department of Defense acquisition phases are introduced.

Chapters 9 and 10 review the roles of the private and public sectors in financing technological progress and innovation and how government agencies and private financiers such as venture capitalists play various roles in funding startups at different stages:

- Chapter 9 begins by explaining the path of scientific progress and how waste and uncertainty are constant companions of the innovation process. The main startup financing stages and the roles played by venture capitalists and other private financiers are explained.
- Chapter 10 explains the linear and alternate models of innovation relevant to the public support of innovation. It contains a brief history of U.S. public support for R&D and innovation in the decades after World War II and outlines current U.S. government investment in R&D, as well as support programs for small business and startup innovation.

Chapters 11 and 12 introduce innovation policy at the national level, starting with the roles played by the main private, public, and academic actors, and culminating with an overview of the public-policy toolkit and the current debates around innovation policy:

- Chapter 11 explains the National Innovation System and related concepts such as the Triple Helix Model, which illustrate the mutually reinforcing roles of the public sector, the private sector, and academia in innovation.
- Chapter 12 introduces major innovation policy tools and instruments, and explains the rationales for government support of technological innovation at particular stages. Recent appeals for more robust innovation policies and calls for mission-oriented policies are reviewed.

Using the Book in a Course

The whole book is intended to support a full two-semester course on *Innovation & Public Policy* with about two weeks spent on the average chapter and the remaining weeks used for group projects, seminars, paper presentations, and so on. When used for a single 14-week semester course, the scope needs to be limited to selections from each, or most, of the 12 chapters with the remaining weeks used as above.

Alternatively, selected chapters (see below) can support semester or block courses more limited in scope, such as *Innovation Management*, *Innovation Policy*, and *Innovation for Industry 4.0*:

Chapter	Innovation Management	Innovation Policy	Innovation for Industry 4.0	Innovation & Public Policy
1. Chapter 1 An Introduction to Innovation	✓	✓	✓	✓
2. Chapter 2 Technological Progress and Industrial Revolutions		✓	✓	✓
3. Chapter 3 Economic Growth and Innovation		✓		✓
0. Chapter 4 People, Creativity, and Organization	✓		✓	✓
5. Chapter 5 Open Innovation and External Collaboration	✓		✓	✓
6. Chapter 6 Game Changers: Business Model Innovation and the Lean Startup	✓		✓	✓
7. Chapter 7 Perspectives on Innovation Management	✓		✓	✓
8. Chapter 8 Portfolio and Project Management	✓			✓
9. Chapter 9 Private Financing of Innovation	✓	✓		✓

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(continued)

Chapter	Innovation Management	Innovation Policy	Innovation for Industry 4.0	Innovation & Public Policy
10. Chapter 10 Public Financing of R&D and Innovation		✓		✓
11. Chapter 11 National Innovation		✓		✓
12. Chapter 12 Innovation Policy Tools and Challenges		✓		✓

Each chapter is concluded by a *Chapter Summary*, *Suggested Exercises and Assignments* (individual and class), and *Recommended for Further Reading* (a short list of important publications for those who want to know more). Where applicable, chapters also contain references to *Recommended Data Sources*.

Further suggestions for course outlines, my current course syllabus, lecture slides, notes, videoclips, and other up-to-date resources can be found on my website: ethicsdriveninnovation.com

Abbreviations and Acronyms

4G	fourth generation broadband mobile
4IR	Fourth Industrial Revolution
5G	fifth generation broadband mobile
ABS	automatic braking system
ACD&P	Advanced Component Development and Prototypes
AI	artificial intelligence
AMA	American Marketing Organization
AMP	Advanced Manufacturing Partnership
ARPA	Advanced Research Project Agency
ARPANET	Advanced Research Projects Agency Network
ATD	Advanced Technology Development
B2B	business-to-business
B2C	business-to-consumer
BAC	budget at completion
BDA	Bayh-Dole Act
BERD	business expenditure on R&D
BM	business model
BMI	business model innovation
BOK	body of knowledge
BU	business unit
CAPM	Capital Asset Pricing Model
CDR	Critical Design Review
CMS	Centers for Medicare & Medicaid Services
CEN	European Committee for Standardization
CEO	chief executive officer
CPG	consumer packaged goods
CPM	critical path method
CRM	customer relationship management
CVC	corporate venture capital
DARPA	Defense Advanced Research Projects Agency
DART	dialogue, access, risk assessment and transparency
DMV	Department of Motor Vehicles
DNA	deoxyribonucleic acid
DOD	Department of Defense
DOE	Department of Energy
DOJ	Department of Justice
DPM	Dynamic Progress Method
DSIP	distribution-sensitive innovation policy
EC	European Commission
EEG	electroencephalography
EFI	equitable growth, finance, and institutions
ES	early finish
ESG	Environmental, Social, and Governance
EU	European Union
EU27	current 27 member countries of the EU
EV	electric vehicle
FFRDC	Federally Funded Research and Development Centers

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FPSP	Flagship Project Support Program
FRED	Federal Reserve Economic Data
FTE	full-time equivalent
FY	financial year
GAO	Government Accountability Office
GDP	gross domestic product
GERD	gross domestic expenditure on R&D
GHG	greenhouse gas
GNI	gross national income
GPS	Global Positioning System
GPT	general-purpose technologies
GS	General Schedule
GSA	General Services Administration
GUI	graphical user interface
H1	Horizon 1 (i.e., the first growth horizon)
H2	Horizon 2 (i.e., the second growth horizon)
H3	Horizon 3 (i.e., the third growth horizon)
HC	healthcare
HHS	Health and Human Services
HR	human resources
HSARPA	Homeland Security Advanced Research Projects Agency
IACS	Institute for Applied Cancer Science
IARPA	Intelligence Advanced Research Projects Agency
ICT	internet, computer, and telecommunications
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMF	International Monetary Fund
IMS	innovation management system
IP	intellectual property
IPM	innovation portfolio management
IPO	initial public offering
IPPM	innovation project portfolio management
IRR	internal rate of return
ISO	International Organization for Standardization
IT	information technology
ITIF	Information Technology & Innovation Foundation
JCESR	Joint Center for Energy Storage Research
JIT	just in time
JTBD	jobs to be done
JV	joint venture
KPI	key performance indicator
LF	late finish
LS	late start
MEP	Manufacturing Extension Partnership
MFP	multifactor productivity
MIT	Massachusetts Institute of Technology
MITI	Ministry of International Trade and Industry (Japan)
MOU	Memorandum of Understanding
MRI	magnetic resonance imaging

MS	Microsoft
MVP	Minimum Viable Product
NA	not applicable
NASA	National Aeronautics and Space Administration
NBER	National Bureau of Economic Research
NGO	nongovernmental organization
NGT	New Growth Theory
NIH	National Institutes of Health
NIS	National Innovation System
NNMI	National Network for Manufacturing Innovation
NPD	new product development
NPDP	New Product Development Professional
NPM	New Public Management
NPO	Nonprofit Organization
NPV	net present value
NSF	National Science Foundation
NSI	National System of Innovation
NVCA	National Venture Capital Association
ODI	outcome-driven innovation
OEC	Observatory of Economic Complexity
OECD	Organisation for Economic Cooperation and Development
OGD	open government data
OI	open innovation
OMB	Office of Management and Budget
OPSI	Observatory of Public Sector Innovation
OSRD	Office of Scientific Research and Development
OSTP	Office of Science and Technology Policy
PARC	Palo Alto Research Center (Xerox)
PC	personal computer
PDK	process design kit
PDMA	Product Development and Management Association
PE	private equity
PERT	Program Evaluation and Review Technique
PMBOK	Project Management Body of Knowledge
PMI	Project Management Institute
PMP	Project Management Professional
PPE	personal protective equipment
PPM	project portfolio management
PSI	public-sector innovation
PV	planned value
QFD	Quality Function Deployment
R&D	research and development
RBC	real business cycle
RCT	randomized-control trial
RFP	request for proposal
ROA	return on assets
ROI	return on investment
RP	Research Policy (journal)
SBIR	Small Business Innovation Research

SBM	sustainable business models
SCAMPER	substitute, combine, adapt, modify, put to another use, eliminate and reverse
SDG	Sustainable Development Goals (UN)
SDR	System Design Review
SOP	standard operating procedure
SOW	statement of work
SPAC	Special Purpose Acquisition Vehicle
SPIS	Science Policy and Innovation Studies
SRR	System Requirements Review
STEM	science, technology, engineering, and mathematics
STI	science, technology, and innovation
STIP	science, technology, and innovation policy
STTR	Small Business Technology Transfer
SUV	sports utility vehicle
SWF	sovereign wealth fund
TFP	total factor productivity
THA	Triple Helix Association
TIP	technology and innovation policy
TMT	technology, media, and telecom
TPS	Toyota Production System
UK	United Kingdom
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UNIDO	United Nations Industrial Development Organization
US	United Sates
USDA	United States Department of Agriculture
USPTO	United States Patent and Trademark Office
UTT	University Technology Transfer
VC	venture capitalist
VOC	Voice of the Customer
VP	vice president
WBS	work breakdown structure
WEF	World Economic Forum
WIPO	World Intellectual Property Organization
WWII	World War II

Chapter 1
An Introduction to Innovation

This chapter is written in the form of an essay on innovation – what it is and how the discipline has developed, especially over the last few decades. The reader is also introduced to the main innovation topics to be expounded in later chapters, with references to the respective chapters.

The chapter starts with the development of a practical definition of innovation and proceeds with an overview of the different types and categories of innovation found in organizations, both private and public. Schumpeter's famous insight that innovation is the engine of creative destruction will be explained. The evolution of innovation as a concept in management thinking during modern times will be related. The public sector's interest and role in innovation and the interplay between the private and public sectors needed to commercialize innovations based on technological advances will be introduced.

In Search of a Definition

There has been a remarkable rise in interest in innovation over the last two decades, not only in the popular and business media but also in academic publications. The year 2021 alone saw over 33,000 new publications on the topic. At the time of writing, the Web of Science™ lists almost 300,000 publications with innovation as a topic, with over one third of those in the fields of business, management, or economics.[1] Figure 1.1 illustrates the rapid increase in innovation-related academic publications over the last decade, which can be seen as a proxy for rising interest in innovation.

For a word that is used almost too freely, it is remarkably hard to find a good practical definition of "innovation." Merriam-Webster's online dictionary defines innovation as "a new idea, method, or device" or "the introduction of something new."[3] The Cambridge online dictionary similarly defines it as "a new idea or method, or the use of new ideas and methods."[4] However, experienced practitioners know that innovation is about much more than having a new idea. Turning ideas – no matter how good – into successful innovations is exceptionally hard and requires a proper process and execution discipline as well as a supportive ecosystem around it. (Some best-practice processes for how to turn ideas into true innovations will be explained in Chapter 4.)

If we move on from the linguistic definition and look for more rigor in a proper economic definition of innovation, we are initially disappointed. In introductory economics courses, innovation does not usually feature as a major topic or as a driver of economic behavior. This may seem strange, but neoclassical microeconomic theory

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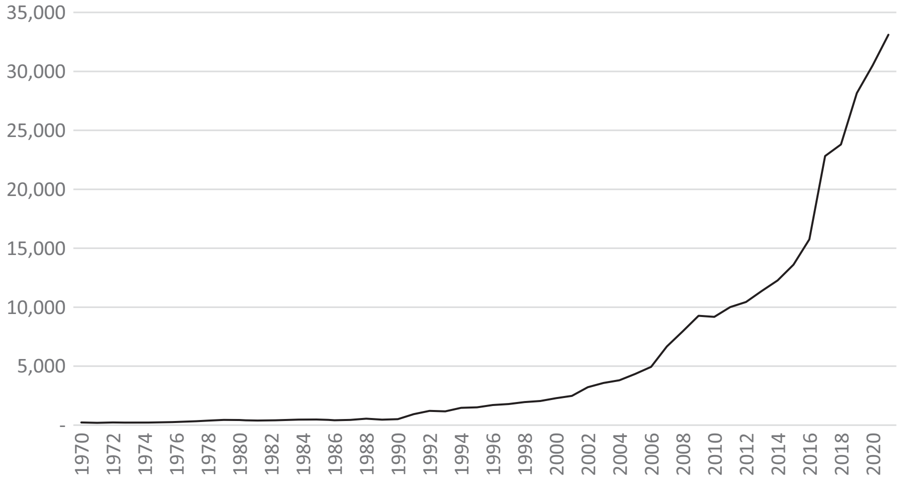

Figure 1.1: Number of Publications per Year (1970–2021) with "Innovation" as a Topic. Source: Clarivate™ Web of Science™ data (2022).[2]

only deals with innovation in passing in the context of a technological change that shifts or modifies the production function (which is explained in Chapter 3), or as a way to explain why products may be differentiated.

Products that are not differentiated at all, are called *commodities*. When commodities or products closely resembling commodities are traded, well-functioning markets will determine the price and quantity sold according to supply and demand in a textbook-like fashion. An ounce of pure gold is the same as another ounce of gold, a barrel of oil is the same as another barrel of oil (with some subtle differences between regional oil markets), and a bushel of wheat is the same as another bushel of wheat. Every time another supplier enters the market, the price is competed down until eventually no economic profits remain to be made. On the opposite end, truly unique products for which there are no easy substitutes are sold to customers by *monopolies*, enabling monopoly profits. According to economic theory, a monopolist supplier can set either the price or the quantity to sell of a product, but not both. In between these two extremes we find *monopolistic competition*, where products are differentiated to some extent but still fairly close substitutes for one another. Most consumer products fall into this intermediate classification. Products with more differentiation – either in terms of real features or perceived superiority – command higher prices.

Firms often pursue innovation because it helps them to differentiate their products from those of their competitors. A breakfast cereal that is crunchier than others, a tasty chocolate bar that has lower calories, or a toothpaste that leaves teeth whiter are all examples of consumer products that can command higher prices and sell more units than their closest competitors' products, at least for a while.

(A price increase of 1 percentage point will generally increase net profits more than a unit sales increase of 1 percentage point.) The same principle applies to higher-priced, more complex products such as automobiles or computer servers. Innovation can be used to add distinct or superior features that differentiate one offering from the other, thereby giving the seller some pricing power and thus excess profits in economic terms. However, competitors will keep imitating any successful innovations in search of profits, making commoditization an ever-present threat.

The only way to make higher profits on commodities is to be a low-cost producer, which is what natural-resource companies that extract commodities have to do. The same is true for most agricultural products. Selling a commodity greatly limits your opportunity to make a profit. Former IBM CEO Sam Palmisano reportedly summed this hard truth up by saying, “Either you innovate or you’re in commodity hell. If you do what everybody else does, you have a low-margin business. That’s not where we want to be.”[5]

However, it should be pointed out that process innovation is applicable to such a situation: Commodity producers such as mining companies or paper mills innovate to lower their process costs, thereby increasing their profits. Furthermore, raw-material commodities can also be transformed into rudimentary products that add value, which customers will be willing to pay a premium for. For example, the mining company Vale converts iron-ore dust into iron pellets, which offer higher efficiency and other processing benefits to steel manufacturers.[6]

Innovation as the Engine of Creative Destruction

Though innovation can indeed increase product differentiation, and yield the price benefits that accompany it, that is too narrow a view for a full definition. It does not offer us a comprehensive explanation of the role that innovation plays in the economy, and it is only one piece of the puzzle.

We have the early 20th century economist Joseph Schumpeter to thank for our understanding of how innovation works in a modern market economy. Austrian by birth, Schumpeter was a colorful character who was briefly the Austrian finance minister in his thirties before going on to make a fortune in banking, which he then lost in the 1929 stock market crash. Penniless, Schumpeter had to use his fame to give paid speeches so that he could afford the transatlantic ship fare to the United States, where he became a professor at Harvard. Schumpeter is perhaps most famous for his coining of the phrase “creative destruction” to describe how in a capitalist system new products and methods displace existing ones. For example, automobiles replaced horse-drawn carriages and streaming video replaced discs. The idea that nothing is ever stable is at the core of Schumpeter’s economic philosophy and his understanding of how capitalism works. Schumpeter believed that everything revolves around entrepreneurs, who are the primary agents of innovation and creative destruction. As such, Schumpeter's explanation of what innovation is and how it works is an important element of his larger explanation of how the capitalist economic system works.

Schumpeter (1943) defined innovation as follows: "Innovation is creative destruction, where entrepreneurs combine existing elements in new ways." He notably defined innovation as the second of three stages in the creative-destruction process: Innovation is preceded by *invention* and followed by *diffusion*.[7]

Schumpeter's distinction between invention and innovation is an insightful and helpful one, which shall be adhered to throughout this book. Invention is the creation of a new technology or new way of doing things. The transistor was a major invention of the last century, but it was not an innovation. Innovation happens when entrepreneurs combine existing elements (including recent and past inventions) to create new products or services for customers. For example, Sony became the first company to commercially exploit the newly available transistor with a mass-market offering, using transistors to make small, affordable radios that filled a real consumer need in post-World War II Japan.

To the innovator goes the spoils, rather than to the inventor: The transistor was invented by scientists at Bell Labs. But while the inventors received the Nobel Prize for this technological breakthrough, it was not they or their employer who created the first blockbuster product that utilized this invention but a previously unknown Japanese company, Sony. Similarly, Kodak can take major credit for the invention of digital-camera technology, but the company failed to turn that new technology into a major innovation, leaving Kodak horribly exposed to other companies who went on to do so. The distinction between invention and innovation helps us to understand many other such puzzling instances where the originator of a breakthrough technology is not the person or organization to profit from it. Profit goes to whomever can create value in the eyes and hands of the paying customer.

The diffusion stage arrives when an innovation has become so ubiquitous that it is no longer the source of any competitive advantage. For example, when it first became available in luxury production cars in the 1980s, ABS (automatic braking system) was a major differentiator for manufacturers, such as BMW, who pioneered it. Nowadays, ABS is standard equipment in all production cars in Europe and North America. More recently, the rearview backup camera made its first appearance in higher-end SUVs, but now it is standard equipment in all such vehicles. Once everyone has copied an innovation, prices decline, and it essentially becomes a commodity. That is why companies have to keep innovating, otherwise they will be overtaken and replaced by entrepreneurs who do. Such is the nature of creative destruction. The government, on the other hand, has a keen interest in seeing beneficial technologies rapidly reach the diffusion stage, where they permeate the economy and their widespread use lifts national productivity. (The process of diffusion is discussed in detail in Chapter 2.)

To escape the relentless discipline of free-market creative destruction, incumbents often petition governments to erect regulatory barriers to keep new competitors out. Thus, the regulatory and legal environment may become an impediment to innovation. Politicians and government agencies have to be vigilant against such *regulatory capture*[ii] by powerful incumbents.

While Schumpeter's explanation of innovation as a force in the capitalist economy is insightful, it does not necessarily help us to understand innovation in all contexts. Non-capitalist countries have produced highly innovative products, too. For example, the AK-47 assault rifle developed in the Soviet Union by Mikael Kalashnikov, and introduced shortly after World War II, gained worldwide popularity (particularly among irregular forces) due to its ease of operation and maintenance and its well-known reliability in the harshest conditions. The AK-47's lack of accuracy was not a drawback in many of the situations it was used, such as in jungle warfare. (The AK-47 was not an invention, because it was based on firearm technology that already existed at the time, demonstrated in a German assault rifle that came into the possession of the Soviets at the end of the war and inspired Kalashnikov.)

This example gives us another important clue as to the true nature of any successful innovation regardless of the economic system in which it is developed: It meets the needs of its user – in this case, affordability and simplicity – and it solves an important and valuable problem for the user – in this case, ease of use and ruggedness. Such user-centric principles are as applicable to the public sector as to the private sector. (How organizations can innovate according to these principles is explained in Chapter 4.)

Definition and Types of Innovation

Peter Drucker, a pioneer of business management thinking who is perhaps not as widely read by today's generation of managers as he should be, further developed our understanding of innovation and entrepreneurship in an eponymous book[8] published in the early 1980s. Drucker (1983) clearly expressed his view of how innovation adds value to society in the hands of entrepreneurs (note the clear alignment with Schumpeter in the first two sentences):

> Entrepreneurs innovate. Innovation is the specific instrument of entrepreneurship. It is the act that endows resources with a new capacity to create wealth. Innovation, indeed, creates a resource. There is no such thing as a 'resource' until man finds a use for something in nature and thus endows it with economic value. Until then every plant is a weed and every mineral is

ii When politicians or regulatory agencies fall under the influence of the industries or companies they are assigned to regulate.

> just another rock . . . Equally whatever changes the wealth-producing potential of already existing resources constitutes innovation.[9] (Drucker 1983, 30–31)

Thus, Drucker (1983) argued for "purposeful" innovation, which means finding a *use* for something that already exists at its core. He also defined what he called *systematic innovation* – emphasizing that innovation is an ongoing organizational practice, not just a single lucky instance – as follows:

> Systematic innovation . . . consists in the purposeful and organized search for changes, and in the systematic analysis of the opportunities such changes might offer for economic or social innovation.[10] (Drucker 1983, 35)

Drucker made the observation that most successful innovations exploit changes that have already occurred, which implies that there is a diagnostic component to innovation as entrepreneurs have to recognize and analyze the relevant changes. Drucker's book, *Innovation and Entrepreneurship* (1983), is organized to discuss the seven major source areas of the changes he identified:

1. The unexpected – success, failure, or outside event
2. The incongruity – between reality as it really is, and as it is assumed that it ought to be
3. Innovation based on process need
4. Changes in industry or market structure that catch everyone unaware
5. Demographics – changes in population
6. Changes in perception, mood, and meaning
7. New knowledge – both scientific and nonscientific[11]

(Drucker 1983, 35)

Like Joseph Schumpeter, Peter Drucker (1909–2005) was born in Austria where he came into direct contact with the ideas of famous free-market philosophers such as Schumpeter, Friedrich von Hayek, and Ludwig von Mises. Schumpeter was a friend of Drucker's father, and Schumpeter's ideas on innovation and entrepreneurship strongly influenced the young Peter Drucker. Like Schumpeter, Drucker emigrated before the Second World War and became a U.S. citizen during the war years. He taught business management at New York University for decades. He later moved to the West Coast and founded a graduate management school (since named in his honor) at Claremont University, where he continued teaching into his nineties. Drucker is widely regarded as the most influential business thinker of the late 20th century and was rightly called the "dean of this country's business and management philosophers" by the *Wall Street Journal*.

As exemplified by the writings of Drucker, who was often at least one step ahead of his contemporaries, by the 1980s innovation had become recognized as a true management discipline, inextricably intertwined with the practice of entrepreneurialism. Drucker emphasized that innovation must be anchored by insights into exploitable *changes*, which requires exploration and analytical rigor on the part of the innovator.

By the early 21st century, an additional aspect of innovation gained prominence, namely *creativity*. Books on creativity and *design thinking* had first started to appear in the 1950s and 1960s, and *human-centered design*, which emphasized developing engineering solutions from a human perspective, emerged as a new discipline in the 1980s. The 1990s set the stage for an explosion of interest in design thinking. IDEO, perhaps still the world's most well-known design firm, was founded in Palo Alto, California in 1991 when Stanford University professor David Kelley and two British-born designers Bill Moggridge and Mike Nuttall combined their three design companies. David's brother, Tom Kelley, was also active in the firm and helped to manage it for many years.

The design approach that was first developed for consumer products eventually got extended to services. By the early 2000s, several business books on design thinking were evangelizing this approach to innovation. Design thinking is fully expounded in Tom Kelley's book, *The Art of Innovation.*[12] In the book, Kelley (2001) describes innovation, but does not formally define it. However, the innovation process followed by IDEO is explained in detail: It starts with observing the customer trying to do a task or a job, followed by brainstorming on how to help the customer do that better, and creating rapid prototypes of the new product to get feedback from the customer. It is in essence a creative process directly informed by the needs of the customer and frequently subjected to field testing. It also borrows from the scientific-inquiry process by setting up hypotheses in the form of tangible prototypes that are quickly tested, improved, and tested again. This design process shall be covered in more detail in the Chapter 4, but for now it is sufficient to summarize it as both creative and rigorous.

In synthesis of the aforementioned concepts, I offer a broad, practical definition of innovation, which is compatible with Schumpeterian innovation but also accommodates innovation from different sources and for different purposes:

Innovation is a creative and analytically rigorous process for organizations to solve valuable problems for their customers and for themselves.

1. The first part of the definition recognizes the *right-brain-left-brain nature* of the innovation process, because this duality is what makes a true innovation more than the sum of its constituent parts. Do only the analytical part without the creativity and you are back in the pure domains of science, engineering, or business analysis. Do only the creative part without the analytics, and you are in the realm of the arts, without any necessary anchoring in facts or the scientific method. True innovation is thus both an art and a science.
2. The second part of the definition focuses on solving valuable problems, thereby *creating value* for both the customer and the innovator and, most likely, also for society at large. An innovation that does not create value is a curiosity or a mild amusement at most. The problem may be one of creating a better product or service, improving efficiency, lowering costs, or anything else worth solving.
3. The third and last part of the definition puts the focus on *whom* the innovation is supposed to serve. Innovation must always have an *end customer,* whether it is an external customer or an internal customer. Without a customer who benefits, innovation is a self-serving exercise that cannot create value.

Innovation can be applied to virtually any area of human endeavor and is not restricted to things (products). Schumpeter (1943) too pointed this out when he mentioned *methods*. In fact, Schumpeter included all the following manifestations (types) of innovation in his articulation of innovation:[13]

1. Introduction of a new product or service
2. Introduction of a new method of production
3. Development of a new market
4. Exploitation of a new source of supply
5. Reorganization of the methods of operation

To Schumpeter's original list can be added some other modern categories of innovation, which typically are multifaceted or involve a combination of Schumpeter's original categories:

6. Process innovation, in operational areas other than production (similar to 2)
7. Efficiency or cost-saving innovation (related to 2 and 5)
8. Business model innovation (entailing any or most of the above)

Once we understand what innovation is and in what areas it may be applied, we also can recognize that not all innovations are of equal magnitude or equally novel. Some innovations represent major changes to the status quo but others are only minor. There are different degrees of innovation based on the scope of the innovation and the extent to which the innovation results in something a little different or completely new compared to the current situation:

– *Incremental innovation* entails small improvements or variations to existing products, services, or processes
– *Radical innovation* or *breakthrough innovation* entails significant departures from current offerings or processes
– *Next-generation innovation* is an additional term used by some to describe a midway point on a continuum between incremental and radical – going further than incremental innovation and taking the evolution of the offering to the next level, without necessarily changing the nature of it totally, as is the case with radical innovation

An important perspective of how innovation plays out over different time intervals is gained by dividing the future timeline into *three horizons*. Originally proposed by consultants at McKinsey & Company as a growth framework (Coley 2009),[14] the three-horizon approach can be applied to all types of innovation, not only those associated with revenue growth such as new product introductions.

– *Horizon 1 (H1)* represents the core of the business that is most identifiable with the company's identity and which provides the greatest current profits and cash flow.

– *Horizon 2 (H2)* encompasses emerging opportunities likely to generate substantial profits in the future but that require considerable investments.
– *Horizon 3 (H3)* contains ideas for profitable growth much farther into the future and can contain research projects, small exploratory ventures, and minority stakes in emerging new businesses.

The exact time frames for these horizons will depend on the industry and business involved. Most typically H1 is thought of as the 12–18 month short term, H2 as the medium term starting at the end of that 12–18 months and continuing three to four years, and H3 is farther out. Some businesses run on longer cycles (e.g., large infrastructure and heavy industrial equipment) and some on shorter cycles (e.g., mobile phones and CPG), but the above time frame is generally a good starting point. Take an automobile manufacturer as an example across all three horizons: Major new car models released every four to five years would be H2, annual model updates would be H1, and projects to develop new propulsion and energy systems for future cars that depart radically from current cars (e.g., hydrogen) would be H3. From this example, it's clear that H1 is usually associated with incremental innovation, next generation innovation is in H2, and radical innovation is usually H3.

The three horizons will be referenced in the chapters that follow, in particular Chapter 4 due to its organizational implications and Chapter 8, in the context of innovation portfolio management.

Another potential distinction is that between *architectural* and *component innovation*, sometimes also referred to as *systemic* and *modular innovation. Component innovation* is when one or more modules nested within a larger system are replaced, while the system itself stays intact. *Architectural innovation* entails changing the overall system design and hence, the way that the parts interact with each other (Henderson and Clark 1990).[15] This distinction is helpful when considering the impact of innovations on large societal systems and particularly in the context of sustainability transformations.

Disruptive innovation is often erroneously conflated with radical innovation. However, its true meaning as defined by its originator, Clayton Christensen, is quite different. Disruptive innovation occurs when large, established companies get outcompeted (i.e., disrupted) by competitors who find ways of meeting the needs of less-sophisticated customers neglected by those large incumbents.[16] For example, Xerox, the erstwhile market leader in enterprise photocopiers, got disrupted by Canon who created a large new market for smaller, cheaper copiers. Thus, disruptive innovation does not fit on the same dimensional axis as incremental through radical innovation. The concept of disruptive innovation was first introduced under the term *disruptive technologies* in Christensen's influential book, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (1997).[17] Disruptive technologies will be further explained in Chapter 2 within the context of technology S-curves.

Market-creating innovation, a more recent contribution by Christensen, Ojomo and Dillon (2019), also does not fit on the incremental-to-radical axis but contains an insight relevant to both private and public sector practitioners of innovation who work in emerging economies. Market-creating innovation is Christensen's answer to the question of how poor, developing countries can create thriving market economies by creating new consumers with spending power: "Market creating innovations transform complex and expensive products and services into simple and more affordable products, making them accessible to a whole new segment of people in a society whom we call 'nonconsumers'."[18]

Organizations typically struggle to get the mix or balance right between the various types of innovation initiatives that they pursue. Frequently they get stuck in a rut such as doing too much incremental innovation, but in other cases they may overinvest in radical innovation. The strategic context determines which mix is right for a particular organization at a particular point in time. Properly aligning the entire portfolio of different innovation projects with organizational goals is an advanced topic that will be covered in Chapter 8.

The Rationales for Innovation in the Private and Public Sectors

In both the private and public sectors, it is fairly easy for advocates of innovation to make a qualitative argument for the need for innovation. In the case of for-profit companies, whether publicly or privately held, innovation is associated primarily with faster revenue growth while cost-savings brought by innovation can also lead to higher profitability. However, the intuitive insight that innovation can increase revenue or lower costs is not always easy to express in quantitative dollar terms, for some very good reasons. This issue shall be further looked at in Chapter 8 where trading off innovation projects against one another is examined in the section on portfolio management.

While private companies may primarily innovate to serve their shareholders, innovation in the private sector can – and should – also serve the interests of a broader set of stakeholders and society at large either by design or at least as a by-product. An example of the former is innovation in the distribution systems of consumer products to enable poor communities to help themselves economically. An example of the latter is higher-efficiency production processes that reduce costs also could reduce environmental pollution.

From a public-policy perspective, the highest societal benefit of innovation is its contribution to national prosperity. Countries that are more innovative outperform those who are not on a number of key public welfare measures. The mechanism through which this happens is covered in Chapter 3, while the policy framework through which this may be promoted is the topic of Chapters 11 and 12.

Innovation is also a way to improve government itself, and a way that agencies can improve their operations to make them more responsive to user needs and more cost-efficient. While the private sector tends to have fairly uniform high-level metrics such as profitability and revenue growth, in the public sector there may be multiple goals that entail either outputs or outcomes, each specific to their part of government and the particular *mission* undertaken by that agency. For example, the U.S. federal government sets annual performance goals by agency, which are published by the Government Accountability Office (GAO 2022).[19] These goals are framed by legislation, typically circumscribed by available budgets, and reflect the priority of the incumbent administration. Performance goals set for the public sector generally come in two types, *outcome-related goals* and *cost-efficiency goals*; the principle being that high-performing agencies create value for citizens by achieving high-value outcomes at high levels of cost-efficiency, thereby serving the interests of both public-sector customers and taxpayers (Cole and Parston 2006).[20]

This complexity and the importance of institutional context is why I advocate for always seeing innovation as *a means to an end*, and never as an end in itself. The question then becomes, "How can innovation help us achieve our organizational goals?" In even blunter terms, the question is simply "What do you want innovation to do for you?" If, for example, you want to grow company revenue by 20 percent year over year, that is something that innovation can contribute to by giving you new products or services to sell or by improving your current products or services. If, for example, you want to increase the accessibility of a particular government service to the public, and you can quantify that goal, innovation can be employed to help you achieve that. For innovation, as for all of life's endeavors, having clarity on the goals you are trying to achieve is always the right place to start.

It is essential that whatever the exact answer to this question is in a particular context, it is always framed in terms of the value that it brings to someone and/or the mission that it fulfills. Tying innovation directly to already established and agreed organizational goals is not only clarifying, but vitally important. You then do not have to justify innovation on its own as a new concept, and it helps you avoid fruitless political debates about the necessity of innovation inside your organization. Goal clarity brings other immediate benefits. Once you can articulate how (and preferably by how much) innovation is expected to contribute to important organizational goals, it becomes much easier to justify an appropriate budget for innovation.

The Multidisciplinary Nature of Innovation

Innovation lies at the intersection of a number of traditional disciplines or corporate functions. The main corporate functions that intersect with innovation are *marketing, product development* together with *research and development (R&D),* and *operations*. Innovation can be beneficial to other functions too, for example, innovation in sales processes or business development. While any so-called creative accounting should be avoided, there is no reason why the accounting or auditing processes themselves cannot be innovated to make them better. The same is true for human resources and legal processes. However, most organizational activity around innovation in the private sector can be expected to occur in the nexus between marketing, development, and operations. While the scopes of these functions vary depending on the industry sector and the entity, they have certain core responsibilities regardless of industry.

Marketing is defined by the American Marketing Organization (AMA 2017) as "the activity, set of institutions, and processes for creating, communicating, delivering, and exchanging offerings that have value for customers, clients, partners, and society at large."[21]

New product development (NPD) is concerned with the inception, development, and launch of new products. These days, the NPD term is commonly extended to services and solutions.

The term *research and development (R&D)* includes exploratory research and technology development under the research component and the development component typically overlaps with the first stage of NPD. The term R&D is used differently by industry but is generally understood to precede full-scale product development. The earliest stages of research may be seen as falling under the Schumpeterian definition of invention when they result in new technologies, but not in new offerings.

In manufacturing industries, o*perations* comprise the superset of functions around production. It includes manufacturing itself, supply chain management, as well as supporting functions such as quality and logistics. In service industries, the term operations is used to describe all the activities that render the services to the customers. In a restaurant, for instance, both the cooks and the servers are part of operations. In a physical (brick and mortar) bank branch, all activities are part of bank operations, as are the call-center and online banking operation. Bank operations also include so-called back- and middle-office activities, which enable the customer-facing front office to function and that continue, support, and complete processes initiated in the front office.

In many industries, one function traditionally assumes a primary leadership role in innovation. For example, in a highly technological or engineering industry, R&D or product development may be the first among equals. In the consumer-products industry, the marketing function is usually in the driving seat.

In the public sector, as in the private sector, cross-functional collaboration is required in the innovation process. In the public sector, there is no marketing function if the political operation is excluded from the definition, which means that cross-functional collaboration usually entails a partnership between product development or R&D on the one side and operations on the other.

It should be obvious how the process of innovation, and bringing forth an innovative new product or service involves each of these three core functions (NPD/R&D, Operations, and Marketing) to a large extent, or at least to some extent. Innovation is indeed a multifunctional endeavor, which is why it will quickly expose any existing disfunction in an organization, and suffer from it.

Innovation requires more than alignment between the official functions within an organization. Innovation relies heavily on the free exchange of knowledge and insights between individuals in different groups and departments. That in turn requires high levels of trust and a propensity for collaboration between coworkers. It should therefore be no surprise that there is a strong association between overall organizational health and the general ability of any organization to innovate. The organizational side of innovation is covered in Chapter 4.

No single organization, however large, can command all the expertise and knowledge required to innovate in today's fast-moving global environment. Therefore, over the last two decades there has been an increased emphasis on collaborating with external actors and organizations. Henry Chesbrough (2003) coined the term *open innovation* in his eponymous book to explain these relationships.[22] (Not everyone has embraced Chesbrough's term, which is why the more neutral term, *external collaboration* will also be used.) Of late, there has been further emphasis on the need for not only one-to-one relationships with external actors, but to be part of a network of collaborating external organizations and individuals. Due to its importance for today's innovator, Chapter 5 is devoted to open innovation and external collaboration.

The Management and Strategy of Innovation

Like any organizational endeavor, innovation needs to be managed properly for it to be successful, and particularly if the organization wants to be consistently good at innovation and yield a continuous series of successful innovations. That is what Drucker (1983, 35) had in mind when he argued for *systematic innovation*.[23] Certainly, innovation projects should be properly managed like any other project, with milestones and checkpoints. But given the special nature of innovation as something that has not been done before, it is never routine either. Another way in which innovation is different is that the process of innovation should not be solely optimized for efficiency like a production or other operational process. Some level of waste or inefficiency needs to be accepted as a natural part of the innovation process. The management of innovation is the topic of Chapter 7. Special considerations that apply to bringing innovation into the public services domain are also reviewed.

Senior executives in particular, but also midlevel executives, need to appreciate the larger strategic context in which they manage their innovation efforts as well as their essential technologies. This includes an understanding of what it takes to construct an effective *innovation management system* that can govern and direct innovation initiatives within their organization. A new *Innovation Management Map* that shows how innovation is managed at different levels in the organization, and how all the components of innovation fit together, is presented in Chapter 7.

Most organizations that are not startups have to manage not only one innovation or innovation project at a time, but dozens or even hundreds of projects. Such a collection of innovation initiatives or projects is called the *innovation portfolio*, and it needs to be balanced and properly managed just like a portfolio of financial holdings. It is also important to incorporate what has been learned from innovation successes or failures in prior projects into best-practices and new directives for later projects. The existence of the portfolio great increases the level of complexity that needs to be managed with important strategic, operational, and organizational implications. For example, the resource needs of projects (including the human resource needs) must be traded off against one another, while any change in the timeline of one project will have knock-on effects on others. Among such complexity, unintended consequences of management decisions must be avoided. Then, there is always the big question of what the optimal set and sequence of projects is to deliver innovation outcomes for the purposes of achieving the maximum value or mission impact possible over a particular number of years, in other words aligning the innovation portfolio with the business objectives or the larger mission. Sound decision-making in the face of this complexity is thus vitally important to any organization engaged in innovation. Fortunately, the modern discipline of behavioral economics sheds much light on the human cognitive biases and distortions to be mitigated in the interest of better decision-making. These topics are further covered in Chapter 8.

The Contribution of Innovation to Public Welfare

In order to truly understand innovation, it is not sufficient to know how it is practiced at a firm or organizational level. The impact of innovation on society and the economy, as well as the societal context within which innovation happens, are equally important.

In a little over two centuries, there has been a remarkable increase in economic growth and prosperity, starting in the Western countries – which were first to industrialize – but since spreading around the world.

The technologies enabling this prosperity were made possible by major advances in scientific understanding and engineering expertise. New ideas are necessary but not sufficient. The water wheel was invented by the ancient Greeks, but it was only when innovation led to large-scale waterwheel designs that they could be used to power mills two thousand years later. Similarly, the ancient Greeks knew the power of steam[iii] and yet never developed a usable steam engine. They lacked the understanding of thermodynamics that only came after the Scientific Revolution.

The initial Industrial Revolution started with waterwheels powering mills and later, steam engines powering factories of all kinds. Steam-powered trains and ships together with electrical telegraphs connected remote cities, including those an ocean away. Then, in the early 20th century came electrical motors and generators, radio communication, and automobiles and aircraft powered by internal (and external) combustion engines. After World War II came jet engines and nuclear power with innovations continually building on one another – for example, nuclear plants use steam engines to turn electrical generators to generate electricity. Then came computers, the internet, and the digital and mobile revolutions. In the case of each technology, Schumpeter's phases of invention, innovation, and diffusion can be discerned. Inventions do not change the world. It is when the invention is used as a building block of innovation that new technologies become truly transformative. And so, the transformation and accompanying productivity gains were not complete until widespread diffusion of the innovations based on new technologies was achieved. The productivity and income gains made by employing such new technological innovations have been truly remarkable and have lifted hundreds of millions of people out of poverty.

It was not until the 20th century that economists started to think seriously about how innovations based on new technologies increase the national income, also commonly referred to as the gross domestic product. The main growth theories that were developed and refined after the Second World War reach quite different conclusions on the role and importance of innovation to national income and changes in the economy, with quite different implications for public policy. This is the main topic of Chapter 3.

The Interplay Between the Private and Public Sector

A discussion on the broader context of innovation within the economy would not be complete without examining how innovation and invention are financed. Again, Schumpeter's insight that innovation is driven by entrepreneurs, who unlike capitalists have to obtain financing from others, is invaluable. It helps us appreciate that the lifeblood of innovation is the funding needed by innovators before their creations may contribute to the success of their venture and to the greater good.

iii Hero of Alexandria constructed a rudimentary steam engine called the *aeolipile* around 100 BC. It was made from a metal sphere that contained water with two L-shaped tubes on either side emitting jets of steam when the water boiled, thereby rotating the aeolipile.

The story of innovation funding does not start with the innovation stage, but precedes it. While private sector-innovators are celebrated for popular consumer products such as the iPhone and GPS navigation devices, the role of government-conducted or government-sponsored R&D to create the technologies that enable these consumer products to function is too often underestimated. Most of such government contributions may be classified as Schumpeterian invention, but there are also cases that are more properly classified as innovation. For example, the Global Positioning System (GPS), which we all use, is a fully functioning system on its own, making use of many underlying technologies. The internet grew out of a military communication network called ARPANET launched in the 1970s (Abbate 2001).[24]

Basic scientific research that becomes available to anyone to use is what economists call a *public good*. A public good is both *nonexcludable*, which means that once it exists there is no way from preventing everyone from accessing it, and *nonrivalrous*, which means that one person's use of it does not prevent anyone else from using it. (A lighthouse is the classic example of a public good.) The economic reason that governments fund public goods is that, due to their very properties, there is no economic incentive for the private sector to invest in them. That is why there is a longstanding consensus that national defense – clearly a public good – must be provided by the government and funded by taxes. Most economists and policy experts would classify basic science and the inventions that accompany it as public goods too. Once government-funded science exploration has yielded results that can be applied, or even directly be incorporated into inventions, the private sector can exploit the knowledge and inventions further. But there may be a gap when the basic science is complete but not advanced far enough for a private investor to invest in commercializing it. This is commonly called the *Valley of Death*, which creates the need for bridging government finance and policies that support commercialization. (The financing of innovation by the private and public sector is the topic of Chapters 9 and 10, respectively.)

The simple dividing line of the government funding science and the private sector funding innovation is often not followed. Governments may also fund innovation and even commercialization because they place a high priority on the value that these innovations must bring to the nation or the *mission* they are required to fulfill. Examples of such missions are the Apollo program to win the space race, defense systems, and innovations that are considered key to a nation's competitive advantage in certain industries. Another reason for governments to spend money on innovation is where there is a public interest to advance to the diffusion stage faster than the private sector would do on its own; for example, this is the case with new products based on sustainable technologies or in producing vaccines to counter pandemics such as COVID-19.

The interest of the public sector in being an active participant in the innovation process is amplified during times of transformative change exemplified by the major industrial revolutions. Governments may direct public spending and coordinate it with trade policy to ensure the growth and survival of certain industries seen as critical to future competitiveness. Lastly, the government also has an interest in mitigating the socially disruptive effects of innovations such as job losses due to automation and loss of privacy or data agency due to new consumer information technologies. (Innovation policy is discussed in Chapter 2.)

Chapter Summary

- Having differentiated products is essential for companies to have both pricing power and to outsell their competition. An undifferentiated product is called a commodity, for which the producer has no pricing power but can only reduce costs to increase profits.
- According to Schumpeter, innovation is central to the creative destruction process in a capitalist system. Innovation is when entrepreneurs combine existing elements in new ways. Brand new technologies are inventions; the invention process precedes innovation. The diffusion stage has been reached when everyone has copied an innovation. Companies have to keep innovating to avoid the commoditization that comes with diffusion.
- Successful innovation requires a systemic process in organizations according to Drucker. This process has to constantly scan for changes in the market, technology, and environment that may present opportunities for innovation.
- The design-thinking approach emphasizes observing the needs of the customer or end user, and rapidly trying out prototypes that may help the customer get a job done or solve a problem.
- The practical definition of innovation used in this book is that innovation is an analytically rigorous and creative process for organizations to solve valuable problems for their customers and for themselves.
- Innovation may take many forms, from product to services to process. It can also be placed on a continuous axis running from incremental innovation to radical innovation based on the degree of the change it contains.
- While private-sector companies pursue innovation to drive revenue growth and higher profits, innovation in the public sector has specific goals depending on the priorities of the particular agency at the time. These have to be seen in the context of the mission of the agency.
- At the highest level, innovation in both the private and public sector contributes to national prosperity and public welfare.
- Innovation is a multidisciplinary process involving many organizational functions. In the private sector, these are typically R&D/product development, operations, and marketing; in the public sector, these are typically R&D/product development and operations.

– Governments enable innovation by directly funding research in pure and applied science. Private-sector innovations often depend on the scientific understanding, inventions, and infrastructure created by public-sector investment.

Suggested Exercises and Assignments

– Ask each one in the group to contribute a news article describing a recently launched innovation. In each case, identify what type of innovation it is (from the extended Schumpeter list), and what differentiates that innovation from the existing offerings that it now competes against.
– Discuss recent technological innovations that you admire; identify the prior inventions that made these innovations possible, and estimate how far each innovation is from the point of diffusion.
– Identify key government sponsored research or inventions behind a popular innovation of your choice; debate whether it is fair that all profits made by the private sector on these innovations be kept in the private sector, and whether it is advisable for some share of the profits to go back into a pool that can help fund the next generation of research.

Recommended for Further Reading

Drucker, Peter F. *Innovation and Entrepreneurship*, New York: HarperCollins, 1983.
Fagerberg, Jan, and Bart Verspagen. "Innovation studies – The Emerging Structure of a New Scientific Field." *Research Policy* 38, no. 2 (2009): 218–233. https://doi.org/10.1016/j.respol.2008.12.006.
Godin, Benoît. "'Innovation Studies': Staking the Claim for a New Disciplinary 'Tribe'." In Fagerberg, Ian, Ben R. Martin, and Esben Sloth Andersen, eds., *Innovation Studies: Evolution & Future Challenges*. Oxford University Press, Oxford, 2014.
McCraw, Thomas K. 2007. *Prophet of Innovation – Joseph Schumpeter and Creative Destruction*. Cambridge, MA: Belknap Press of Harvard University Press.

Chapter 2
Technological Progress and Industrial Revolutions

The remarkable improvement in living standards enjoyed by most citizens of developed countries over the last couple of centuries was the result of transformative technologies and accompanying innovations in production and consumption systems. An understanding of the nature of technological progress, as well as its implications for the economy and for society, is essential for anyone interested in deriving value from the next generation of innovations. Policymakers interested in harnessing technology and innovation to support their stated missions also need to understand the main propagation mechanisms of technological progress and innovation.

The chapter starts with an exploration of the acquisition of knowledge and scientific progress and the role of uncertainty in that process. It then introduces several key concepts related to technological progress and the diffusion of innovation that are essential for industry leaders and government policymakers to understand. Diffusion curves that represent the adoption of innovations in different phases are explained in their sociological and other contexts. Technology S-curves are introduced, and their implications for disruptive innovation are explained.

The apparent paradox that technological advances over the last few decades have not lifted productivity growth as much as expected is explored and the most likely explanations are discussed, along with their policy implications. The intriguing idea that major technological advances come in decades-long waves known as Kondratieff waves is presented, as well as what insights that offers for past industrial revolutions. This is followed by a brief introduction to the Fourth Industrial Revolution, a provocative term recently coined to represent a seeming acceleration of technological advances in areas as diverse as computing, biotechnology, materials science. The related concept of Society 5.0, a vision of increased human welfare enabled by the new technologies, is introduced.

Knowledge, Uncertainty, and the Path of Scientific Progress

In order to understand how scientific progress is made in society and how innovations follow, it is necessary to briefly review how our modern technological society developed.

The origins of all modern scientific method lie in what is today called the Scientific Revolution, which refers to two and half centuries of rapid scientific progress made in Europe between roughly 1500 and 1750 AD. Early in this period, the Polish astronomer Nicolas Copernicus published a book based on his observations with the telescope, one of the big new technologies of the age. Subsequently, Galileo became the father of modern physics because he used mathematics to describe the

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behavior of objects such as earthly projectiles and heavenly bodies. Galileo also insisted on testing his hypotheses empirically.

The use of mathematics to model and predict the real world and the use of experimentation to confirm theories are foundational to scientific progress. Both these practices broke with tradition as mathematics was mainly concerned with abstract entities and experimentation was previously not regarded as a reliable way of gaining new knowledge. In the 17th century, the French scientist and philosopher René Descartes developed a radical philosophy which described the physical world as comprising of matter particles that interacted and collided with one another. Descartes believed that the laws governing these interactions could be discovered by observation, which influenced many other scientists.

Newton built on the Cartesian philosophy when he presented his three laws of motion and principle of universal gravitation.[iv] Newtonian physics formed the foundation of sciences for the next two centuries. Because Newton's theories were so successful in explaining almost anything, confidence in science grew, and many scientific advances were made in chemistry, electromagnetism, thermodynamics, and optics through the 18th and 19th centuries. These basic scientific advances led to inventions, followed by innovations, as the new technologies were applied. For example, the first Industrial Revolution made ample use of the new field of thermodynamics in the design of steam engines.

In the life sciences, Darwin's theory of evolution by natural selection published in the mid-19th century quickly became accepted by scientists despite theological opposition. In the mid-20th century, Watson and Crick discovered the structure of DNA, the hereditary material that make up genes in all creatures. By 2003, the human genome was finally completely mapped, providing a foundation for accelerating further scientific progress in medicine and biotechnology. Genome mapping technology has improved rapidly and sharply decreased in costs since then. For example, in early 2020, mere months after the COVID-19 pandemic began, scientists sequenced the full genome of SARS-CoV-2, the virus that causes the COVID-19 infection. Gene sequencing has also kept up with the many mutations of the virus to inform public policy and guide vaccine development (Trafton 2021).[25]

In Chapter 4, it will be explained how fear of uncertainty is an inhibitor of innovation in organizations. The same is true at a societal, national and international level. In the preface to her book, *The Cunning of Uncertainty*, Helga Nowotny (2016), a noted scholar of science and technology, points out that the attitude of our society toward uncertainty influences how we invest in knowledge and how much we fear or welcome innovation:

> The future is the ultimate inexhaustible reservoir of uncertainty for the inhabitants of this planet. Notions and imaginaries of the future continue to change. Currently, it appears as fragile

iv Every mass in the universe attracts every other mass by means of gravitational force.

> and fragmented, as a plural and contradictory mixture of desired and feared imaginations. Ever since modern societies manifested an unprecedented preference for generating novelty, the future became an open horizon with science and technology at the forefront, pushing further into the unknown. Yet what is exciting for some feels threatening to others. Innovation, to use this ubiquitous term, remains a double-edged sword. (Nowotny 2016, Preface)

The Enlightenment brought a big change in how the future was perceived. With confidence in scientific progress, the future was considered with optimism and seen as an open horizon for progress. However, in the late 20th century, that optimism faded and a darker view of the future started to set in. There is now an emphasis on predicting the future to avoid or mitigate undesirable outcomes, as there is an implicit anticipation of future deterioration. In this mindset, uncertainty is more closely associated with threat than with opportunity.

Nowotny (2016) asserts that it is a human tendency to conflate risk, uncertainty, and danger.[26] The understanding from previous eras that risk and uncertainty had both an upside (where creativity and serendipity can flourish) and a downside (of undesirable outcomes that have to be avoided) has given way to a view that risk is mainly associated with the downside, leading to risk-aversion. This aversion is reflected in the insistence of funding agencies on assurances regarding what they will receive for their research grants, and a temptation for grant applicants to over-promise on deliverables.

The Process of Technological Innovation

Our current mental model of how technological innovation happens owes much to the work of MIT economics professor W. Rupert Maclaurin, a contemporary of Schumpeter, who developed Schumpeter's ideas into a more complete theory of technological innovation as a process. In his recount of Maclaurin's research, which we follow in this section, Benoît Godin (2008) points out that Schumpeter himself did not provide much analysis of the process of innovation beyond his idea that technological innovation was a new combination of the factors of products to produce outputs in the form of products.[27] Schumpeter did acknowledge that invention does not necessarily induce innovation. As director of MIT's Industrial Relations Section during World War II,[v] Maclaurin became interested in technological change and sought advice from Schumpeter, who recommended a historical analysis of industries and businesses. With Schumpeter actively pressing him along, Maclauren devoted himself to empirical historical analyses of technological change within its economic context, looking both at

v Maclauren later served as secretary on one of the committees that assisted Vannevar Bush in the preparation of his 1945 report, *Science the Endless Frontier*, that would lay out the map for U.S. scientific research after the war (Bush's report is further discussed in Chapter 10).

the factors responsible for technological development in an industry and the conditions that enabled this technological progress. According to Godin (2008, 347), Maclauren's first subject was the fluorescent lamp,[vi] after the study of which he identified four factors leading to change in the lighting industry:[28]

1. Capabilities in research and product engineering (laboratory)
2. Degree of competition, particularly the presence of small firms
3. Demand
4. Competition, particularly the presence of alternative technologies (the incandescent lamp)

Using radio as another case study, Maclaurin investigated the steps needed to bring a new scientific concept from the theoretical stage to a successful commercial product. He noted that none of the pioneering scientists (Maxwell, Hertz, etc.) were consciously thinking about commercial development, but that independent inventors such as Marconi took that role. Maclaurin also noted that none of the established large industries (AT&T, Western Union, Postal Telegraph) made any major contributions to radio in its early years. (The established companies were in the business of wired telecommunications, which radio would disrupt.) Maclaurin concluded that managerial skills and venture capital were essential to commercialize a breakthrough innovation based on a new technology. The initial scientific research was also essential, as radio depended on understanding the physics of electromagnetic transmission and electrical circuits. He noted that new discoveries were commercialized by "inventor-entrepreneurs" who were able to visualize the potential of the new technologies and not by established companies, whom he perceived to be more interested in buying up competition or taking prospective stakes in the new ventures. After a decade of gathering these insights, Maclaurin was able to propose a staged, sequential model of technological innovation that represents a continuum between pure science and application engineering. According to Godin (2008), Maclaurin's five steps and related metrics are:[29]

- *Pure science*: major contributions, classified by field, country, and over time; prizes, awards, and medals; budget; forecasts on commercial applications
- *Invention*: patents (major/minor); research workers (because they are correlated with the volume of invention); records of inventions by firms
- *Innovation*: inquiry over time, industry by industry on annual sales volume, productivity figures, investments for new/minor products and new firms/ established (great) corporations

vi A fluorescent light is a type of electric lamp that excites mercury vapor to create luminescence. Peter Cooper Hewitt patented the first mercury vapor lamp in 1901. It was preceded by the incandescent light bulb, which had many inventors but was first successfully commercialized by Thomas Alva Edison in the 1880s.

- *Finance*: number of new firms launched each year, their capital investments; new plant constructed
- *Diffusion* (which Maclaurin called acceptance): growth curves for a wide variety of products and services under different types of conditions, by region, between cultural groups; length of time required for mass acceptance

In the Post-WWII era, Maclaurin's steps evolved into what is now called the *Linear Model of Innovation*.

During the 1950s, Maclaurin changed his views on the role of large firms, upgrading the importance of large firms with their research laboratories for technological innovation. He devised a three-level nomenclature of technological progressiveness based on products and processes introduced between 1925 and 1950 and ranked the industries of his day as high (e.g., airplane, chemical, radio, and TV), medium (automobile, steel, paper), and low (food, cotton and textiles, house construction).

Maclaurin's work has been very influential in our understanding of technological innovation. He was able to analyze the process of technological innovation that Schumpeter did not cover, and he used historical insights and statistics to justify his findings (Godin 2008).[30] This process framework, which today is called the *Linear Model of Innovation*, has been very influential and it will be revisited in Chapter 10.

In the next section, the last innovation stage of diffusion will be examined in more detail, as diffusion is the most economically consequential of all the stages.

Diffusion and S-Curves

Diffusion is the third and last stage defined by Joseph Schumpeter in his description of how entrepreneurs change the capitalist economy. It is preceded by innovation (the middle stage) and invention (the first stage). For the entrepreneurial firm, diffusion is the stage where its innovation is successfully copied and imitated by competitors, which is not something most firms look forward too unless they anticipate strong network effects. For example, the first car makers benefited from the public buying cars from their competitors because that promoted the construction of roads, gasoline stations, and other infrastructure which made owning a car a better proposition. Today, the same is true for the electric vehicle (EV) ecosystem: While EV manufacturers compete for market share, they all benefit from a growing market for EVs, both because it drives down battery and other component prices, and because it creates a demand for more infrastructure such as charging stations.

For society as a whole, and the economy in general, diffusion is the most important stage where productivity benefits from new technologies become widespread enough to drive economic growth and prosperity. Policymakers are therefore keen to promote the diffusion of beneficial technologies. In fact, from a policymaker's point of view, diffusion may be the most consequential of Schumpeter's three stages. As Bronwyn Hall (2004) points out:

> Understanding the diffusion process is the key to understanding how conscious innovative activities conducted by firms and governmental institutions, activities such as funding research and development, transferring technology, launching new products or creating new processes, produce the improvements in economic and social welfare that is usually the end goal of these activities. For entities which are 'catching up,' such as developing economies, backward regions, or technologically laggard firms, diffusion can be the most important part of the innovative process.[31] (Hall 2004)

The diffusion of seemingly promising technologies can be frustratingly slow, and variations in the rates of adoption and acceptance can disappoint, especially when those organizations or countries that theoretically could benefit most from such technologies are the slowest to adopt them. Indeed, innovations based on new technologies do not get adopted instantly, nor is their adoption assured. Every potential individual or organization which is a potential user of the new technology has to be persuaded to adopt the technology, as well as any intermediaries such as dealers, service companies, and retailers. The economic calculation, as well as other factors that enter the adoption decision, is different for everyone. Also, different people are persuaded by different arguments.

That is why the diffusion of innovation has often been defined and described in sociological terms. The most well-known *sociological definition of diffusion* comes from Everett Rogers (1962, 5): "Diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system."[32] In this sense, communication is the process whereby information about the innovation or new idea is exchanged. Rogers emphasizes that diffusion is a type of social change that results in alterations to the structure and function of a social system. Rogers (1962, 10) also defined innovation very broadly as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption."[33] Note that the novelty is in the perception of the receiver and not objective.

According to (Rogers 1962, 20–21), there are five steps in the innovation-diffusion process:

1. *Knowledge*, when an individual (or other decision-making unit) learns of the innovation's existence and gains some understanding of how it functions.
2. *Persuasion,* when an individual (or other decision-making unit) forms a favorable or unfavorable attitude toward the innovation.
3. *Decision,* when an individual (or other decision-making unit) engages in activities that lead to a choice to adopt or reject the innovation.
4. *Implementation,* when an individual (or other decision-making unit) puts an innovation into use
5. *Confirmation*, when an individual (or other decision-making unit) seeks reinforcement of an innovation-decision that has already been made. (But this

previous decision may be reversed if exposed to conflicting messages about the innovation.)

Rogers (1962, 15–16) proposed that the spread of a new idea is determined by four elements: the innovation itself, the communication channels used, the passage of time, and the (prevailing) social system.[34] He also defined five analytic categories to classify the attributes that influence the potential adopters of an innovation:

- The *relative advantage* of the innovation
- Its *compatibility*, with the potential adopter's current way of doing things and with social norms
- The *complexity* of the innovation
- *Trialability*, the ease with which the innovation can be tested by a potential adopter
- *Observability*, the ease with which the innovation can be evaluated after trial[35]

Innovations are diffused sequentially through five types of adopters as can be seen in Figure 2.1:

1. *Innovators*, who are willing to take risks and typically have higher social status, means, and are in direct contract with the originators of the innovation
2. *Early adopters*, who are opinion leaders with higher social status and means
3. *The early majority*, who have above-average social status and are in contact with early adopters
4. *The late majority*, who are skeptical about innovations, have below average social status, and are in contact with the early majority and others in the late majority group. In short, they are followers
5. *Laggards*, who have an aversion to changes, and lower social status and financial means. In short, they are holdouts

The diffusion curve is usually represented as a normal curve, where the early and late majorities are within one standard deviation (34 percent) on either side of the mean, together representing 68 percent of the total population. The early adopters and laggards are beyond one standard deviation from the mean on either side. The laggards are the last 16 percent to adopt. The first 16 percent to adopt may all be called the early adopters for simplicity, but Rogers preferred to call the very first 2.5 percent the innovators and the remaining 13.5 percent the early adopters.

The cumulative adoption curve, representing the total percentage of the market penetrated as more and more units are adopted, is the well-known *S-curve of adoption*. The shape of the curve represents the observed tendency for adoption to start slowly, then to accelerate as it spreads through the potential adopting population, only to slow down at the end again as that population is saturated and holdouts remain. It represents the number of users of the innovation. The 50 percent cumulative

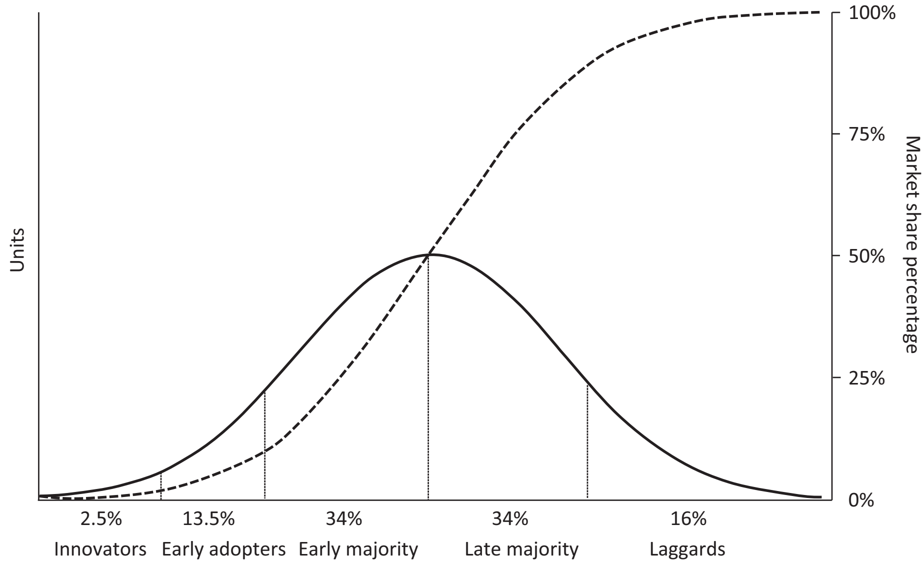

Figure 2.1: Innovation Diffusion: Adoption and Market Share.
Source: Based on Rogers (1962, 10).[36]

adoption point – where half have adopted the innovation and half have not – coincides with the mean of the adoption curve.[vii]

Rogers's book on innovation diffusion is one of the most-cited works on innovation of all time, which is a reflection of how influential his ideas on this topic have been.

The sociological approach to understanding diffusion and the adoption of innovations is, however, not the only school of thought on the matter. Economists, for example, have attempted to model the diffusion process as a *sequence of rational microeconomic decisions* rather than a sociological process. Potential adopters consider the costs as well as benefits of switching to a new technology. For example, for a new information-technology system to be used in business operations, the adoption costs may include one-time costs such as installation and the acquisition of new software as well as the time spent training workers on it. This is traded off against the anticipated efficiency gains from employing the new software when it is fully up and running. Such diffusion decisions are taken every day by business managers and by consumers. Examples of typical consumer diffusion decisions would be whether to upgrade to a 5G mobile phone or an electric car. In both cases there are costs and benefits to the new technology, but the electric car decision is far more consequential and requires a much bigger investment.

vii The normal curve is a symmetrical curve with equal areas on either side of its mean.

Other researchers have emphasized the *institutional context* in which entrepreneurs try to introduce their innovations into and the role that design can play in gaining adoption. Institutions are a social force for stability, while innovation is a social force for change. Institutional elements may hold up or delay adoption and diffusion of new technologies and should be addressed as part of any large-scale transformation. Hargadon and Douglas (2001) provide a detailed account of the introduction of Thomas Edison's system of electric lighting as a historical example of an innovative technology that gained widespread acceptance and an instructive example of how design can be used to gain acceptance and promote adoption. Edison cleverly designed his incandescent lighting system using many of the design features and cultural elements of the prevailing gaslight system with which consumers were very familiar. His electric lighting system was design to seamlessly replace the incumbent gaslighting system. He deliberately designed his system to utilize the gas burners and chandeliers already in use, running the electric wires through the existing gas pipe infrastructure. Edison even founded his illumination company in New York under existing New York gas statutes to gain legitimacy and afforded his operation the legal rights to dig up streets to bury copper wire rather than gas pipes. Everything was designed to mask the new electric lighting system within the trappings of the old gas system.[37]

> The *Gartner Hype Cycle* (2022),[38] which is popular with technology journalists and some executives, should not be confused with a diffusion curve. The Gartner Hype Cycle's vertical access represents *expectations* for the technology, as assessed subjectively by Gartner analysts, not percentage adoption of the technology as for a proper diffusion curve. The distinctive feature of the Gartner Hype Cycle is that it aims to illustrate the tendency for seemingly promising new technologies to be overhyped and that expectations for the technology prematurely rise too fast to reach a peak, only for the technology to then disappoint. That leads to a sharp drop of expectations as disillusionment with the technology becomes widespread. But after this "trough of disillusionment" steady progress with a maturing technology lifting expectations again as the technology proves useful and improves productivity. The Gartner Hype Cycle is good at telling a story, but it offers no new insight. Often, exciting new technologies will disappoint. It could end there as the technology is discarded, but in some highly publicized cases improvements to the technology do lead to its reputation eventually being restored as it becomes a productive new technology. It is at this point that the technology will enter widespread use and be widely diffused.

The S-curve of adoption in Figure 2.1 is the aggregate of the diffusion curve, reflecting the summary effects of initial slow adoption by only innovators and early adopters, rapidly accelerating adoption as the bulk of the population joins, and final slow adoption as the laggards join the others. The growth of an individual business relying on a single innovation (like a startup) may follow the same pattern: initially slow growth as the new business struggles to gain customers, accelerating growth as the business scales up to meet increasing customer demand, and then tapering to slow growth as the business is constrained by external demand or internal scaling constraints.

By some coincidence, the performance of successive technologies over time also follows an S-curve. It is important to differentiate between S-curves of adoption and S-curves of technology performance as these reflect entirely different underlying mechanisms and should not be confused with each other.

An illustrative example of three successive *S-curves of technology performance* is shown in Figure 2.2. The vertical axis represents the performance of the technology, and the horizontal axis represents the effort put into increasing the performance of the technology. In practice, the time worked on the technology is usually a good proxy for effort, though that is not always the case.

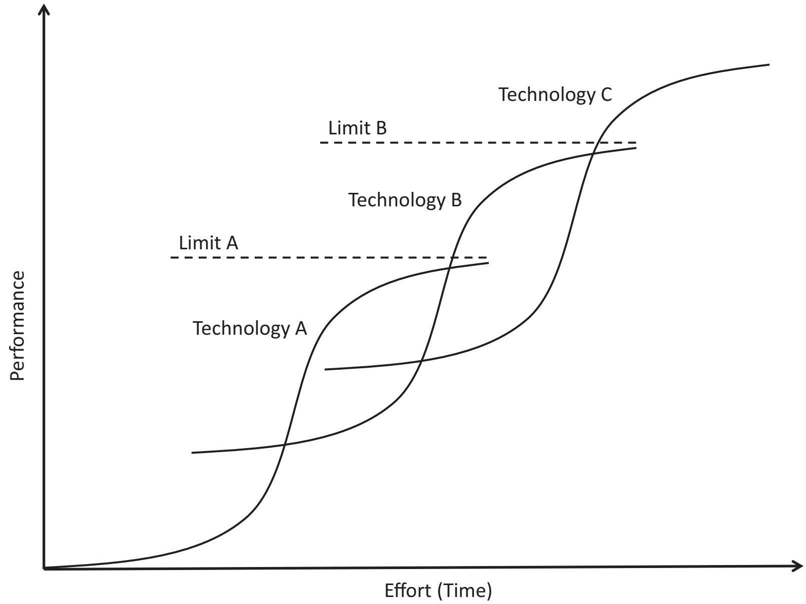

Figure 2.2: S-curves of Technology Performance.

Each S-curve has a lower portion as initially the performance of the new technology grows only slowly, and much time and effort have to be invested to improve it. This is also a time during which the design is held open while several exploratory improvements are tried out. Then comes a fast-growing middle portion when most of the major technical obstacles have been overcome, the design is being standardized, and the performance of the technology rapidly improves. Finally, as it matures, the technology starts to approach its *technological limit*, as increasing time and effort have to be invested to squeeze incremental performance gains out of it in the face of fundamental constraints to further progress. In the case of Technology A in Figure 2.2, the technological limit is Limit A, and similarly for Technology B. What usually happens is that the next technology, in this example Technology B, already enters R&D while its predecessor, Technology A is performing well because developers would plan ahead as they are aware of the limitations of each technology. If both technologies reside in a single company, and if the technology road mapping was done properly, the successor technology will have been mostly mastered by the time its predecessor is approaching its technological limit and be ready to take over from it.

Observe how during the initial development of Technology B, its performance is inferior to that of Technology A. This is typical because major technical challenges still need to be overcome before the successor technology is mature, even though it has the potential of being superior. Eventually, Technology B will become the dominant technology, but R&D of Technology C should also be started in time to eventually replace Technology B, and so on. Technical challenges that need to be overcome to make technologies mature, do not only include R&D challenges but also manufacturing challenges, sometimes distribution challenges (e.g., a drug that requires a new cold chain, as was necessary for the mRNA COVID-19 vaccinations), and potentially also support challenges (such as having to train auto technicians on fixing electrical cars).

The concept of a disruptive technology was proposed by Clayton Christensen in his famous book, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (1997).[39] Disruption can happen when a large and successful incumbent firm is fully invested in a technology that seems to be the best technology in terms of performance, and even in price per performance terms. The incumbent firm sells products made from the established technology (e.g., Technology A in Figure 2.2) to customers who have a strong voice in guiding the innovation efforts of the firm, while the company continues to perfect the technology through incremental improvements (the flattening part of the S-curve). It competes with firms who are also invested in Technology A and making incremental improvements to it.

New entrants innovating products with seemingly inferior technology (e.g., Technology B in Figure 2.2) start selling their products not to the incumbent firm's customers, but target a lower-end customer base who cannot afford the price point for Technology A. This is a new market which the incumbents are not serving. At the beginning, these new entrants seem like no threat because their products do not have the performance levels of the incumbent, and the price/performance is worse. Yet, the lower-end customer base is gaining value from Technology B as they can acquire it at a much lower price point. The lower-end customer base is typically much larger in numbers than the incumbent high-end base. The growing market for Technology B results in its rapid improvement, and eventually it surpasses the performance of Technology A. At this point, Technology B can disrupt the market for Technology A. The incumbent firm is now in serious trouble because it is facing competition that can meet or exceed its products in performance and beat them on price. Even if the disrupting products do not exceed the performance of the incumbent products fully but get close enough to it, that may be sufficient commercial reason for peeling off a large percentage of the incumbent's customers, given the attraction of the lower price.

Christensen used the example of small (5.25”) disk drives that were unwanted by the makers of minicomputers but found a rapidly expanding market in the new personal computers (PCs). The sheer volume of sales to the PC market enabled the disk-drive makers to rapidly improve performance to the point where they completely disrupted the incumbent disk-drive industry. The PC itself disrupted the minicomputer industry, which initially saw PCs as toys, but PCs then caught up with the much more expensive minicomputers in performance, destroying their business.

In closing, the full process of technological innovation does not happen in isolation, but it is an accumulation of knowledge capital beyond R&D. Adopting a new technology requires R&D but also the physical capital (tools and machinery) to make it, workers who are trained to operate machines, upgraded management skills to plan and run projects, a supply chain and logistics system, well-trained engineers and technicians, entrepreneurs who can take new concepts to market, and private-sector financiers to provide funding. Completing the process of technological innovation also often requires regulatory enablement and supportive public policies. As a simple example, Gigabyte internet speeds at offices and homes would not have been possible without providers being allowed by local authorities to dig up city and neighborhood streets to lay fiberoptic cables. (Innovation policy, with its various tools and instruments, is the subject of Chapter 12.)

Induced Innovation

The influential 20th-century British economist Sir John Hicks[viii] introduced the concept of *induced innovation* (Hicks 1948).[40] It has since become a foundational economic theory of technical change. According to this theory, changes in the relative prices of factors are expected to induce development and implementation of new technologies to use less of the relatively more expensive factors. For example, when labor becomes more expensive, firms will have an incentive (i.e., be induced) to come up with labor-saving innovations to keep the cost of production down. Or, if a particular raw material becomes more expensive, firms will innovate to use less of it while maintaining output. In both these examples, one could easily see how the rise in one factor price may lead to *induced technological change*: in the former through the introduction of labor-saving technologies and in the latter by revising the process or recipe to use less of the more expensive raw material.

It is, of course, also possible for the government to induce innovation by making a particular production input more expensive, or even banning it (e.g., banning lead in gasoline led to engine innovations). While government regulation may induce desirable innovations, it could also lead to unforeseen and potentially undesirable

viii Among his many accomplishments, Hicks summarized the Keynesian view of macroeconomics by devising the IS–LM diagram, which became a staple of undergraduate macroeconomics courses.

innovations. In the case of policies that increase the price of labor, such as minimum wage or benefits laws, opponents are quick to argue that it will lead to reductions in employment. (The minimum wage issue is still hotly debated, and beyond the scope of this book.) Government action on combatting climate change often reaches for policy instruments that are intended to induce innovation and changes to technology, for example, by specifying fuel-economy standards, subsidizing electrical vehicles and solar panels, or by taxing carbon emissions.

American agricultural economist Vernon W. Ruttan, in collaboration with his Japanese colleague Yūjirō Hayami, studied the processes by which technological adaptation results in increased food production and ultimately, how agriculture drives economic growth (Ruttan and Hayami 1984).[41] Their studies focused on the concepts of induced innovation and induced technological change, and they considered the cultural and institutional context in which technological advancement takes place, including cultural elements that may be hindrances to innovation. For example, farmers may resist mechanizing even though it makes economic sense because they are fond of their horses or water buffaloes, having grown up with them (Ruttan et al. 2011).[42]

Externalities, Complementarities, and General-Purpose Technologies

An *externality* is a cost or benefit caused by an economic agent that is not financially incurred or borne by that agent. A producer that causes environmental pollution is causing a *negative externality*. A scientific researcher that produces knowledge which is useful to other economic agents is causing a *positive externality*. The presence of both types of externalities provides a rationale for government intervention; in the case of negative externalities to impose a cost on the producer that would otherwise only be carried by society, and in the case of a positive externality to subsidize the activity as its benefit to society exceeds the benefit received by the producer alone. The government intervention is based on the principle that societal and private incentives should be more closely aligned either way.

A *technological spillover* is a type of externality where the initiating agent's innovation creates an opportunity for receiving agents to conduct further potentially profitable R&D. A *technological complementarity* arises in any situation in which the past or present decisions of the initiating agents – with respect to their technologies – have an effect on the value of the receiving agents' existing technologies and/or their opportunities for making further technological changes (Carlaw and Lipsey 2002).[43] A modern example of a powerful complementarity is how broadband internet connections made personal computers much more useful, in turn driving further technological advances in computing devices.

Only a handful of new technologies are powerful and consequential enough to drive growth throughout the entire economy. Relatively few technologies can impact a wide variety of sectors. Steam power in the 18th and 19th centuries, electrification in the early 20th century, automobiles in the mid-20th century, and digital computers in the late 20th century are prime examples of technologies with such breadth and magnitude of impact. Manuel Trajtenberg and Timothy Bresnahan (1995) coined the term *General Purpose Technologies (GPTs)* to describe such special technologies. GPTs have the following defining characteristics:

1. GPTs are by nature pervasive so that they spread into many sectors. That is because GPTs have many applications.
2. GPTs continue to improve (develop) over time in terms of performance, quality and continuously lowering the cost of their use.
3. GPTs enable the invention and innovation of a proliferation of subsidiary technologies and products that leverage the GPTs.[44]

A more rigorous economic definition of GPTs can be found in Bekar, Carlaw, and Lipsey (2018), who would add to the above definition that GPTs do not have close substitutes but have many *complementarities* – with the cluster of technologies that define and support them, with the cluster of technologies enabled by them, as well as technologies that end up being socially, politically, and economically transformative.[45] Consider, for example, how the internet has enabled ecommerce and social media, which have been economically and socially transformative, as well as politically.

Vernon Ruttan (2006) analyzed the development of major GPTs ("technology complexes" as he calls them) such as information technology, internet, nuclear power, and aviation technology and concluded that long-term, large-scale U.S. government defense spending was essential in developing almost every major GPT of the 20th century.[46] A discussion of the role of U.S. government spending in innovation will follow in Chapter 10.

Problems with Productivity Growth

Erik Brynjolfsson, Seth Benzell, and Daniel Rock (2020) acknowledge that despite major technological advances – such as digitalization and artificial intelligence – with enormous potential, the rate of productivity growth in recent decades has been disappointingly slow. This problem is known as the *Modern Productivity Paradox*. Brynjolfsson, Benzell, and Rock (2020) examined four possible explanations for the disappointing productivity growth, expounded as follows:[47]

– *The technology is insufficient*. The earlier IT-driven growth has fizzled out, and the recent 21st century innovations are not comparable with plumbing, mechanization, and electrification in terms of their transformational effect in the 19th and 20th centuries. Growth prospects could be drying up as some of the biggest innovations have already been made, and the rate of truly impactful innovations have slowed. Suggested remedies would be to increase research output and close the gaps between basic research and applied research.

- *New sources of economic activity are being undermeasured.* This is a favored counterargument by technology optimists in Silicon Valley. It suggests that digital goods such as search engines and social networks are being undervalued, or that prices in the digital space are simply being mismeasured. While there may be some mismeasurement, this has been true for past technological advances as well.
- *Rent-seeking*[ix] *and misaligned incentives.* According to this explanation, businesses have been innovating but in a way that have boosted private interests more than social interests. For example, by using technology to substitute workers with automation, private profits could have increased at the expense of societal welfare. One hypothesis is that due to poor incentives, firms are innovating to come up with technologies that are just better than human labor, but not so much better that they free up additional capital for complementary workers. (Previous labor-saving technologies such as automated teller machines in banking enabled complementary new lines of business that drove net increases in the total industry workforce.) Tax policies that subsidize capital over labor may be part of the problem. Another misaligned incentive is that current compensation schemes attract the brightest minds to zero-sum specialties in law and finance rather than science and engineering.
- *The economic gains are still to come.* The paradox is explained by the time that is still needed for complementary innovations to be developed and put into use. New technologies, especially general-purpose technologies (GPTs), will only have their full impact once the economy's processes have been reinvented and reconfigured so the new technology can be exploited to the fullest. This takes time and requires significant investments; many of which are intangible investments. This is the most persuasive explanation according to the three authors. The policy implication is that government should support an increase in the level of human capital needed to make this transition, as well as ample funding for R&D.

An analysis by the Organisation for Economic Cooperation and Development (OECD) found that the productivity slowdown is not caused by lower productivity growth at the global frontier (i.e., by the top players in each industry), but by an increasing *divergence in productivity* between the top global firms and the laggards (Andrews, Criscuolo, and Gal 2016). Thus, the expected economic gains are already there for the leading firms globally but have not yet been achieved by a long tail of laggards. The

ix Rent-seeking is an economic term referring to the process by which an individual or an organization seeks to increase their own wealth without creating any benefits to society.

root cause is likely that it is hard for laggard firms to master the new technologies, as they face increasing costs to switch from an economy based on manufacturing to one based on knowledge.[48]

Past transitions are also instructive. Paul David (1990) points out how the transition to another powerful GPT, electrification, a century ago was slowed by *legacy infrastructure*. Factory electrification did not come to full fruition and achieve its full productivity potential until the mid-1920s. Existing factory infrastructure was based on mechanical power generation from water and steam. It was unprofitable to replace serviceable factories based on the older technologies, which meant that the industries where there was more growth – with new factories being built – were the ones to adopt electrification faster. Retrofitting existing plants with electrical motors instead of steam engines did not achieve the full productivity benefits until unit-drive electrical motors replaced the older group-drive systems, which transferred power from one engine via overhead pulleys and belts to each workstation.[49]

A second accompanying factor is *generational acceptance:* The last generation of engineers adept at designing intricate power transfer systems with pulleys, belts, and many axels, had to make way for the first generation of engineers who grew up and was trained on the new electrical technology before widespread architectural changes in industry could be made. Third, the new technology may simply not be mature enough to fully replace the old technology. It should be remembered that the new technology is at the bottom of its S-curve when it is competing with an old technology at the top of its S-curve (see Figure 2.2). In the factory example above, it took a generation before electrical motors small, powerful, and reliable enough were available to power individual workstations.

Diego Comin and Martí Mestieri (2018) studied the cross-country evolution of technology diffusion over the last two centuries. They found that the contribution of technology to a country's productivity growth depends on two different parameters which can be discerned by studying historical diffusion curves:

- *Adoption lag*. This is the difference in time it takes for a technology to be adopted in a laggard country compared to the leading country and may be seen as a horizontal shift between the two respective diffusion curves. The faster new technologies arrive and are adopted, the faster the rise in aggregate productivity growth.
- *Intensity of use*. The more units of the new technology used throughout the economy, the more units of labor or capital will benefit from the productivity growth.[50]

Two important trends emerged from the extensive analysis by Comin and Mestieri (2018, 172), which involved 25 technologies and 139 countries over a period of two centuries. First, the adoption lags between countries have converged; that is, they narrowed. Second, the intensity of use of technology has diverged between rich and poor countries for technologies introduced recently. Their important conclusion is that differences in technology-diffusion patterns can explain a major part of the evolution of the world-income distribution over the last two centuries: "In particular, differences in the evolution of adoption margins in Western and non-Western countries account for around 75 percent of the income per capita divergence observed between 1820 and 2000."[51]

Productivity differences do not only occur between countries, but also within countries. In fact, national analysis can overlook widely divergent outcomes and increasing wealth disparities within countries. A McKinsey Global Institute analysis (Lund et al. 2019) of technological and labor market changes related to automation in the United States illuminates stark differences between high-growth cities and struggling rural areas. It highlights the importance of policies which make growth more inclusive.[52] Innovation policy and inclusive-innovation policy are discussed in Chapter 12.

In summary, there is a significant dispersion in productivity growth associated with innovation and new technologies between countries, regions, industries, and between firms in the same industry. Much of the disappointment with overall productivity growth can be ascribed to these differences. While leading companies, industries, and regions make the best use of new technologies, the large proportion of those who are left behind hold back the overall productivity growth. Therefore, the diffusion of productivity-enhancing technologies should be a top priority for governments at all levels.

Linking Innovation and Productivity Growth

The linkages between innovation and productivity have long been studied by economists, but several methodological hurdles exist. First, measures of innovation or innovative activity are incomplete. Typically, R&D spending and patent counts (an output variable) are used. However, both these metrics are more suitable for technological innovation related to manufactured products rather than services, processes, and other types of innovation. R&D spending is an easy metric to collect,[x] but it is an input variable that does not necessarily predict innovation success. Patent count is an innovation output metric but does not necessarily imply commercial success since only a few patents are for valuable innovations, and most patents have little value. Sometimes the number of patent citations is used as a metric, based on the notion that higher-quality patents are more frequently cited. Other

x There are, however, problems with R&D spending numbers because they depend on the reporting firm's interpretation of what should be classified as R&D, which may be influenced by tax considerations and a desire to track industry norms. Some industries are more R&D intensive by nature, which is reflected in national aggregates being higher for countries solely because they have a higher proportion of R&D intensive industries.

measures of innovation success are by necessity even more subjective; for example, experts are asked to rank the innovativeness of various new products. The OECD's Oslo Manual (2018)[53] has aided the measurement of innovation through standardized definitions of innovation in later (non-R&D) phases of innovation.

Bronwyn Hall (2011) surveyed the published empirical evidence on the relationship between innovation and productivity. She found an economically significant impact of product innovation on revenue productivity and a somewhat more ambiguous impact of process innovation. Given the available evidence, and in spite of the fact that innovative activity is not well measured in many cases, it would be fair to say that, generally, innovation will increase an individual firm's ability to derive revenue from its factor inputs.[54] A follow-up survey by Pierre Mohnen and Bronwyn Hall (2013) more definitively found that, based on the empirical literature on innovation and productivity, innovation leads to a better *productivity performance* – defined as better revenue-per-employee performance. It should be noted that some of the effect of innovation goes to real output, and some of it to the price at which the output is sold (revenue being the product of the number of units sold and the average per unit). Mohnen and Hall (2013) noted that, methodologically, it is hard to dissociate these two effects in the absence of good individual price measures.[55]

Another perspective on technological change is obtained by assessing *technology-improvement rates*. The improvement rate of a technology is presumed to be a significant indicator of the potential future importance of that technology. The field of research of technological change now has precise definitions of what technology is, how technology evolves, why technology evolves in ways that differs across sectors and countries, and how these differences affect economic growth differentials at these two levels. An analysis (Singh, Triulzi, and Magee 2021) mapped 97.2 percent of all U.S. patents into 1,757 technology domains and then predicted the improvement rates of each domain yields insights on which technological domains are most closely tied to economic growth: More than 80 percent of the technologies improve at less than 25 percent per year. The fast-improving domains are concentrated in only a few technology areas. The highest rates – even rates higher than the rate predicted by Moore's Law[xi] for semiconductor integrated circuits – are predominantly based in the domains of software and algorithms. The industries that are the traditional drivers of economic growth – automotive, energy, and healthcare – rely on technologies that have improved at slower rates than software technologies. The question is whether these industries will be able to adapt to the new software-driven world.[56]

xi Semiconductor pioneer Gordon Moore observed in 1965 that the number of transistors on a state-of-the-art microchip doubled about every year. Moore's Law became a proxy for the rate of increase of computing power.

Kondratieff Waves

Technological change does not seem to happen in equal measures over time, but instead humanity goes through apparent periods of rapid technological advances, followed by periods of less-rapid advances. This observation poses interesting questions about whether periods of rapid technological progress and resulting economic growth are randomly distributed, or whether there is a cyclical pattern to them.

In the 1920s, the Russian economist, Nikolai Kondratieff,[xii] proposed a theory that economic and major political events happen with a cyclic regularity. He believed that economists and policymakers needed to understand these cycles better so that they could make better economic forecasts and policies. *Kondratieff cycles* – also known as *K-waves, long waves*, or *major cycles* – occur over long periods, typically 50 to 60 years. Waves imply both up and down cycles; Kondratieff noticed that during the recession of a long wave, several important inventions would be made, which would then be applied at scale at the beginning of the next upswing (Kondratieff 1979).[57]

These long waves are quite different to the normal business cycle where the economy goes through an extended period of expansion (output growth) followed by a shorter period of negative growth (recessions) around every 7 to 11 years (Grable 2019).[58] Not all economists accept the existence of K-waves, but K-waves represent an intriguing hypothesis that major technological and demographic changes drive both long-term growth and historical events. As such, these long, technology-dependent waves are germane to the notion of successive industrial revolutions, each built on a new set of technologies.

Kondratieff was not the first economist to suggest the existence of such cycles as earlier economists in the Marxist tradition – and Karl Marx himself – had referred to long-term fluctuations related to investments in fixed capital. Kondratieff attempted to provide empirical proof of the existence of long cycles by analyzing the period from 1780 to 1920, which he divided into three long waves. He believed that technological inventions were concentrated in the downswings and that their large-scale application occurred during the following large upswings (Solomou 2017).[59] The three waves originally defined by Kondratieff himself, and the leading sectors in each of them, were:

1. The (first) *Industrial Revolution (1787–1842)* riding the development of textile, iron, and other newly mechanized industries. The mechanization of industry (e.g., cotton spinning) was initially water-powered before the adoption of steam power. The boom began in about 1787 and turned into a recession at the beginning of the Napoleonic Age in 1801 and, in 1814, deepened into a depression.

xii Alternative English spelling, Kondratiev.

The depression lasted until about 1827 after which there was a recovery until 1842.

2. The *Bourgeois Kondratieff (1843–1897)* as a result of the widespread steam power and railroad adoption in Northern Europe and America and the accompanying expansion in the coal and iron industries. The boom ended approximately in 1857 when it turned into a recession. The recession turned into a depression into 1870, which lasted until about 1885. The recovery began after that and lasted until 1897.
3. The *Neo-Mercantilist Kondratieff (1898–1935)* initially driven by electrification of industry, which lasted until about 1911. The recession that followed turned into depression in about 1925, which lasted until around 1935. The depression was eventually ended by the Second World War, at least in the United States. The war thus interrupted the normal cycle.

Subsequent K-waves were identified by other economists, following in Kondratieff's footsteps. A fourth Kondratieff wave – driven by motorization – started in the mid-forties and lasted until about 1974 when the oil crisis recession set in, with a recovery cycle starting in the mid-1980s or early 1990s. This was followed by the fifth and most recent Kondratieff wave driven, by computer and internet technologies, which also enabled rapid globalization. A future Kondratieff wave is predicted to start in the 2030s and will entail the merger of breakthrough medical technologies – such as biotechnology and nanotechnology – with the tail end of the information and robotics revolution – what Grinin, Grinen, and Korotayev (2016) call the *Cybernetics Revolution*.[60]

Angus Maddison (2007) relates how Schumpeter himself performed a voluminous analysis of long cycles, which today is considered statistically dubious but still highly informative because of Schumpeter's accompanying commentary that reveals his reasoning. Writing in the 1930s, Schumpeter attempted to explain the long waves he discerned in German, British, and American history. It is noteworthy that for Schumpeter depressions were a necessary part of the capitalist process, representing periods of creative destruction during which the old (products and firms) were destroyed by the new, and resources were freed up to become factors of production in the new industries. Schumpeter's long waves correspond remarkably closely to those identified by Kondratieff. According to Madisson (2007), the main weaknesses of Schumpeter's long-wave theory are that he did not explain why innovation and entrepreneurial drive should be cyclical rather than continuous; that Schumpeter's theory did not differentiate between leader and follower countries by assuming all would be affected simultaneously; and that Schumpeter exaggerated the scarcity of entrepreneurial ability and its importance as a factor of production.[61] The latter has also been a more general objection to Schumpeter's theory of entrepreneurialism.

Schumpeter developed a cluster-of-innovation version of the K-waves theory, whereas Kondratieff's waves were based primarily on discontinuous rates of innovation.

Each K-wave is therefore associated with a leading sector or technological system. For example, the third K-wave was associated with steel, electricity, and heavy engineering. The fourth K-wave was associated with oil, the automobile, and mass production. The fifth K-wave was associated with information and telecommunications technologies. And some predict that the sixth wave will be based on nano- and biotechnologies (Korotayev, Zinkina, and Bogevolnov 2011).[62]

Depending upon the researcher, GPTs and other technologies may be allocated to waves in a somewhat different order. There is ample observational evidence for the existence of long cycles, but they have not been fully proven and their causes are still debated. Kondratieff theory is therefore not an exact science and subject to judgment. For example, a longer list of technologies for the third and fourth waves with somewhat different timelines can be found in Ayres (1989).[63] These descriptions of what Ayres calls *technological transformations* are useful because they are more comprehensive and better illustrate the proliferation of new technologies that have driven rapid economic growth over the past one-and-a-half centuries:

– *The Third Technological Transformation* (1870–1890) – steel, coal-tar chemistry and color, petroleum, sewing machines and bicycles, internal-combustion engine, electric light and power, electrochemistry and electrometallurgy, telephone, automobiles, photography and moving pictures
– *The Fourth Technological Transformation* (1930–1950) – chemicals (petrochemicals, synthetic fibers, plastics, and pharmaceuticals), radio, television, and microwaves, solid-state electronics and computers, aircraft, and air transportation

Kondratieff or long waves, and their incorporation of technology development, are part of what is sometimes called neo-Schumpeterian growth theory within the endogenous-growth tradition (see next chapter). Schumpeterian thinking can be discerned in a description of the six life-cycle phases of each long techno-economic wave as originally defined by Freeman and Loucã (2001)[64] and summarized as follows by Köhler (2012):

1. *The laboratory/invention phase,* with early prototypes, patents, small-scale demonstrations, and early applications.
2. *Decisive demonstration(s)* of radical technical improvement and commercial feasibility, with widespread potential applications, creating excitement in society in general. The opening of the Liverpool and Manchester railway in Britain in 1830 is an outstanding example.
3. *Explosive, turbulent growth,* characterized by heavy investment and many business startups and failures. There is a period of structural crisis in the economy as society changes to the new organizational methods, employment and skills and regime of regulation, brought about in response to the new technology. This is a period of competition between alternative technological solutions and unstable economic behavior, characterized by booms and busts in the new industries.

4. *Continued high growth,* as the new technology system becomes the defining characteristic of the economy, with impacts on most if not all sectors of the economy. The "regulatory regime" is reconfigured to support the new technologies and industries' products.
5. *Slowdown,* as the technology is challenged by new technologies, leading to the next crisis of structural adjustment (with unemployment and social unrest).
6. *Maturity,* leading to a (smaller) continuing role of the technology in the economy or slow disappearance.[65]

(Köhler 2012)

Carlota Perez (2010) points out that "technology revolutions" (as she calls the transformations) do not take place in isolation, because innovation is a collective endeavor and process that increasingly incorporates many agents including suppliers, distributors, and customers. The clusters that Schumpeter described were a representation of techno-economic and social interactions between producers and users who weave complex dynamic networks. Major innovations induce other innovations, causing complementary innovations both upstream and downstream. Truly radical innovations stimulate whole industries. For example, television stimulated the rise of hardware industries such as receiving and broadcasting equipment; content industries in the creative realm such as film and music; and new advertising businesses, as well as retail, maintenance, and distribution activities. This type of *technology system* describes how the Schumpeterian clusters are formed. So, individual innovations are interconnected in technology systems. At a higher level, technology systems are interconnected in *technology revolutions*. A *technology revolution* is defined by Perez (2010) as "a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies; a cluster of clusters or a system of systems." A technology revolution can be distinguished from a random collection of technology systems by means of two features: First, a strong interdependence of interconnected participating systems in technologies and markets. Second, the capacity to transform the rest of the economy and eventually society.[66]

A fascinating recent analysis of U.S. patent data spanning almost two centuries (1840–2010) by Bryan Kelly et al. (2021) seems to support the idea of long technological waves.[67] The researchers identified breakthrough innovations and used these to construct technology indices that capture the evolution of technological waves over a large time span. (Text-based patent indicators were devised that are significant predictors of future citations, thus constructing a measure of patent significance.) The indices were found to be strong predictors of productivity both at an aggregate and sectoral level. The aggregate innovation index (number of breakthrough innovations per capita per year) was found to be a strong predictor of aggregate total-factor productivity, and it revealed three major technological waves:
1. The beginning of the second Industrial Revolution (1870–1880), associated with breakthroughs in electricity and transportation (railroads)
2. The 1920s and 1930s, associated with breakthroughs in chemistry yielding new plastic compounds

3. The post-1985 period, associated with breakthroughs in electronics, computers, and telecommunication and subsequently, in genetics[68]

The trajectory of the S-curve of performance (refer to Figure 2.2 above) represents a technical paradigm that includes improvements of technology over time, starting with a limited number of radical innovations that lead to initial success, and followed by numerous incremental innovations as the technology is perfected. Taking the example of the airplane, think of the radical breakthrough innovations in aerodynamics and propulsion made first by the Wright Brothers to literally get it off the ground in 1904, a subsequent proliferation of airplane designs in the first two decades (including biplanes and triplanes), and a later convergence of the airplane form toward the Second World War.

The Fourth Industrial Revolution and Society 5.0

While different authors divide previous and current industrial and technological transformations (or revolutions) into slightly different eras, there seems to be a general acceptance that such eras do in fact exist. Each era is characterized by a set of technologies that have enabled the technological and economic progress made during that era. We shall now proceed to discuss a classification of our current era that has gained widespread attention (if not acceptance) in recent years; that we are currently living in an era named the *Fourth Industrial Revolution*. (Industry 4.0 is a common synonym and 4IR is sometimes used as an acronym.)

The *Fourth Industrial Revolution* is the brainchild of Klaus Schwab, the founder and executive chairman of the World Economic Forum (WEF).[xiii] *The Fourth Industrial Revolution* (2017) is also the title of a book authored by Schwab to expound his theory.[69] In the initial article written to announce the idea, Schwab (2015) explained his typology of the successive industrial revolutions as follows:

> The First Industrial Revolution used water and steam power to mechanize production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution is building on the Third, the digital revolution that has been occurring since the middle of the last century. It is characterized by a fusion of technologies that is blurring the lines between the physical, digital, and biological spheres.[70] (Schwab 2015)

Schwab (2015) offers three reasons for why we are not living in an extension of the Third Industrial Revolution, but in a Fourth:

– The current breakthroughs are coming at much higher *velocity* than previous revolutions.

xiii The WEF is a not-for-profit foundation headquartered in Geneva, Switzerland.

- The *scope* is much larger, as it is disrupting almost every industry.
- The changes are having *systems impact* by transforming entire systems of production, management, and governance.[71]

Many technologies are considered to be part of this Fourth Industrial Revolution. They include mobile devices, the Internet of Things, artificial intelligence, robotics, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing. Schwab (2015) points to both powerful technological systems and the interaction between them as a defining characteristic of the Fourth Industrial Revolution. For example, exponential increases in computing power and available data have made possible both artificial intelligence (AI) and new drug discovery algorithms. Innovations that combine computers, materials engineering, and biology have the potential to transform healthcare as well as agricultural products.[72]

Schwab acknowledged the dark side of the Fourth Industrial Revolution in his original article, and more problems than he initially acknowledged have already emerged. Social media platforms can lower social cohesion and individual self-esteem as well as propagate extreme ideologies. Ubiquitous sensors and data gathering pose privacy concerns and provide authoritarian governments with new tools of oppression. The use of robots and other intelligent systems creates major ethical dilemmas as well as physical safety concerns (e.g., self-driving vehicles). The rapid technological advancements are displacing workers and driving inequality as the job market bifurcates into poorly paid routine jobs and well-paid knowledge jobs. Regional inequality is exacerbated as some regions – especially large metro areas – benefit disproportionality from the technologies while others – particularly rural areas and small towns – are left behind. All these problems create major challenges for public policymakers as they try to take full advantage of the productivity-enhancing features of the new technologies, while being mindful of the potential deleterious impacts on individuals and society.

There are differences of opinion on whether Schwab's Fourth Industrial Revolution is merely clever branding and good publicity, and whether we can even be certain that this period is distinct from the Third Industrial Revolution, which may still be ongoing. Another objection I would offer is that industrial revolutions are probably best classified when they are mostly behind us, like other major economic phenomena such as market bubbles. The utility of the 4IR concept to policymaking – despite many excited discussions – is not clear either. Would the policy implications of current and emergent technologies be any different if they were not named as part of a wave? On the other hand, 4IR has captured the popular imagination and has, at least, been helpful in drawing much-needed policy attention to the effects of the disruptive and transformative technologies of our time.

While Klaus Schwab announced the Fourth Industrial Revolution, a related paradigm emerged from Japan. Society 5.0 was put forward by the Government of Japan (2016) in *the 5th Science and Technology Basic Plan,* which was approved by a cabinet decision in January 2016. Notable about this government plan is that it not only contains a vision and plan for future industry but also for the accompanying social transformation, as well as addressing economic and social challenges. Sustainable growth, regional development, quality of life, and global development are all part of the plan.[73]

Since 1995, when it published the first *Science and Technology Basic Plan*, the Government of Japan has published new plans at five-year intervals. These plans are official science and technology policy documents (Government of Japan 2022).[74] Society 5.0 thus became an official innovation-policy goal. The commitment to the realization of Society 5.0 has continued in Japan's latest five-year plan, now titled the *Science, Technology, and Innovation Basic Plan* (Government of Japan 2021).[75]

According to Kayano Fukuda (2020), science, technology, and innovation (STI) ecosystems are subject to short-term shocks, such as economic bankruptcies and technological breakthroughs as well as to slowly changing long-term stresses, such as demographic changes and globalization. Japan's STI ecosystem was shocked by rapid ICT[xiv] development during the 1990s (e.g., PCs, internet, and mobile phones), which brought radical changes to the manufacturing industry and the business environment. These stresses continued in the 2000s as Japan's manufacturing economy was challenged by the move to software, services, and content. Japan is cognizant of the coming next round of shocks from AI and other technologies, which is why it is looking beyond Industry 4.0 to Society 5.0.[76]

Mayumi Fukuyama (2018) explains that the goal of Society 5.0 is "to create a human-centric society in which both economic development and the resolution of societal challenges are achieved, and people can enjoy a high quality of life that is fully active and comfortable."[77]

Society 5.0, which is starting in the 21st century, is characterized by Fukuyama (2018) as the "super-smart society" that follows four previous versions of human society, which were:

1. The *hunting society,* where humans lived in coexistence with nature
2. The *agrarian society,* where human settlements were established (around 13,000 BC)
3. The *industrial society,* initiated by steam power and characterized by mass production (end of the 18th century)
4. The *information society,* initiated by computers and characterized by the start of widespread information distribution (latter half of the 20th century)[78]

The definition of Society 5.0 according to the Government of Japan (2016) is:

> What is Society 5.0? It is a society that can be expected to facilitate human prosperity. Such a society is capable of providing the necessary goods and services to the people who need them

xiv Internet, computer, and telecommunications.

> at the required time and in just the right amount; a society that is able to respond precisely to a wide variety of social needs; a society in which all kinds of people can readily obtain high-quality services, overcome differences of age, gender, region, and language, and live vigorous and comfortable lives.[79] (Government of Japan 2015)

Society 5.0 and its enabling technologies have also been mapped to the UN's 17 Sustainable Development Goals (SDGs), making it a comprehensive innovation policy directed to most areas of human and environmental wellbeing.[80] The architecture of Society 5.0 contains a diverse set of 12 service platforms required to create this society, such as smart manufacturing, energy value chains, and inclusive healthcare systems. The service platforms will be developed by fully utilizing technologies such as the Internet of Things, big data, AI, and robotics (Shiroishi, Uchiyama, and Suzuki 2018).[81]

The apparent paradox between the goal of a truly human-centered society and the surrounding cyber-physical technologies, such as robots and artificial intelligence, has been commented on by researchers in the social sciences such as Matthew Gladden (2019). Gladden identifies multiple categories of prospective human and nonhuman members of Society 5.0 and demonstrates that all have analogues in earlier societies.[82] There is rich ground for further research on the evolution of human society alongside super-smart machines, but a further discussion of this topic is beyond the scope of this book.

Industry 4.0 is framed as a technology-driven revolution that is happening to society, and to which society has to adapt. On the other hand, the Japanese vision of Society 5.0 has a proactive goal "to realize a society where people enjoy life to the fullest" (Mayumi 2018).[83] The application of new technologies (e.g., digital transformation) is seen to achieve this goal. Another big difference is that Industry 4.0 is a concept advanced by a private nonprofit organization, the WEF, while Society 5.0 is an integral element of the official science, technology, and innovation policy of the government of Japan, a major industrialized economy.

Chapter Summary

- According to the *Linear Model of Innovation*, technological innovation starts with basic research which leads to invention, and then to innovation and diffusion.
- The *diffusion curve* models the adoption of innovations as having a slow initial phase with innovators and early adopters, followed by rapid adoption by most as the early and late majorities adopt the innovation, and then slowing down toward the end when only laggards are left to adopt.
- *General Purpose Technologies* are a handful of extremely powerful technologies, such as electricity and the PC, that can drive productivity growth in multiple sectors across the economy.

- The *Modern Productivity Paradox* is the apparent gap between productivity growth and the diffusion of powerful new technologies that are expected to increase productivity. A plausible explanation is that there is a significant dispersion in the adoption of new technologies between countries, regions, industries, and between firms in the same industry. This implies that the leaders are enjoying the predicted productivity gains, but the laggards are pulling the aggregate down. Policymakers nationally and internationally should focus their efforts on helping the laggards catch up.
- Kondratieff or long waves are based on the observation that major technological advances tend to cluster together during certain eras followed by other eras during which less progress is made. The concept of successive Industrial Revolutions is related to Kondratieff waves.
- Some believe that we are currently living during the *Fourth Industrial Revolution* (Industry 4.0), which is characterized by advanced technologies such as artificial intelligence, the Internet of Things, biotechnology, nanotechnology, and quantum computing.
- *Society 5.0* is a vision by the Government of Japan that entails building greater human prosperity using the technologies associated with Industry 4.0.

Suggested Exercises and Assignments

- Attempt to plot the diffusion curves of rising technologies, such as electric cars, residential solar energy, and intelligent robots, by obtaining actual data from industry or government sources. Contrast these diffusion curves with those of preceding technologies; for example, contrast 5G mobile phone with 4G mobile phone diffusion and discuss the reasons for the differences.
- Each student contributes a recent news article about a cutting-edge technology associated with Industry 4.0. Everyone shares their articles by posting a link with a one-sentence description ahead of class. Then, have a class discussion on each or some of the articles, discussing the implication of the technology for industry, society, and public policy. The student who selected the article is in each case responsible for leading and facilitating the discussion.
- Sketch a vision of a future public sector transformed by the innovative application of Industry 4.0 technologies. Discuss the practical implications for people, processes, organization, and governance.

Recommended for Further Reading

Kuhn, Thomas S. 1962 (2012). *The Structure of Scientific Revolutions*. University of Chicago Press.

Freeman, Christopher, and Luc Soete. 1997. *The Economics of Industrial Innovation*. 3rd ed. Cambridge, MA: MIT Press.

Gordon, Robert J. 2016. *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War*. Princeton: Princeton University Press.

Landes, David S. 2003. *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*. 2nd ed. Cambridge, UK: Cambridge University Press.

Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.

Schwab, Klaus. 2017. *The Fourth Industrial Revolution*. New York: Crown Business.

Chapter 3
Economic Growth and Innovation

It is important for anyone interested in innovation policy to have had at least an introduction to the key economic ideas and differing schools of economic thought that link growth to innovation and technological advancement. This is a very large area of study, and economists have written entire textbooks and countless papers just on the topic of growth. It is not the intent of this chapter – nor is it realistic given the space available – to exhaustively cover economic growth theory in all its complexity. But the introduction given here should equip the reader to better understand and analyze policy debates on what the government can and should do to encourage innovation-related economic growth.

The fundamental value of innovation to society is that it can improve living standards, which historically has happened through economic growth. In order to appreciate the contribution that technology and innovation make to national prosperity, the chapter will therefore start with an overview of how economists think about economic growth generally. Major data sources on economic growth will be introduced. In addition, the role that innovation plays in driving growth will be explored. As will become apparent, the contribution of innovation is caught up in a larger and continuing debate among economists over how growth occurs, what determines the growth rate, and whether growth can be maintained in the long run. The debate is not settled, and Nobel Prizes have been awarded to economists who have taken quite different positions on growth. The major schools, including neoclassical, endogenous, and evolutionary growth theories, will be introduced, and their respective implications for public policy will be pointed out.

The Nature of Growth Theory

Labor, capital, and land are the fundamental resources used in the production process and are accordingly called *factors of production*. (Capital includes buildings, machinery, and tools such as computers.) The *production function*[xv] expresses the relationship between the production output and the factors of production used to produce that output. If the increase in an input, such as capital or labor, results in a proportional increase in output, it is called a *constant return to scale*. For example, if a farm has one tractor and adding a second tractor doubles farm output, that is a *constant return to scale*. But it is more common to see the second tractor add to the

xv The most common production function in the economic literature is the *Cobb–Douglas production function*.

https://doi.org/10.1515/9783110711066-003

farm output, but not double it. And adding a third tractor will increase the output even less than the second tractor. This case – when increasing inputs leads to a proportionally smaller increase in output – is called *decreasing returns to scale*. The opposite case is *increasing returns to scale*, when an increase in input results in a larger proportional increase in output. Highly capital-intensive industries with few incumbent companies usually suggest increasing returns to scale. Examples are passenger-airplane manufacturing (an effective duopoly between Airbus and Boeing for large-bodied jets), shipping companies, telecommunication companies, and semiconductor foundries.

Growth theory in economics is concerned with changes in the *aggregate production function,* which is conceptually obtained by adding up all the production functions in an economy. The sum of the outputs of all the production functions in the economy is the gross domestic product (GDP), which is the sum of all goods and services produced in an economy over a certain period (usually one year). Economic growth is commonly defined as growth in GDP (percent increase per year, or per quarter). Growth theory comprises the study of how increases in factors of production drive increases in GDP, and how changes in the production function drive increases in GDP.

GDP is the modern measurement of the total size of the economy, which Simon Kuznets (Acting Secretary of Commerce 1934) proposed as a measure of national economic activity to the U.S. Congress during the Great Depression.[84] Subsequently, GDP came into worldwide use in the Post World War II years.[xvi] The conventional way economists think about living standards is that they are expressed as per capita wage income, output, or consumption. The commonly used measure is *GDP per capita*, that is, GDP divided by population size.[xvii]

Kuznets initially used the related, but not identical, term *national income*. Today, *gross national income* (GNI) is defined as gross domestic product plus net receipts from abroad of compensation of employees, property income, and net taxes less subsidies on production. This and other official international definitions may be found in *The System of National Accounts* (2008), which is the latest version of the international statistical standard for national accounts maintained by the United Nations.[85]

Productivity is a measure of how efficiently the productive capacity of an economy can turn factor inputs into outputs. Higher productivity is associated with higher

xvi Whether GDP and GDP per capita are the best measures of prosperity is questionable, because they do not account for inequality, nor negative externalities such as environmental damage, nor true enjoyment of life. For reasons of simplicity, the GDP measure of prosperity will be used for the purposes of this discussion.

xvii It is possible to have a high GDP per capita with a very unequal distribution of income between the population. Therefore, other measures, such as the *Gini coefficient*, are used to measure the inequality of distribution.

living standards. For example, if farmers manage to double the crop yield per acre or hectare on their farms (land being a factor of production), they will clearly be better off. It is usually assumed that improvements in physical equipment, as well as knowledge and expertise (human capital), can increase productivity.

A key productivity metric in the modern economy is *labor productivity*, defined as the output produced per the labor hours worked to produce that output. At the country level, labor productivity is simply GDP per total hours worked. In the United States, the Bureau of Labor Statistics (2022) publishes current and historical labor productivity data.[86] *Total factor productivity* (TFP), also called *multifactor productivity* (MFP), is the ratio of output to the combined factor inputs (labor, capital, energy, materials, and purchased services) used to produce that output. The Bureau of Labor Statistics (2022b) also publishes MFP metrics.[87]

A longstanding point of contention is whether growth is *endogenous*, that is generated from within the system; or *exogenous*, that is coming from forces external to the economy. The latter is more closely associated with neoclassical models of the economy. The main exogenous forces are either the savings rate or the rate of technical progress. Changes in the size of the labor force are also usually considered to be exogenous (depending on the model used). The contribution of innovation, knowledge, and human capital are given more prominent roles in the endogenous view of growth. These models will be discussed in more detail later in this chapter.

These are not mere academic questions. They are existential to the wellbeing of the population. If economic growth can continue to outpace population growth, as it has done in the major industrialized countries since the First and Second Industrial Revolutions in prior centuries, then there will be more output for everyone to share and consume. However, if economic growth cannot keep up with population growth, there will be less and less for the population to consume until many of them starve to death, which is the dystopian prediction originally made by Thomas Malthus (1798).[88]

It is easy to forget how fortunate we are today compared to generations past. Economic growth over the last two centuries has been exceptional compared to earlier centuries in human history when Malthus's theory seemed to be in full operation. Prior to 1800, living standards were stagnant for the vast majority of the population. Any increases in production led to population growth, not to an increase in the standard of living. An analysis of the English economy from 1240 to nearly 1800 AD (Hansen and Prescott, 2002) shows real wages were stagnant for most of the period, except for the period after the Black Death when the plague had wiped out enough of the population to make laborers relatively scarce for a while. After that, as the population recovered, wages declined again.[89]

But then, at the end of the 18th century, everything changed as labor productivity and – along with it – living standards started to rise. Between 1780 and 1989 English labor productivity increased by a factor of 22 at least (Hansen and Prescott 2002).[90] An analysis for the United States (Ferguson and Wascher 2002) shows a comparable rise of labor productivity of 2.2 percent p.a. average (about a factor of 17) for the later period between 1873 and 2003.[91]

It would not be an exaggeration to say that the welfare of our society depends on maintaining beneficial economic growth, and on accelerating such growth in low-income economies, where large parts of the population seem to still be stuck in the Malthusian trap.

Major Data Sources on Economic Growth and Wellbeing

A few reference works provide rich narratives and detailed data on the historical growth in the Western and world economy. The following references are highly cited and are recommended for research purposes:

- The OECD (2022) *Productivity Statistics* database includes indicators on labor productivity, multifactor productivity, and GDP per capita.[92]
- Angus Madisson (2003) extensively researched the development of the world economy over two millennia, using ingenious methods to estimate output for earlier eras for which no conventional statistics exist.[93] The University of Groningen, where Madisson was a professor, continues his work at the Groningen Growth and Development Centre, which maintains an online repository of his data, the *Maddison Historical Statistics* (2021).[94]
- The OECD's Development Centre has published Madisson's two greatest works as *The World Economy: Volume 1: A Millennial Perspective* and *Volume 2: Historical* (2006).[95]
- A related resource is the *Penn World Table, which* is the most widely used data source for international comparisons of economic output over time. It is maintained by the Groningen Growth and Development Centre at the Faculty of Economics and Business, University of Groningen, Netherlands. An introduction to the database can be found in a paper by Feenstra, Inklaar, and Timmer (2015).[96] As of writing of this book, the current *Penn World Table* (Groningen Growth and Development Centre 2022) is version 10.0, which contains information on relative levels of income, output, input, and productivity, covering 183 countries between 1950 and 2019.[97]
- An OECD research report, inspired by and building on the contributions of Angus Maddison's seminal work, *How Was Life? Global Well-Being Since 1820* (Van Zanden et al. 2014), goes beyond GDP to track country-level indicators of wellbeing such as life expectancy, personal security, and environmental quality since the First Industrial Revolution.[98]
- The importance of technological change to the rise of Western economies over the last couple of centuries has been documented by David Landes (2003) in his book, *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*.[99]

- *FRED Economic Data (2022)*[100] maintained by the Federal Reserve Bank of St. Louis is the primary aggregator of authoritative economic data for the economic community. At the time of writing, FRED offers 816,000 U.S. and international time series from 108 sources available for download, graphing, and tracking. FRED is free to use, and it has an intuitive online interface that facilitates rapid graphing of one or more data series.

Classical and Neoclassical Growth Theory

Adam Smith (1776) researched and wrote his famous work, *An Inquiry into the Nature and Causes of the Wealth of Nations*,[xviii] because he was intrigued by the question of why Britain seemed to have a higher standard of living than the continental European countries he had visited. Smith concluded that market competition allocates the existing stock of productive inputs to maximize wealth. Another proposition by Smith is that savings, which is the accumulation of capital over time, is the main process through which the stock of inputs will grow over time, thus enabling higher output. In short, *capital accumulation* is what drives economic growth. All classical and modern neoclassical economists subscribe to some version of this theory.

However, David Ricardo (and Thomas Malthus) pointed out that the returns to any particular factor of production, including labor, would diminish as its quantity increased relative to the quantities of other factors of production, such as land. For example, adding more laborers to a farm will increase its output, but each laborer added will increase the output less than the previous laborers added. This is called the *law of diminishing returns*. If this principle also applies to capital accumulation, it means that there are limits to the increase of output by capital accumulation, calling into question Smith's proposition. Because this would be a very unattractive conclusion, many economists have tried to modify the theory so that savings accumulation would retain a substantial role in economic growth. Most notably Alfred Marshall disputed the diminishing returns to accumulation, instead supposing that increasing returns may occur (Romer 1989).[101]

Thus, the classical growth tradition, starting with Adam Smith, holds that the long-run growth of the economy is *exogenously* determined and depends on savings, leaving no role for technological development or innovation. In an *exogenous model* of economic growth, technological progress occurs outside of the model. However, modern *neoclassical growth theory*, first advanced by later Nobel laureate Robert Solow (1956), ties economic growth to the rate of technological progress.[102] In Solow's model, the aggregate production function is a function of capital stock, total employment, and technology. But technological progress occurs outside his

xviii Often shortened to *Wealth of Nations*, but the full title better reveals Smith's research goal.

model and the processes it describes, which means Solow's neoclassical growth model is still an exogenous model. Solow's emphasis throughout is on capital accumulation as the main driver of growth in a capitalist economy. In this paradigm, public policy should be designed to promote increased savings and investment.

Like Smith, Solow argued that aggregate savings grow the capital stock of a nation. But Solow's theory allows for changes in the capital-labor ratio to play a role. An economy with an initially low capital-labor ratio will have a high marginal product of capital, and so investment in new capital will result in output increases that exceed capital depreciation. Over time the amount of capital per worker will rise (with constant returns to scale and fixed technology), so that the marginal product of capital declines, which in turn will lower the savings that can be invested in new capital until it becomes just enough to replace worn-out capital. At this point, the economy will be in a new steady state and standards of living will stop rising. However, if exogenous advances in technology kept on increasing the productivity of labor, the marginal product of capital need not fall as capital per worker rises. Therefore, technological advances could keep driving labor productivity so that capital stock will keep growing to keep up with the more efficient labor force (Grossman and Helpman 1994).[103]

In the Solow (1957) model, increases in knowledge are accommodated by a *shift* in the aggregate production function.[104] Adding this exogenous component of technological advances to Solow's growth model, which had growth only as a function of capital and labor, was in fact a clever way to fix the model because the pure labor-capital function was not good at all at explaining actual economic growth data. In the hard sciences, a model that fails to explain such a large part of the outcome variable is not considered a good model, but in economics one seems to be able to away with it by adding a "plug" that acknowledges a substantial portion of the outcome left unexplained by the postulated model. Given this remarkable statistical flexibility, the Solow model lent itself well to curve-fitting of actual data by a whole generation of economists. Solow received the Nobel Prize (1987) in Economic Sciences for his contribution to economic-growth theory.[105]

However, several predictions of the Solow model did not come true. A major departure from his predictions is that countries are not converging to a common level of GDP per capita because poorer countries would presumably grow faster. In fact, the growth rates of countries that are technological leaders are rising, not falling. Solow had assumed that all firms can access the same knowledge and use the same production technology. He thus totally ignored the process of technology diffusion (see Chapter 2), which is often a major reason for differences in economic performance between firms and countries.

Among other strong assumptions, the neoclassical growth models exemplified by Solow's model assume perfect competition, where price competition between sellers of identical products continuously drive down profits. It is intrinsically hard to find a place for innovation in growth models based on such assumptions. As explained in Chapter 1, one of the main rationales of innovation is that by differentiating its products, a firm gains the power to charge a price premium. The term *monopolistic competition* describes a midway point between perfect competition and pure monopoly. This is a world of imperfect market competition with many producers selling products that are somewhat differentiated from one another.

The model of monopolistic competition has room for innovation, and it should therefore not be surprising that Joseph Schumpeter assumed monopolistic competition as an assumption in his growth theory. Completely breaking with the classical tradition of his time which emphasized capital accumulation, Schumpeter believed that long-run growth depends on innovation. Growth-driving innovation comprise *process innovations*, which increase the productivity of the factors of production (labor or capital); *product innovations* such as new product introductions; and *organizational innovations* to increase the efficiency of production. Schumpeter also believed that innovations require investments such as R&D, skills training, and searching for new markets. Lastly, his paradigm of creative destruction entails that the latest innovations make old innovations, technologies, and skills obsolete. This also explains why innovation-led growth in countries, such as the United States in the late 20th century, is associated with higher rates of firm and labor turnover (Aghion and Festré 2017).[106] Many subsequent growth theorists have attempted to construct growth models that are more faithful to Schumpeter's philosophy.

It should be clarified that economists in the Schumpeterian tradition, such as Grossman and Helpman (1994), do not dispute that investment leads to growth. While they believe that the real force driving growth is advances in technology, they stress that it requires intentional investment in new knowledge by risk-taking, profit-seeking entrepreneurs to create advances in technology. The implication for policymakers is that such investments should be encouraged.[107] This distinction between relying on growth driven by passive capital accumulation (the neoclassical position) versus intentional investment by risk-taking entrepreneurs (the Schumpeterian position) has important policy implications either way.

Business cycles are assumed to be comprised of fluctuations in outputs, prices, employment, consumption, and investment. In the 1980s, economists coming from the neoclassical tradition postulated that business cycles are caused by changes in technology that change factor productivity. (Long and Plosser 1983).[108] What is now known as the *real business cycle (RBC) theory* sees business cycles as the result of exogenous shocks to the economy. Thus, real business cycle theory remains solidly within the classical tradition of treating innovation and technology advances as exogenous to its economic model. The RBC model has also been criticized by prominent neo-Keynesians such as Lawrence Summers (1986) for not providing sufficient evidence of large technological shocks.[109]

Public Goods and Technology

Before moving on to a discussion of endogenous growth theory, and the role that technological innovation plays in these models, it is necessary to briefly review some important economic terms that will aid in the understanding of this theory, especially within the policy context.

The term *public good* was introduced in Chapter 1. An economic good (including a service) can be classified on two attributes, the degree to which it is *rivalrous* and the degree to which it is *excludable*. Rivalry is purely determined by technology. A rival good used by one person or firm cannot be used by another, while a purely nonrival good may be used by a limitless number of persons with the use by one in no way limiting the use by another. Coastal lighthouses and over-the-air public broadcasting are examples of goods that are nonrival. Excludability exists if the owner can prevent others from using it. As such, excludability depends not only on the technology used but also on the legal system. For example, computer software may be made excludable by both technical measures that prevent copying or by legal measures. Most goods that we buy are both rivalrous and excludable. However, *public goods* are both nonrival and nonexcludable. For example, all citizens enjoy the defense against foreign invasion provided by the national defense system.

Goods that are rival but not excludable are subject to the so-called *tragedy of the commons*, a term originating from medieval times when land surrounding cities was common land, meaning that anyone was allowed to bring their cows or sheep to pasture. This resulted in land overexploitation and degradation. A more recent example is overfishing in national or international waters. Rival but nonexcludable goods require policies, laws, and international treaties to govern them for everyone's benefit. In a common example, public roads are rivalrous because the more vehicle drivers use them, the harder it becomes for the next driver to use them. This may necessitate measures such as direct exclusion (e.g., no vehicles with less than three passengers during certain hours); or road tolls that impose usage costs that will lower usage and thereby mitigate congestion.

Endogenous Growth Theory

Exogenous growth theories, starting with Adam Smith's original propositions and continued by neoclassical economists in modern times, assume that the causes of economic growth and, by implication, economic cycles originate outside of the economic system. Technological innovation as a cause is most relevant for the purposes of this book. However, other causes could be the growth and decline of natural resources including resource exhaustion due to climate change, demographic changes, and even wars and other political miscalculations.

Endogenous growth theory is the exact antonym of exogenous growth theory: It brings technological change that was left out of Solow's and other neoclassical models – which is why they are called exogenous growth models – into the growth model. According to the endogenous school of thought, technological change is a crucial driver of economic growth, not an external factor or add-on. This is closer to Schumpeter's thesis that innovation drives growth.

Since technological progress is accounted for inside the model, the fact that firms will invest in new technologies because they perceive new opportunities for profit can be accommodated. Investment is still important, but because it is investment that improves technology, not simply because it is capital accumulation. Here innovation is the primary engine of growth, not capital accumulation. However, firms cannot keep their successful innovations totally private, and some of the new knowledge spills out and is used by their competitors. This is a positive externality (a benefit) for society, but firms may underinvest in new technology and knowledge because they anticipate not keeping all the benefits to themselves, since new knowledge cannot be kept secret for long. In order to correct for the resulting underinvestment in R&D by the private sector, public policy should internalize the externalities by, for example, subsidizing R&D.

Paul Romer received the Nobel Memorial Prize in Economic Sciences for "integrating technological innovations into long-run macroeconomic analysis."[110] Romer introduced what is now called *New Growth Theory (NGT)*, a theory of growth where growth is endogenously driven by technological change. NGT is perhaps the most well-known, but not the only, endogenous growth model. In Romer's model, technological change is brought about by many intentional investment decisions made by a myriad of profit-maximizing firms. Like Schumpeter, Romer assumes monopolistic competition. In addition, Romer's model has as first premise that technological change drives capital accumulation, as in Solow's model. Romer believes that, taken together, *capital accumulation and technological change* account for much of the observed increases in labor productivity. The second premise of the Romer model is technological change happens because of the intentional actions taken by actors responding to *market incentives*. This premise is what makes the Romer model endogenous, and has a clear similarity to Schumpeter's views. Romer's third premise is that *technological knowledge* (defined as "instructions for working with raw materials") is by nature different in that once the cost of creating such instructions have been incurred, they can be used again and again at no additional costs. This makes knowledge development akin to incurring a fixed cost and is seen by Romer as a "defining characteristic" of technology (Romer 1990).[111]

According to Romer's third premise above, technology is a *nonrival input*. However, according to his second premise, technological benefits must at least be *partially excludable*, otherwise self-interested actors responding to the market would not make improvements in technology. Combining these insights with Romer's first premise implies that economic growth is driven by accumulating the partially excludable, nonrival input that technology is. Romer (1990) emphasizes the importance of building the stock of human capital in an economy since a larger stock of human capital will drive faster growth.[112]

The major policy implications of Romer's model are that a government subsidy to increase the accumulation of physical capital is inferior to direct subsidies that increase the incentive to conduct research and create knowledge, and that free international trade can speed up growth if it increases the national stock of human capital (Romer 1990).[113] Other policy implications are that in addition to financing R&D that creates knowledge, and subsidizing universities where knowledge is created and transferred to human capital, government should take additional measures to promote the creation of knowledge capital, such as protecting intellectual property rights.

The *Aghion-Howitt model* extends Romer's endogenous growth theory by adding the creative destruction process of new products making old products obsolete. *Obsolescence* means that scientific- research and innovation-driven growth creates losses as well as gains. In the model, growth comes only from technological progress, which in turn is the outcome of competition among the firms that generate innovations. Firms are motivated to invest in R&D by the monopoly rents (profits) they can capture when they patent a successful innovation. But then these rents are destroyed by the next innovation (Aghion and Howett 1992).[114]

In response to the 1990s revival of endogenous growth theory initiated by Romer, Solow (1994) questioned the assumptions made about how innovation will increase the output of the production function: If increasing R&D spending results in a proportionate increase in production output, the case for endogenous growth is easy to prove. However, if an innovation only generates an absolute increase in the production output, the greater R&D spend has only bought a one-time jump in productivity, which does not mean a faster productivity growth rate.[115]

While the newer endogenous-growth models that started with Romer – and are sometimes collectively referred to as *New Growth Theory* – claim to more closely reflect Schumpeter's legacy, they have been criticized as still being some distance from Schumpeter's original thinking on how economic development happens in practice (Alcouffe and Kuhn 2004).[116] This point will be further pursued below in the subsection on evolutionary growth theory, which aims to make a cleaner break with the earlier theories.

New Growth Theory has the important feature that it views technological progress as a product of economic activity. This *internalization of technology* is what makes it an endogenous-growth theory. The fundamental paradigm is that knowledge drives growth which holds promise in explaining today's knowledge economy. Knowledge has the important characteristic that it can be infinitely shared, copied, and reused. Because of this characteristic, knowledge is not subject to diminishing returns to scale. On the contrary, knowledge and the network effects associated with knowledge plausibly have increasing returns to scale. These *increasing returns* *to knowledge* can propel economic growth, and thereby resolve the original contradiction in Adam Smith's theory of growth. As Romer himself asserted:

> Ultimately, all increases in standards of living can be traced to discoveries of more valuable arrangements for the things in the earth's crust and atmosphere . . . No amount of savings and investment, no policy of macroeconomic fine-tuning, no set of tax and spending incentives can generate sustained economic growth unless it is accompanied by the countless large and small discoveries that are required to create more value from a fixed set of natural resources.[117] (Romer and Griliches 1993, 345)

This statement was made in 1993, before the full effect of the personal computer and internet revolution was apparent, and before mobile data and the Internet of Things. But the mere notion of increasing returns to scale from knowledge and technology is a major departure of traditional economic thinking that took diminishing returns to scale – whether land, labor, machinery – as a given. It is important to point out how deeply ingrained the notion of diminishing returns to scale is to traditional microeconomics: They result in increasing marginal costs – meaning that the cost of producing one more unit starts rising at some point. Decreasing returns and rising marginal costs are core assumptions in the general equilibrium models that economists use to describe how the economy will settle down.

Furthermore, the technological spillovers in endogenous models lead to increasing returns to scale at the aggregate level, even if production functions of firms have constant returns to scale. Technological spillovers make endogenous growth possible. But they do present a problem that policymakers have to deal with, which is that the social benefits of R&D exceed the private benefits at the firm level. This implies that individual firms will rationally underinvest in R&D, which creates an argument for the government subsidizing R&D (Verspagen 2005).[118] This topic will be further discussed in Chapter 10.

The accomplishment of endogenous growth models was that they put technological change at the heart and center of economic growth. This, in turn, created room for accommodating long-run growth trends in the models, as well as their accompanying policy implications. Endogenous growth models, such as the Aghion-Howitt model, are built on a dynamic general-equilibrium framework. They acknowledge Schumpeter's concept of temporary market power by containing a mechanism for product obsolescence, along with imperfect competition. And the R&D components of these models do reflect Schumpeter's thoughts on entrepreneurial risk and uncertainty. However, the continued reliance of endogenous growth models on classical concepts, such as rational agents and general equilibria, is still neoclassical in nature and in contradiction to a true evolutionary approach to economic development (Alcouffe and Kuhn 2004).[119]

Evolutionary Economic-Change Theory

Mid-19th-century economists took an early interest in Darwin's published work on evolution of species and natural selection. Darwin's ideas inspired Karl Marx in his formulation of the concept of class struggle and social evolution. Schumpeter, in turn, acknowledged inspiration from Marx's economic analyses but arrived at a different conclusion than Marx. Whereas Marx focused on class struggle, Schumpeter focused on the entrepreneur as the major source of creative destruction in the economy.

In the mid-1970s, Richard Nelson and Sidney Winter started to advance a growth theory which they identified as Schumpeterian in its interpretation of the process of technological change and how that drives economic growth. Their work was later more fully expounded in a noteworthy book, titled *An Evolutionary Theory of Technical Change* (Nelson and Winter 1982).[120] This book is the most highly cited work in the field of innovation policy. The reason for its prominence is that evolutionary economics provide an alternative to the neoclassical economics that is particularly useful in the field of innovation. The theory recognizes technological change and innovation as central to economic growth. It draws clear analogies with biology: new products and services developed by firms are akin to genetic variation; the development processes (which they call "routines") inside firms are akin to the self-replication mechanism of genes; and the market success or failure of innovations is akin to the natural selection process described by Charles Darwin.

Proponents of the evolutionary theory of economic change are of the opinion that Schumpeter-derived endogenous-growth models have not made a complete-enough break with classical thinking. The evolutionary models proposed are intended to be a truer reflection of Schumpeterian thinking on innovation's role in driving economic growth. Accordingly, Nelson and Winter (1982, 14) got rid of much of what they found objectionable in the neoclassical model, including "the global objective function, the well-defined choice set, and the maximizing choice rationalisation of firms actions." The two main mechanisms driving innovation in the Nelson-Winter evolutionary model are the *search for better techniques*, and *the market's selection of successful innovations*.

There is an important distinction between biological evolution as proposed by Darwin and the concept of evolution as applied to the theory of economic change. Biological evolution has two major steps: random variation and selection. The idea is that random variations occur in a species, and the superior random variations will survive by means of natural selection (survival of the fittest) and procreate themselves to become the dominant variation, with the others eventually dying out. In the evolutionary economic-growth model, however, the variations are not random at all but come in the form of deliberate innovations, which each innovator hopes will be superior to the competition. The selection is done by the competitive market, with only the most desirable innovations surviving because of their commercial success.

Thus, the selection mechanism is similar to Darwin's, but the variation mechanism is deterministic rather than random (stochastic).

Carlota Perez (2010) elaborates on the business-decision process inherent to the variation mechanism in evolutionary economics:

> The decision processes involved are not random. They are shaped by a context that includes relative prices, regulatory and other institutional factors and, obviously, the perceived market potential of the innovations concerned. They are also path-dependent, because market potential often depends on what the market has already accepted and because the incorporation of technical change requires the coming together of several preexisting explicit and tacit knowledge bases and various sources of practical experience.[121] (Perez 2010, 4)

Thus, the role of existing knowledge as well the incorporation of new knowledge in the form of technological advances are integral elements of the evolutionary model. While the evolutionary model shares its emphasis on knowledge accumulation with endogenous models, it provides a more nuanced, path-dependent view of knowledge accumulation. The notion that a market's or nation's starting knowledge is a determinant of the kind of technological innovation it can pursue has implications for innovation policy, particularly in developing countries.

Seeing variations as the result of deliberate attempts by entrepreneurs to come up with successful innovations is another area in which the evolutionary model differentiates itself from endogenous models. For example, the Aghion and Howitt endogenous model assumes by contrast that the outcomes to R&D are random (Aghion and Howitt 1992).[122] The importance of deliberate innovations implies that government could guide the path of innovation in an economy by adopting innovation policies that influence entrepreneurial investment choices.

The Demand Side of Economic Growth

The models of economic growth so far discussed, whether endogenous or exogenous, are all in essence supply-side models. This is fitting because technological innovation is inherently a supply-side phenomenon due to its impact on the production function. For completeness, a few brief remarks on the demand side of growth will be offered here.

The Keynesian and Neo-Keynesian approaches to economic growth focus on demand rather than on supply factors. In his analysis of the cause of the Depression, and what to do about the shortfall of economic activity that caused mass unemployment, John Maynard Keynes pointed the finger at deficient aggregate demand. Keynes (1936) took issue with the faith that classical economists had in markets always balancing and expounded his contrary position (which he called the "general theory"[xix]) in the famous book, *The General Theory of Employment, Interest, and Money*.[123] According to Keynes, uncertainty caused a breakdown of coordination between private sector spending and investment. Consumers did not want to buy products because they were unsure of being employed in the near future. But in aggregate, consumers are also workers who end up not being employed to make products that businesses are unsure of selling. The solution, according to Keynes, was for the government to step in to cover the shortfall in aggregate demand by directly spending public money (borrowed if needed). Government thus has the role of smoothing out the economic cycle by making up for deficiencies of demand in the private sector.

In the *General Theory*, Keynes (1936) coined the now-famous term "animal spirits" to describe the often irrational, yet fragile, optimism that drives entrepreneurs:

> Even apart from the instability due to speculation, there is the instability due to the characteristic of human nature that a large proportion of our positive activities depend on spontaneous optimism rather than mathematical expectations, whether moral or hedonistic or economic. Most, probably, of our decisions to do something positive, the full consequences of which will be drawn out over many days to come, can only be taken as the result of animal spirits – a spontaneous urge to action rather than inaction, and not as the outcome of a weighted average of quantitative benefits multiplied by quantitative probabilities.[124] (Keynes 1939, 161)

The arguments made by Keynes met with fierce resistance from the old guard during the Depression. To the extent that his ideas were first put into practice by spending on peacetime public-works projects, the magnitude of deficit spending was insufficient stimulus for the economies of the United States and United Kingdom. It was only when the World War II provided a different and more persuasive imperative for spending (i.e., a mission) that public spending rose to the levels needed to pull these economies out of the deep depression they were in. This is a deep and painful irony: With governments being too choosy about picking peacetime projects with sufficient returns, these economies were ultimately only sufficiently stimulated by spending on the war effort, the most destructive and wasteful spending of all.

From the innovation-policy perspective, the government stimulus of general demand in the economy is not that relevant beyond the point that a thriving economy with ample customer demand creates more favorable conditions for innovators who want to bring new products to market. However, there are specific government actions within innovation policy that can be considered demand-side instruments. For example, public-procurement programs that create a demand for new products and technologies are an important tool of innovation policy, as will be discussed in Chapter 12.

xix The term was inspired by Einstein's general theory of relativity – another case of an economist influenced by the natural sciences.

Another aspect where the insights of Keynes on the Depression is useful regards human capital. Keynes was not only concerned that unemployed workers represented a massive waste in productive capacity, but he also pointed out that the skills of the unemployed will atrophy. The maintenance of human capital, therefore, is another rationale for the government to maintain a healthy level of aggregate demand in the economy.

A Preview of Public Policy for Innovation-Led Economic Growth

In the classical tradition, the rationale for public-sector funding of innovation is limited to situations in which there are market failures,[xx] particularly where research that expands basic knowledge that is a public good would not be undertaken by the private sector. Early-stage research that will result in the general advancement of knowledge without particular applications immediately being apparent is considered by most to be a market failure worthy of public funding.

However, in practice, public-sector funding also frequently extends beyond cases associated with market failures. An example of one such area is where the state envisions new areas in which the nation has to invest; for example in biotech, quantum computing, or the next generation of semiconductors. This suggests a role for the state in anticipating economic growth and competitiveness trends, and putting the nation on a path to take advantage of the technologies of the future.

Schumpeterian insights matter greatly to growth-policy design in the context of an innovation-led economy. Philippe Aghion and Agnès Festré (2017) point out that to apply these insights requires more than just a liberalization of markets but an investment in the knowledge economy and a more strategic role for the state. On the one extreme, they believe that the old late-20th-century concept of a welfare state is not well-suited for an economy which needs to grow through innovation. On the other extreme, the minimal state is not the solution either. Instead, they call for a *strategic state*, which smartly reconciles the need for growth with budget constraints. This requires proper governance, both of the sectors that the state invests in, and of the state's own investment choices (Aghion and Frestré 2017).[125]

According to New Growth Theory, economic growth comes from increasing returns to labor and capital by using new knowledge (in the form of technology or process). Knowledge does not behave like ordinary economic goods. It is nonrival and partly excludable (e.g., through patents or trade secrets). The need for government

xx In general, a market failure is when a market fails to deliver the efficient allocation of resources that we would normally expect from a market, in accordance with the laws of classical and neoclassical economics.

intervention arises from markets failing to produce enough knowledge because innovators are unable to capture all the gains from the new knowledge they create. Knowledge can be infinitely reused at zero marginal cost. The development of knowledge-based economies is shaped by history, institutions, and even geography. Institutions can set the conditions and shape the environment for the generation and application of new knowledge. Historical returns to knowledge generate positive feedback loops that lock in the advantage of technologies and particular geographical locations. Silicon Valley is a prime example of this. Since NGT emphasizes the importance of investing in new knowledge-creation to economic growth, but also emphasizes the importance of institutional factors and the possibility that the private sector may underinvest in new knowledge, it underlines the need for the public sector not only to invest, but also for policymakers to help create conditions favorable to knowledge creation and sharing (Cortright 2001).[126]

In an insightful comment, Joseph Stiglitz[xxi] (1994, 2) points out that the causality between economic growth and innovation goes in both directions: "fluctuations in economic activity not only cause fluctuations in innovation, fluctuations in innovation may give rise to fluctuations in economy activity."[127] Depending on the conditions, this feedback loop between innovation and economic activity may result in multiple steady states (equilibria). Since the free market left to itself may not choose the best among all these possibilities, this creates a role for government financing and innovation policy – topics which will, respectively, be covered in Chapters 10 and 12.

Chapter Summary

- Labor, capital, and land are the fundamental inputs used in the production process and accordingly called factors of production. The production function transforms the factors of production into output, based on a given technology. The aggregate production function is the sum of all production functions in the economy.
- Productivity is measured by how much output can be produced with a given amount of factor inputs. It was a technology-driven rise in productivity that lifted many people out of poverty across the last two and a half centuries.
- Total economic output is measured by GDP. GDP per capita is an approximate measure of living standards, though it does not account for inequality in the distribution of income.
- Modern neoclassical growth theory acknowledges the role of technological progress but considers it an exogenous (i.e., external) influence on the aggregate

xxi A Nobel laureate, Stiglitz received his Nobel Memorial Prize in Economic Sciences for his analyses of markets with asymmetric information, not for work on economic growth.

production function. The theory assumes perfect competition and that all technological knowledge is available to everyone. It concludes that capital accumulation to fund additional productive capacity is the route to economic growth.
- The neoclassical model's predictions of income convergence between poor and rich countries have not come true, instead the divergence between per capita incomes has increased in recent decades.
- Endogenous growth theory incorporates technological change within the growth model. Innovation, not capital accumulation, is the primary engine of growth as countless investment decisions made by individual entrepreneurs to improve production technology led to growth. Romer's New Growth Theory is the most prominent, but not the only, endogenous growth model. It emphasizes the benefits of direct government support for knowledge creation, which will drive growth.
- Nelson and Winter's evolutionary economic theory is closest to Schumpeter's views of innovation as a force of creative destruction. Modeled on biological evolution, but with intentional variation through innovation, it sees the market as the selection mechanism that ensure the propagation of the best innovations. Entrepreneurial decision-making on which technologies and innovations to pursue determines the path of innovation, and could potentially be guided by appropriate government policies.

Suggested Exercises and Assignments

- Analyze recent arguments used by politicians who are advancing various elements of industrial and innovation policy. Identify which of their arguments are influenced by exogenous versus endogenous growth beliefs.
- Discuss the differences in tax and industrial policies that would arise from the government embracing endogenous versus exogenous views of growth.
- Select a fast-growing industry that is highly dependent on technological advances (e.g., the smartphone industry). Use the evolutionary model to explain the growth of that industry, as well as changes in the industry ranking of individual firms over time.

Recommended for Further Reading

Acemoglu, Daron. 2009. *Introduction to Modern Economic Growth*, Princeton: Princeton University Press, 2009.

Hospers, Gerrit J. 2005. "Joseph Schumpeter and His Legacy in Innovation Studies." *Knowledge, Technology, & Policy* 18, no. 3: 20–37.

Nelson, Richard R., Giovanni Dosi, Constance E. Helfat, et al. 2018. *Modern Evolutionary Economics: An Overview*, Cambridge, United Kingdom: Cambridge University Press.

Verspagen, Bart. 2005. "Innovation and Economic Growth." In Fagerberg, Jan, David C. Mowery, and Richard R. Nelson, *The Oxford Handbook of Innovation*: 487–513. Oxford: Oxford University Press.

Recommended Data Sources

Bureau of Economic Analysis, Gross Domestic Product, U.S. Department of Commerce. Current release with detailed tables can be found at https://www.bea.gov/data/gdp/gross-domestic-product.

The *Penn World Table* is the most widely used data source for international comparisons of economic output over time. It is maintained by the Groningen Growth and Development Centre at the Faculty of Economics and Business, University of Groningen, Netherlands. An introduction to the database can be found in a paper by Feenstra, Inklaar and Timmer (2015).[128] As of writing of this book, the current Penn World Table is version 10.0, which contains information on relative levels of income, output, input, and productivity, covering 183 countries between 1950 and 2019. It can be found at https://www.rug.nl/ggdc/productivity/pwt/.

Van Zanden, Jan Luiten, Joerg Baten, Marco Mira d'Ercole, Auke Rijpma, Conal Smith, and Marcel Timmer. *How Was Life?: Global Well-Being since 1820*. OECD Publishing, 2014.

Additional data sources were provided in on pages 50–51.

Chapter 4
People, Creativity, and Organization

This chapter is dedicated to the "soft" side of innovation management. As such, it focuses on people, creativity, and organizational challenges. It will show how people can cooperate in teams to come up with creative solutions to valuable problems, despite challenges. Proven processes for how to innovate solutions that have true value to the end customer, despite the inherent uncertainties, will be explained. The "hard" side of innovation management – strategic frameworks, project stages, and operational processes – will be primarily covered in Chapters 7 and 8.

The creativity needed to come up with useful new ideas relies on novel connections being made in human brains, and on people having the courage to share their ideas. A quick introduction to the modern neuroscience of creativity will help readers gain an understanding of how the human brain perceives creativity and what the typical barriers to creativity are. Techniques for breaking barriers to creativity will be introduced, and some major techniques will be explained. The importance of crafting proper problem statements and combining insights from multiple sources will be explained.

Design thinking, which puts humans and their needs at the center of the innovation process, will be introduced, along with how properly crafted problem statements and combining insights from different sources can yield effective solutions to real user needs, thereby creating value and meeting mission objectives.

Innovation is not a solitary occupation but depends on people working together in some form of organizational setting. The century-old history of the efficiency paradigm that often inhibits innovation in organizations will be related, followed by a discussion of major theories of motivation, which have implications for the recruitment and management of innovation teams. The fundamental organizational challenges of accommodating both creativity-dependent innovation and efficiency-orientated operations within one organization and under one leader will be explained, as well as the latest thinking on how this challenge may be overcome. Special innovation organizations and their relationship with the parent company will be explored, as well as why they often fail, and what questions should be asked when they are designed. Lastly, the roles that people with different profiles need to play on innovation teams, and what it takes to nurture a culture of innovation will be discussed.

Creativity and the Human Brain

Creativity in business has been much in vogue the last couple of decades. No doubt it is partly influenced by the ascendancy and prevalence of the design-thinking movement since the turn of the century, and the importance which creativity has in

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that process. But it is perhaps also because there is a belief that human creativity is now better understood and, therefore, can be more easily marshalled. Advances in neuroscience, largely enabled by new brain-imaging technology and accompanying popular media articles touting insights into the workings of the brain, have put creativity on the business agenda. Almost every month, the *Harvard Business Review* publishes some piece that has creativity in the title or subtitle. Some of the neurological-research insights (Waytz and Mason 2013)[129] that have made their way into the management lexicon are:

- The value of unfocused free time for coming up with breakthrough insights. For example, Google reportedly allows engineers to work 20 percent of their time on anything they want.
- The effectiveness of nonfinancial incentives and rewards, such as praise and recognition, and intrinsically interesting work in stimulating innovation.
- The potential usefulness of hunches and emotional impulses in decision-making, which makes them worth exploring instead of outright dismissing them as subjective.
- The importance of focusing on one task at hand rather than multitasking (juggling multiple activities and objectives).

Much lip service is paid to the importance of creativity in business. Creativity is, of course, an important element of innovation, and the business media love to feature stories about creativity and innovation. But in reality, there is a deep built-in reluctance in organizations to be truly creative and innovative. Indeed, we have all experienced how people can resist creative and novel ideas. Most of us have likely done it ourselves when we said, “That is a good idea, but here is why it won’t work.”

Despite the value that people seem to attach to creativity, they also have a paradoxical tendency to reject creative ideas. Research has shown that people associate creativity and novelty with uncertainty, and that a negative bias against creativity occurs when uncertainty is perceived, interfering with their ability to properly judge the creative idea offered (Mueller, Melwani, and Goncalo 2012).[130] In addition, people also implicitly associate what is proven with what is practical. If something has already been done, it is considered practical. If something has never been done, it is considered impractical. These two associations – creativity with uncertainty and unproven with impractical – together explain why new ideas are often rejected. Managers who would like to encourage creativity need to find ways of helping their team members to cope with the anxieties associated with uncertainty and doing things in new ways.

In the last decade, there were close to a thousand published studies on the neuroscience of creativity. Such studies typically rely on accessing the creative task performance of test subjects by means of brain imaging technologies such as functional magnetic resonance imaging (fMRI) and electroencephalography (EEG). These imaging technologies still impose major experimental constraints – for example, requiring subjects to lie down while they think creative thoughts. Nevertheless, these have proven to be powerful tools and neuroscience researchers have gained a deeper understanding of what it takes to put the brain into a creative mode for the purposes of innovating as neuroscience researchers. Neuroscientists Andreas Fink and Mathias Benedek (2019) explain the mental process of innovation as follows:

> For example, envisioning possible improvements to products, requires memory processes to build novel representations of these products, sustained internally-oriented attention to guide active imagination, and vigorous executive control to realize effective and useful task solutions by evaluating/elaborating preliminary thinking results, and by inhibiting prepotent/conventional responses.[131] (Fink and Benedek 2019, 3)

In simple terms, this means that would-be innovators can get more creative about their product offerings if they frame these offerings in new and different ways, employ techniques that guide their creative thinking, and constantly guard against jumping to conventional solutions.

An important insight about the human brain is that it often optimizes for efficiency, which in many instances is the enemy of creativity. The human brain comprises only about 2 percent of body weight but uses 20 percent of energy consumed while the body is at rest. Researchers estimate that the human brain has about 86 billion neurons. For comparison, a cat's brain has only 250 million neurons and a chimpanzee, 7 billion (Cherry 2020).[132] Regardless of its exact number of neurons, the human brain is clearly a marvelous organ capable of outstanding intellectual feats at higher efficiencies than any current computer can approach. But even so, it is subject to constraints imposed by its size and energy-consumption budget.

About two thirds of the brain's energy is used to help neurons (or nerve cells) fire or send signals; the remaining third is used for housekeeping (Swaminathan 2008).[133] In its attempt to avoid wasteful thinking that consumes unnecessary energy, the brain takes shortcuts and makes assumptions all the time. An eerie insight from contemporary neuroscience is that what we perceive as our conscious reality is actually a type of elaborate virtual-reality simulation (some call it a "controlled hallucination") constructed by our brains. Perception is a series of guesses by the brain, a reconstruction of reality. Put another way, perception is not a window on reality as it is, but more like a 3D desktop on a computer that is designed to hide the complexity of the real world and guide our adaptive behavior (Seth 2021).[134] We literally live our entire lives in a virtual reality created by our brains. If the brain gets it more or less right, this virtual reality is useful to us. If it doesn't, we can make surprisingly big errors in judgement. Stage magicians have always understood this instinctively, which is how they manage to trick their audience by distracting them and making the audience "see" only what the magician wants them to see.

Breaking Barriers to Creativity

The more you know about a topic, the more your brain's efficiency will become a barrier to seeing things differently. Experts can be the most intransigent and resistant to innovation because they have such strongly formed and well-practiced constructions of what they believe to be the correct reality. Experts feel that they have "seen it all before" and tend to think they already know the answers. They are also fond of *conventions* – well-established ways of doing things – because their conventions have served them well across their careers: "It's just the way we do things." *Shortcuts* are closely related – they are quicker and more efficient ways of doing things that people have done before, typically many times. Shortcuts are efficient, and therefore useful. However, when people take shortcuts, they are not fully applying their minds.

Young children are more disposed to creativity than most adults. As we further our education, we are trained well in asking the "What," "Why," and "How" questions. But we stop asking one question that young children ask all the time: "What If?" For example, "What if I could fly?", "What if I could make myself invisible?" or "What if my dog/cat/teddy bear could talk?" "What If" questions have the marvelous ability to transport us from the familiar world of what is to the unfamiliar world of what could be. For adults to become creative again, they need to revive their childlike ability to ask "What If" questions.

In order to get well-trained brains out of conventional mode and into creative, innovative mode, they need to be jolted. Such jolts come in a couple of categories, but they both involve *perception* – what people perceive. *Changing perspective* to look at the same things in new and different ways is one way to jolt the brain out of the rut it is in. Techniques include leaving the office to spend a day in the customer's shoes. Another way to jolt the brain is to present it with a strong dose of *new information* – strong in the sense of almost overwhelming it. That is why it is said the travel broadens the mind. Indeed, going on a trip to a place where things are done to different rules can deliver an inspirational jolt to the brain.

Coming up with creative ideas is only one half of the battle. The other half is to overcome the organizational resistance that creative ideas encounter all too often and that kills them in their infancy. While people like to think of themselves as open-minded and welcoming of creativity, they often resist creative ideas when these are actually presented to them. This *bias against creativity* has been confirmed in psychological studies and shown to be closely associated with the human desire to reduce uncertainty (Mueller, Melwani, and Goncalo 2012).[135] The bias against creativity is not overt, which makes it tricky to address. It lurks in the background, interfering with our ability to recognize the value of a creative idea.

Much of our resistance comes from our inability to see novel ideas as practical – we have a strong association between proven and practical and conversely, a strong association between novel and impractical. Indeed, innovators are often told by naysayers that while their idea is certainly novel and deserves to be applauded for its originality, it is unfortunately not practical and cannot be implemented successfully.

There is a social norm that requires us to value creativity, so people hide their opposition to creative ideas. They cloak their objections in other terms; with concerns about the lack of practicality of the novel solution being the most frequent tactic. This poses a great contradiction: Organizations say they want creative solutions, but frequently reject creative ideas when they are presented. Innovators need to pay just as much attention to getting organizational buy-in for their ideas as coming up with the ideas in the first place.

The good news is that any individual, or any team, can be creative. It does not require special talent or innate abilities. Fairly simple techniques can unleash creativity in people at all levels of seniority, from the most senior executives to entry-level workers. In order to unleash the creativity of a team, people first need to be given permission to be creative. That may require a special occasion and a safe space, as well as an introductory talk by a senior leader telling them that the organization needs their creativity to solve real and valuable problems. Then, people need to be taught and walked through some creative exercises, ideally by a facilitator who has experience with the exercises and can help keep the session on track when people get stuck or veer off on a tangent, which will inevitably happen.

There are an almost infinite variety of creativity techniques, some more suitable for some types of problems and situations than others. Below, only a few types of proven techniques will be introduced and the principles behind them will be explained. This list is far from complete; there are many existing variations of the techniques in the list and all lend themselves to tailoring to the situation, as well as further modification.

For a comprehensive resource on innovation and creativity techniques, the reader is referred to *The Innovator's Dictionary: 555 Methods and Instruments for More Creativity and Innovation in Your Company* (Buchholz and Aerssen 2020). This voluminous compendium details a full 555 techniques. It provides explanations of all the methods, and step-by-step instructions for each technique.[136]

Overthrowing Orthodoxies

An orthodoxy is a deeply ingrained belief about the way things are or how things should be done. For example, the pre-Copernican belief in Medieval Europe that the earth was at the center of the universe was a powerful orthodoxy that impeded progress in astronomy. This orthodoxy had to be challenged and overthrown for scientific progress to be made.

We saw how resistance to creativity has deep roots in an attachment to the conventional way of doing things. An orthodoxy-breaking technique works on the principle that the often-unsaid assumptions which support the conventional thinking must first be brought out into the open where they can be challenged. Step 1 is, therefore, to explicitly document all the core beliefs behind the conventions. Step 2 is to look at these core beliefs skeptically, asking whether they are even true anymore. Step 3 is to look at the core beliefs that might still be true, but could be overtaken by events, and ask what would happen if they were not true anymore.

An orthodoxy can also look like a simple assumption. For instance, up until recently everyone assumed that restaurants would have menus and that the customer would always receive a hard copy from their server. Recent trends in digital-only menus, accelerated by the hygiene concerns of the COVID-19 pandemic, have led to the abandonment of printed menus in many restaurants in favor of scanning a QR code that links to the restaurant's online menu. And of course, digital-only menus may enable other restaurant innovations, such as dynamic pricing of menu items.

A related creativity technique is for the innovating team to undergo immersive experiences where they can see firsthand how things can be done differently. This may take the form of visiting other industries that have adopted innovations to address their different-in-kind, though relatable, needs and seeing first-hand how that works. For example, it has become popular for established corporations to make trips to Silicon Valley to visit mature startups and new digital giants from whom they think they can learn something about digitizing their existing business.

The most radical orthodoxy overthrow is perhaps to completely redefine the market that the firm is innovating for, thinking differently about market boundaries and which market to compete in. *Blue Ocean Strategy,* which became popular with innovation practitioners in the mid-2000s, is inspired by Schumpeter's view that market boundaries and industry structures may by changed over time by the deliberate actions of industry actors. In their eponymous book expounding the method, Chan Kim, and Renée Mauborgne (2005) urge innovators to go looking for business opportunities in market spaces that are uncontested, untapped, and profitable. These represent "blue oceans" as opposed to the "red oceans" which comprise the current known market space. In the red oceans, competition has limited growth and profit prospects. In the blue oceans, there is no competition yet and ample opportunity to create innovate offerings that will be profitable. Blue oceans entail *reconstructing* the market boundaries and industry structures. Integral to the Blue Ocean method is the concept of v*alue innovation*, which creates value for both the buyer and seller in new ways. Similar to some of the other methods, the Blue Ocean method requires innovators to challenge implicit beliefs and assumptions about the basis of competition in the market.[137]

Constructing Analogies

An analogy is a comparison between two things that suggest an apparent similarity. Some analogies are useful for innovation, but some are not and could lead one astray. A good start can often be made by questioning prevailing analogies. (A long-used analogy may be yet another orthodoxy to be questioned.)

Would-be pilots tried for centuries to build heavier-than-air flying machines that would fly like birds flapping their wings. These were all abysmal failures because their inventors did not understand the real aerodynamics of flight. And because of that flawed analogy, their mental models were all wrong. The Wright brothers instead saw an analogy to a machine they were already familiar with, the bicycle. Like a bicycle in two dimensions, an airplane is an unstable vehicle in three dimensions. Both require control and will fail if they lose too much forward momentum. In addition, the Wright brothers benefited from a new scientific understanding of aerodynamics, thanks to Bernoulli, and the recent availability of a sufficiently powerful propulsion source in the form of the internal combustion engine. The Wright brothers put their superior analogy to work with a proper scientific understanding of airflow and lift and a suitable new propulsion technology, making aviation history in 1904.

A bad analogy can be a trap for the aspiring innovator, but a good one can unlock a solution nobody has yet thought of. It is, therefore, advisable to play around with more than one analogy before picking the most useful one, or even making use of more than one analogy. Charles Darwin used two analogies to develop his theory of evolution. The first was the parallel between the geological phenomenon of a small stream of water eroding grains of sands over eons to eventually create a deep canyon. This suggested that small, random changes in the relative survival of plants or animals could modify their forms over many generations. His other analogy was the similarities and differences between agricultural breeding and natural selection in the wild.

Powerful analogies often come from sources outside of a firm's industry. It's good to look at how other industries solve similar problems to your own. The automobile assembly line was conceived by a Ford mechanic, Bill Klann, while watching butchers at a meatpacking plant work on carcasses moving past them via an overhead trolley. Despite management's skepticism of this novel idea, Klann and his colleagues built the first moving auto assembly line. It drastically cut the production time of a Model T Ford from 12 hours per car to only 90 minutes per car (Pollack 2014).[138]

Thinking Like the Customer

There are several creativity techniques that put would-be innovators in the shoes of their customers. The general idea is that seeing the world through the eyes of their target customers will illuminate shortcomings in current products and solutions that can then be addressed by means of an innovation. The expectation is that there are *latent customer needs* which have not yet been met by current offerings and, therefore, can provide a market opening for innovators.

Tony Ulwick (the founder of the consultancy, Strategyn), is the originator of the *Jobs-to-be-Done* (JTBD) framework. Originally called *Outcome-Driven Innovation®* (ODI), the framework was expounded in Ulwick's book, *What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services* (2005), and in several magazine articles.[139] JTBD has since been adopted by other innovation thought leaders, such as Clayton Christensen, and it is popular with consultants and practitioners. The essence of the approach is to understand what the customer is trying to accomplish (the job) and then crafting an innovation that will be "hired" by customer to help get their job done. It thus shifts the focus from the product to the customer, and in particular, to what the customer really needs. For example, the customer may not need a better drill (the superficial solution), but a better way of creating a well-drilled hole. The JTBD is thus not the product itself, but the higher-level problem that the customer needs a solution for.

Prior to the JTBD method to providing customer insights, two related frameworks emerged from the intersection of the quality and marketing disciplines in the 1980s and 1990s: the *Kano Model* and the *Voice of the Customer* method:

The *Kano Customer Satisfaction Model* emerged from the world of quality management. Noriaki Kano (1984), a professor at the Tokyo University of Science, created the framework based on his insight that there are two dimensions of quality in the eyes of the customer.[140] On the one dimension, the customer's expectations are either fulfilled or not fulfilled. On the other dimension, the customer is either delighted or extremely dissatisfied. Combinations of these two dimensions yield three different types of quality:

1. *Must-be requirements*, which are the basic criteria of a product. If these requirements are not met, the customer will be extremely dissatisfied. For example, punctual delivery by a rail service is a must-be requirement. But it depends on what the customer's exact definition of punctuality is. For example, if the customer expects delivery on Tuesday as long as it is by end of day, delivering Tuesday morning instead of Tuesday afternoon will not increase customer satisfaction.
2. *One-dimensional requirements*, like, for example, the gas mileage of a car. The higher the gas mileage, the more satisfied the customer will be.
3. *Attractive requirements* (sometimes called "delighters" or "exciters"). These are the product criteria that have the greatest impact on customer satisfaction and often result in disproportionate increases in satisfaction. For example, an airline that offers a full meal service on a route where its competitors only serve rudimentary snacks may delight especially business customers. Yet, the absence of this service will not result in dissatisfaction as it is not expected.

Using the Kano framework in product design starts with questioning customers on their requirements and what matters to them in a similar way to the JTBD approach.

The Kano method is especially helpful when hard design tradeoffs (often driven by cost) have to be made. But it always starts with establishing the importance of individual features to the costumer (Matzler and Hinterhuber 1998).[141]

Kano's method is also frequently combined with a technique called Quality Function Deployment (QFD), which is a quality management technique that maps customer-desired attributes to design functions (Wu et al. 2015).[142]

The Voice of the Customer (VOC), developed by Abbie Griffin and John Hauser (1993) is a related term for capturing customers' requirements. The method has its origins in marketing. The VOC was intended to provide key requirements for the QFD framework after interviewing customers to determine their needs. VOC structures customer needs into a hierarchy of primary, secondary, and tertiary needs.[143]

An obvious way to take customer input into account when developing a new product or solution is to put the customer in the driving seat of the innovation process. Methods that are based on this principle are called *lead-user methods*. Depending on the method, the customer may dictate the specification of the product to be developed, or the customer may partner with the innovating company to co-develop the product. The lead-user method requires a willing lead user to be found prior to major development efforts starting. It is quite popular in industries where the cost of development is very high, such as in defense equipment, semiconductor chip manufacturing, or the development of major software solutions. The advantage of the method is that there is a lead customer who will ensure that their requirements are met and will typically pay for much, if not all, of the development. The risk of being overly reliant on this method is that the innovating company may be captured by one dominant customer and be oblivious to the needs of the rest of the market. Another drawback is that the lead-users themselves may suffer from all the creativity inhibitors and orthodox thinking discussed earlier. The lead-user method therefore works best where the lead-user is highly representative of the rest of the market, and is also very progressive in their thinking about innovation and open to new ways of satisfying their needs.

Imposing Constraints

Brainstorming is the most common ideation technique used in organizations. It can be a perfectly good technique with simple rules that any group can quickly learn to apply, provided it is done right. The basic rules of brainstorming are:
1. Come up with as many new ideas as possible.
2. Encourage out-of-the-box or unconventional solutions.
3. People must build on the ideas of others.
4. Judgment must be withheld until the final evaluation phase.

The main problem with brainstorming is that most groups do it very poorly because they do not properly understand the nature of the process and all too often break the rules, which makes their brainstorming fruitless. Another problem is that it is too unstructured and lacks focus. Simply asking people for a list of ideas without focusing or stimulating their minds is unlikely to yield anything truly novel. Part of the problem is that when people think of creativity, they often use the expression "thinking outside of the box." This creates the impression that creativity requires a complete lack of structure. This is not a useful paradigm at all because choosing the right constraints can be very helpful to creativity. In fact, they are essential. A good structure for creativity requires a proper definition of the challenge, and clear boundaries for the *solution space*, the universe of solutions that will be considered.

Far from being inhibiting to creativity, imposing the right constraints can result in fruitful ideation. There are several *constraint-based techniques* that can be applied during brainstorming sessions to spark creative solutions that are also very productive. Boyd and Goldenberg (2013) explain a few of the most common ones in their book, *Inside the Box: A Proven System of Creativity for Breakthrough Results*, on how to use constraints to further creativity:[144]

- *Subtraction*. Remove elements that were assumed to be essential. For example, the Sony Walkman was a cassette player with the recording function removed.
- *Task unification*. Combine tasks or functions in new ways. The credit card payment terminals in taxis now show passengers advertisements during the ride.
- *Multiplication*. Copy an essential element, and then alter it through multiplication. The Gillette Twin Blade razor system was the first shaver to feature two blades instead of one. Due to its success Gillette has kept adding shaving blades over the years, and currently their flagship product features five blades.
- *Division*. Separate essential elements and rearrange them. At first, air-conditioning units contained all the components in a single box, but when the motor and fan of the cooling unit were taken away from the other parts, they could be placed outside the house. This became central air-conditioning.
- *Attribute dependency*. Make one product attribute change in response to changes in other attributes. Examples are rain-sensitive windshield wipers or transition lenses.

These approaches all start with an existing product or configuration. This approach was first described by the psychologist, Ronald Finke (1992) in his seminal work on *creative cognition*.[145] Finke perceived that most people are better at tweaking given configurations rather than coming up with totally new concepts "out-of-the-box." This particular approach to innovation is to continually look for improvements to something familiar. When overused, it may result in an overemphasis on incremental innovation, but more radical innovations are possible if this approach is correctly applied to the most suitable innovation challenges.

Design Thinking

The evolution of Stanford University's design-thinking approach between 1957 and 2005 is documented in a recent paper by Jan Auernhammer and Bernard Roth (2021).[146] They note that the design philosophy is deeply rooted in humanistic-psychology theories, particularly as they concern creativity and human values. The modern design-thinking approach is the culmination of many collaborations between psychologists, industrial researchers, and designers. The emphasis of the approach is to identify human needs and problems, and create value for people through designs and innovations that address these needs.

The Hasso-Plattner Institute of Design at Stanford, or d.school as it is called for short, is the origin of the design-thinking approach. The five modes (sequential steps, to be iterated) of design thinking are:

- *Empathize*. This is the foundation of human-centered design since it requires innovators to build empathy for users by understanding their values and needs as well as their emotions. This is accomplished by observing users in the context of their lives, engaging them in interviews and other encounters, and immersing the designer in the users' experiences (walking in their shoes).
- *Define*. Translate the empathy findings into needs and challenges. Define a *Point of View* that is an actionable problem statement that clearly defines the problem to be addressed by the design.
- *Ideate*. Generate radical ideas for the design through brainstorming. Use the strengths of the whole team to come up with collective perspectives, building on the ideas of others. Push hard to go beyond obvious solutions. This step is meant to "go wide" in the interest of exploring a wide solution space, both in terms of the quantity and diversity of ideas.
- *Prototype*. Turn ideas into something physical. Keep prototypes inexpensive and rough in the early stages to learn quickly and cheaply. Make prototypes so that people can experience and interact with them. A prototype could be an object for product offerings, or a role-playing or cartoon storyboard for services.
- *Test*. The prototype is tested by users so they can provide feedback, and data may be gathered. New insights about user requirements may emerge during this step (deeper empathy), as well as deriving feedback that can be used to design the next iteration of the prototype. At this step the Point of View is also refined. Failure should be embraced as it brings new learning.[147]

(d.school 2022)

These five steps are iterative and may be repeated until a high-quality solution emerges from the process. At the conclusion of the process, there is an assessment where all the feedback is integrated.

Problem Statements and Sources of Insight

Properly defining any problem takes us halfway to a good solution. Redefining a problem in an unusual way opens the possibility of more creative solutions.

A good problem statement is typically written in the format of an open question:

How might we help <fill in description of the target user/customer using a noun preceded by multiple adjectives> to <fill in the problem that they are trying to solve, or the task that they are trying to complete by using a phrase that contains at least one verb and one subject>?

There is an art and a science to formulating good problem statements. The science is adhering to the correct format and rules. The art is formulating it at just the right level to encourage productive thinking. For example, asking how we help dieters to eat lower calorie foods is too high level. Asking how we can come up with a better low-calorie snack bar is maybe too low level, because it constrains our creativity so that we are only thinking about snack bars. Asking how we can help dieters to not blow their diets when they get hungry mid-afternoon is a more interesting question. It adds an insight about what the customer finds difficult and is phrased at a level that allows for good creativity. The solution may be a bar or a beverage or some offering of mixed nuts and fruits. The problem is specific enough to focus on, but the solution space is not unduly constrained.

The insight contained in the example problem statement above is helpful. This particular *customer insight* likely came from interviewing dieters to ask them when they were most likely to overindulge and why. Customers interviews are indeed a good source of insight if they are conducted properly. Surveys can also be useful if they test interesting hypotheses, but too many organizations fail to do that in their market research. A powerful way to understand how you can help the customer is to accompany them as they go through their day, whether is when they are on a jobsite or another place of work, shopping or cooking at home, or doing any other activity that your business or organization hopes to help them with. The reason on-site observation is so helpful is that customers may not tell you everything in interviews. They may omit important details because they think something is not worth mentioning, or they may be somewhat embarrassed mentioning it, or they are simply so used to doing a task in an inefficient way and have never thought to question it. Being there to see what they do, or attempt to do, can lead to great insights.

Customer insights are not the only type of insights that should be used as inputs into the creative process. *Technology insights* are very important too, as new technologies may be able to serve customers in new and improved ways. For example, even if your own offering does not currently make use of mobile-phone technology, it is very useful to survey the best examples of how your competitors, or others in related but adjacent industries, are using mobile technology to enhance their offering.

A third important source of inspiration is *business insights*. This is a broad category that includes how offerings are changing, and how they are produced, and delivered. For instance, the trends toward software-as-a-service (Saas) and away from license fees is a business insight that is highly relevant for anyone in the technology industry. So is the trend toward cloud computing rather than managing your own servers.

Major progress is often made when insights from different fields are combined. Such combinations of insights from different disciplines which inspire innovation – some call them *intersections* – can occur in a happenstance way, and many famous innovation stories start with the unfolding of such events. However, knowing that combining insights from different areas sparks creativity and subsequent innovation makes us want to engineer more occasions on which this can happen. That way firms can be more systematic about creativity and innovation, in the way that Peter Drucker envisioned.

This poses a question as to what environments are more conducive to creativity coming from intersections. In an eponymous book, Frans Johansen (2004) coined the term *The Medici Effect* to describe how breakthrough creativity will happen at the intersection of different fields, ideas, people, and cultures. The reason for the name is that Renaissance-era Florence under the leadership of the Medici family was a hotbed of creativity. The wealthy Medici bankers provided a welcoming environment for scientists, artists, financiers, philosophers, and architects to intermingle, thereby breaking down barriers between cultures and disciplines. This is what fueled the Renaissance, the benefits of which we still enjoy today.[148]

If creativity is enhanced by combining ideas from many fields, people, and cultures, it follows that diversity aids innovation. One would, therefore, expect that more diverse innovation teams would outperform less diverse innovation teams. Research by Sylvia Ann Hewlett, Melinda Marshall, and Laura Sherbin (2013) confirmed that firms with higher diversity are more likely to report growth in market share and much more likely to have captured new markets. A useful distinction is that there are two dimensions to diversity, and that both are needed for these favorable outcomes: *Inherent diversity* involves traits such as gender, ethnicity, and sexual orientation. *Acquired diversity* involves traits gained from life experiences. Diverse teams are better at appreciating unmet customer needs in underserved markets. In order for diverse teams to function optimally, it is necessary to make it safe for all team members to contribute ideas, and to empower them with decision-making power. This requires the right type of leadership style to make sure everyone is heard and feels valued. In particular, leaders need to model the following seven behaviors to ensure the freedom for all to contribute their ideas:

1. Ensuring that everyone is heard
2. Making it safe to propose novel ideas
3. Giving team members decision-making authority
4. Sharing credit for success

5. Giving actionable feedback
6. Implementing feedback from the team[149]

(Hewlett, Marshall, and Sherbin 2013)

The importance of *curiosity* to creativity cannot be overemphasized. Leonardo da Vinci, the Renaissance master whose name is synonymous with creativity in many different fields, had an insatiable and, some might say, obsessive curiosity about everything. A true polymath, Leonardo's prolific notebook (of which more than seven thousand pages survive) contains lists of hundreds of subjects that he wanted to explore. Da Vinci had the crucial ability of all creative geniuses to ask interesting questions that other people did not even think to ask. His mental wandering crossed the disciplines of science, engineering, art, and even the humanities. His knowledge of how light strikes the retina in the human eye enabled him to construct the perspective in "The Last Supper." His dissections of human cadavers informed his drawing of Mona Lisa's lips. Da Vinci was meticulous. Leonardo told his employer at the time, the Duke of Milan, that creativity requires time and patience. He insisted on gathering all the possible facts and practiced skilled observation. He appreciated the beauty of a mathematical equation just as much as a natural phenomenon, such as a bird in flight or a fish swimming through the water (Isaacson 2018).[150]

Today, our education makes us err on the side of specialization, but true innovators do not respect the boundaries between disciplines, particularly those between the sciences and the humanities. Steve Jobs understood this and would often present a slide showing the intersection between two streets named "Liberal Arts" and "Technology."

The Social Nature of Innovation and the Efficiency Legacy

Innovation is a highly social enterprise, requiring many people to collaborate and invest in helping one another on work that is not guaranteed to lead to a successful outcome.

There is a strong correlation between general *organizational health* – succinctly defined as the ability of an organization to align around and achieve its strategic goals (McKinsey 2022)[151] – and innovation success. The concept implies that just like humans, organizations can be classified as healthy or sick. A sick – that is, a dysfunctional and ineffective – organization will be unlikely to be able to innovate. There are several obvious reasons for this:

- Innovation is a team endeavor. Bosses cannot innovate alone, nor can they simply mandate innovation by decree.
- Innovation relies on complex knowledge flows and many instances of cooperation between individuals, teams, and groups. Such knowledge flows and cooperation are severely inhibited in sick organizations.

- Creativity requires trust and entails some risk taking. In sick organizations, such trust among employees, and between employees and managers, is severely lacking.
- Innovation requires effective execution, typically under challenging deadlines. Sick organizations often suffer from operational disfunction, too, and are typically unable to execute anything new.
- Innovation initiatives are all fragile, especially in their infancy. As such, they are easily killed or suppressed by an unsupportive decision-making culture. Such cultures are typified by nonpermissive rules with the practical effect that 99 people can say no, but only one person can say yes.

Because of its sensitivity to organizational dysfunction, innovation can be thought of as the canary in the coal mine of organizational health. Accordingly, if managers see many obstacles to innovation, they also should have good reason to be concerned about the general health of their organization. Conversely, a successively completed innovation (or even better, a stream of such innovations) will be good for general organizational health.

Today's organizational structures and philosophy on how work should be divided between employees is the legacy of 20th-century manufacturing. Few organizations have yet figured out how to organize for the Information Age, or for the Fourth Industrial Revolution. Even those who have innovated their organizations retain many legacy elements from the 20th-century paradigm. To better understand common organizational obstacles to innovation, it is helpful to understand how the efficiency paradigm developed and what it involves.

In the study of efficiency, no single person has been as influential as Frederick Winslow Taylor, who started studying factory operations in 1911. Taylor can also be thought of as the father of *Scientific Management*. In a nutshell, this is the belief that there is a single, most-effective way of performing any task. That method is to be found through trial and error, and careful measurement. Once the single, best way is found, it needs to be entrenched in processes and job descriptions, and followed to the letter. This also requires specialization, often very narrow specialization. For example, on a production line, a worker may be assigned a discreet number of limited tasks and expected to do these tasks faster and better than anyone else. And so, the individual worker became a cog in an efficient machine. As Taylor himself predicted: "In the past the man has been first. In the future the System will be first" (Kanigel 2005).[152]

Taylor's prediction was prescient: While efficiency was the goal, the only way it could be accomplished was through well-managed formal organizations, which became the standard template for business and society. The prediction came to full fruition after World War II, when millions of former servicemen were attracted to the rigid structure and purpose that large business enterprises offered, a system which they had become used to during military service. This regimented business culture was fully explored in the classic book, *The Organization Man* by William Whyte (1956).[153]

The benefits of Taylorism (as it came to be called) in the early twentieth century were clear. It enabled mass industrialization because it provided a way of making unskilled workers, who were streaming from farms to cities, productive quickly. For ages before, manufacturing was based on the artisanal model. For example, the village blacksmith took many years to learn his trade, and was able to manufacture on demand virtually anything made out of steel or other metals that were malleable in his smithy. But it also took a long time and a lot of labor to make each item, which was often customized. The former farmhand employed in the tool factory, on the other hand, had to learn only a few standard steps that allowed him to be one of many workers making, for instance, a steel shovel. The Model T Ford assembly line relied on the narrow specialization of each worker doing very simple steps. Not surprisingly, the Taylor-prescribed way has never been associated with deep job fulfilment. Unlike the blacksmith, the factory worker does not get the pleasure of seeing his finished product and the simple, repetitive work is boring, without variety, and may cause repetitive stress injuries. The same organizational and efficiency model also came to be applied to office work, with the same effect.

In 1916, Henry Fayol established the template for what the responsibilities of managers are. According to Fayol, managers have to do five things: *plan, organize, command, coordinate*, and *control* the activities of their workers. Building on these ideas, Max Weber formulated *Bureaucratic Theory* in 1947, which emphasize the use of standard rules and procedures in organizations, and, in particular, the need for a clear hierarchy (chain of command) and task specialization.

Elton Mayo, who formed his *Human Relations Movement* (1941) based on the observation that productivity increases when people feel that they belong and see that their managers are taking an interest in them is the most prominent standout who emphasized the people-side rather than the task-side of productivity.

Late in the 20th century, the concept of *Lean Manufacturing* was imported into America from Japan, where it was known as the Toyota Way. John Krafcik (1988) coined the term lean manufacturing in his work explaining the method and benefits of the Toyota Way to an international audience. The Toyota Way was developed in the 1930s in Japan by Taiichi Ohno and others. It entails a relentless focus on customer value and continuous improvement in operations, and emphasizes the flow of work and the elimination of waste.[154]

Business Process Management with its corollary, *Business Process Reengineering*, were added to the efficiency canon by Michael Hammer and James Champy (1994).[155] The need for reengineering was supposedly based on the premise that most work in organizations adds no value, and that business processes should be changed – that is, reengineered – to eliminate wasteful work. This became all the rage among consultants and CEOs in the 1990s, leading to drastic efficiency overhauls accompanied by layoffs of workers whose tasks had been made redundant.

Theories of Motivation

In the second half of the 20th century, several theories of worker motivation were developed. As early as 1943, Abraham Maslow (1943)[156] postulated his now well-known *Hierarchy of Needs* (a concept that he kept developing over the next couple of decades) culminating in a book, *Motivation and Personality* (Maslow 1954).[157] Maslow's Hierarchy became a staple of business textbooks and has had a major influence on management thinking. Subsequent motivation theorists were influenced by it and expanded parts of it. In later years, data-driven research called some parts of the theory into question, but its enduring value is its conceptual simplicity.

Maslow's hierarchy is a pyramid of needs that need to be fulfilled in a particular sequence before the individual can be motivated by the next need. The lowest motivators involve physical survival and security. From there, in ascending order, are *affiliation*, *esteem*, and *self-fulfillment* or *self-actualization*, which is the highest-level motivator. If people fear for their survival, they cannot be motivated by the higher-level motivators until their need for safety is first met. This theory has applicability to setting up innovation teams and special innovation organizations. If people who are invited to join these organizations are genuinely fearful that failure may be a career-killer, appealing to them by offering attractions such as rewards, status, and fulfillment may fail. These higher-level motivators will only influence them if their concerns about career risk can be assuaged.

Frederik Hertzberg, Bernard Mausner, and Barbara Snyderman (1959) proposed the *Two-Factor Theory* after conducting interviews with a couple hundred engineers and accountants.[158] The essence of the theory is that some factors are *motivators*, and some are *hygiene factors*. Motivators are intrinsic job factors that give positive satisfaction, such as rewarding work, status, and self-realization. Hygiene factors, that can be also thought of as maintenance factors, are extrinsic to the job itself and include things such as salary, management practices, and company policies. When workers have a positive view of these, the factors do not motivate, but a negative view of hygiene factors cause dissatisfaction. With two factors that can be either high or low, there are four possible combinations; high hygiene and high motivation is the ideal. Where there is high hygiene and low motivation, workers do not complain but just see the job as a paycheck. This is obviously not conducive to innovation. Where there is high motivation but low hygiene, workers find the job rewarding but are experiencing many irritants that they complain about. Innovation projects have a risk of falling into this category if work conditions, supervisory practices, and rewards are not in line with the ambition of the contribution they are supposed to make.

Shortly after Herzberg, Douglas McGregor (1960) put forth his *Theory X* and *Y*.[159] It contrasts different management styles within different contexts. Theory X entails tight control of subordinates while Theory Y entails presenting a rewarding environment to motivate workers to exhibit the desired behavior.

Then, David McClelland and Eric Johnson (1961) proposed the *Need for Achievement Theory*,[160] which states that there are only three human needs: achievement, power, and affiliation. McClelland's concept of achievement is related to Herzberg's motivators. McClelland's socially acquired needs, power and affiliation, are similar to Maslow's needs for affiliation and esteem.

Victor Vroom's (1964) *Expectancy Theory* highlights the fact that individual workers will make a calculation about the linkages between the effort that they put in, the expected outcome or performance due to their efforts, and the rewards that would come their way if the desired performance were achieved.[161] There are two linkages in this chain: First, workers have to believe that their efforts will result in the desired performance. Second, workers have to believe that good performance will get them personally rewarded. This is a useful framework to consider when organizing for innovation performance. Team members will be motivated if they judge that their efforts will lead to performance and if they can reasonably expect to be rewarded for such performance. If either or both links break down, the innovation team may suffer from motivation problems.

While there is no unified theory of motivation, there are substantial similarities between these theories. The traditional motivation theories above have been developed largely with a production workforce in mind, which raises the question as to what, if anything, may be different for innovation team members.

Being part of an innovation team working on an exciting cutting-edge product that would bring value to customers will activate the higher-order motivators. But these motivation theories do not address what may discourage people from wanting to join such a team, especially if it is a temporary team working on a project that has no guarantee of success, as is the case for radical innovations and corporate startups. Vroom's Expectancy Theory points to a potential motivation pitfall with an innovation assignment. Both Vroom's linkages are uncertain – the outcome and the reward. This situation of high uncertainty creates career risk for a worker considering an innovation team assignment – leaving a safe, predictable role in the organization to go work on a project that may not succeed and for which there may be no reward.

In practice, addressing career risk is the most important additional part of motivating people to work on innovation projects. Executives have to assure prospective innovation team members that no matter whether the project is successful or not, they will still have a place in the organization, and that it will not reflect poorly on their performance if the project fails. In fact, performance has to be rewarded even when the desired innovation outcome was not achieved. This is easier said than done, given how most large organizations' performance management systems work, but removing the fear factor is vital if the best talent is to be attracted to important innovation projects.

Fundamental Organizational Challenges

The existential challenge of innovation in established organizations is that it is different from typical operational activities. The well-oiled engine of a modern corporation is designed to run only in one way, and to reject variation and inefficiency, as was explained in the discussion on efficiency earlier in the chapter. Innovation, on the other hand, requires trying out different ways of doing things, and being willing to tolerate some waste when some ideas do not work. As a result, it requires a different leadership style. In many situations, organizations decide that innovation is so different from their normal activities that it also requires ringfencing into a dedicated structure, though that type of solution brings new challenges of its own as will be explained below.

Academic research into organizational theory and innovation provides further insight on the exact nature of this problem. Michael Tushman and Charles O'Reilly (1997) first suggested *ambidextrous organizations* as a solution to the challenge of managing the existing business alongside managing innovation.[162] They argued that successful innovation organizations are ambidextrous in the sense that they can handle both evolutionary and revolutionary change. Ambidextrous organizations can learn through variation, selection, and retention. Such organizations can promote variation by eliminating bureaucracy and encouraging autonomy, experimentation, and risk taking. But they can also select winning innovations and successfully execute them. Tushman and O'Reilly acknowledged that managing innovation streams successfully means managing the contradictions inherent between these two styles. An ambidextrous organization effectively handles the Darwinian process that Schumpeter envisioned, which comprises both variation and selection activities.

A further contribution to understanding and managing the tensions inherent in innovation leadership was made by Kathrin Rosing, Michael Frese, and Andreas Bausch (2011).[163] They point out that innovation requires two different-in-kind activities, *exploration* and *exploitation*, and the flexibility to switch between those two activities. This is because innovation requires two different processes: creativity and implementation (execution). Creativity is associated with exploration, and implementation with exploitation. *Exploitative leadership* is what is required for a production organization with settled processes and outputs where rules have to be followed, risks have to be minimized, and variances have to be minimized. On the other hand, *explorative leadership* is required for innovation situations where experimentation, doing things differently (variance in behavior), risk taking, and searching for different solutions are encouraged. Being able to manage in both styles is termed *ambidextrous leadership*, a metaphor for the ability to balance explorative and exploitative management.

Exploitation requires *closing* behaviors, and exploration requires *opening* behaviors. Closing in this sense means streamlining processes and narrowing down options so that variances are minimized and goals that are set are achieved. Opening means encouraging doing things differently and experimenting, allowing room for independent thinking (Rosing, Frese, and Busch 2011).[164]

The differences between the two styles are summarized in Table 4.1.

Table 4.1: Exploitation versus Exploration.

Exploitation	Exploration
– Reducing variance in behavior – Adherence to rules – Risk avoidance – Closing behaviors – Evolutionary change	– Increasing variance in behavior – Experimentation, doing things differently – Risk taking – Opening behaviors – Revolutionary change

Source: Compiled from Rosing, Frese, and Busch (2011)[165]; Zacher and Rosing (2015).[166]

The exploration-exploitation duality needs to be managed in two different organizational contexts: The first is innovation of new offerings and processes versus the larger part of organizational activities that are concerned with delivering the current offering in the usual ways. The second is within the innovation initiative or project itself, which requires both creativity (linked to exploration) and implementation (linked to exploitation). Successfully completing an innovation project requires the team and innovation leadership to manage both, and to know when to be creative and when to implement. The innovation roles introduced in the next section will further illustrate this.

Yan Chen (2017) further contrasted the different logics of exploitation versus exploration.[167] Exploitation assumes that the firm has complete information about external opportunities and internal capabilities. Exploitative firms, therefore, like to work within well-established frameworks under which the problems they will encounter are well understood and the solutions defined. A way of accommodating both these modes, exploration, and exploitation, inside an organization needs to be found. Chen (2017) observed that the three solutions that are commonly found each have its drawbacks:

– *Contextual ambidexterity*. In this format there is a specific organizational context that indicates to employees that they may switch from exploitative to explorative mode. The most obvious way to do this is allotted time. Alphabet (parent of Google) gives engineers 20 percent free time to work on exploratory projects. But even Alphabet has found that for highly explorative initiatives far from its core, more exploration time is required, which is why it has dedicated organizational units for its moonshot initiatives.
– *Sequential ambidexterity*. This is a project-level solution where designated times are set aside for exploration and other times for exploitation. Earlier on in the

project there will typically be a higher proportion of time for exploration. While effective at the project level, this solution does not translate to the organizational level.

- *Structural ambidexterity*. This is the typical organizational solution of separate business units or groups explore, others only exploit. The drawback of dedicating some business units to exploration and some to exploitation, is that it places the burden of ambidexterity squarely on the top executives to which both explorative and exploitative units report.[168]

In order to overcome the problems with each of these solutions while taking advantage of their strengths, Chen (2017) proposes a hybrid model called *dynamic ambidexterity*, which is structural at the corporate level, contextual at BU level, and sequential at project level.[169]

While Chen's solution may be a decent general rule of thumb to start with, each organization must find its own optimal organizational design and develop its own internal processes to make it work. In my own research and experience, there is no perfect innovation structure that works for everyone. There is no escaping the burden of ambidextrous leadership, which requires a diverse set of skills and the willingness to shift modes by whoever is at the integration point between explorative and exploitative activities. The burden of structural ambidexterity always falls on a leader at some level of the organization, whether at the top, middle, or bottom. All innovation project leaders need individual ambidexterity, given that each innovation project will comprise a mix of explorative (creative) and exploitative (implementation) activities. In fact, any leaders who have both explorative and exploitative activities reporting to them need ambidexterity. This means that ambidexterity is a definite requirement for the CEO and other senior leaders who have both innovation and operational groups reporting to them.

Innovation Organizations and Team Roles

Special innovation organizations should be created only for valid reasons, not simply as a reflex solution to innovation problems or bottlenecks that may have other, less drastic, remedies. The most common rationale for creating a special innovation organization can be explained with the use of the three-horizon framework introduced in Chapter 1. H1 is the core of the business, which is built and managed for efficiency and can only handle incremental innovation to existing product lines. A special innovation organization is tasked with pursuing radical innovations associated with H2 and H3, and can be viewed as a radical-innovation generator. While the special innovation organization is built for radical innovation, it cannot scale the innovation on its own and for that, it needs the core (the parent). Additional reasons for considering a separate special innovation organization are:

- Obtaining consumer or user insights not available in the core
- Adopting and adapting new or emerging technologies alien to the core
- Collaborating extensively with external parties (e.g., external networks, partnerships, JVs)
- Identifying and pursuing entirely new business opportunities
- Establishing a footprint in new or emerging markets
- Scaling innovations faster than the core is equipped to do

The original special innovation organization with its own set of rules, is the famous *Lockheed Skunk Works®*, an official pseudonym for Advanced Development Programs (ADP). The Skunk Works® was conceived by Lockheed chief engineer, Kelly Johnson, in 1943 to rapidly develop U.S. jet technology after the first jet-powered German fighter-bomber (the Messerschmitt Me 262) had appeared. Johnson promised the first prototype jet in 150 days, and his engineers delivered in 143 days. Four years later, the U2 spy plane came out of the Skunkworks, and later its successor, the SR71 Blackbird. Decades later, the first stealth plane, the F-117 Nighthawk –debuting operationally during Operation Desert Storm in 1991 in a first-strike role – also came out of the Skunkworks (Lockheed Martin 2022).[170] When founding the Skunk Works®, Johnson had insisted on substantial freedom from central decision-making, which was codified in *Kelly's 14 Rules & Practices*, the first of which delegates the Skunk Works® manager complete control and guarantees a reporting relationship to a division president or higher. Other key elements are separate offices, a much-reduced team size, a simplified engineering design system, and its own contracting authority.

Eager to capture the magic of startup innovation inside their own organizations, and fearful of getting disrupted by startups who can easily adopt business models based on new technologies, many established companies have launched corporate innovation labs. The idea is usually to replicate a startup environment inside a big company. There is a proliferation of these innovation labs with companies ranging from Cisco and HP in the technology industry, to CapitalOne and State Farm in financial services; to Staples and Lowes in the retail industry, all operating various versions of innovation labs.

The term "innovation lab" is often used for a special innovation unit, but there are other names, from the generic "innovation center" to more catchy names such as "garage," which tend to follow trends set by companies considered to be leaders in innovation. An innovation lab can mean many things to many people, from a fully-fledged Skunkworks® to nothing more than a marketing showcase for customers; or a faddish office with bean bags, foosball tables and standing desks to recruit younger talent or improve morale. It is not the name of the facility that matters, but the substance: What its mission is, what it is empowered to do, and what its relationship with the parent is.

In recent years, the use of innovation labs in the public sector has also increased. Such *public-sector innovation (PSI) labs* typically apply new approaches borrowed from the private sector, in particular design thinking, for the purpose of better policy and service design. Their activities are part of a movement in the public sector to pursue a more entrepreneurial orientation. After a survey and analysis of such labs around the world, Michael McGann, Emma Blomkamp, and Jenny Lewis (2018) identified four main archetypes:[171]

- *Design-led labs* that apply design thinking and its user-centric methods to policy design
- *Open government labs* that apply new digital tools to open and interrogate public datasets
- *Evidence-based labs* that focus on the application of rigorous evaluation techniques and randomized control trails (RCTs) to inform evidence-based policies
- *Mixed-method labs* that have no discernable methodologies

Many special innovation structures created with the best of intentions fail. Failure is often preceded by several symptoms or warning signs, each worthy of immediate intervention. There may be execution failures with a once-promising concept disappointing. Milestones may be slipping because of resource bottlenecks. The relationship with the parent may be fraught, with the innovation unit perceived as a black box within the parent organization, and needing the innovation unit to work too hard to sell back its innovations to the parent, or failing to leverage the scale of the parent.

The root causes of innovation-organization failure are often a lack of strategic focus and alignment with the parent's strategy. Another trouble area is lack of leadership support within the parent, and insufficient delegation of power to the innovation unit to make and follow its own rules. On the other hand, too much separation from the parent may call into question the very existence of the innovation unit, as will an inability or disinterest in leveraging the core assets of the parent.

The interdependence between the organization and its parent cannot be denied and should be actively managed and nurtured so that it is a true partnership. It is essential to have a clear charter and governance structure with a steering committee ("steerco") representative of the parent. C-level sponsorship from the parent is vital. Personnel rotation can mitigate an us-versus-them mentality. Budgets and cross-charging mechanisms should be designed to align incentives on both sides.

There are a number of major design choices to be made when designing a special innovation organization, including:

1. A strategic mission or objective directly linked to parent's growth strategy
2. The choice of geographic location and office and/or technical facility
3. Governance and reporting relationships
4. Decision-making rights, particularly the parent's role in major decisions
5. Details of parent CEO involvement (both formal & informal)
6. Operating model (spelled out in a Playbook)
7. Staff capabilities, selection, and incentives

No matter what the outer organizational shell is, any innovation project is pursued at the team level. IDEO founder Tom Kelley has popularized the idea that innovation team members need to take on different types of personas (or "faces") to bring a truly creative idea to fruition. These personas are introduced in the book, *The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate & Driving Creativity Throughout Your Organization* (Kelley and Littman, 2005).

Kelly defined these personas based on his observations of what roles people can play to foster innovation and ideas. He emphasizes the need to counter the inevitable naysayers, represented by the undesirable *devil's advocate* persona (not one of the 10), who are always quick to raise questions and state concerns that kill new ideas and projects in their infancy, while not claiming any personal responsibility.

There are three types of personas: *learning personas* (creative roles) that can be closely associated with explorative behavior, *organizational personas* (implementation roles) that can be associated with exploitative behavior, and *building personas* that perform a mix of creative and implementation tasks (see Table 4.2).

Table 4.2: IDEO's Ten Faces of Innovation.

Learning Personas	Organizational Personas	Building Personas
– Anthropologist – does field work to observe how users interact with products and services – Experimenter – models and tests new ideas – Cross-Pollinator – draws associations and connections between seemingly unrelated ideas	– Hurdler – solves problems and perseveres despite setbacks – Collaborator – coaxes people out of their silos to make the team function better – Director – understand the big picture and motivates others	– Experience Architect – creates individual customer experiences – Set Designer – livens up the workspace to stimulate creativity – Storyteller – captures the imagination with compelling narratives – Caregiver – exercises empathy to understand each customer and create relationships with them

Source: IDEO (2022).[172]

While these personas need to be kept in mind to assemble a balanced team, not every innovation team will have individuals who will naturally default to each of the ten behaviors. The point of the personas is that these are all roles that need to be played to complete the innovation project with its mix of creative and implementation activities. When teams are cognizant that these specific roles need to be played, they can agree ahead of time who on the team will play which roles. If there is no one who is a natural fit for a particular persona, the person who is best able to stand in for that persona should deliberately take on that role. For instance, if no natural hurdler can be found on the team, the most organized person should be designated to play the hurdler persona. Otherwise things may simply not get done.

An issue not specifically addressed by the IDEO framework is what the impact of creative conflict is on the performance of innovation teams. Various observers have suggested that creative conflict among artists – such as between Paul McCartney and John Lennon of the Beatles – enhances creativity, but there has so far not been much of a scientific basis for that belief. However, recent National Aeronautics and Space Administration (NASA) research reported in *The Economist* (2021) suggests that there is something to this hypothesis. In preparation for an eventual manned voyage to Mars – which would entail an 18-month round trip as well as a year spent on the planet – NASA has been doing research into the dynamics and performance of small, closely knit teams. At the Johnson Space Center in Houston, NASA built a structure that simulates space missions and in which they can observe the crew members confined together. One of their recent insights was that avoiding conflict can discourage the creative frictions that generate newer and better ideas. Interpersonal conflict is problematic, but conflict over ideas and how to perform tasks can be helpful and lead to better outcomes.[173]

When selecting individuals for innovation teams – whether through external recruiting or internal assignments – one of the most important attributes to screen for beside a particular skill set is *intrinsic motivation.* According to Harvard professor Teresa Amabile (1988), a noted creativity researcher, intrinsic motivation is visible when people are personally intrigued and challenged by the innovation opportunity. Such people are more likely to produce creative work than otherwise-qualified people who are not so motivated. A natural curiosity is a very important related trait. Another thing to look for when staffing an innovation organization is for people within the existing organization who are already exhibiting creative behavior. No matter how much of a creativity desert an organization is, there is almost always some oasis of creativity to be found inside it.[174]

The Elusive Concept of an Innovation Culture

The existence of an innovation culture is hard to measure scientifically, but several academic attempts have been made. For example, Timothy Michaelis, Roberly Aladin, and Jeffrey M Pollack (2018) reviewed several previous definitions and measurements of innovation culture, each comprising multiple elements, before synthesizing their own, comprised of nine elements. They tested the nine elements – each element in turn comprised of multiple practices – and found a strong correlation with new product success.[175] The problem, however, is that several of their measures that have been assigned cultural-sounding names are actually made up of constituent items that are too often noncultural, but easy to measure. For example, "democratic communication" was measured by whether the team has a dedicated space on the firm's intranet and uses video conferencing and groupware. While leadership and collaboration measures were more properly measured by testing observed behaviors of managers and colleagues, the overall supposed culture measure is hardly more than an assessment of whether certain innovation capabilities are in place and best-practice processes are followed. This example also points to the methodological difficulties of measuring culture inside organizations.

Organizational executives like to talk about innovation culture and agonize over whether one exists in their organization. But trying to create an innovation culture prior to starting to innovate is putting the cart before the horse. An innovation culture is a result, not a prerequisite. It is a byproduct of successful innovation, not an input. In my opinion, the ingredients for success are simple, but not easy. They are:

- *Leadership*: As with any other corporate endeavor, innovation needs to be led from the top down; otherwise it won't happen.
- *Permission*: People are naturally innovative and creative, but years of rigorous academic study and efficiency-driven management methods have inhibited these capabilities. Leaders need to establish a permission space (with proper guardrails) for innovation.
- *Capabilities*: There needs to be an innovation process that everyone understands and can follow, whether it is conventional or more startup-like (see Chapters 7 and 8), and people need to be trained on it as well as key aspects of creativity (e.g., how to run a proper brainstorming session).

When these three things are in place, innovation can happen and an innovation culture will result, with each success strengthening the culture and making subsequent innovation easier.

Chapter Summary

- People fear creativity because they associate it with uncertainty. The human brain's preference for efficiency is an additional impediment to creative thinking.
- Creativity requires the brain to be jolted by new ways of thinking, new experiences, and new information. Many techniques can accomplish this goal, if properly applied.
- Innovation starts with a proper problem statement of how to help a particular user overcome a particular problem. Combining insights from different fields can lead to novel solutions.
- Design thinking is a human-centered innovation approach that focuses on user needs and emphasizes rapid experimentation to arrive at the best solution.
- The efficiency legacy of the last century often hinders creative thinking and innovation because it abhors variation and any form of waste.
- Understanding what motivates workers and what discourages them is essential to attracting talent to innovation initiatives.

- It is very challenging for an established corporation and for its leaders to juggle both explorative activities associated with creativity, and exploitative activities associated with efficiency in operations. An ambidextrous leadership style is required to juggle both types of activities.
- A well-functioning innovation team requires team members to take on multiple roles, and diversity makes innovation teams stronger.
- Dedicated innovation organizations are not a panacea for success and often fail to achieve their goals. If such organizations are to succeed, their goals, governance, resourcing, and relationship with the parent organization need to be carefully deliberated.
- An innovation culture is not the starting point but the end point of innovation success.

Suggested Exercises and Assignments

- Share your experience with pushback to innovation and creativity within organizations that you worked for. What types of creativity biases did you encounter?
- Research the SCAMPER[xxii] brainstorming method for generating new product or service ideas by using the current product or service as a starting point. Pick a product or service that your organization currently offers and run it through each of the SCAMPER steps with your team. Report back on the insights you gained and any innovation opportunities that you have identified.
- Explain the organizational challenges arising from the need to pursue Horizon 1, 2, and 3 innovations in parallel within one organization. What suggestions can you offer for organizations to overcome these challenges? Use brief examples to illustrate your points where possible.

Recommended Further Reading

Abraham, Anna. 2018. *The Neuroscience of Creativity*. Cambridge, UK: Cambridge University Press.
Berkun, Scott. 2010. *The Myths of Innovation*. Sebastopol, CA: O'Reilly Media.
Boyd, Drew, and Jacob Goldenberg. 2013. *Inside the Box: A Proven System of Creativity for Breakthrough Results*. New York: Simon & Schuster.
Buchholz, Christian, and Benno Aerssen, eds. 2020. *The Innovator's Dictionary: 555 Methods and Instruments for More Creativity and Innovation in Your Company*. Berlin/Boston: Walter de Gruyter GmbH.

xxii Substitute, combine, adapt, modify, put to another use, eliminate and reverse.

Gailly, Benoît. 2011. *Developing Innovative Organizations: A Roadmap to Boost Your Innovation Potential*. Houndmills, Basingstoke, Hampshire: Palgrave Macmillan.

Kaufman, James C., and Robert J. Sternberg. 2019. *The Cambridge Handbook of Creativity*. Second edition. Cambridge, UK: Cambridge University Press.

Kelley, Tom, and Jonathan Littman. 2005. *The Ten Faces of Innovation: IDEO's Strategies for Beating the Devil's Advocate and Driving Creativity Throughout Your Organization*. New York: Currency/Doubleday.

Penker, Magnus. 2021. *Play Bold: How to Win the Business Game through Creative Destruction*. Leaders Press.

Wisnioski, Matthew H., Eric S. Hintz, and Marie Stettler Kleine. 2019. *Does America Need More Innovators?* Cambridge, MA: MIT Press. (Free online version available via Open Access: https://direct.mit.edu/books/book/4198/Does-America-Need-More-Innovators)

Chapter 5
Open Innovation and External Collaboration

No organization can effectively innovate today by only relying on internal resources and expertise. An organization may also benefit in financial and other ways by sharing its knowledge with external parties, instead of keeping it locked up inside. The concept of open innovation, therefore, encompasses both incoming and outgoing knowledge flows. This chapter explains how much additional value can be created if organizations extend their innovation collaborations beyond their organizational boundaries.

The chapter starts by comparing closed (traditional) and open innovation. The main principles of open innovation, as well as the major types of open innovation, are explained. The roles that the main actors – the public sector, the financial sector, businesses, academia, and citizens – play in the open-innovation ecosystem are introduced. While open innovation holds much promise, there has also been many false starts. The common stumbling blocks to open innovation success are pointed out, and practical advice is given on how to design a well-functioning open-innovation program.

Government agencies also rely on open innovation to execute their missions. Some examples of public-sector open-innovation programs are provided followed by a discussion on the challenges faced by government agencies who wish to pursue open innovation.

Open versus Closed Innovation

Open innovation (OI) as a defined term is fairly recent, though many of the practices now associated with open innovation have been around for a longer time. Open innovation entails much more than obtaining external ideas and technologies for your product development and innovation activities; it also involves a total paradigm shift in how you think about bringing your products to the market and about what creates value for your organization. In order to appreciate this important point, it is necessary to go back to the origin of the concept.

Henry Chesbrough (2006) famously coined the term *open innovation* in his eponymous book, and he has continued to be one of the thought leaders in this area. Chesbrough created the term open innovation as the anthesis of the way things were previously done, which he called *closed innovation*. In closed innovation, firms do all their R&D inhouse, using it to develop new products for their current markets. Studying Xerox's famous Palo Alto Research Center (PARC) and its spinoffs, Chesbrough became intrigued with why so many good ideas and ground-breaking technologies emerging from PARC were not commercialized by Xerox, but instead ended up enriching the

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shareholders of other companies. For example, the graphical user interface (GUI) was first commercialized in the Apple Macintosh computer, and PARC's Bravo word processor became the ancestor of Microsoft Word.[176]

Xerox was a highly successful company, making its money in the office photocopier market, when it founded PARC in 1970 to give it a foothold in what Xerox correctly predicted would be the coming computer revolution. Its R&D programs were well-managed, yet the value of its inventions in independent spin-offs companies (typically started by former employees) greatly exceeded the value of those inventions to Xerox itself. (Xerox was generous to allow researchers who worked on technologies that it decided not to pursue, to take those projects with them when they left the company.) Chesbrough calculated that by the year 2000, the market value of the top 10 spin-offs using Xerox technology would be more than twice that of the entire Xerox company itself. In Chesbrough's analysis, informed by over a hundred interviews with present and past PARC employees, the reason that Xerox passed on so many promising technologies coming out of PARC was that these technologies could only come to fruition and create value in a different context. First, these technologies typically had applications outside of Xerox's current market and customer base, which is why they got rejected by Xerox management. Second, Xerox was a vertically integrated company, but the independent startups that spun off its technologies could not afford to be. They were forced to come up with new business models to commercialize those technologies, including making their systems interoperable with those of other companies. And the technologies spun off from Xerox typically went through major transformations outside of Xerox before they became commercially viable, transformations that would not be possible inside Xerox (Chesbrough 2006, 11–19).[177]

As Chesbrough (2006, 11–19) points out, resolving uncertainty about both the market and technology cannot be done in the conventional Stage-Gated model (see Chapter 8 for an introduction to the model) used by Xerox. It requires making a prototype quickly and trying it out in different markets to get feedback, an approach we would today call the Lean Startup model (the Lean Startup is introduced in Chapter 6). Large companies like Xerox find this kind of market experimentation – trying out new technologies in new markets – very hard to do. Xerox's businesses were focused on growing in their current markets. They actively practiced early testing of new technologies within their existing customer base by inviting customers to the PARC facility. However, they got the wrong feedback on promising technologies outside of their market since customers could not relate to them.[178]

This is another manifestation of Christensen's Innovator's Dilemma. Being overly focused on current customers while missing the potential of new technologies is the same flaw that leaves established companies open to disruptive innovation, as described by

Christensen (1997).[179] Christensen's thinking no doubt influenced Chesbrough in this regard. (Disruptive innovation was introduced and explained in Chapters 1 and 2.)

Chesbrough (2006, 11–19) presents open innovation as the new paradigm suitable for the modern knowledge economy. Closed innovation emerged out of a knowledge landscape a century ago, when expertise and knowledge were much less abundant. It made sense to centralize the R&D organization internally to create a critical mass of expertise. However, today, knowledge is abundantly available. Suppliers often have deep expertise. Skilled workers are widely available and move much more often between companies than in the previous century. Venture capitalists and angel investors are willing to provide capital to develop ideas that have yet to be proven. Knowledge itself is now at the stage of diffusion, from scientific databases and journals that are easily accessible online, to academic institutions all over the world full of professors with deep expertise supported by graduate students. Huge numbers of patents are now held by non-U.S. companies. This drastically changes the role of the internal R&D department. Today, these R&D departments exist to find, select, and synthesize the information needed for product development, and to do research only on the missing pieces that cannot be found elsewhere. They can also directly generate revenues for the enterprise from selling research outputs, rather than final products, to other firms.[180]

Chesbrough's early, concise definition of open innovation was:

> Open innovation is the use of purposeful inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively.[181]
> (Chesbrough 2006, 2)

Later, Chesbrough updated and expanded his definition of open innovation as follows:

> Open innovation is a distributed innovation process that relies on purposively managed knowledge flows across organizational boundaries, using pecuniary and nonpecuniary mechanisms in line with the organization's business model to guide and motivate knowledge sharing.[182] (Chesbrough 2017, 35)

This definition signifies an innovation process enabled and enriched by knowledge flows occurring both ways: *inside-out* and *outside-in,* as Chesbrough would call them. Outside-in means incorporating external knowledge as inputs into an organization's innovation processes. The outside-in part is too often conflated with open innovation as a whole, a misperception that Chesbrough was keen to correct. The inside-out part of open innovation, which is just as important, involves the organization allowing knowledge that it cannot fully exploit itself to be used by other organizations and businesses (Chesbrough 2017, 35–38).[183] This may take the form of actively selling intellectual property (IP), along with buying it when needed. The implication is that a good IP strategy needs to be part of any open-innovation strategy.

The determination as to which knowledge should be kept, and which should be released, what IP to buy and what to sell, will ultimately be influenced by the business model the organization has adopted. The business model is what determines how value is created by an organization (see Chapter 6). Chesbrough has also suggested that the inventive output of a firm should not be restricted to the current business model – which is only to have "first right of refusal" – but that it must have the opportunity to go to market via alternative channels (Chesbrough 2006).[184]

In contrast with Chesbrough's rather academic definition, I propose a hopefully noncontradictory, but perhaps more practical, definition:

Open innovation happens when organizations go beyond their external (and/or internal) boundaries to access and exploit valuable ideas, knowledge, and technologies that are not available within the confines of their usual organizational boundaries, and to share knowledge and technologies that can be better exploited by others.

More Types of Open Innovation

The early 2000s brought forth a rich set of new collaboration models, which could be included under the open-innovation umbrella. Several prominent authors advanced new innovation models based on what they were already seeing happen in industry, as well as in the consumer and user world.

In his book, *Democratizing Innovation*, which was published contemporaneously with Chesbrough's book on OI, Eric von Hippel (2006)[185] points out that the users of products and services are increasingly able to innovate products and services for themselves. This is enabled by the design capabilities (innovation toolkits) made possible by advances in computer hardware and software, and by the internet, which enables groups of individual users to combine forces and coordinate their innovation activities.

Another component now included in OI is *crowdsourcing*, a concept popularized by James Surowiecki (2005) in his book, *The Wisdom of Crowds*.[186] Surowiecki argues that large groups of people together can be smarter than an elite few, and can come up with better solutions to problems, superior innovations, and even predictions about the future. In innovation, crowdsourcing has become an ideation technique in which large groups of employees, customer, users, or the public participate, typically via an online platform. Crowdsourcing is also used to outsource work to a large network by appealing to people to contribute to the project independently, usually for free. For example, professional astronomers are using citizen scientists to help them scan and interpret a now endless stream of images and measurements of the universe from new telescopes and sensors (Hadhazy 2016).[187]

Coimbatore Prahalad and Venkat Ramaswamy (2004) point out that in today's connected, data-rich world the role of the consumer in the industrial (and innovation) system has changed from isolated, unaware, and passive to connected, informed and active. *Co-creation* is not just another open-innovation model, but a new way of creating value.[188] Prahalad and Ramaswamy (2004) define four key building blocks of co-creation (the so-called DART model) which may be combined to yield different models of co-creation:

- *Dialogue:* This refers to a two-way exchange of information between companies and customers, implying shared learning between equal problem solvers.
- *Access*: This entails providing both information and tools to customers that allow customers to access data on design and manufacturing.
- *Risk assessment*: The risk is the probability that the consumer may be harmed. Managing such risks associated with using products or services require a properly balancing of informed consent on the side of consumers and acceptance of responsibilities on the producers' side.
- *Transparency*: The traditional advantages of information asymmetry between firms and consumers enjoyed by producers are disappearing as information on products, technologies, prices, and costs are becoming more accessible.[189]

Co-creation is an activity done with others. The term *co-creation ecosystem* has become popular to describe collaborations with a defined set of partners on specific types of solutions and concepts. Sometimes, there is one large central player, a big company, who collaborates with many smaller players, that could be startups. For example, Johnson & Johnson has set up labs and innovation centers that host startups around the world, and estimate that they have obtained $5 billion in value from follow-up startup investments as a consequence (*Innovation Leader*, 2019).[190]

An analysis of the rate of collaboration on U.S. triadic[xxiii] patents suggests that about 10 percent of inventions involve an external co-inventor, and about 23 percent involve external collaborators who are not listed as co-inventors (Walsh, Lee, and Nagaoka 2016). Following the usual Schumpeterian model where the first stage is invention and the second stage is innovation, the researchers also suggest that the nature and effectiveness of external collaboration may be different in the invention stage than in the innovation stage.[191]

Corporate-startup collaboration combines the nimbleness of a potential high-growth startup with the resources of a large, established company. Startups can benefit from capital injections from established companies as well as access to several types of corporate resources. The established company gets access to new technologies and entrepreneurial talent, and early insights into new market innovations that may have the potential to transform their industry. Consultants at Fuel, a consulting company (owned by McKinsey & Company) that specializes in startups, estimate that

xxiii Patents filed in Japan and the European Patents Office and granted by the USPTO. Having a patent filed in multiple jurisdictions is a proxy for patent quality.

75 percent of Fortune 100 companies now have an active corporate venture capital (CVC) unit. The top three motives for larger companies to partner with startups are: to get access to faster innovation and product development, to gain insights into new technologies and previous unserved customer segments, and to gain insights to new ways of working. The top three motives for startups are: to utilize the corporate partner's market access, to send a positive signal to the industry and investors, and to gain the corporate partner as a future customer (Henz, Wang, and Sibanda 2020).[192]

In an *innovation contest* (also called *tournament* or *competition*), the organization (the seeker) desiring a solution to an innovation-related problem posts this problem to a population of independent agents (the solvers) and provides an award to the agent who provided the best solution. There may be concerns that the larger the number of solvers, the less incentive there would be for each solver to invest effort in a solution – everyone but the winner receives no reward for their efforts. Economists have therefore recommended using only two solvers. However, it has been demonstrated by Terwiesch and Xu (2008) that the seeker benefits from a large population of solvers. The reason is that the solvers' underinvestment is outweighed by the benefits of receiving a larger, more diverse set of solutions. Further mitigation is possible by awarding a performance-contingent rather than a fixed price award.[193]

Given the complexity of the innovation process, it should be no surprise that there has always been a role for *intermediaries* (also called middlemen, brokers, or third parties) between the various actors. Intermediaries could be involved in any of the Schumpeterian stages: invention, innovation, or diffusion. Jeremy Howels (2006) offers the following generalized definition of an innovation intermediary:

> An organization or body that acts an agent or broker in any aspect of the innovation process between two or more parties. Such intermediary activities include: helping to provide information about potential collaborators; brokering a transaction between two or more parties; acting as a mediator, or go-between, bodies or organizations that are already collaborating; and helping find advice, funding and support for the innovation outcomes of such collaborations.[194]
>
> (Howells 2006)

There is a large variety of intermediary types active in the OI space. Many intermediaries are associated with *diffusion and technology transfer activities* within the total OI environment. Third parties can help to disseminate information and influence the adoption rates of new technologies. They can also support the specification-writing, or standard-setting, approach. A major role intermediaries play is that of matchmaker on both ends of the technology transfer processes – helping to identify partners, selecting suitable suppliers for technology building blocks, and aiding the deal-making process between the parties. *Technology or knowledge broker* roles can extend beyond just linking or matchmaking, but also help to transform and adapt the ideas and knowhow being transferred.

Open Innovation 2.0

In 2012, the European Commission set up an Independent Expert Group on Knowledge Transfer. Their resulting report, *Open Innovation Open Science Open to the World – a vision for Europe* (European Commission Directorate General of Research and Innovation 2016), endorsed the concept of OI as a way for Europe to make better use of its innovation talent and scientific knowledge.[195] It emphasizes the role of *user innovation,* a term coined by Eric von Hippel (2006),[196] and combines that with Chesbrough's concepts of inside-out and coupled innovation models into a new concept called *Open Innovation 2.0*.

Open Innovation 2.0 adds the user-innovation component as well as the concept of co-creation happening in a well-functioning ecosystem (including crowdsourcing) to the original OI concept. Perhaps most instructive of this vision is the roles that are defined for the respective actors, starting with the public sector. Other key actors are the financial sector, which is to provide funding for the inherently risky venture of innovation: the innovative businesses themselves; and academia, where universities should act not only as producers of knowledge and skilled human capital, but also as centers for co-creation. Most notably, it also envisages a clear role for the citizenry in OI:

OI Goals, Models, and Processes

As with any endeavor in life, establishing clear goals at the outset are vitally important for the eventual success of an OI initiative. Goals for OI may vary by organization, but can typically be classified into three main categories:

- *Market intelligence goals*: Such OI goals support the innovation process at its initiation and may include gaining new consumer insights and finding potentially useful emerging technologies through technology scouting as well as signaling to the market and particularly prospective partners that the organization is investing in innovation in a specific area.
- *Ideation and technology access goals*: These OI goals support the development of the innovation and its associated technologies, and may include accessing new technologies and related research, diversifying sources of technologies used in the innovation, tapping new ideas from outside, and generally lowering the access costs to outside expertise.
- *Development and commercialization goals*: These OI goals include one or more of the following: accelerating R&D, lowering the cost of the R&D, hedging R&D risks by sourcing alternate technologies, and better testing of concepts, prototypes, and products – for example, with future end users or by accessing important technical test facilities outside of the organization.

Depending on the goals of a particular OI program, multiple societal actors may be involved in it apart from the organization that owns the OI program. Table 5.1 overviews the main roles that various organizations and individuals in society play in furthering OI.

Table 5.1: The Roles of the Different Actors in Open Innovation.

Actor	Role
The Public Sector	The public sector has a central role to play in promoting Open Innovation. First and foremost it creates the regulatory environment in which all other actors operate. It puts in place rules and tools that can incentivise an open circulation of knowledge and cooperation among different actors with the aim to develop and market innovative solutions. Secondly, it offers better modes of coordination among the economic actors involved in order to enhance productivity and value. Thirdly, it can create a demand for innovation, both through the above-mentioned regulatory means and, for instance, through the procurement of innovative solutions.
The Financial Sector	Innovation can be a risky business, therefore accessing funding and / or finance is not always easy for those who have innovative ideas. Building more innovation-friendly financial instruments and institutions and promoting the integration of existing funds and tools is essential to support Open Innovation. It is important that investors of all kinds find their interest in investing in innovation.
Innovative Businesses	Businesses play a key role in innovating. In order to be able to bring innovations to the market, they must be able to maximise their returns on the resources allocated to innovating. This is the reason why it is important to reduce European market fragmentation, while fostering faster market access and development.
Academia	Universities, Higher Education Institutions, and Public Research Organisations/ Research and Technology Organisations have a key role to play in the innovation eco-system, not only as knowledge producers, but also as co-creators and generators of skilled human capital. Challenges in this component of the ecosystem include the co-creation capabilities of universities, the design of incentives for academics when working with users and the absorptive capacity of academic knowledge within firms.
Citizens	Citizens, users and Civil Society Organisations have a central and transversal role to play in bringing innovation to the market. They create a demand for innovative products and services, they can fund and/or finance projects that are relevant to them, they can be at the source of innovative ideas worth spreading and scaling up and they can have a say in what research is meaningful to them and can impact their lives.

Source: Directorate General of Research and Innovation, European Commission (2016, 17).[197]

Oliver Gassman and Ellen Enkel (2004) built on Chesbrough's open-innovation theory to define three core processes at the heart of OI, which they call *process archetypes*:[198]

1. The *outside-in process* operationalizes the inside-outside concept defined by Chesbrough. It entails the enrichment of the organization's own knowledge base through integrating external knowledge coming from suppliers, customers, and other sources.
2. The *inside-out process* entails profiting from transferring ideas outside of the company – for example, by selling IP.
3. The *coupled process* involves coupling the former two processes by working in partnerships or alliances where there is both give and take. Different organizations may rely more heavily on one of these processes than the others, depending on their business model and strategy.

Even more important than having the right process in place to support OI is that an organization has to make the mindset change from closed to open innovation. Some of the most important mindset changes are contrasted in Table 5.2.

Table 5.2: Closed versus Open Innovation.

From (Closed Innovation)	To (Open Innovation)
– Coming up with innovative ideas only in your own R&D department – Asking your best customers about their needs and testing new product ideas only on existing customers – Asking "your neighbor" for help (e.g. a university in the same town) – "Doing it yourself" unless it is too expensive – Pushing a new product into the market	– Combining your own ideas with systematic screens of "the world out there" – Tapping participants along the full length of value chain in for insights and collaboration – Scanning systematically for outside contacts with optimal expertise – Using a clear set of processes and criteria to select external partners (including M&A, licensing, venturing) – Actively shaping the market through a network of well-connected opinion leaders

The Openness of Innovation and Its Policy Implications

Carliss Baldwin and Eric von Hippel (2010) point out that the assumption in the traditional model of what they call *producer innovation* as the only model of innovation can lead policymakers astray in a world that is increasingly making use of two or more collaborative models of innovation, namely *user innovation* and *open collaborative innovation*.[199]

The basic assumption behind producer innovation is that the most important innovations are developed by producers who then sell them to customers as goods or services. In a free-market economy, producers must be able to aggregate customer demand for their product. The producer-innovation model was also implicitly assumed by Schumpeter and other economists who described the nature of innovation as a force of endogenous growth, or as a driving force in monopolistic competition, most likely because they were commenting on the prevailing innovation processes they were observing at the time. The producer-innovation model was indeed valid for its time and technology. The technological factors that dictated this model, making it cheaper to design and produce standardized products in most of the 20th century, were:

- The scarcity of computing resources, which meant that the cost of creating individualized designs was high
- The constraints of the processing technologies, which favored uniformity of design
- The lack of appreciation and understanding of modular design methods
- The lack of cheap and fast communication technologies to distribute design tasks among physically separated design participants[200]

However, today these constraints are not operative anymore, leading us to expect more variation of innovation methods as well as final products. A survey of empirical studies by Baldwin and Von Hippel (2010) highlights the importance of user innovation: In fields as diverse as oil refining, scientific instruments, and semiconductor manufacturing, user firms have performed a leading role in innovation. Between 6 to 40 percent of users are now involved in developing or modifying products.[201]

There is a distinction between open innovation (as per Chesbrough) and the *openness of an innovation* (or *innovation openness* for short) that Baldwin and Von Hippel (2010) focus on. They define an innovation as open when "all information related to the innovation is a public good – non-rivalrous and nonexcludable." For example, open-source software meets these conditions and is perhaps the most widely known example of an open innovation in the latter sense. This concept of innovation openness should not be confused with the openness of the organization doing the innovation.[xxiv] Policymakers have long assumed that such innovation openness is undesirable to private innovators because it will reduce their ability to profit from their innovations and hence, depress their willingness to invest in innovation. Governments grant patents because they assume that the losses to society incurred due to granting intellectual proper rights will be exceeded by gains from increases in investment and disclosure of information that would otherwise be kept

xxiv For Chesbrough, "open" is an adverb modifying the verb, "innovation." For Baldwin and Von Hippel, "open" is an adjective modifying the noun, "innovation." The first is about the nature of the innovation process, the second is about the nature of the innovation itself.

hidden as trade secrets. However, there is evidence that innovators freely reveal information about their innovations more often than these assumptions would predict. Innovators can benefit from revealing their innovations when others make further improvements to the innovation or by obtaining a supply source for their innovation at lower cost than in-house production. There are sometimes also positive network effects related to the increased diffusion of their innovation. The incentive to reveal is reduced when competition is involved for the same end product or customers. In the open-software industry (e.g., Linux), producers maintain two models: open modules on which they wish to collaborate and closed modules on which they compete (Baldwin and Von Hippel 2011).[202]

Today, the three models – *producer innovation*, *user innovation*, and *open collaborative innovation* – coexist with economics and technology determining the most viable choice between them. The models may also be combined. The producer model is still viable in some situations and have even made inroads in the software industry where Software-as-a-Service (SaaS) is the ascendant model. In the case of SaaS, the software producer can offer more software functionality at a lower price to multiple users than could be developed by each of them on their own, or on their behalf. It helps that SaaS software products are highly customizable on the front end by their end users, even though they share a common software platform. SaaS technology allows the benefits of both individualization and mass production, which it is why it has become the dominant industry model for software delivery.

Hybrid models currently also thrive in industry. For example, in the case of integrated circuits (microelectronics), most chipmakers do not operate their own semiconductor factories anymore. The reason for this is the enormous and ever-increasing fixed cost of the latest chipmaking equipment, which can only be offset by aggregating demand across many firms. Semiconductor foundries perform extensive R&D to perfect their new technologies (a form of producer innovation), which are then made available through computer-aided-design environments for chip designers called *process design kits* (PDKs). The PDKs enable chip designers at customer companies to design unique chips by combining the many building blocks offered to them by the foundries, and which can be manufactured by that particular foundry. Crowdsourcing is another example of a hybrid model, where the producer innovator frames and poses a problem, soliciting solutions from numerous third parties (the crowd), and then picks the best solution offered.

OI Program Design Considerations

After initial enthusiasm for OI in the mid-2000s, some firms became disillusioned with it because they were not realizing the benefits they expected, and the costs of OI were higher than they anticipated. Of course, focus and execution is an important part of making OI successful, and it takes time for organizations to build the capabilities and processes needed for OI. Furthermore, nothing in life is free, and neither is operating an OI initiative.

It is important that the organization is willing to accept the reasonable costs needed to achieve its OI goals, and that there is an approved budget for the monetary costs and an acceptance of the time burden that comes with these initiatives. Typical costs that organizations should expect depending on the particular OI activities are:
- Fixed search costs to find ideas and manage OI – for example, dedicated staff, idea scouts
- Variable search costs – for example, travel expenses, conference fees, third party services
- Idea screening costs – for example, meeting time
- IP protection costs – for example, lawyers, patent costs, negotiations, and litigation
- Internal knowledge-sharing costs to keep staff informed – for example, IT tools and staff time
- External knowledge-sharing costs – for example, publications, conferences, and marketing material
- Transaction costs – for example, payment for technology or company acquisitions, grants, and incentives
- Product management costs – for example, time to incorporate external inputs, or redesign products

An underestimation of the costs of OI initiatives could easily lead to disillusionment when such initiatives sap a lot of organizational bandwidth without delivering the expected results. This can be avoided by properly designing OI initiatives from the outset – and ensuring that in aggregate all the OI initiatives do not take too much time and effort. A helpful mental model for thinking about the bandwidth demands of any particular OI initiative is that the bandwidth required is the product of three main factors:
- *The Type of Relationship (R).* A highly collaborative relationship will consume much more bandwidth than a purely transactional relationship.
- *The Scope of the Collaboration (C).* The more ambiguous the scope of the collaboration, the higher the bandwidth requirement will be. A narrowly defined scope will reduce the bandwidth requirement.
- *The Number of Target Participants (P).* The higher the number of participants (e.g., suppliers, universities, or users) in an OI program, the higher the bandwidth requirement.

Thus, the bandwidth requirement of an OI relationship = R x C x P.

For instance, if there will be a large number of target participants (P), then R x C must be kept low. That implies that the scope of collaboration (C) needs to be limited, and the relationship (R) is best kept simple and transactional. For example, General Mills operates a website, the General Mills Worldwide Innovation Network (G-WIN), for the purpose of soliciting solutions from potential partners. Specific challenges are posted, and solutions may be submitted in the required format (General Mills 2022).[203] On the other hand, if the relationship (R) is intended to be highly collaborative and the scope of the collaboration (C) is wide open, then only a handful of such relationships will be feasible.

In a similar vein, Tina Saebi and Nicolai Foss (2015) point out that inbound OI strategies can usually be classified based on two dimensions: the *breadth* versus the *depth* of the knowledge search:[204]

- *Market-based innovation strategy (low depth/low breadth).* The knowledge input into the innovation process is acquired through the market by, for example, shopping for readily available new technologies, inward licensing of IP, or acquisition of startups. R&D outsourcing is also a type of market-based strategy. Market-based strategies are characterized by the low diversity of external resources as well as a low level of integration of these sources.
- *Crowd-based innovation strategy (low depth/high breadth).* The knowledge input is sourced from many external actors. Digitization and low communication costs (internet) enable organization to access distributed knowledge at low cost. Crowdsourcing is when a task is outsourced to a crowd or community rather than to a designated agent, as is the case with market-based innovation strategy.
- *Collaborative innovation strategy (high depth/low breadth).* The organization enters into collaborative agreements with only a few partners, characterized as knowledge-intensive relationships that typically require the deep integration of external partners into the organization's innovation processes, and building up a high level of mutual trust. Close partnerships with universities, research institutes, and other companies fall in this category.
- *Network-based innovation strategy (high depth/high breadth).* As with the collaborative innovation strategy model, this model entails deeply integrating external partners. However, this model follows a network strategy by engaging a network of relationships with external partners, making the organization part of a larger ecosystem that may include other firms, individuals, and communities.

Each of these models have implications for the type of the business model that the firm operates. (Business models are reviewed in Chapter 6.) If they wish to succeed at OI, firm leaders need to ensure that several essential elements are put in place:

1. *A business model conducive to OI.* OI needs to be aligned with strategy and integrated in the core innovation process.
2. *An OI methodology that works for that particular organization.* This requires clearly defining the OI goals and OI partner-engagement model, as well as how the resulting ideas will be commercialized.

3. *Upgraded organizational capabilities and roles*. Workers in both OI-dedicated roles and those that are not will need enhanced skills to support OI methodology.
4. *New management processes*. OI must be conducted effectively, efficiently, and in a repeatable manner.
5. *A supportive culture*. This may require significant chance in mindsets and behaviors across the company. Senior leaders must ensure that OI is seen to be sufficiently supported.

Public-Sector OI Practices and Barriers

The public sector can benefit from OI in two major ways: First, by forging new collaborative relationships between citizens and their government and second, by improving public-sector innovation in areas where it is most challenged and where conventional closed innovation processes have failed (Pedersen 2018).[205] A major theme within the latter is that government budgets are increasingly strained. OI offers the promise of tapping private-sector and citizen-level expertise and know-how that governments may not be able to afford otherwise. Mutually beneficial (win-win) OI models can be constructed so that everyone benefits. When the relationship between the government and private-sector firms is purely that of a vendor (the firm) and a buyer (the agency), it is too often a zero-sum game. However, when government orchestrates and enables public–private collaboration using various possible OI models, the relationship transforms to a nonzero-sum game from which both parties can gain.

OI in the public sector has generally lagged OI in the private sector, which means that we are still fairly early in the process of governments learning how to use OI for maximum benefit. Some types of public-sector OI practices are listed in Table 5.3, following the outside-in and inside-out terms originally defined by Chesbrough.

Table 5.3: Types of Public-Sector OI Practices.

Outside in (inbound) Practices	Inside-out (outbound) Practices
Strategic alliances and joint R&D programs	Spin-off creations
Exchange of scientists	Patent licensing to universities and industry
Involvement of non-R&D in innovation	Technology transfer offices
New IP tools and utilization of intermediaries	Open-source software
Crowdsourcing and technology solution sourcing	Technology commercialization teams
Technology transfer offices	
Collaborative research centers with universities and industries	

Major examples of current U.S. federal government OI programs include DARPA, 10X, citizenscience.gov, and Challenge.gov. Since 2010, the U.S. federal government has been running an online platform called Challenge.gov on which agencies can post their problem statements, and invite and collect ideas from the public.

However, the nature of the highly regulated government acquisition process for innovation is the antithesis of OI processes, which are intended to be subject to only a few simple rules. An empirical analysis by Ines Mergel (2018) of Challenge.gov using both data and interviews with agency managers revealed systemic barriers that hinder public-sector organizations in their adoption of OI.[206] These barriers are instructive because they apply generally to OI in the public sector:

Legal barriers. In the absence of a proper legal framework, agency managers may perceive OI activities as too risky. Personally identifiable information collected by agencies are subject to legal privacy provisions, which may need to be updated or adapted. Intellectual property (IP) rights are another area of concern when not dealt with through conventional acquisition processes. While the private sector has evolved models for co-ownership, practical concerns when someone submits a technology to the government include: Does that unique technology then provide justification for a sole-source acquisition contract? What can the government do with the technology, that is, what rights do they receive?

Cultural factors. These factors depend on the type of agency, how comfortable they already are with external innovation, and the level of top management buy-in. Agency R&D teams may pride themselves on being able to solve the hardest problem in their space, and staff may see it as an existential career risk to outsource part of their innovation process. This is the public-sector manifestation of the "not invented here" attitude also seen in private companies.

Technological barriers. Agencies are used to communicating their solution needs through well-established RFP processes. Such RFPs typically include jargon and industry terms only familiar to industry insiders. However, OI problem statements need to be expressed in much plainer language, not only to make them accessible to a wider audience that may include amateurs, but also so that they are open-ended enough not to exclude potential solutions the agency itself may not have considered.

Uncertainty about innovation outcomes. The standard acquisition process – as codified in agency manuals and operating procedures – entails clear expectations, narrowly defined goals, and deliverables subject to legally binding contractual language. But the nature of OI is that it is a process to come up with an answer to a problem that may not have a predetermined solution. The best way to solve a problem may only become apparent down the road.

Institutionalization barriers. Institutional barriers to OI may reflect more general barriers to innovation, such as the lack of a proper organizational structure for innovation, the absence of innovation leadership, or a culture of experimentation supported by all management levels. The central institutional challenge to OI is that it requires a change from closed innovation to open innovation.

Inter-organizational barriers. When two or more agencies have to collaborate with OI partners, interagency bureaucratic challenges quickly emerge. Each agency has its own funding to execute its mission, and cooperation with one or more other agencies require a formal framework (typically captured in a Memorandum of Understanding or MOU) to be first negotiated between the agencies before outside engagement can even start. This could be alleviated by more direction from a central governing agency such as the Office of Management and Budget (OMB) in the U.S. federal government.

Extra-organizational and societal factors. The main barrier here is concern about how the nontraditional procurement processes entailed by OI may be perceived by taxpayers and their representatives. Conventional public-procurement processes have many accountability mechanisms built into them, but rewarding a private individual or startup with a substantial money prize in an innovation competition may raise eyebrows.

Public Sector OI Strategies

The traditional public-sector governance structure is top-down since it is driven by political decisions and directives that have to be implemented by public servants. The so-called *New Public Management (NPM)* approach implemented in the 1980s was intended to give agency managers more responsibility for efficiency-improving innovation, but ultimately discouraged knowledge sharing across organizations thereby, impeding at least some types of innovation (Hartley, Sørensen, and Torfing 2013).[207]

According to the U.S. Government Accountability Office (GAO 2017), the following five OI strategies are used by federal agencies:[208]

1. *Crowdsourcing and citizen science*. Crowdsourcing typically entails agencies submitting an open call over the internet asking for voluntary assistance from a large group of interested individuals to aid in defined tasks. In the case of citizen science, participants may be asked to help collect, analyze, and interpret data and reported results.
2. *Idea generation or ideation*. Agencies may put out a specific issue or problem and ask for ideas on how to address it. This may be supplemented by allowing participants to comment and vote on ideas submitting by others.
3. *Open data collaboration*. Agencies may request help in analyzing publicly available (open government) data sets; or to develop visualizations and/or web and mobile applications to help the public access such datasets.

4. *Open dialogue*. This term describes the interaction between agencies and the public via online forums or in-person meetings for the agency to collect information or perspectives from a wide range of citizens, experts, and other stakeholders.
5. *Prize competitions or challenges*. Similar to idea generation, this involves requests for solutions to a particular problem, but adds a monetary or non-monetary reward to the winning proposals.

The relevant policies currently guiding these OI strategies within the U.S. federal government are listed in Table 5.4.

Table 5.4: U.S. Government Policies and Guidance for OI Strategies.

Strategies	Name of Policy/Guidance
1. Crowdsourcing and Citizen Science	Office of Science and Technology Policy (OSTP) Memorandum, Addressing Societal and Scientific Challenges Through Citizen Science and Crowdsourcing (September 2015)
	General Services Administration (GSA), Federal Crowdsourcing and Citizen Science Toolkit (launched September 2015)
2. Ideation and	GSA, U.S. Public Participation Playbook (launched February 2015)
3. Open Dialogues	
4. Open Data Collaboration	Office of Management and Budget (OMB) Memorandum M-13-13, Open Data Policy (May 2013)
	OMB and OSTP, Project Open Data (launched May 2013)
5. Prize Competitions and Challenges	OMB Memorandum M-10-11, Guidance on the Use of Challenges and Prizes to Promote Open Government (March 2010)
	OMB Memorandum, Prize Authority in the America COMPETES Reauthorization Act (August 2011)
	GSA, Challenges and Prizes Toolkit (launched December 2016)

Source: GAO 2017, 9.[209]

A *living lab* is a particular kind of innovation intermediary that provides an environment intended to support public-sector OI. In living labs, users are involved as co-creators of innovations on an equal footing with other participants, such as government employees, and experimentation is conducted in as close as possible to real-world settings (Gascó 2017).[210] The modern concept of a living laboratory or living lab can be traced back to MIT where Bill Mitchell, professor of Architecture, Media Arts and Sciences, pioneered the idea of constructing test environments to which real users could be invited, and, once there, interact with the technology solutions being tested (Dias and Salmelin 2018).[211] This method is closely related to the rapid prototyping and user-feedback elements of the design-thinking approach. In the biological sciences, the concept is even older and referred to as in-situ testing or experimentation (Fulgencio, Le Fever, and Katzy 2012).[212]

Public-sector participation in OI should also be seen within the overall context of national innovation and, in particular, the Triple-Helix Model, with its emphasis on collaboration between government, industry, and universities. (This will be further explained in Chapter 11.)

Open Government and Open Data

We live in an era in which innovation is increasingly fueled by data. As a major collector of data, the public sector has a central role in the triad formed by the government, the private sector, and the general public, because data can help drive innovations of benefit to one or more of these parties. For the public sector itself, such data-driven innovations can improve efficiency, transparency, accountability, service levels, and trust in the government (Jansen et al. 2017).[213]

The Open Knowledge Foundation, a nonprofit, defines and explains the attributes of open knowledge as follows:

> Open knowledge' is any content, information or data that people are free to use, re-use and redistribute – without any legal, technological or social restriction. Open knowledge is what open data becomes when it's useful, usable and used.
>
> The key features of openness are:
>
> – *Availability and access:* the data must be available as a whole and at no more than a reasonable reproduction cost, preferably by downloading over the internet. The data must also be available in a convenient and modifiable form.
> – *Reuse and redistribution:* the data must be provided under terms that permit reuse and redistribution including the intermixing with other datasets. The data must be machine-readable.
> – *Universal participation:* everyone must be able to use, reuse, and redistribute – there should be no discrimination against fields of endeavour or against persons or groups. For example, 'non-commercial' restrictions that would prevent 'commercial' use, or restrictions of use for certain purposes (e.g., only in education), are not allowed.[214]
>
> (Open Knowledge Foundation 2022)

Open data are the building blocks of open knowledge. Open data are defined as "data that can be freely used, reused and redistributed by anyone – subject only, at most, to the requirement to attribute and share alike" (Open Knowledge Foundation 2022).[215] In economic terms, open data are both nonexcludable (since everyone can access it) and nonrival in consumption (one person's use of the data does not preclude anyone else's use of the data). That makes open data a pure public good.

Open government data (OGD) is defined as open data collected by the government. As such, OGD is a subset of all open data available globally, but the public sector is one of the largest creators and collectors of data in the world. The often-high fixed costs of collecting such data make it unfeasible for the private sector to do so (Jetzek, Avital, and Bjorn-Andersen 2014).[216] Originally, OGD may typically have been collected as a core part of managing government operations, which is why it is paid for by taxpayers. But these days OGD have become a shared resource which can provide benefits to the public beyond the original value of its use in the public sector. For example, Data.gov is the U.S. federal government's OGD portal.

The *Global Open Data Index* (Open Knowledge Foundation 2022), maintained by the Open Knowledge Foundation, rates governments by their degree of openness.[217] The dimensions comprising the index are:

– Government Budget	– Draft Legislation	– Election Results
– National Statistics	– Air Quality	– Locations
– Procurement	– National Maps	– Water Quality
– National Laws	– Weather Forecast	– Government Spending
– Administrative Boundaries	– Company Register	– Land Ownership

Entrepreneurs can create valuable and profitable innovations using open knowledge and open data. This potential is too often untapped because supposedly public data is neither easy to find nor easy to use. Major challenges frustrate would-be innovators:

- The data are fragmented, forcing potential users to check many online sources and to stitch the data together.
- Data are hidden deep in government websites, with naming conventions that are not self-explanatory or meaningful.
- Users are forced to experiment with random queries to find the data they need
- Broken URLs (web links) or missing web pages result in dead ends.

The challenges related to usability typically come down to the way governments publish data, which is in many forms such as maps or charts, but that the underlying raw data are often not shown. Public employees cannot anticipate how would-be innovators would want to use data or which data would be most relevant to external parties. This means the best policy is to make as much data available as possible, and make the raw data available in file formats that are easily accessible and processable. Easily found metadata which includes explanations of terms, variables, and data structure are also crucial. The last big set of challenges involve the legal framework in which OGD is made available. Too often governments have license terms that are not standard open-data licenses and contain unnecessarily restrictive clauses, or a license does not make clear what exactly it applies to. Sometimes, the license terms are simply missing and at other times, confusing. It is very important that the open licensing terms should be published right next to the data they pertain to. Contradictory copyright notices in website footers should also be cleaned up (Lämmerhirt, Rubinstein, and Montiel, 2017).[218]

Shortly after taking office in 2009, President Obama instructed the Director of the Office of Management and Budget (OMB) to issue an Open Government Directive to all federal departments and agencies. This included directives for each agency to publish government information online, to improve the quality of government data, to institutionalize a culture of open government, and to create an enabling policy for open government (White House 2009).[219] As part of this initiative, Digital.gov (a central team under the General Services Administration) was created to help federal agencies provide better digital services.

Chapter Summary

- Open innovation happens when organizations go beyond their external (and/or internal) boundaries to access and exploit valuable ideas, knowledge, and technologies that are not available within the confines of their usual organizational boundaries, as well as to share knowledge and technologies that can be better exploited by others.
- The goals of an OI program need to be clear upfront. Typical goals are gaining market intelligence, sourcing external ideas or technology, accelerating internal R&D, or getting leverage in the commercialization process.
- OI programs must be carefully designed, ensuring compatibility with the organization’s strategy and way of doing business, and budgeting for the full costs of running each program.
- Organizations should be particularly mindful of the bandwidth requirements (time and effort) required by different types of OI programs, and ensure that the aggregate bandwidth requirement of all OI programs does not exceed the organization’s capacity.
- There are many types of public-sector OI programs ranging from inbound practices, such as crowdsourcing and scientist exchange, to outbound practices, such as spinoffs and patent licensing to universities and private firms.
- Government agencies have to overcome additional impediments to OI such as legal, technological, and institutional barriers.

Suggested Exercises and Assignments

- Take a current organization that you know well and make an inventory of all its OI programs. Classify them according to the three parameters: type of relationship, scope of collaboration, and number of participants. Identify and map the organizational resources that are currently supporting each program, and comment on their adequacy.

- Pick a valuable problem that would be interesting for the group to solve. Run an innovation competition to generate and then filter the best ideas. Use one of the commercial ideation software platforms (most offer free evaluation licenses) to collect, share, and group ideas online.
- Select and analyze a public-sector OI program. Identify the goal of the program (whether it is explicitly stated or not), determine what kind of OI program it is, and develop a view on whether the program is achieving its goals. Offer suggestions for how the program may be improved.

Recommended Further Reading

Chesbrough, Henry W. 2020. *Open Innovation Results: Going Beyond the Hype and Getting Down to Business*. First edition. Oxford: Oxford University Press.

European Commission, Directorate-General for Research and Innovation. 2016. *Open Innovation, Open Science, Open to the World: A Vision for Europe*. Publications Office. Available at https://data.europa.eu/doi/10.2777/552370

Howe, Jeff. 2009. *Crowdsourcing: Why the Power of the Crowd Is Driving the Future of Business*. New York: Three Rivers Press.

Surowiecki, James. 2005. *The Wisdom of Crowds*. New York: Anchor Books.

Terwiesch, Christian, and Karl T. Ulrich. 2009. *Innovation Tournaments: Creating and Selecting Exceptional Opportunities*. Boston, MA: Harvard Business Press.

Chapter 6
Game Changers: Business Model Innovation and the Lean Startup

The two major additions to the innovation canon covered in this chapter both have their origins in the rapid invention and diffusion of information, computing, and telecommunication technologies since the 1990s. To these can be added new biotech technologies such as genomics. These powerful general-purpose technologies have brought impressive gains for many, but also left painful disruptions in their wake. In practical terms, the fast-changing technology landscape has increased the number of moving parts in the system, and has heightened the levels of uncertainty that both the private and public sectors now have to cope with. These challenges created the need for new management and policy tools, which have indeed emerged.

In the last two decades, there has a proliferation of business-press articles and academic papers on business models (BMs) and on business model innovation (BMI). This interest is due to the emergence of firms with powerful new BMs, who have gone on to disrupt their industries and create enormous value for their customers and themselves. Firms are keen to understand how they can add value through BMI while, at the same time, being concerned about falling victim to newcomers with new BMs that they cannot easily copy.

This chapter starts with a brief introduction to BMs and BMI based on a sampling of salient articles and papers. While there is no single universally agreed taxonomy of the components of a business model, there are many commonalities between the analyses by different authors. It will be shown how the interest in BMI has largely been driven by the internet revolution and subsequent technological innovations, as well as by globalization. BMI will be illustrated by using the popular and user-friendly *Business Model Canvas* introduced by Alexander Osterwalder. The public-sector version of the canvas, the *Mission Model Canvas*, will be introduced. The Mission Model Canvas enables a public-sector agency with a mission, rather than a profitmaking goals, to use BMI principles to create new value for its stakeholders.

Later in this chapter, the Lean Startup method is introduced as a solution to the problem of how to do innovation under conditions of high uncertainty. Experimentation is the best way to deal with uncertainty, and the Lean Startup is, therefore, built on this principle. The Lean Startup is comprised of several recent innovation techniques, namely design thinking (introduced in Chapter 4) as well as business model innovation, customer development, and agile development (which will be explained in this chapter).

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The Concept of a Business Model

There are many definitions of what a business model is, with different academics and consultants all coming up with their own variations. A comprehensive survey of BM definitions of various kinds can be found in Massa, Tucci, and Afuah (2017)[220] but for practical purposes, the following concise definition by David Teece is as good as any:

> The essence of a business model is in defining the manner by which the enterprise delivers value to customers, entices customers to pay for value, and converts those payments to profit. It thus reflects management's hypothesis about what customers want, how they want it, and how the enterprise can organize to best meet those needs, get paid for doing so, and make a profit.[221] (Teece 2010, 172)

Even more concisely, *a business model can be defined as the system by which an organization creates, captures, and delivers value*. It is comprised of multiple interlocking components or elements including the *value proposition*, the means to deliver the value proposition, and how it is paid for. The value proposition is simply the perceived value or benefit of the firm's offering, as seen by the customer. Another major component is the *financial model* (also called the profit model), which defines the capital requirements, revenues, and expenditures of the BM. Perhaps the most helpful aspect of a BM analysis is that it can provide insights not only on how value is captured by the enterprise, but also how it is created (Zott Amit, and Massa 2011).[222] Therefore, the concept has also lent itself well to adaption by researchers and practitioners interested in the broader impact of a firm's business activities – for example, in the context of environmental sustainability or inclusive growth.

BMI entails fundamentally changing at least one – but usually multiple – business model components and how the components interact with one another. Amit and Zott (2012) suggest three ways this can happen: adding novel activities, linking activities in new ways, or changing which parties perform any of the activities.[223] In general, the scope of business model innovation is larger than any product, process, or organizational innovation on its own – mainly because BMI typically entails all these combined.

The term "business model" is over 50 years old but has seen significant reinterpretation over time. A literature overview of BM research since the 1970s can be found in Wirtz et al. (2016).[224] The BM literature represent three streams of research (Foss and Saebi 2017):[225]

- The BM can be used as a basis for enterprise classification
- The BM can be used to explain performance differences between firms
- The BM is a potential area of innovation (BMI)

Clayton Christensen, Thomas Bartman, and Derek van Bever (2016) divide a business model into four elements, which are all interdependent and need to be integrated:[226]

- **A value proposition** – A product that helps customers to more effectively, conveniently, and affordably do a job they've been trying to do
- **A profit formula** – Assets and fixed cost structure, and the margins and velocity required to cover them
- **Resources** – People, technology, products, facilities, equipment, brands, and cash that are required to deliver this value proposition to the targeted customers
- **Processes** – Ways of working together to address recurrent tasks in a consistent way: training, development, manufacturing, budgeting, planning, etc.

(Christensen, Bartman, and Van Bever, 2016)

Lorenzo Massa and Christopher Tucci (2013) see BMI as a late stage of market development. According to this view, the market is created with product innovation to meet customer needs; that is followed by process innovation as the market grows and then, when the market has matured, BMI becomes the last available method of innovation to increase revenues.[227]

What is true for the market is not necessarily true for the individual firm in the market. It is harder for established firms to succeed at BMI than for startups, which is why established firms can get disrupted in seemingly mature markets. According to Christensen et al. (2016), the reason is that the interdependencies between their four elements become entrenched over time as these get codified into firm processes. Established firms struggle with BMI (as opposed to how easy it is for startups) because business models are not designed to be changed once they are established. In fact, firm BMs become less flexible and resistant to change over time. A three-stage process of the life cycle of a firm BM depicts this journey (Christensen et al. 2016):[228]

1. *Creation*, when the founding team of the business develops a meaningful value proposition that is focused on a customer's unmet needs or *job-to-be-done* (see Chapter 4).
2. *Sustaining innovation*, when the business scales up its operations rising to meet rising customer demand for the successful innovation. Sustaining innovations are better products that can be sold at higher markets. The focus in this phase is no longer on unmet needs, but in directly responding to the voice of the customer, and building processes that lock down the BM.
3. *Efficiency*, when product improvements no longer yield sufficient additional profitability, and when cost reductions become the primary way to maintain profitability. At this point, the voice of shareholders' free cashflow dominate over the voice of the customer.

The implication is that established businesses need to assess in which stage of the BM journey each of their business units (BUs) are before attempting BMI. Any new business should be started by first exploring the customer job to be done, rather than the market or the firm's capabilities. New businesses should not be shoehorned into existing businesses and structures so that the quest for efficiency does not prematurely set in. But running an enterprise with different business models is hard, and can be viewed as another form of the ambidexterity challenge as pointed out by Constantinos Markides (2013).[229]

The Context of Business Model Innovation

Even before the BM became a topic of discussion, it was always there because firms need a BM to do business. But it was when the ways of doing business radically changed that awareness of the BM increased. For that, as with so many other changes, we have the internet to thank. The modern interest in BMI has its origins in the first internet boom from the mid- to late-1990s. "E-business" firms with online business models emerged, leveraging fast-improving internet and computer technology. Some of these business models proved durable, but many did not. Excessive speculation and heady valuations of so-called dotcoms with questionable BMs resulted in the *dotcom bubble*. The dotcom bubble was followed by the *dotcom crash* of 2000–2002, which saw the demise of many once-prominent companies. Yet others such as Amazon, eBay, and Dell survive to this day. Dell's novel BM of selling PCs online directly to customers instead of through retailers became a classic case of BMI. The Dell BM enabled it to manage its inventory better than any other PC maker which, during a time of fast obsolescence of rapidly improving PC components, was a major advantage. Dell's rivals could not easily follow because they risked alienating the retail channels that they relied on to sell their PCs. There was a lot of talk about business models at the time – especially among dotcom founders, investors, and the business press – but also much confusion. A contemporaneous survey of the BM landscape can be found in Linder and Cantrell (2000), who provide a comprehensive list of business models in vogue during the dotcom bubble.[230]

In the wake of the dotcom crash, the early 2000s saw interest in BMs and BMI surges as academics, consultants, and industry leaders tried to make sense of what made a successful and durable business model, and what did not. This was also a time when some leading corporations made prominent changes to their business models, such as manufacturing and software companies turning products into services. High-tech startups were also able to disrupt incumbents by offering new business models – for example, Salesforce founded in 1999 rose to success and a dominant industry position by offering its CRM[xxv] software as a service (SaaS) when incumbents in the CRM software market such as Siebel were still selling licenses. Most of these BMIs were enabled by the availability of new and improved technology. Salesforce

xxv Customer relationship management.

would not have been possible before broadband internet access became widely available to businesses in the late 1990s (see Salesforce 2021).[231] On the consumer side, residential broadband internet enabled Netflix's business model of streaming movies.[xxvi] The interest in BMI by established corporations is driven by their fear of being driven out of business by upstarts, in the way that Netflix drove the brick-and-mortar video store chain, Blockbuster, out of business. The aspiration is to disrupt your own business model before another company (e.g., a startup) does it.

Another driver for interest in BMI has been the desire of Western firms to enter emerging markets and sell to new customers at the bottom of the income pyramid. That necessitated a complete rethinking of not only their products but also how to deliver and charge for them. Pablo Sanchez and Joan Ricart (2010) review several BMI cases in low-income markets. They differentiate between *isolated* business models, that facilitate entry into new markets by leveraging firm's current resources and capabilities, and *interactive business models*, where the entrant firm combines, integrates and leverages its internal resources with an ecosystem's capabilities.[232]

It is no coincidence that the interest in BMI arose contemptuously with the interest in open innovation. OI thought leader Henry Chesbrough also actively contributed to the development of BMI. When the firm extends beyond its organizational boundaries to innovate, new business models are not only possible but sometimes a necessity. In fact, Chesbrough's observation that Xerox's spinoffs became more valuable as spinoffs (see Chapter 5) can be explained by an analysis that those spin-offs were mistakenly analyzed by Xerox through the lens of its own business model. Xerox missed the opportunity because it did not innovate the BMs internally (Chesbrough and Rosenbloom 2002).[233] One of the Xerox spinoffs, 3Com (which commercialized the Ethernet networking protocol) needed considerable experimentation before its founder, former Xerox employee Robert Metcalfe, could arrive at a BM that succeeded in creating value (Chesbrough 2010).[234]

The business model of a firm is very closely connected to its strategy. In fact, the strategy of an enterprise can be formulated and analyzed using a BM framework (Richardson 2008).[235] Certainly, BMI is the most strategic form of innovation, as it can totally transform the way a company or industry conducts business, like how Netflix has changed how consumers access movies for home viewing. BMI can not only transform the product or service, how it is made, delivered, or sold, but also the entire enterprise and its external value chain. In recent years, the move toward sustainability has driven interest in innovating *sustainable business models* (SBMs) for companies and for whole industries. BMI for a circular economy and environmental sustainability has indeed received much attention lately. While SBMs are

xxvi Netflix started with a mail-order DVD model which disrupted the cost structure of Blockbuster Video, which rented DVDs out of hundreds of brick-and-mortar stores. Netflix transitioned to streaming as residential broadband became ubiquitous, keeping essentially the same business model but switching from mail order to instant online delivery.

beyond the scope of this introduction to BMI, a comprehensive literature review can be found in Pieroni, McAloone, and Pigosso (2019).[236]

Platforms and the Digital Transformation

Another major development that can be considered a new type of BMI is the rise of gigantic, online platform-based businesses such as Airbnb, Uber, and Amazon Kindle that are enabled by new technologies such as cloud-based computing and smartphones. In their book, *Platform Revolution*, Geoffrey Parker, Marshall Van Alstyne, and Sangeet Paul Choudary (2016) define a *platform* as follows:

> A platform is a business based on enabling value-creating interactions between external producers and consumers. The platform provides an open, participative infrastructure for these interactions and sets governance conditions for them. The platform's overarching purpose: to consummate matches among users and facilitate the exchange of goods, services, or social currency, thereby enabling value creation for all participants.[237]
>
> (Parker, Van Alstyne, and Choudary 2016, 5)

A typical platform BM is built on several powerful economic effects:

- *Demand-side economies of scale*.[xxvii] Such economies of scale mainly occur in networks where the value of the product or service increases the more customers it has. Platforms are particularly good at aggregating customer demand, so that current customers benefit by the addition of more customers.
- *Two-sided network effects*. Sellers attract buyers and buyers attract sellers. For example, Uber riders benefit when more riders sign up as it increases the availability of drivers in their location. The higher availability of drivers makes the service more attractive, which draws in more riders.
- *Scalability and frictionless entry*. Digital platforms are almost infinitely scalable with cloud-based technology. It is very easy for new suppliers and customers to enter. For example, Amazon Kindle publishing has enabled self-publishing by authors who only need to upload their manuscripts. New readers can sign up at the touch of a button.

Other characteristics of platforms are the removal of gatekeepers and replacing this type of central control with the discipline of user reviews. For example, short-term vacation-rental company Airbnb's quality control depends entirely on reviews by both hosts and guests, with both groups needing good reputations to keep using the service. In the case of Amazon Kindle, there is no publisher who decides whether a

xxvii Also known as *Metcalfe's Law*, which states that the value of a telecommunications network is proportional to the square of the number of users. Internet pioneer Robert Metcalfe was a coinventor of the Ethernet and founder of 3Com.

book is worth publishing. Author success is entirely dependent on user reviews and social-media influencing.

With today's digital technologies, any industry in which information has value is open to platform innovation and, therefore, to disruption. Platforms generate immense value because they can solve big economic problems that could not be easily solved prior to the digital transformation: most notably *information asymmetry,*[xxviii] *high transaction costs, high market-entry costs*, and *inefficient use of expensive fixed assets*.

The removal of fixed costs and their replacement with low marginal costs is a central characteristic of platforms. Bill Janeway (2018, 314–315) points out that this is reminiscent of the rollout of railways and electric utilities a century or more ago. These were massive investments, but they had the advantage of having marginal costs to users (e.g., the cost of one more passenger getting on the train) substantially lower than their average costs, which had to reflect the amortization of high fixed costs (e.g., cost to build the railway line). Under competitive conditions, prices will be driven down to marginal costs as, for example, happened for Uber and Lyft in the last decade. This leads to a large gap between the total revenue and total cost of the network. This financial deficit can only be financed by investors who are willing to make the bet that once the network has grown large enough, it will have monopoly pricing power. That is effectively what happened with Amazon, Alphabet (Google), and Meta (Facebook), which were all initially cashflow negative but were heavily financed by investors who saw their staggering potential profitability. But once the eventual stable point is reached, an effective monopoly will exist which has major regulatory implications for the government.[238]

This prediction is reflected by what happened in the market. A McKinsey analysis (Bhatia et al. 2017) of companies in the technology, media, and telecom (TMT) industries shows that economic profits generated by TMT companies grew 100-fold or by $200 billion from 2010 to 2014, mainly among companies with software-enabled business models. Economic profit was also highly concentrated with the top 20 percent of companies in TMT capturing 85 percent of the value. The top 5 percent of companies (including Apple, Microsoft, and Alphabet) generated a full 60 percent of total economic value.[239]

Platforms can also be seen as a type of *sharing business model* (SBM). SBMs can vary from intimate (e.g., carpooling) to local (e.g., peer-to-peer rental) to public (e.g., Airbnb). SBMs also vary depending on the type of compensation expected, from none to token to market value compensation (Boons and Bocken 2018).[240]

xxviii *Information asymmetry* occurs in transactions where one party has more or better information than the other; for example, a car dealer knowing the true cost of the car when the negotiating buyer does not.

More generally, the digital transformation, which is part and parcel of the Industry 4.0 concept, has led to the proposal of BMs specifically associated with Industry 4.0. Frank et al. (2019) offer the following definition:

> Industry 4.0 can be conceptualized as a new industrial maturity stage of product firms, based on the connectivity provided by the industrial internet of things, where the companies' products and process are interconnected and integrated to achieve higher value for both customers and the companies' internal processes.[241] (Frank et al. 2019, 4)

Industry 4.0-driven BMI typically follows three types of innovation approaches, according to Ibarra, Ganzarain, and Igartua (2017):[242]

- A *service-oriented approach*, which is a continuation of product-to-service BMI, enabled by the digital industry
- A *network-oriented approach*, which expands the boundaries of firms through horizontal and vertical integration of value chains
- A *user-driven approach*, which makes manufacturing more responsive to user-driven design and aligns it better with the value-creation processes of customers

Some governments have tried to help their domestic companies make the transition to Industry 4.0 BMs. For example, the Korean government's BMI program, *Flagship Project Support Program* (FPSP), gives effect to an innovation policy goal to support laggards in the adoption of Industry 4.0 technologies. The program helps firms to overcome market entry barriers to business ecosystems that have been established by big technology companies in fields such as smart cars, IoT, and virtual reality (Yang, Kim, and Yim 2019).[243]

The Business Model Canvas

In order to illustrate how a BM can be developed or modified in practice, the *Business Model Canvas framework* by Alex Osterwalder will be used. While there are many other BM taxonomies, Osterwalder's Canvas has become highly popular among practitioners due to its self-explanatory nature and ease of use. The iterative, experimentation-heavy process of BMI is akin to the Lean Startup approach (in fact, there is much shared DNA between these two approaches), and therefore the process of BMI iteration will not be discussed in much detail in this section.

The Business Model Canvas is a visualization of a BM that has proven to be a quick and effective way for teams in both startups and established companies to design new, and review existing, BMs. Refer to Figure 6.1. The component blocks of the Business Model Canvas are as follows:

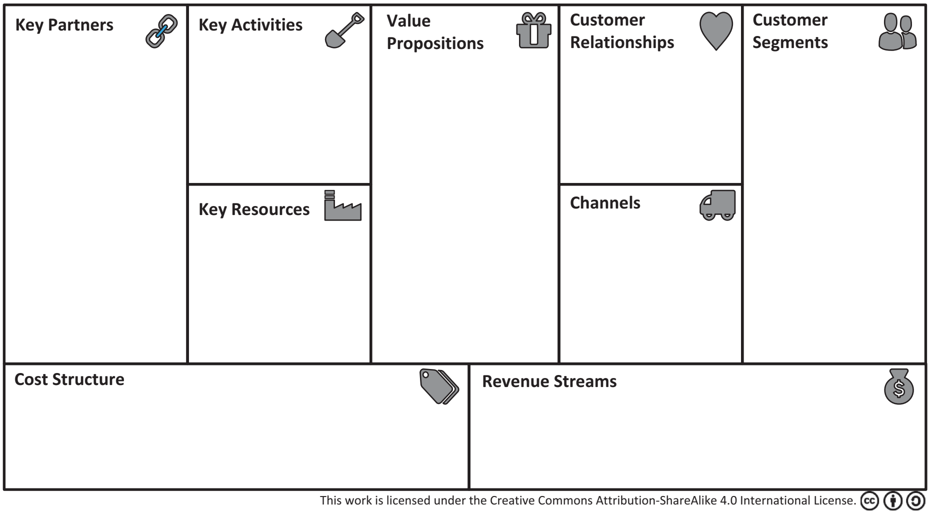

Figure 6.1: The Business Model Canvas.
Source: Based on Osterwalder and Pigneur (2010)[244] © Strategyzer. Licensed under Creative Commons Attribution.

- *Customer Segments*. These are the different groups of customers or organizations that the enterprise aims to serve.
- *Value Propositions*. The bundle of products and services that create value for a specific Customer Segment. (There may be multiple Value Propositions for multiple Customer Segments.)
- *Channels*. These are how the enterprise communicates with and reaches the Customer Segments to deliver the Value Proposition.
- *Customer Relationships*. The types of relationships the enterprise has with various Customer Segments. (There may be different types of relationships for different Segments.)
- *Revenue Streams*. The cash earnings (revenues minus costs) that the enterprise generates from each Customer Segment.
- *Key Resources*. The most important assets required to make the BM work.
- *Key Activities*. The most important things the company must do to make the BM work.
- *Key Partnerships*. The network of key suppliers and partners needed to make the BM work.
- *Cost Structure*. All the costs incurred to operate the BM and deliver the Value Proposition.[245]

The Business Model Canvas can easily be used along with other innovation and ideation tools. For example, *Blue Ocean Strategy* (introduced in Chapter 4) can be used to sharpen the value proposition and ensure that it is sufficiently differentiated from that of competitors. Osterwalder et al. (2014) have also created a complementary tool, the *Value Proposition Canvas*, to facilitate value-proposition development within the Business Model Canvas model.[246]

The use of the Business Model Canvas can be illustrated with one of the most famous BMIs of the last century, the disposable safety razor invented by King Camp Gillette. The standard "cutthroat" shaving blades at the time were expensive and needed to be sharpened often. Men commonly went to barbers for a professional shave. Gillette worked for years with another inventor, William Nickerson, to make a machine that could harden, grind, and sharpen thin, disposable razor blades. The Gillette® razor set first sold in 1903 consisted of a razor handle – that only needed to be purchased once – and disposable blades – that would last about a week each. The blades were sold in packets of 10 for 5 cents each, a price most working men could afford. The Gillette® razor became standard issue for U.S. soldiers during World War I.[xxix] By the mid-1920s, the Gillette Company produced over 2 million blades each day, and barbers had lost most of their shaving business (National Inventors' Hall of Fame 2022).[247]

The Gillette BM is depicted in Figure 6.2. The most distinctive components of the BM are first the lock-in customer relationship as only Gillette blades fit the Gillette handle, which is not an inconsiderable purchase; and second, the recurring revenue stream from regular blade purchases. While initially competitors were kept at bay with the patent, the strong branding of the Gillette shaving system as well as ubiquitous retail distribution later created effective barriers to entry.

The Gillette BM principle of an affordable platform purchase (the blade) with recurring purchases of disposables that only fit that platform has been much emulated. The user is locked in by purchasing the basic product (e.g., the Gillette shaver handle), which is sold at very low margins (or could even be given away for free). But the consumables (e.g., the disposable razors) needed to use it are sold at much higher margins. Modern examples of this business model are the Swiffer® Wetjet™ mop with disposable pads, inkjet printers with disposable ink cartridges, and PlayStation® and X-box® consoles with video game subscriptions.

When starting a new venture, the entrepreneur starts with a literally blank canvas of the startup's BM. Filling in the components of the BM – Osterwalder's Business Model Canvas is a great tool for doing this – is a great starting point and an essential step if the entrepreneur is to be able to communicate what the startup will be.

xxix World War I soldiers needed to be clean-shaven to wear gas masks.

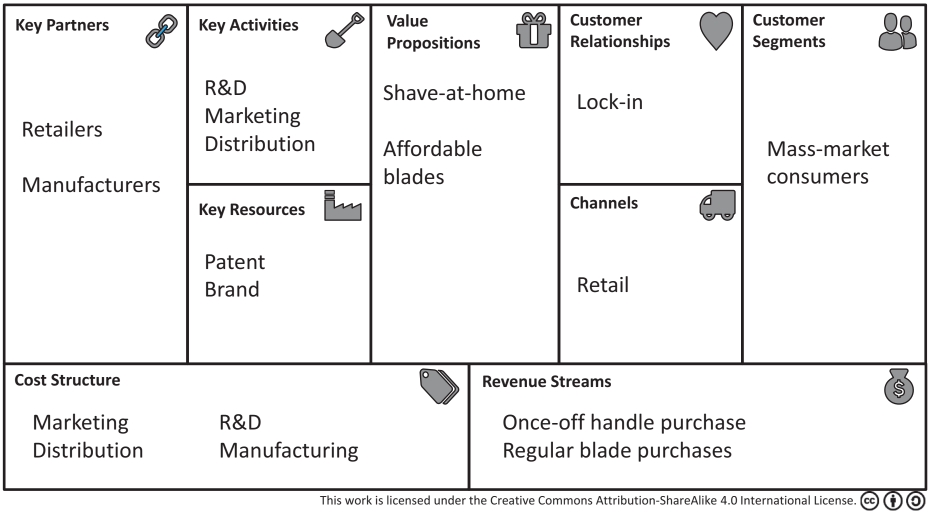

Figure 6.2: Gillette Business Model Example.
Source: The template is based on Osterwalder and Pigneur (2010) © Strategyzer. Licensed under Creative Commons Attribution.

According to Jim Euchner and Abhijit Ganguly (2014), BM concepts are fraught with unknowns and risks, which should be clarified up front. They identify three main types of risk:[248]

1. *Business execution risks*, which can be best assessed by building a financial model based on best estimates, e.g., pricing, cost of goods, customer acquisition, and servicing costs. Each of these cost elements must be given a range to make them explicit and indicate the level of uncertainty.
2. *Interdependence*, also called *co-innovation uncertainties,* involves other innovations that need to be successful (e.g., enabling technologies or new manufacturing processes) for your BM to work.
3. *Adoption (integration) uncertainty* focuses not only on the target customers but on who else would need to be on board, e.g., a dealer network that would need to be sold on a new product or service offering.

The entrepreneur is highly unlikely to start off with the ideal BM. In fact, an important activity of the startup founders is to engineer an experimentation process that can as quickly and cheaply as possible arrive at the BM that can take the startup to its next stage of development. The experimentation process should address all the main risks, starting with the ones of highest magnitude or impact. For example, if the product pricing is a concern, an experiment should be designed to assess what price typical consumers would be willing to pay. If the enabling technology is uncertain, a proof-of-concept of the technology needs to be expedited. If the buy-in of the dealer network is essential but uncertain, representative dealers need to be involved in the testing process along with customers.

This process of BM iterations is an integral part of the *Lean Startup*, which also entails product development experimentation and customer discovery and validation. The Lean Startup will be covered later in this chapter.

The Mission Model Canvas

The Mission Model Canvas is an adapted Business Model Canvas for mission-driven organizations. Steve Blank, who will be introduced as the originator of the Lean Startup later in this chapter, wanted to bring the power of the Business Model Canvas to a defense-oriented group. Some of the components, such as revenue streams, do not fit a public-sector organization. Accordingly, Blank and Osterwalder (2016) together adapted the Business Model Canvas, keeping the same component boxes but changing the content of five to make them suitable for mission-oriented organization. The changes are reflected in Figure 6.3 and are as follows:

- Customer Segments is changed to *Beneficiaries*. This is based on the public-sector reality that there are always multiple stakeholders who are the beneficiaries, or multiple layers of customers being served. This is called a multisided market.
- Cost Structure is changed to *Mission Cost/Budget*.
- Revenue Streams is changed to *Mission Achievement*, which is understood as the aggregate value created for all the Beneficiaries.
- Channel is changed to *Deployment*. In the commercial world there are different types of distribution channels, but in the mission-driven world the focus is on deployment – how to get the service/product to those who need it.
- Customer Relationships is changed to *Buy-in/Support*. In the public sector, buy-in is needed from many different gatekeepers and stakeholders, which requires nurturing relationships with all the critical people whose buy-ins are needed.

The relationship between component boxes is also reinterpreted for the context, even though some of their titles stay the same. In particular, the relationship between the Value Proposition and Beneficiaries (of which there are multiple) changes to what is called the *Product/Market Fit*. Further details, including instructional videos on using the Mission Model Canvas, can be found on Steve Blank's website (Blank 2016).[249]

Though developed for defense users, the Mission Model Canvas is widely applicable to the public sector. Nonprofits and nongovernmental organizations (NGOs) have a choice of whether to use the Mission Model or original Business Model Canvas. If a nonprofit is funded by grant income that has to be solicited from many

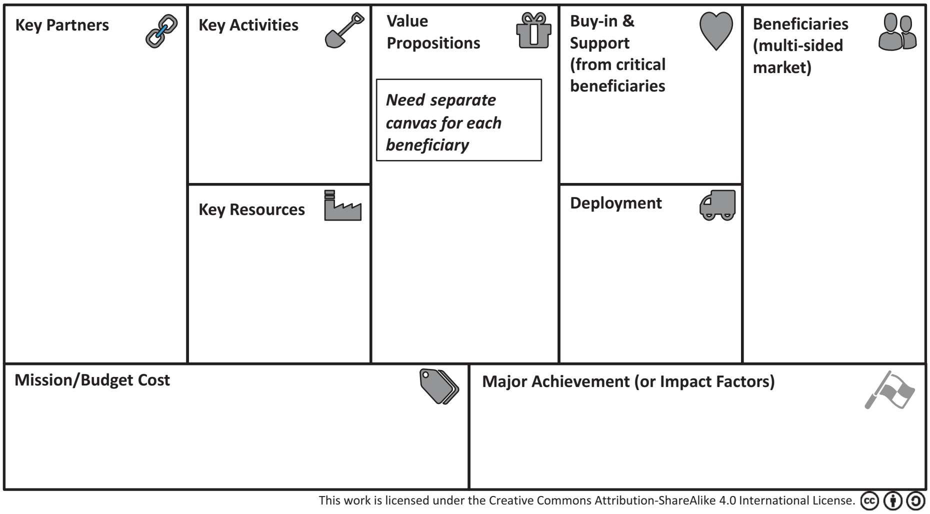

Figure 6.3: The Mission Model Canvas.
Source: Based on Blank and Osterwalder (2016)[249] © Strategyzer. Licensed under Creative Commons Attribution.

diverse sources, it may be best to use the Business Model Canvas, simply substituting revenue for grant funding and reinterpreting or relabeling other components as needed. If on the other hand, the organization is funded by a single entity, whether government or private, the Mission Model Canvas may be the better fit.

The Lean Startup

Eric Ries (2011) popularized the *Lean Startup* in his eponymous book.[250] However, Steve Blank, a serial entrepreneur, investor, and professor at multiple universities, is the founder of the concept. The essence of the Lean Startup, the *Customer Development Model*, was described in Blank's book, *The Four Steps to the Epiphany: Successful Strategies for Products That Win* (Blank 2007), first published in 2003.[251] The Lean Startup developed from an application of Blank's Customer Development Model when IMVU, a startup in which Ries was a founder, ran into difficulties. (The IMVU story is related in a paper by Steve Blank and Bob Dorf (2005)[252] and in Ries's book.) Ries became a student of Blank's as a condition of Blank's investment in his startup. Ries and Blank have subsequently collaborated closely on the genesis and further development of this methodology. A later *Harvard Business Review* article by Blank (2013) popularized the Lean Startup methodology more widely.[253]

Steve Blank's insight – based on his own experience in the startup world – was that startups are not smaller versions of large companies and, therefore, startups should not have to write business plans and have five-years forecasts like established companies. Blank explains the cardinal problem that he observed in startups, and which he set out to solve, as follows:

> If you were ever involved with a startup in the 20th century, you knew the drill: you'd write a business plan, start building the product, use waterfall[xxx] engineering to build the product, and go through alpha tests and beta tests and first customer ship – and then no one would buy the product. The VP of sales might be fired, then the VP of marketing, and eventually the founder. What was not considered was 'Maybe we ought to fire the plan.' For whatever reasons, the plan was considered sacrosanct; after all, the VCs had funded it. No one ever questioned whether that original set of hypotheses were correct about customers and pricing and feature set. What we now call product-market fit, we just kind of assumed; anything that didn't work was a failure of an individual rather than a failure of strategy.[255]
>
> (Blank and Euchner 2018)

Startups need to quickly develop and launch an offering that will appeal to enough paying customers to create a viable business. Under high uncertainty, a startup's first attempt at this is usually wrong or doesn't work, and they then need to pivot to the next attempted offering. Multiple pivots are often needed. Successful startups manage to pivot to a viable offering before they run out of money. Unsuccessful startups run out of money before they can pivot to a viable business model.

The problem, Blank realized, was that a startup faces too many unknowns: unknown customer, unknown channel, unknown pricing, and unknown functionality desired by the customer. The constructive way to deal with unknowns is to turn them into hypotheses that have to be tested and, thereby, either validated or invalidated. And this requires a methodology, which became the Lean Startup (Blank and Euchner 2018).[256]

The Lean Startup is a solution to the management problem that all startups face: They are operating under high uncertainty. Traditional management models do not recognize that reality, and therefore following those models will at the very least slow startups down or worse, could lead them down into the abyss. On the other hand, the unstructured "just-do-it" approach startups often fall back on invite chaos and high failure rates. The Lean Startup is a management system that organizations can follow to efficiently develop new products or services under conditions of high uncertainty. It is characterized by hypothesis setting; rapid development; and testing cycles to get answers quickly, iterative product releases; and a philosophy of continuously learning and exploring, and then adapting to new facts (Ries 2011).[257]

The Lean Startup concept itself is an innovation in the Schumpeterian sense since it combines existing management elements into the Lean Startup approach.

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xxx The waterfall model entails breaking project activities into linear, sequential phases. Each phase depends on the deliverables of the previous one. On a project Gannt chart with time as the horizontal axis, the sequential project tasks visually resemble a waterfall, with the top activities ending earliest, and the bottom activities ending latest.

As such, the Lean Startup is a synthesis of major bodies of existing thought; in particular, *design thinking, customer development*, and *agile engineering*. It also borrows the term "lean" from the world of lean manufacturing. If you have been exposed to one or more of the three constituent components, you will find much that is familiar in the Lean Startup. Steve Blank would add business model innovation in the form of *business plan iteration* as the first component. (Blank contains design thinking within customer development in his exposition.)

Design Thinking was introduced in Chapter 4. As a reminder, design thinking is an innovation process characterized by an exploration of the needs of the customer, the use of creative techniques, and a nimble development process that entails rapid prototyping and field testing. Design thinking was pioneered at Stanford University and subsequently widely adopted.

Customer Development was proposed by Steve Blank as a solution to the drawbacks of the traditional new-product-development process when used in a startup environment. The primary flaw of the traditional development process is that it provides no customer feedback until a beta[xxxi] product is produced, which is considered by Blank to be too late. The customer-development model emphasizes early customer validation of the new business concept to ensure that demand exists before developing the product. It requires the startup to translate the founder's vision into a set of hypotheses that are to be tested by experiments in the real world. Blank calls this "get out of the building" to show prospective customers the concept and get their early feedback. If there are no customers for the idea it will not be successful, and that is the first thing to find out. Blank calls this step Customer Discovery. The model emphasizes the equal importance of business and marketing functions in a start-up relative to the engineering and product development functions. The model is intended to result in several pivots as feedback is obtained.

Agile Development (originating in the software industry with the *Agile Manifesto* in 2001) is an approach that involves rapidly building a product piece by piece, getting feedback on the working product pieces after each sprint (Agile Alliance 2022).[258] Agile development is done by small, self-organizing, cross-functional teams rather than relying on processes and tools. In agile development, the highest priority is customer satisfaction, which entails continuous customer involvement. This is why agile was such a good building block for Lean Startup, which is built on the customer development methodology.

The word "lean" in the Lean Startup seems to be there more for branding than for substantive purposes. While the methodology indeed may result in some cost saving over traditional methods, that is not the main thrust of it. The word "lean" has,

xxxi A beta product is a nearly finished product made available to a fairly large group of target users in order to test product performance in the real world.

however, turned out to be very successful branding because major corporations have been adopting lean manufacturing for a generation, mostly with good results.

Lean Manufacturing is also known by its original name, the Toyota Production System (TPS). It was developed by Taiichi Ohno and Shigeo Singo at Toyota Motor Corporation to maximize quality and minimize waste. It is known for *just-in-time* (JIT) production, meaning that each process only produces what is needed by the next process in production. Continuous improvement (Kaizen) is an integral part of the system as well as the concept of *jidoka*, which entails a human touch to automated production. Jidoka gives any person on the line permission to stop the process if they see a quality problem.

Lean Startup Principles and Core Processes

Ries (2011) wrote his whole book around five key principles, which he calls the principles of the Lean Startup:[259]

1. *Entrepreneurs are everywhere*. Since entrepreneurs can be found in any organization, the Lean Startup approach can work in any size company, and in any industry.
2. *Entrepreneurship is management*. Since a startup is an institution not just an offering, it requires a "new kind of management" that can handle the startup context of extreme uncertainty.
3. *Validated learning*. Since startups exist not only to make an offering, but to learn how to build a lasting business, frequent experiments must be run to test all elements of the vision.
4. *Build-measure-learn*. Startups exist to turn ideas into products, measure customer response, and learn whether to pivot or persevere. All startup processes should accelerate this feedback loop.
5. *Innovation accounting*. Progress must be measured, milestones must be set, and work must be prioritized. People must be held accountable, and each startup need a kind of accounting system suitable for a startup.

More than one major hypothesis should be tested and iterated within the Lean Startup. The *value hypothesis* is used to test the value proposition of the product or service, in other words whether it delivers value from the perspective of the customer. The *growth hypothesis* is used to test how new customers will find and adopt the product or service.

The existential problem a startup has to solve is iterating a successful offering and business model before it runs out of money. Under conditions of high uncertainty, false starts can be expected, and multiple pivots are typically needed before winning business model is found. The two main ways of dealing with radical uncertainty in the startup environment are fast experimentation and having sufficient cash on hand to sustain the trial-and-error innovation process. (The financing of innovation is the subject of Chapters 9 and 10.)

Therefore, fast experimentation is core to the Lean Startup. The experimentation process within the Lean Startup is governed by the *Build-Measure-Learn* loop. In order to solicit customers' reaction to the conceptual offering, a Minimum Viable Product (MVP) must be built. The reaction of customers to the MVP is then measured, and the organization learns from that reaction by either pivoting to another concept or persevering.

In essence, the Build-Measure-Learn loop is an adaption of the classic scientific approach that poses a hypothesis, and then designs and executes an experiment to test the validity of the hypothesis. In the case of a product offering, for example, the value hypothesis is that potential customers will value a particular feature set and functionality. The quickest way to test that hypothesis is to put an MVP in the hands of several typical customers, watch how they interact with it, and get their feedback. The price point can be similarly tested.

It is important to understand what the MVP is, and what it is not. According to Ries, the MVP is "a version of the product that enables a full turn of the Build-Measure-Learn loop with a minimum amount of effort and the least amount of development time." It is important to resist overinvesting in any particular MVP because any unnecessary effort is waste. A good rule of thumb is that you should be somewhat nervous or embarrassed to show the MVP to customers. If you are too confident, you have likely overinvested your time and effort. Overinvesting in the MVP is very hard to resist, particularly for managers in established companies who are risk averse and new to the approach. It requires self-control and courage to declare that an MVP is good enough for the purposes of getting the first customer feedback.

Learning and Uncertainty

The conventional phase-and-gate model of sequenced development used in some form by many corporations is entirely suitable for situations of low uncertainty, such as when the market, technology, and user needs are known and well understood. There is no need for established corporations to throw out proven innovation processes familiar to their workers, and start using the Lean Startup in full for all innovations. However, some of the Lean Startup techniques could be integrated with the conventional approach to good effect. For example, many companies have adopted components of the Lean Startup, such as design thinking and agile engineering, into their development methodologies.

It is important to understand when the Lean Startup methodology should be chosen over the conventional development model. The answer, in principle, is simple: The conventional model fails under conditions of extreme uncertainty, such as when the technology and the market are unproven. The conventional model's

Achilles heel is allowing the accumulation of large costs prior to adequately resolving major uncertainties. Too much money is thus expended before important learning takes place. In contrast, the Lean Startup is a learning method that tackles high or radical uncertainty head on. The conditions of high or radical uncertainty are typical of a startup environment, but equally relevant for established companies innovating with new technologies, new markets, or new ways of doing business.

Skeptics of the Lean Startup may admit its effectiveness in software applications development and less complex products, but claim that it is not suitable for advanced industries that make complex systems for which reliability and safety are critical requirements, such as the automotive and aerospace industries. However, Elon Musk, the founder of both Tesla (which makes electrical vehicles) and SpaceX (which makes rockets and satellites) has shown that the startup approach can also work well in these industries. The reusable rocket technology that SpaceX pioneered to increase the frequency and lower the costs of space launches is a prime example. Musk challenges his teams with the mantra that if things are not failing, they are not innovating hard enough. Despite some well-publicized initial failures as new technologies were being tried, SpaceX has had over one hundred successful launches of its Falcon 9 rocket in a row without failure, making it one of the most reliable rockets ever flown. The Falcon rocket family has reached about a 50 percent market share. SpaceX is developing the largest rocket ever, called Starship, which could carry a large payload to Mars and other planets. When the original carbon-fiber-composite frame presented development problems, SpaceX made a complete switch to a stainless-steel frame, which is cheaper but will require strengthening through cooling, demonstrating the company's willingness to radically change designs and technologies when they do not work (*The Economist* 2022).[260]

As the SpaceX example above shows, it is not the complexity of the product that should determine whether the Lean Startup is the preferred method, but whether innovation will be done under conditions of very high uncertainty, which was clearly the case for novel reusable rocket technology.

There is a third method to mitigate radical uncertainty, alongside rapid experimentation and ample cash on hand. This method is often overlooked because it is related to organization and management style: The more diverse the perspectives of team members, and the more open the startup's management style is to dissenting views, the less chance that it will suffer from blind spots because of groupthink. In most man-made disasters, there was someone who identified the key risk ahead of time but was not heard, or someone who knew the risk but was reluctant to speak up. Team diversity and an open exchange of ideas and opinions increase the likelihood that someone will identify a hidden showstopper, or suggest a novel solution. As was mentioned in Chapter 4, diverse innovation teams outperform less diverse innovation teams, but they may have more conflict to manage, making it somewhat uncomfortable to serve on them. Diversity here should be understood, in the broadest sense of the word, to mean not only inherent diversity (gender, ethnicity, age, etc.) but also acquired diversity, which is life and work experience.

While having ample capital is always a buffer against uncertainty because it buys time, being willing to go outside our comfort zone early and often is the best way to innovate in the face of radical uncertainty. Acknowledging the uncertainties, constantly experimenting, showing customers MVPs, and having robust team conversations all make innovators uncomfortable, but pay off handsomely in the long run.

Chapter Summary

- The business model (BM) is the system by which an organization creates, captures, and delivers value. Its major components are the value proposition, a financial/profit model, and the processes and resources required to deliver the value proposition.
- Business model innovation (BMI) entails fundamentally changing at least one – but usually multiple – business model components, and how the components interact with one another.
- A platform is a digital BM that provides an open, participative infrastructure that enables and governs value-creating interactions between external producers and consumers. As such, a platform offers demand-side economies of scale, two-sided network effects, scalability, and frictionless entry to newcomers.
- Platforms are highly valued because they solve big economic problems; however, they have a natural tendency to grow very large and become monopolies, which may require government regulation.
- The Business Model Canvas and its public sector equivalent, the Mission Model Canvas, make it easy to visually map out new and existing business models.
- The Lean Startup method is a solution to the problem of how to innovate under conditions of high uncertainty, which is an innate challenge for startups but just as applicable for any other innovation endeavors with many unknowns.
- Fast experimentation to validate or refute hypotheses is at the core of the Lean Startup. The Build-Measure-Learn loop entails rapidly building a Minimum Viable Prototype to get customer feedback, and then to use what is learned to iterate the offering multiple times.

Suggested Exercises and Assignments

- What areas within the public sector are ripe for platform innovation? Why and how? Can you provide an example of a successful platform innovation in the public sector?
- Compare and contrast the Lean Startup innovation process with the traditional innovation process, using examples as needed. Highlight the conditions under

which the Lean Startup would yield superior outcomes and explain the conditions under which the traditional innovation process would be preferred.

– Identify an innovation opportunity best addressed by the Lean Startup model in an organization (private sector or government agency) that you know well. Write a two-page memo to the executive heading the organization proposing the application of the Lean Startup model to innovate a particular type of product/service/solution for this organization. Describe the innovation challenge, and briefly refer to previous attempts that may have failed. Then, explain why the Lean Startup is the better model for this situation and lay out a step-by-step plan for conducting the project, including suitable metrics, resource needs and governance. Make sure you address each of the five principles.

Recommended Further Reading

Blank, Steven Gary. 2007. *The Four Steps to the Epiphany: Successful Strategies for Products That Win*. 3rd ed., 4th rev. printing. California: S.G. Blank, 2007.

Osterwalder, Alexander, Yves Pigneur, Tim Clark, et al. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, New Jersey: Wiley.

Parker, Geoffrey G., Marshall Van Alstyne, and Sangeet Paul Choudary. 2016. *Platform Revolution: How Networked Markets Are Transforming the Economy and How to Make Them Work for You*. New York: W. W. Norton & Company.

Ries, Eric. 2011. *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*. London: Portfolio Penguin.

Chapter 7
Perspectives on Innovation Management

Volumes have been written about how to manage product development and innovation, and it would be unwise to even attempt to cover this expansive terrain in one book chapter. The approach followed here will not be to summarize the many frameworks presented in dedicated works on innovation management, but rather to provide the reader with a good top-level view of what innovation management is all about, and what the main challenges are. There is substantial value in gaining such a high level of understanding and an appreciation of the main principles involved (i.e., seeing the forest for the trees).

Innovation lies at the intersection of several disciplines, all having to collaborate to generate value for multiple parties, and to fulfill the mission at hand. Innovation is executed at the strategic and the tactical level, and everywhere in between. Therefore, it needs various management structures and mechanisms across all organizational levels. The *Innovation Management Map*, a new contribution to the architecture of innovation management introduced here, is an attempt to tie everything together in a way that shows how the elements relate to one another.

Innovation metrics will be introduced, and guidelines provided on their selection and use. The importance of innovation governance and establishing clear decision-making rights will be explained. The discipline of innovation management has been maturing and is increasingly becoming codified. The latest international standards for innovation management and the concept of an Innovation Management System will be introduced. The chapter will conclude with a section on the special challenges of managing innovation within the public sector.

> Note: For the purposes of this chapter, it will be assumed that the reader is familiar with the fundamentals of project management, including its basic terminology. If not, the reader should consult authoritative resources on project management, such as the *PMBOK® Guide* by the Project Management Institute (2021),[261] or the latest edition of Harold Kerzner's (2017) classic book on project management.[262]

The Essence of Innovation Management

Ultimately, innovation management is business management. Any innovation should be seen as a new business in its own right. This means that all aspects of business management must be called upon to make an innovation successful. The constant companion of innovation is uncertainty, which makes innovation management much more challenging than managing most other business areas.

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We shall start with an existential question: Why do we need to manage the innovation process? I propose the following answer:

> *The objective of innovation management is increasing value while reducing uncertainty.*

Some decades ago, the Total Quality and Sig Sigma movements established the principle that every organizational activity has to add value to the end customer and that activities that do not are superfluous, wasteful, and need to be eliminated. The value dimension is equally important to innovation, but innovation occurs amid uncertainty (often a great deal of uncertainty). The reduction of uncertainty is, therefore, valuable and worthy as a goal of equal standing.

Innovation management can be complex and intricate because it requires alignment and coordination across multiple organizational layers and parallel process, but this objective applies to each instance of innovation management, no matter how large or small in scope. As an innovation progresses, value must increase to the target level while uncertainty must decrease to an acceptable level, as depicted in Figure 7.1.

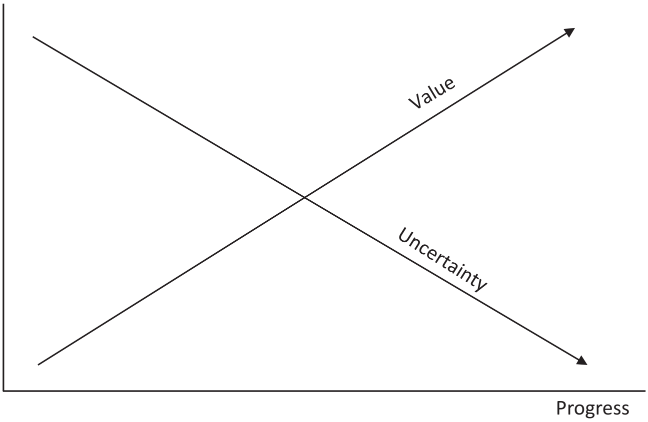

Figure 7.1: The Objectives of Innovation Management.

These dual objectives of innovation management acknowledge that uncertainty is an ever-present challenge for any innovator. Good innovation management seeks to mitigate, and sometimes even harness, the inherent uncertainty of the innovation process. Any element of an innovation management process, and in fact any innovation task or process, should be justified by explaining exactly how it will increase value or reduce uncertainty, or, preferably, do both at the same time. If it does neither, it is redundant.

It should also be understood that there is a price to be paid for reducing uncertainty, and that price is tolerating some waste. Managing innovation is not like managing a well-established operation, where maximum efficiency – achieved by minimizing waste – is the highest goal. Waste is unavoidable when truly innovating because progress amidst high levels of uncertainty can only be made by trial and error. In fact, waste in the form of experimentation, search, and transactions costs is integral to innovation. This is not to say that waste should be welcomed, but that it should be properly managed as the cost of making progress in innovation.

It is important to gain a more precise understanding about what we mean by *uncertainty*. People too easily talk about risk when they really mean uncertainty. The term "risk" will be avoided from here on because risk as defined by Knight (1921)[263] and Zeckhauser (2006),[264] means that the distribution of outcomes and the probabilities of each possible outcome are determined, such as a turn of a roulette wheel or a throw of the dice. Risk is, therefore, not a helpful model for innovation. Innovators face uncertain outcomes with odds that can only be guessed. Therefore, framing innovation challenges in probabilistic terms is not helpful at all. The spectrum of uncertainty and the definitions of related terms will be covered in more detail in Chapter 9, in the context of the financing of innovation.

There are multiple drivers of uncertainty in innovation, but the two largest determinants of uncertainty are the market for which the innovation is intended and the technology on which the innovation relies.

The newer the technology, the less assured are the chances of making it work. This is often referred to as technology risk though uncertainty is a better, more precise term. However, even if a new product or service can be made to work perfectly, its acceptance in the market is far from guaranteed. Not enough units may be sold at the target price, putting in jeopardy both the revenue and profit goals set for the innovation. This is usually referred to as market risk, but again the term "uncertainty" is better. Innovation is, therefore, subject to both technology (making it work) and market (selling it) uncertainty.

There are tradeoffs between these two uncertainty categories. By using proven technology and incremental innovation, technology uncertainty may be minimized, but then the product may be undifferentiated and not be successful in the market. On the other hand, striving to launch a market-beating innovation by relying on cutting-edge technology, or technology entirely new to the organization, will greatly increase the technology uncertainty, and the product may not work.

Market uncertainty includes whether the innovation will be accepted by the market and adopted by its intended users, as well as whether it can be sold for a high enough price to make a profit (refer to Figure 7.2). As such, market uncertainty encompasses most of what is usually referred to as business risk. Technology uncertainty includes whether the innovation can be made to work as intended, reliably produced at scale, and whether it can be brought to market at a low-enough cost to allow for a profit. The market uncertainty is amplified by the unfamiliarity of the market to the company, with the current market being the least uncertain, adjacent markets being more uncertain, and completely new markets providing the highest uncertainty challenge. Similarly, technology already known to and mastered by the company presents

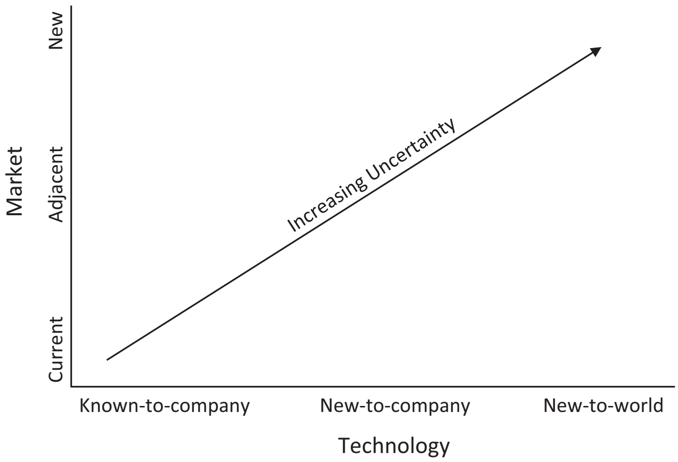

Figure 7.2: Major Determinants of Innovation Uncertainty.

the least uncertainty, while technology new to the company (even though it has been mastered elsewhere) presents a much greater uncertainty challenge. The uncertainty from basing an innovation on new-to-world technology is always going to be extremely high and very hard to manage.

Market and technology uncertainty combine to increase the total uncertainty that has to be managed. An innovation based on new-to-world technology for a market that the company is totally unfamiliar with is clearly going to suffer from such high uncertainty that it is hardly worth undertaking, at least for an established company. But radical uncertainty on multiple axes is not that unusual for a startup. On the other hand, established companies tend to move a maximum of one increment of uncertainty at a time on each axis; for example, developing a product for a new market based on familiar technology or developing a product for its core market based on new-to-company technology. Assessing the inherent uncertainty along these dimensions before approving an innovation project is an essential part of innovation management.

R&D and product innovation are inherently wasteful processes occurring under conditions of high uncertainty where success can never be guaranteed. This poses the question of who is best placed to finance such activities and bear the risk of losing the funds? Market uncertainty that manifests over the short term may be better borne by private investors such as venture capitalists. On the other hand, the extreme uncertainty about the viability of new unproven technology is best carried by the public sector. This is an issue that will be more closely looked at in Chapter 10, Public Financing of R&D and Innovation.

Alternatively, long-term technology uncertainties may be better borne by stable monopolies, rather than by firms engaged in cutthroat competition. Examples are the transistor and other inventions that originated from the famous Bell Labs, and the graphical user interface (GUI) from Xerox's equally famous Palo Alto Research Center (PARC), which inspired Steve Jobs.

The Organizational and Strategic Fit for Innovation

The reason it is so hard to find a single functional home for innovation is that innovation, by its very nature, is a multifunctional endeavor. In most firms, innovation can be found somewhere at the intersection between the R&D, marketing, and operations functions, but even this observation is an oversimplification.

From the strategy on down, innovation touches and affects many elements of an organization, whether it is a for-profit business or a government agency or nonprofit. With innovation being almost omnipresent, yet diffuse, it confounds the organizational leadership as they attempt to form a coherent conceptual model of innovation so that it may be managed. However, lacking such a model will make the role of innovation in the organization hard to grasp for employees and managers alike and thus, almost impossible to manage.

Most organizations therefore make do with rough classifications, such as that innovation is about technology, or innovation is about customer satisfaction, or innovation is about operational improvements. Innovation is accordingly assigned to the area and managerial responsibility/locus where it best seems to fit. Following this logic, companies in technology-driven industries will most often associate innovation with R&D or product development; companies in the consumer-packaged-goods (CPG) industry will see innovation as closely intertwined with their product management and consumer marketing activities; and companies in the services or materials-processing industries will see innovation as integral to operational improvements and cost efficiency. While such simplifications allow the organizational leadership to assign primary responsibilities for innovation to departments whose activities most closely resemble what the organization deems to be innovation, these simplifications also leave major gaps that could become very damaging. For example, innovation managed by the marketing function may miss out on new technologies, whereas innovation managed by the R&D department may be blind to shifts in the user market.

In this section, a more comprehensive and nuanced framework of where innovation fits in will be developed. It is instructive to start by looking at where innovation fits into corporate strategy and management by using an established framework: The *Strategy Map* introduced by Robert Kaplan and David Norton (2004) provides a multidimensional visual checklist for executives to enable discussions on how their organization creates value.[265] The Strategy Map follows the strategy philosophy originally encapsulated in the *Balanced Scorecard*, introduced earlier by the same authors in an eponymous book (Kaplan and Norton 1996).[266]

The Kaplan-Norton Strategy Map looks at the firm through four different perspectives and it is based on five principles (refer to Figure 7.3). The four perspectives are the *financial perspective*, the *customer perspective*, the *internal perspective* (for internal management processes), and the *learning and growth perspective* (mostly concerning intangible assets – also see the fifth principle below). The five principles according to Kaplan and Norton (2004)[267] and their relevance to innovation are:

1. *Strategy balances contradictory forces*. The main contradiction – highly relevant for innovation – is that the needed investment in intangible assets for long-term revenue growth usually conflicts with cutting costs to achieve short-term financial performance.
2. *Strategy is based on a differentiated customer value proposition*. Satisfying customers is the source of sustainable value creation. This is also highly relevant to innovation since the primary output of innovation activities in business is most often the value proposition, which is judged by the customer.
3. *Value is created through internal business processes*. Internally managed processes such as innovation, operations, and customer management provide value to the customer in the form of products and services, and to the firm in the form of financial rewards.
4. *Strategy consists of simultaneous, complementary themes*. The different clusters of internal processes deliver benefits at different points in time and at different cadences. Operational improvements generally deliver short-term cost savings, but innovation processes take longer to produce higher revenues and margins. Good strategies should balance these benefits.
5. *Strategic alignment determines the value of intangible assets*. The organization's intangible assets are human, information, and organization capital. Human capital comprises skills, talent, and know-how. Information capital comprises knowledge and information contained with strategic information infrastructure. Organization capital comprises the culture, leadership, alignment, and teamwork inherent in the organization.

The Kaplan-Norton Strategy Map provides a holistic overview of how an organization achieves its strategic goal, which originally was defined only as *long-term shareholder value*. However, long-term shareholder value is only an appropriate goal for private-sector, for-profit corporations. It is fairly easy to substitute other strategic goals for organizations as appropriate, and for government agencies and nonprofits to substitute a clear mission statement. In the case of a government agencies and nonprofits, the customer perspective will have to be adapted, too.

My primary purpose is, however, not to tailor the Kaplan-Norton Strategy Map for general use, but to develop an analogous framework inspired by it that is specific to innovation and can encapsulate the expansive terrain of innovation management. This is the topic of the next section.

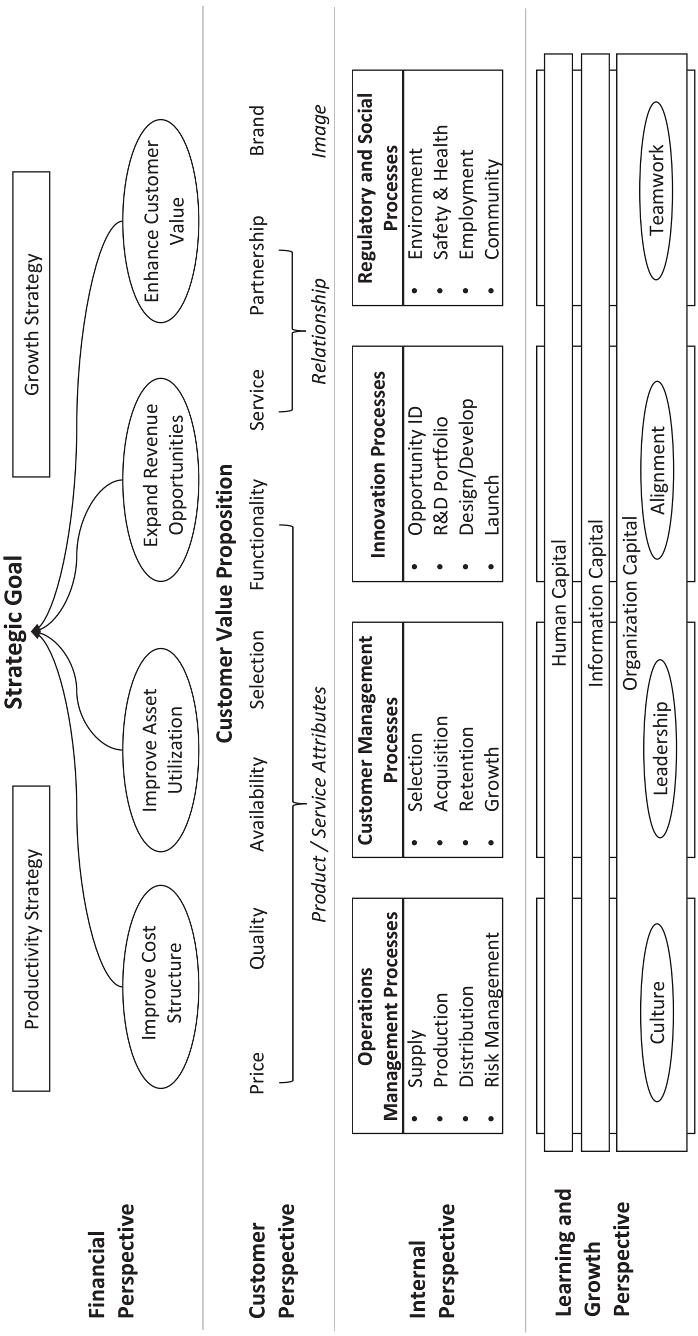

Figure 7.3: The Kaplan-Norton Strategy Map.
Source: Reproduced from Kaplan and Norton (2004, 12).[268]

Introducing the Innovation Management Map

While Kaplan and Norton (1996) did account for *Innovation Processes* in their Strategy Map, the scope was limited to their Internal Perspective – a serious limitation that omits the contribution of innovation at other levels.[269] There is a need for a more complete and holistic treatment of innovation management that recognizes the management interfaces and strategic alignment of innovation needed across the hierarchy of corporate activities.

My proposed *Innovation Management Map* depicted in Figure 7.4 takes inspiration from the format that Kaplan and Norton used in their Strategy Map, but it focuses on innovation strategy and management in the full context of organizational value creation and management along multiple perspectives. The Innovation Management Map also contains a more complete organizational dimension on the far right, since innovation needs to be governed, led, and managed at all different levels of the organization – from the board and executive leadership, through business unit (BU) and functional leadership, innovation and R&D leadership, and team leadership at the functional, cross-functional and BU level.

The Innovation Management Map depicts how and at what levels the innovation creates value for the organization and its stakeholders using six perspectives. Starting from the top, these perspectives are:

Innovation Goal and Key Performance Indicator (KPI) Perspective. This is the perspective that determines the strategic alignment of innovation within the firm and translates the corporate strategy into specific, quantified innovation goals. As such, it requires a framework for how to translate the organization's strategy (including its growth strategy) into innovation goals, and how organizational budgets and resources will be allocated to innovation in accordance with the firm's priorities. Thus, the top-level innovation KPIs are analogous to the top-level financial perspective in the Kaplan-Norton Strategy Map and may include cost reduction, revenue growth, customer satisfaction, market share, ESG,[xxxii] and other targets. Innovation means nothing if it cannot be tied to the major strategic goals of the organization. In fact, innovation needs to be derived from these goals so that it is made clear how innovation contributes to them.

Linking innovation to growth targets is the most common – but not the only – strategic linkage in for-profit firms. For example, if a firm has 20 percent growth goal, the contribution of new offerings to that goal should be quantified. The same is true for productivity, regulatory, and ESG goals. An example of the latter is setting a target for the contribution of process innovations to the reduction in greenhouse gas emissions of a factory. By quantifying the expected contribution of

xxxii Environmental, Social, and Governance.

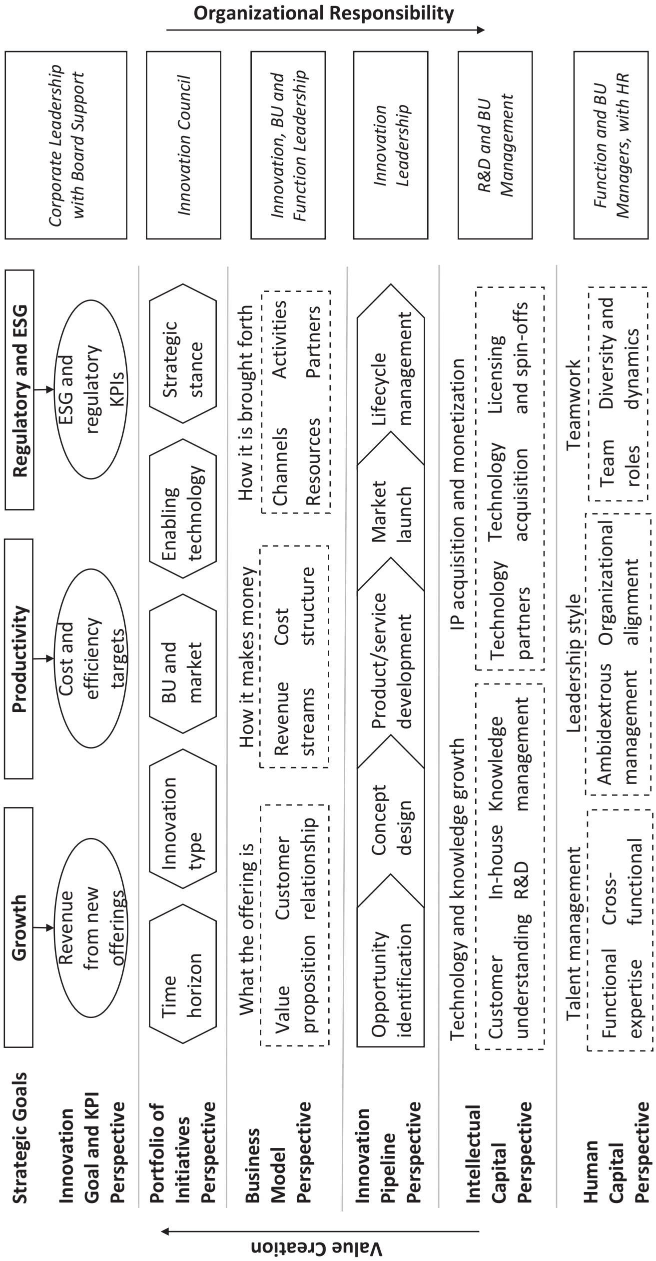

Figure 7.4: The Innovation Management Map.

innovation to important corporate objectives, it becomes easier to set and allocate budgets to the innovation initiatives intended to meet those respective targets.

Innovation KPIs and metrics will be discussed in more detail in the next section.

Portfolio of Initiatives Perspective. Unless a firm is effectively a startup with only one innovation initiative, the senior innovation leadership will have to manage a portfolio of innovation initiatives, all competing for time and resources. Any organization with more than a handful of innovation projects needs a coherent means of managing a portfolio of innovation initiatives on an ongoing basis, which has to include a mechanism for aligning and periodically realigning the initiatives with evolving organizational strategy.

Innovation projects and initiatives comprising the innovation portfolio initiatives may be classified in terms of time horizon (short, medium, long term), the type of innovation (incremental or radical), the business unit or product line the innovation is for, the intended market for the innovation, the strategic stance the initiative represent, or the underlying enabling technology (e.g., electric vs. gasoline-powered engines, 20nm vs. 5nm semiconductor chip technology, and so on). An example of a strategic stance is whether the initiative has as its goal to expand the breadth of the firm's offerings or to secure market leadership in a current offering.

How to manage the innovation portfolio of initiatives will be covered in Chapter 8.

Business Model Perspective. The business model defines how value is created by the firm and received by the customer, and how exactly the firm profits from its innovation efforts. (Business Model Innovation and its public-sector equivalent, Mission Model Innovation, were covered in Chapter 6.) Key business model elements include the value proposition, the types of customer relationships, the customer and stakeholder segments that the innovation is directed at, and over which channels the innovation is delivered. It also includes the key internal activities, operations, resources, and external business partners required to bring forth the innovation. The financial value of the innovation is an important part of the business model, including both the revenue streams from the innovation and the cost structure needed to produce it and bring it to the customer.

Innovation Pipeline Perspective. This is the perspective that is too often conflated with innovation management as whole, but it is only one perspective on innovation management, albeit an important one. The innovation pipeline perspective covers how innovation is progressed through the organization from idea through development, to market launch and beyond to the support stage and the ultimate retirement of the offering, the latter concept being part of product-lifecycle management. Innovation project management will be discussed in Chapter 8.

Intellectual Capital Perspective. Technology and knowledge growth, and IP acquisition and monetization are contained within the Intellectual Capital Perspective. More broadly, intellectual capital comprises all relevant customer, technical, and other knowledge created by the organization in its pursuit of value, as well as any intellectual property acquired and managed through various channels for the purpose of enabling innovation. (IP may also generate value through direct monetization.)

In Schumpeter's definition of innovation (see Chapter 1), entrepreneurs innovate by combining *existing* elements. This implies that enabling technologies and other fundamental building blocks for new products or services were created prior to innovation, an activity which Schumpeter called *invention*. Separating the management of technological intellectual capital as well as other knowledge, such as customer and market intelligence, from managing the innovation pipeline follows in this Schumpeterian tradition. New scientific insights and technologies are created through basic research and further matured by means of R&D. The management of these activities is separate from managing the innovation process, but it needs to be closely aligned and coordinated with the innovation pipeline perspective. For example, a new battery technology needed for a future generation of electric vehicles will need to emerge from the research department in time to be mature enough for incorporation in the innovation pipeline for a new model vehicle intended to kick off two years from now.

Virtually everything that comes into focus through this perspective can be thought of as either *knowledge stocks*, *knowledge flows, or knowledge generation*. The total knowledge stock comprises all firm repositories of knowledge, such as internal knowledge databases, recorded processes, and research findings as well as externally visible patents.[xxxiii] There are many types of knowledge, including strategic, technological, and market related knowledge. Knowledge flows represent all activities associated with transferring, sharing, and exchanging knowledge. It is akin to the blood flow in a human body. Knowledge can indeed be thought of as the lifeblood of the innovation process, which involves knowledge exchange and then generation in multiple forms. Christian Rupietta and Uschi Backes-Gellner (2019) point out that firms generate new knowledge that leads to innovations by recombining existing knowledge sources. The firm's existing knowledge stock together with its knowledge flows form its *knowledge-creation system*.[270]

The maturity of technologies employed in innovations will vary by industry; for example, the high-tech and software industries tend to use the most recently available technologies, while other industries are more conservative in their adoption of new technologies. The aggressiveness in using either cutting-edge or proven technologies in innovation also depends on the organization's innovation strategy and risk appetite. Regardless of industry, innovation leaders need a clear understanding of which technologies are relevant for current and future innovations in their pipeline and where these technologies will come from, in particular if they are going to be internally developed or externally sourced. In as far as the technology creation is

xxxiii Researchers usually use patents, which are public information, as a proxy for knowledge stock, but that omits many forms of knowledge stock that is not externally visible.

a precondition for innovation, the R&D endeavors of the organization also need to be managed to yield the technologies required for use by its innovation projects on schedule, and within the cost and performance parameters required.

Customer understanding requires a comprehensive set of tools for learning about customer, end-user, and market needs as well as for relevant technologies. This should include feedback mechanisms from end-users to innovators after products or services have been released, and how users will be involved ahead of, and during, the innovation process

In an article provocatively titled, "If Only We Knew What We Know," Carlo O'Dell and C. Jackson Grayson (1998) articulate the need for large organizations to better tap into the vast treasure trove of knowledge and know-how that already exists within their organizations.[271] It is notoriously difficult to internally spread best practices from high performing to other groups. Internal knowledge transfer remains a people-to-people process, but results can be improved by creating the organizational forums and processes to facilitate it, through overt encouragement by senior leaders, and by using modern information technology to capture and disseminate information quickly and at scale.

Intellectual property and technology management are advanced topics that are out of scope for this book.

Human Capital Perspective. Human capital comprises talent, leadership skills, and the ability to work together on innovation in teams. Innovation is a social endeavor, accomplished by people working together within teams and with other teams. Innovation also requires expertise (talent) in both the various functional disciplines that come together to innovate and in managing the innovation process itself. The leadership role in innovation is particularly important due to the often-conflicting demands innovation places on leaders up and down the seniority ladder. Innovation requires leaders to manage both exploitative and explorative activities, requiring an ambidextrous ability as explained in Chapter 4.

> Another way to think of the innovation activity within the firm is that it is a kind of production process, which transforms factors (inputs) into outputs. As noted in Chapter 3, the classical economists believed that there were three factors of production – land, labor, and capital – which are the inputs to a production function that transformed these inputs into outputs. For example, farmland, farm laborers, and tractors (capital) produce crops. Schumpeter suggested entrepreneurship as a fourth factor of production. In the modern innovation economy, land is less important and not represented here, though it is, of course, still crucially important to the agricultural and natural resources industries.
>
> In the Innovation Management Map, human capital takes the place of labor, intellectual capital represents capital, and entrepreneurship is represented by the skill of managing the innovation pipeline. The analog of the production function is the business model, whereby the aforementioned new factors of production create value for customers and stakeholders. (Note: While financial capital is essential to fund innovation, it is not included in the Innovation Management Map but discussed as a topic in its own right in Chapters 9 and 10.)

The team dynamic and people issues related to creative and innovation processes were covered in Chapter 4. A more in-depth discussion of talent and leadership issues is out of scope, with the exception of the hierarchy of organizational responsibilities for innovation, which will be covered in a later section in this chapter.

***

In conclusion, Kaplan and Norton's five accompanying principles for their Strategy Map may be retained or modified as follows for the Innovation Management Map:

1. *Strategy balances contradictory forces**. The main contraction – highly relevant for innovation – is that the needed investment in intangible assets for long-term revenue growth usually conflicts with cutting costs for short-term financial performance.
2. *Innovation is essential to the creation of a differentiated customer value proposition***. Satisfying customers is the source of sustainable value creation. This is highly relevant to innovation since the primary output of innovation activities in business is most often the value proposition, which is judged by the customer.
3. *Innovation is a major contributor to value****. Innovation provides value to the customer in the form of products and services, to the firm in the form of financial rewards via the business model, and to society at large through benefits such as environmental sustainability and community and supply-chain spillovers.
4. *The innovation portfolio consists of complementary themes****. The portfolio of innovation initiatives comprises projects across different time horizons, with varying cycle times and risk profiles. Incremental innovations generally deliver value over the short term, while next-generation initiatives will deliver value over the medium term. Radical innovation projects generally take longer to produce higher revenues and margins, with less certain outcomes. The innovation portfolio, therefore, must reflect the firm's objectives as well as risk tolerances.
5. *Innovation that is aligned with strategy both determines and amplifies the value of intangible assets****. The organization's main intangible assets relevant to innovation are its intellectual capital and its human capital. The intellectual capital is accumulated and exploited through the proper employment of the organization's human capital. The value of both these types of capital is maximized through proper innovation management that is aligned with the organization's strategic goals.

   Key: * retained verbatim; ** minor modification; *** major modification

Once the strategic goals are set, they should be cascaded down level by level, in each case asking a question on whether that level is aligned with the strategic goals:

– Will reaching our stated innovation goals and KPIs sufficiently contribute to the organization reaching its strategic goals?

- Is our portfolio of innovation initiatives aligned with the strategic and innovation goals?
- Will our current and future business models deliver on these goals?
- Is our innovation pipeline process efficient and effective enough to deliver the innovations that we need to meet our goals?
- Do we have the technology and IP required for the innovations we need to deliver and if not, how will we develop or acquire these technologies and IP?
- Do we have the quality and quantity of human talent needed to successfully complete the needed innovation and development activities, and, if not, who do we need to add to our talent pool?

Innovation Metrics and KPIs

Innovation metrics should communicate the strategic alignment of innovation with organizational objectives, and drive the performance of innovation projects and activities. Metrics must be formulated so that each metric can have a quantifiable target. Without targets, metrics are useless. But targets cannot be arbitrary. Metrics need to make sense to all stakeholders involved, and targets must have the buy-in of the participating parties.

The most important metrics are often referred to as KPIs. Typical mistakes that organizations make are having too many metrics and having a set of metrics that does not provide comprehensive coverage of the organization's innovation activities. An example of the former mistake is to have more than 10 KPIs, and an example of the latter mistake is to only have metrics for the latter stages of innovation. Another mistake is too much complexity, which makes metrics hard to understand, causes fruitless debates, and undermines metric credibility with stakeholders.

Good metrics are self-explanatory and simple in their definition and application. They are not easily gamed. Metrics also need to be balanced between financial and nonfinancial metrics. Having only, or too many, financial metrics is another common mistake to avoid. Metrics, as with most other endeavors, require prioritization. But they also require balance, so that all important aspects of the innovation process are tracked. A basic classification system of available innovation metrics divides them into *input, process, and output metrics*. Dividing metrics into types such as *financial* and non*financial* can provide further context (see Table 7.1).

Another way to categorize innovation metrics is by *thematic area*. After an extensive review of the literature on innovation measurement, Adams, Bessant, and Phelps (2006) derived a framework comprised of seven thematic categories. Each of the categories is subdivided into several measurement areas for which metrics may be defined (see Table 7.2).

Table 7.1: Innovation Metrics by Type.

	Input metrics	Process metrics	Output metrics
Financial	– R&D intensity: Percentage of revenue spent on R&D and innovation – Pipeline value: Financial potential of innovation pipeline	– Total development cost per project – Project spend variance to budget – Cost per innovation stage – Average headcount cost per developer	– Percent of revenue from new products (called the *Vitality Ratio*) – Financial performance (revenue growth, profit growth, NPV,[xxxiv] ROI[xxxv]) – Forecast revenue accuracy – Price and cost accuracy – Percent of new products achieving launch-year revenue targets – Revenue from spin-offs or licenses
Nonfinancial	– Number of new ideas explored – Number of new ideas obtained from outside the organization – Strategic alignment of new projects – Portfolio mix/balance (e.g., by incremental vs. radical, by business or product line, by theme)	– Number of projects advanced vs. discontinued – Schedule adherence: Percent of projects on schedule – Development time variance: actual vs. planned – Throughput time per stage/major activity – Gate pass rate – Number of projects with issues	– Number of new products launched – Customer satisfaction – Change in market share – On-time launch percentage – Average time to market – Number of patents granted – Number of spin-off projects or technologies

The categories and measurement areas in Table 7.2 offer a useful checklist to help ensure the selection of a comprehensive set of innovation metrics that covers all areas of potential interest, and to make sure the metrics selected are balanced. As a rule of thumb, there should be at least one metric from each category. They do not all need to be tracked in a monthly scorecard, and some may be more appropriate to track annually.

xxxiv Net Present Value.
xxxv Return on Investment.

Table 7.2: Innovation Measurement Categories and Areas.

Framework category	Measurement areas
Inputs	– People – Physical and financial resources – Tools
Knowledge management	– Idea generation – Knowledge repository – Information flows
Innovation strategy	– Strategic orientation – Strategic leadership
Organization and culture	– Culture – Structure
Portfolio management	– Risk/return balance – Optimization tool use
Project management	– Project efficiency – Tools – Communications – Collaboration
Commercialization	– Market research – Market testing – Marketing and sales

Source: Adams, Bessant, and Phelps (2006).[272]

The old saying is true: You get what you measure. Just as metrics should not be easy to game, any unintended consequences of using a particular metric, to the extent that it might encourage undesirable management behavior, should be always guarded against. Undesirable unintended consequences are more likely if there is an overemphasis on one particular metric. For example, only focusing on the number of new products launched could lead to a slew of disappointing product launches, as managers prioritize quantity over quality. But if this metric is complemented by others, such as the percent of new products achieving first-year revenue targets, it is less likely to be abused. This is another reason why a balanced set of KPIs is desirable, despite the allure of choosing a singular KPI that can be easily communicated.

Another balance that should be struck in the set of metrics tracked is between *effectiveness* and *efficiency* types of metrics, where effectiveness means working toward the right outcome, and efficiency means doing things in the best and most cost-efficient way possible.

Lastly, the set of metrics and KPIs tracked used should never be completely static. The so-called Goodhart's Law (that when a measure becomes a target, it ceases to be a good measure) is perhaps a cynical way to express a truism that care should be taken so that metrics are not gamed. But metrics also lose their usefulness for other reasons and with time. There are metrics that are useful at one point in time because they shine a light on a particular challenge but become obsolete once that challenge has been adequately addressed. While KPIs should generally persist for many years, secondary metrics can be phased in and out as need be. For example, if accurate budgeting is a problem, a metric such as spend variance to project budget may be needed to shine a light on the progress made in that area. But after budget accuracy and spending discipline have been improved, this metric may be retired in favor of a new metric to address the next challenge, which could be development time variance.

The metrics in Table 7.1 are all firm-level or BU-level metrics. Some of these metrics are aggregated and captured at a national or industry level, but others are not suitable for aggregation beyond the firm. Of the ones tracked, R&D Intensity is the most frequently tracked metric. The national equivalent of R&D as a percent of revenue is R&D as a percentage of GDP, also called BERD/GDP, where BERD stands for Business Expenditure on R&D.

The methodology for capturing R&D metrics at a national level is contained in a document published by the OECD called the Frascati Manual. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities* (OECD 2015) is the latest version of this authoritative, international methodology for collecting and using R&D statistics.[273] Further reference to the Frascati Manual will be made in Chapter 10.

There are several problems with the R&D Intensity metric. First, it is by definition an input metric. As such, it contains no information on how efficient or productive the R&D was, only that money was spent on R&D. Second, what is counted as R&D expenditure is subject to multiple criteria, which are always open to interpretation. Third, R&D Intensity ratios vary substantially by industry. When it is used for national comparisons, the industry mix of the respective countries are a major determinant of the countries' R&D Intensity. Even so, R&D Intensity metrics are fairly easy to capture and analyze because both R&D expenditures and revenues are published in standard financial statements. These metrics have, therefore, been used for a long time as a proxy for innovative effort, despite their shortcomings.

Governance and Decision-Making Rights

Every organization engaged in innovation needs an innovation governance model (or methodology). The model should cover all important innovation decision-making points. For these, it should define clear decision-making rights that establish when, how, and by whom decisions will be made to commit organizational resources to innovation activities. Since innovation involves several corporate functions, the governance model needs to specify how these functions will collaborate and share innovation execution and decision-making responsibilities.

Putting a single executive in charge of innovation can create more problems than it solves. And saying the CEO is the Chief Innovation Officer may rhetorically emphasize the importance of innovation to the organization but has little practical effect. Given its multifunctional nature, innovation is best managed by various committees or councils, starting at the top with the strategic level. The following exposition refers to Figure 7.4: The Innovation Management Map, in particular, to the right side of the map.

The organization's strategic goals are the responsibility of corporate leadership (i.e., the so-called C-suite) with board support and sign-off. What exactly the strategic goals are will determine the innovation goals, as the latter must be derived from the former. For example, the revenue-growth goal may determine the expected revenue contribution from new offerings that need to be innovated. Or the target for the reduction of greenhouse gas (GHG) emissions will determine the innovation goals for that. Most importantly, this is also the right level for deciding the innovation budget since the budget can be compared and justified against the goals it is supposed to achieve.

The highest-level dedicated innovation governance organization is the Innovation Council. The Council should be comprised of the most senior executives leading innovation, the most senior direct organizational stakeholders of innovation (such as relevant BU and functional heads), and a C-level executive sponsor of innovation – who should chair the Innovation Council. It is the job of the Innovation Council to guide, scrutinize, and ultimately, approve the full portfolio of innovation initiatives.

The business-model perspective calls for a similar multifunctional mix of leaders, with the presence of key decision-makers in the businesses being essential to ensure that innovative new business models not only can, but will be implemented. Depending on the depth and breadth of an organization's hierarchy, the joint leadership team taking responsibility for new business models may be the Innovation Council itself, a subcommittee of the Council, or a separate committee one level below that of the Council.

The Innovation Leadership itself is responsible for orchestrating the whole innovation pipeline process, but the presence and buy-in of other organizational leaders will be needed at each of the decision-making gates in the pipeline. This process will be elaborated on in the next chapter.

The intellectual capital that powers the innovation process, comprised of both internally developed and externally acquired knowledge, patents, and know-how is the responsibility of mainly senior R&D management but with support from business management, particularly as it concerns purchasing or selling intellectual capital for the benefit of a particular business unit. Technology strategy and management may also be part of this perspective. The decisions made on which technologies to pursue and when they will need to be mature to support product innovations will result in a technology roadmap, which will need to be approved not only by the most senior R&D and technology leaders but also by the users of the technology (i.e., the innovation leaders) and by the main stakeholders on the side of the relevant businesses.

Lastly, the governance and management of the human capital of innovation is the direct responsibility of the managers at various level in the relevant functions and businesses, with advice and assistance from human resource (HR) professionals where appropriate. The challenges of ambidextrous leadership and organizational alignment have been discussed in Chapter 4, as were the unique challenges of teamwork under uncertainty and creativity.

An important management area that is adjacent, but also tangential, to innovation management is that of *product management* – also sometimes called *solution management*, in the IT industry in particular. Products (and services) need to be managed across their lifecycles: from inception, to design and development, launch, support, and phasing out (sometimes called sunsetting). In some industries (e.g., CPG, consumer electronics), the product manager is a key decision-maker in the innovation process. In each case, the responsibilities and decision-making rights of different organizational functions across each of the product lifecycle phases will need to be spelled out. The details of product management are out of scope for this book.

The Innovation Management System

In the most general terms, a management system is the set of elements required to make a particular organizational function perform well in executing its mission and mandate. Over the years, different authors have offered their views of what an innovation management system (IMS) ought to be. Fortunately, we now have the benefit of years of work on a set of innovation management standards by ISO[xxxvi] committees, and do not need to reinvent the wheel. According to ISO 56002 (2019):

> An innovation management system is a set of interrelated and interacting elements, aiming for the realization of value. It provides a common framework to develop and deploy innovation capabilities, evaluate performance, and achieve intended outcomes.

Note the emphasis on the *realization of value* as the primary goal of innovation – a consistent message in this book as well. The ISO IMS follows a Plan, Do, Check, Act (i.e. continuously improve) cycle typical for management standards. And the seven main elements in the ISO IMS are the same for all management-system standards issued by the ISO:

- Context
- Leadership
- Planning
- Support
- Operations

xxxvi The International Organization for Standardization.

- Evaluation
- Improvement

ISO 56002 built on, and was preceded by, the European guiding specification CEN/TS 16555–1 published in 2013. Older publications on innovation management may still refer to CEN/TC 16555–1.

The ISO IMS framework applies to all types of organizations, regardless of type, sector, or size. But ISO standards are developed to be guidelines, rather than requirements. It is up to each organization to select the relevant parts of the system it wishes to implement, given its situation.

The ISO IMS standard recognizes the following eight principles for managing innovation activities in organizations:

> 1. *Realization of value* – Value, financial or nonfinancial, is realized from the deployment, adoption, and impact of new or changed solutions for interested parties.
> 2. *Future-focused leaders* – Leaders at all levels, driven by curiosity and courage, challenge the status quo by building an inspiring vision and purpose, and by continuously engaging people to achieve those aims.
> 3. *Strategic direction* – The direction for innovation activities is based on aligned and shared objectives and a relevant ambition level, supported by the necessary people and other resources.
> 4. *Culture* – Shared values, beliefs, and behaviors, supporting openness to change, risk taking, and collaboration, enable the coexistence of creativity and effective execution.
> 5. *Exploiting insights* – A diverse range of internal and external sources are used to systematically build insightful knowledge, to exploit stated and unstated needs.
> 6. *Managing uncertainty* – Uncertainties and risks are evaluated, leveraged, and then managed, by learning from systematic experimentation, and iterative processes, within a portfolio of opportunities.
> 7. *Adaptability* – Changes in the context of the organization are addressed by timely adaptation of structures, processes, competences, and value realization models to maximize innovation capabilities.
> 8. *Systems approach* – Innovation management is based on a systems approach with interrelated and interacting elements, and regular performance evaluation and improvements of the system.[274]
>
> (ISO 2019)

The above principles and guidance are contained in *ISO 56000:2020 Innovation Management – Fundamentals and Vocabulary (2019)*,[275] which may be purchased directly from ISO. ISO has a family of documents on innovation management. Their titles and status at the time of writing are provided below along with the relevant OECD and CEN standards.

Major International Standards for Innovation Management
OECD
Oslo Manual – Guidelines for Collecting, Reporting and Using Data on Innovation, 4th edition (2018)

European Committee for Standardization (CEN)
CEN/TS 16555 series of standards for Innovation Management (2013–2017)

International Organization for Standardization (ISO)
ISO 56000, Innovation Management – Fundamentals and Vocabulary (2020)
ISO 56002, Innovation Management – Innovation Management System – Guidance (2019)
ISO 56003, Innovation Management – Tools and Methods for Innovation Partnership – Guidance (2019)
ISO/TR 56004, Innovation Management Assessment – Guidance (2019)
ISO 56005, Innovation Management – Tools and Methods for Intellectual Property Management – Guidance*
ISO 56006, Innovation Management – Strategic Intelligence Management – Guidance*
ISO 56007, Innovation Management – Idea Management*
ISO 56008, Innovation Management – Tools and methods for innovation operation measurements – Guidance*
*Under development at the time of writing.

Organizations should always codify their own IMS within a master document, which may be titled appropriately but is often called an *Innovation Playbook*. The Innovation Playbook spells out the organization's innovation terminology, articulates how different types of innovation will be handled, and elaborates on all the core innovation processes and decision-making. As such, it provides a detailed roadmap for how each part of the Innovation Management Map will be implemented. The Innovation Management Map should be reflected in the table of contents of the Innovation Playbook. For instance, the different layers of the Innovation Management Map should each be the subject of a chapter within the playbook.

The playbook will articulate the governance model for different types of projects; for example, that incremental projects will follow a standard process, but that some radical projects will be conducted inside a special innovation organization (e.g., within a skunkworks – see Chapter 4). The decision-making hierarchy for innovation, as well as the budgeting and projection selection and approval processes, should also be spelled out. All innovation metrics and KPIs should be defined in the playbook as well as the hierarchy of these metrics and the organizational responsibility for achieving each. The playbook should also contain the protocols for cross-functional and cross-department collaboration on innovation. Furthermore, the playbook may contain guidance on how an innovation culture (culture of experimentation or learning culture) will be fostered in the organization, and how knowledge and intellectual property will be managed.

Innovation Management in Government – Special Challenges

Volumes have been written about the management of government agencies. This topic falls within the field of political science and, as such, is beyond the scope of this book. However, it will be helpful to review observations about the mission and management of agencies that are relevant to the endeavor of innovation management. These observations will aid our understanding of the special challenges associated with innovation management in the public sector. The two most salient aspects that will be covered below are the challenges of setting innovation goals for public agencies, and the organizational constraints to innovation over and above those found in private-sector firms.

Setting Innovation Goals for Agencies

In his seminal book on bureaucracy, James Q. Wilson (1989) explains the nature and peculiarities of management in government agencies, elaborating on the constraints under which public-sector managers work, and which often make it more difficult for them to innovate than their counterparts in the private sector. Wilson distinguishes between agency *outputs* (what an agency does) and agency *outcomes* (what happens because of those outputs). The former is what agency employees do on a day-to-day basis; for example, doctors, teachers, and policy officers have output activities that can be observed. The latter, outcomes, is about what changes because of the outputs. The outcomes are the results of the agency's work. These may be harder to observe than the agency's activities.[276]

According to Wilson (1989, 158–171), four different types of agencies – *Procedural, Production, Coping, and Craft Organizations* – can be discerned based on whether their outputs and outcomes, respectively, are easily observable (refer to Figure 7.5).[277]

Are *outcomes* easy to observe?		**Are *outputs* easy to observe?** Yes	**Are *outputs* easy to observe?** No
	No	Procedural Organizations e.g., Occupational Safety and Health Administration, armed forces during peacetime	Coping Organizations e.g., Diplomats, police, educational organizations
	Yes	Production Organizations e.g., Social Security Administration, Internal Revenue Service, Postal Service	Craft Organizations e.g., Armed forces during battles, antitrust division of DOJ, Army Corps of Engineers

Figure 7.5: Wilson's Four Types of Agencies.
Source: Adapted from Wilson (1989, 158–171).[278]

Much emphasis was given earlier in this chapter to tying innovation goals and KPIs to organizational goals. Wilson's differentiation between different types of agencies makes it clear where and how applying this principle to government will be hard. It is easiest to set innovation goals for agencies with easily observable outputs. For these two types of agencies, the innovation goals can be directed related to the agency's expected outputs. In the case of *Production Organizations*, a new processing system may be expected to reduce processing times per filing for the Internal Revenue Service and Social Security Administration, or to help the Postal Service to deliver mail at a lower cost per item. Similarly, for *Procedural Organizations,* a new type of training simulator may reduce training costs and increase proficiency for pilots or other members of the armed services, or innovative new tools may help the Occupational Safety and Health Administration to increase the number of workplace inspections it does.

So, for both Production and Procedural Organizations with easily observable outputs, innovation goals can be set in a very similar way to private-sector firms by deriving the goals from the expected outputs of the agency. Some of these goals may even be set in monetary terms, such as targeted cost reductions or efficiency gains, and other goals may be equivalent to revenue in the private sector, such as increasing the number of public-sector customers served by an agency.

However, setting innovation goals for agencies that do not have easily observable outputs is much harder, and private-sector analogies break down. *Craft Organizations* have easily observable outcomes, but not easily observable outputs. This poses the question of whether innovation goals can be tied to their outcomes rather than their outputs. The short answer to that is yes, as long as the strategy or plan to achieve the outcome can be articulated in sufficient detail so that the innovations needed to make it happen can be derived from it. It boils down to sketching out the new vision for the outcomes that the agency should achieve and then asking: Why can we currently not do it? Just as in the case for the missing revenue of a private-sector firm's growth aspirations, isolating the missing piece in the agency's desired outcomes can help you to infer the required innovation goals.

A well-known example from World War II illustrates this thought process. In 1940, the German Army unexpectedly routed the larger and stronger French Army using the novel blitzkrieg tactic that entailed fast-moving tank formations with close-air support in the form of dive-bombers. The French, in fact, had both more and better tanks, but they lacked tactical radio communications (which the Germans had) and used with devastating effect to coordinate their attacks better between tanks, aircraft, and infantry. German general Heinz Guderian was recognized as the father of the blitzkrieg, including by his colleague and friend, Erwin Rommel, who said:

> In Germany, the elements of modern armored warfare had already crystallized into a doctrine before the war – thanks mainly to the work of General Guderian – and had found practical expression in the organization and training of armored formations.[279] (Nicola 2016)

Note that the blitzkrieg doctrine was well articulated in Guderian's writings *prior* to it being operationalized. The blitzkrieg was clearly a major innovation in warfighting, and so was the use of the new-at-the-time tactical radios in each vehicle. If you went back in time before these events, how would you have set the innovation goals to bring them about? The answer lies in understanding Guderian's strategic vision surrounding his desired outcome, which was a fast, decisive victory to avoid the trench-based stalemates of the previous war. You could then have worked back from his doctrine to understand that an innovation goal supporting this outcome had to be real-time communication with and between each tank in the field, which would enable you to define the innovation requirements for that radio equipment.

Thus, the trick with setting innovation goals for Craft-style agencies is to make clear what the outcome is envisaged to be and, most importantly, what actions and abilities would be required to bring about that outcome. The innovation goal is then derived by asking: Why it is that we currently cannot achieve such an outcome? The answer in the example above would be: We cannot current achieve such an outcome because we lack the means of communication to coordinate our attacks that is called for by the doctrine. Is there then a currently feasible technology that may enable that? The answer would be: Yes, the invention of radio technology can be innovated for this purpose. And thereby you would arrive at the innovation goal: Outfitting tanks, warplanes, and infantry with a mobile, interoperable radio-communication system within a certain period.

Coping Organizations lack both observable outputs and outcomes. Setting innovation goals for them is, therefore, the hardest. It first requires a strategic vision, similar to that for the Craft Organizations. Wilson (1989, 168–171) points out that with both outputs and outcomes unobservable, conflict between managers and operators in agencies is likely. The operators (e.g., teachers in classrooms, or police officers on patrol) have to deal with immediate situational imperatives, while managers will have different goals such as minimizing complaints from constituents (e.g., parents, or the public at large).

Administrators are too often tempted to try to manage Coping Organizations as if they were Production Organizations, implementing highly standardized procedures and setting detailed metrics, with the result that operators focus on what gets measured instead of what may be most important in terms of the mission of the agency (Wilson 1989, 168–171).[280]

Similar to Craft Organizations, the innovation goals for Coping Organizations can be derived from sketching out a vision of what successful completion of their mission looks like, and then asking what is currently preventing them from doing that. For instance, if police desire new nonlethal methods of enforcing laws in particular situations for which they currently lack the tools, that missing ability can be turned into a requirement and a higher-level innovation goal. Metrics can also be devised, for example, to change the doctrine and methods used in dangerous encounters where suspects have mental-health issues to result in a 50 percent reduction of use of lethal force. This overall KPI would then spawn innovation goals that apply to both new tools and tactics.

Managing Innovation in Bureaucracies

The *Standard Operating Procedure* (SOP) is at the core of how operations in public agencies are managed. Wilson (1989, 221–222) points out that "stability and routine are especially important in government agencies where demands for equity (or at least the appearance of equity) are easily enforced." Variations are troublesome because constituency groups may demand explanations as to why case B was handled differently than case A. Agencies tend to avoid any course of action that may set controversial precedents, which is the reason for the bureaucratic adage: "Never do anything for the first time." The anti-innovation nature of this adage needs no further explanation. The bias against changing task definitions lead bureaucracies to adopt new technologies (such as new information technologies) without understanding their significance or fully realizing their potential. True innovation requires the redefinition of core tasks. However, in government agencies changes consistent with existing task definitions are fairly easily accepted, while changes that require a redefinition of tasks are often rejected.[281]

Potential technological gains in productivity are too often squandered because processes are not changed to make the best use of the new technology. I can offer an example from personal experience: During the COVID-19 pandemic, the Virginia Department of Motor Vehicles (DMV), wanting to minimize the time that customers spent inside DMV offices, encouraged applicants for driver's licenses to complete application forms online in PDF format. Customers had to print out these applications at home and bring the printed forms to the DMV, where all the information was manually reentered by the operator into the DMV's IT system. Had the DMV enabled the customer's online application to upload directly into its own system subject to subsequent operator checking and approval (akin to the well-established process of applying for a bank account or credit card online), it could have realized major productivity gains. This would have been a trivial implementation with modern information technology.

Another perverse tendency of public agencies is to use new information-gathering and transmission capabilities not to empower frontline managers, but to further centralize control. Wilson (1989, 228–229) argues that if it is technologically possible to check with higher authority before making a decision, then that will be done. And if higher authority is able to hear what is going on, it will be told what it wants to hear. Lastly, processing greater quantities of information will require new specialized bureaus, who will demand more and more information to process. Wilson's comments were prescient as they preceded the explosion of email communications and big data.

As in the private sector, bottom-up innovation from people closest to the problem at hand should be encouraged. It is not desirable for public servants to see their bosses as the primary source of all ideas for innovation. But sometimes, strong agency heads are the only people who can drive innovations through the inherent organizational resistance and inertia. However, even the most senior people can have trouble effecting change in agencies. Top-down innovation efforts in agencies, even more so than in the private sector, are often frustrated by mid-level bureaucrats who do not want to change anything and will wait things out, expecting career executives to be rotated out or political appointees to move on. It should, however, not be assumed that operators and other lower-level staff will always be hostile to innovation. Understanding the incentives that they operate under and changing the incentives where needed to enable innovation are crucial.

An important perspective on agency innovation that should never be omitted is that of customers and the multiple internal and external stakeholders of the agency. Innovations in the name of efficiency that reduce customer-service levels can meet with strong backlash.

Indeed, public-sector innovation is not easy, given the context. It requires innovation management skills that are honed to the public-sector environment. Sandford Borins (2011) argues that successful public-sector innovators are not loose cannons. Instead, they proactively solve problems before they arise: Taking opposition seriously and attempting to overcome it through persuasion of accommodation rather than by playing power politics; having a clear vision of an innovation and staying focused on it; and always being objective about their innovation, constantly evaluating the innovation to see if it is having the intended benefits.[282]

Chapter Summary

- The objective of innovation management is increasing value while reducing uncertainty. The two largest determinants of uncertainty are the market for which the innovation is intended and the technology on which the innovation relies.
- Each component of the innovation management process should be justified by explaining how it will increase value, or reduce uncertainty, or, preferably, do both at the same time.
- Innovation is a multifunctional endeavor that touches and affects many elements of an organization at all levels, whether it is a for-profit business or a government agency or nonprofit.
- The Innovation Management Map depicts the main innovation processes across various organizational levels. It provides different perspectives on where and how innovation creates value, and contributes to the organization's strategic goals, as to how innovation governance is cascaded down from the strategic to the tactical level.
- Innovation metrics and KPIs must be selected to be representative of innovation inputs, processes, and outputs, and include both financial and nonfinancial measures.

- An Innovation Management System comprises all the management elements that are in place to realize value from innovation. It is often documented in the form of an Innovation Playbook that spells out how the particular firm or agency will govern and conduct innovation.
- In the public sector, setting innovation goals is especially hard for some public agencies when they do not clearly have observables outputs and/or outcomes. The public sector's aversion to changing processes is a major roadblock to innovation.

Suggested Exercises and Assignments

- Use the Innovation Management Map as a checklist to determine which elements of an Innovation Management System your current organization has in place, and which may be missing.
- Make a list of the current innovation metrics and KPIs of your organization. Divide them into buckets for input, process, and output metrics. Also, classify each metrics as financial or nonfinancial. Identify and discuss any apparent gaps in metrics coverage, and then suggest metrics that would fill those gaps.
- Analyze a real-life public-sector innovation success to gain insight on how the agency's innovation management system was changed to allow this innovation to succeed. Contrast the management system in the case with how the bureaucracy usually functions.

For case sourcing, the OECD maintains the following repository of public-sector innovation case studies sourced globally. It is arranged by country, level of government, sector, stage of innovation, year of launch and other filters.

OECD, Observatory of Public Sector Innovation (OPSI), 2022. Available at https://oecd-opsi.org/case_type/opsi/

Recommended Further Reading

Dodgson, Mark, David Gann, and Nelson Phillips, eds., 2014. *The Oxford Handbook of Innovation Management*. New York: Oxford.

Epstein, Marc, Davila, Tony, and Shelton, Robert. 2005. *Making Innovation Work: How to Manage It, Measure It, and Profit from It*. Wharton School Publishing.

Tidd, Joe, and John R. Bessant. 2020. *Managing Innovation: Integrating Technological, Market and Organizational Change*. John Wiley & Sons.

Trott, Paul. 2020. *Innovation Management and New Product Development, Seventh Edition*. Pearson Education.

Chapter 8
Portfolio and Project Management

Organizations invest substantial resources in innovation projects. Two important, but separate, management actions are required to maximize the value from these investments and achieve the stated innovation goals or missions. The first is to ensure that the portfolio of innovation initiatives contains the right set of projects and that the diverse types of projects comprising it is an optimal mix, well-aligned with the strategic objectives. This is a highly complex problem to solve. The second is to ensure that each innovation project is run efficiently and effectively. Uncertainty, the ever-present companion of innovation, challenges both these endeavors and must be addressed through different management processes at the portfolio and project level. Improving organizational decision-making under uncertainty is an important success factor for such processes.

Accordingly, this chapter takes a closer look at the relevant two perspectives from the Innovation Management Model introduced in Chapter 7. Following a top-down approach, innovation portfolio management will be discussed prior to innovation project management (the pipeline perspective).

The chapter starts with a discussion of complexity, explaining why an innovation system is a complex system and how human brains cope with complexity. The concept of an innovation portfolio of initiatives is then introduced with reference to the linkages between the innovation portfolio and strategy. This is followed by an explanation of the process of portfolio management and rebalancing, with the purpose of maximizing the value of the portfolio. The portfolio represents the cumulative effect on many decisions taken, which makes it necessary to introduce the topic of decision-making biases, and what modern neuroscience can tell us about the cognitive biases that cause people to make the wrong decisions.

The criteria for selecting and approving innovation projects must reflect strategic priorities. A generic framework for that is introduced. A complete overview of project management is beyond the scope of this text, but some particular challenges related to managing innovation projects will be discussed. Finally, the concept of staged development, with phases and decision-making gates, is introduced.

Complexity and How We Deal with It

A *complex system* is any system comprising of a large number of autonomous or semiautonomous entities that interact in some way. Complex systems have different levels of organization and are characterized by *emergent properties*, which are properties that occur at higher levels, but which are not present at lower levels. For example, an automobile can move because it has a chassis, an engine, wheels, and so

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on. But neither of these subsystems can move on its own. Thus, moving is an emergent property found only at the systems level. As Aristotle would have said, "the whole is more than the sum of its parts."

An *innovation system* is essentially any collection of entities that combine to innovate. That could happen at the level of a private firm or government agency, within specific industry sectors or subsectors, within a region, country, or even between countries. The country-level system has been called the National Innovation System, which will be more precisely defined and covered in Chapter 11.

From the above, it should be obvious that innovation systems are also complex systems. The very nature of the Schumpeterian definition of innovation is of "combining existing elements" implying that innovations themselves are complex systems with emergent properties. And the innovation system that brings forth such innovations must also have complex properties, being comprised of many elements which contribute different parts of the innovation.

More formally, innovation systems are complex systems because they are based on complex behavioral patterns and result from nonlinear and nonpredictable choices. Following this logic, Muller, Héraud, and Zenker (2017) summarized the main features of innovation systems by using the terminology of innovation economics as follows:

> i. central role of learning
> ii. importance of historical processes
> iii. influence of institutions (public actors, legal framework, norms, etc.
> iv. existence of feedback loops between nonfully rational actors
> v. numerous and diverse interrelations between scientific, technological, and organizational innovations[283]
> (Muller, Héraud, and Zenker 2017, 2)

These insights on the complexity of innovation systems are largely consistent with the evolutionary approach expounded in Chapter 3 and, consequently, have policy implications, especially at the national level (which will be discussed later in Chapters 11 and 12). In this chapter, the focus will be on what system complexity means for how innovation is managed in practice within a private firm or government agency.

As humans, our brains have not evolved to simply stare at a jumble of raw information about anything, especially something complex like innovation management, and be able to understand what it means. In order get a grip on complexity and make information accessible so that humans can make decisions and take actions, we usually take some of the following actions:

1. We make a list, and order the items on the list so that related items are grouped together.
2. We visually display the relationships between different entities, such as by making charts, to make it easier to see the relationships between various quantities (e.g., drawing graphs with growth percentages of different product lines).
3. We graphically display the relationship between different entities (e.g., by making a flow chart, or drawing a Venn diagram).

4. We use advanced analytical software to infer and tease out the relationships between entities that are not apparent to us in any other way.
5. We drastically reduce a complex set of facts down to a single number, such as a financial value or some type of index.

Such techniques are helpful for innovation portfolio and project management. In the next sections, some proven frameworks and tools for handling the complexities of innovation portfolio and project management will be explained.

Introduction to Innovation Portfolio Management

Innovation portfolios – like any portfolio of projects – quickly get complex. Imagine a company having only ten innovation initiatives. Even with ten initiatives, the start and end dates, along with the resource demands they will place on the same talent pool comprising the different functional groups along with project managers, become hard to manage. That is largely a project and resource management problem, which can be managed with appropriate project management tools. However, since any organization has finite resources, the constraints imposed by resource limits on how many projects can be conducted at any one time force at least some form of portfolio management to happen. For example, project A may have to be delayed in favor of project B because they use the same specialist resources but completing project A is more urgent.

The annual budgeting process is a natural forcing device for planning and reconsidering which projects the organization can support in the following year, and which resources will be allocated to each. Hard tradeoffs are often needed when making such decisions as not only financial resources are finite, but also human resources and equipment.

From a strategic point of view, it is vitally important to assess whether the innovation initiatives in the current portfolio are the best ones for the organization to be spending its time and resources on if it wants to maximize the value generated from innovation and/or achieve its mission. Maybe some initiatives should be retired or slowed down while others need to be sped up, or maybe there are initiatives missing that could be vital to the future success of the company. Does the collection of current projects as a whole reflect the innovation strategy, or does the mix look wrong?

Addressing such questions is a strategic exercise for which only senior leadership can be responsible. It is called *innovation portfolio management* (IPM), and it is the hinge point between the innovation strategy and the individual innovation projects or initiatives. Every organization with a portfolio of innovation portfolios does IPM, whether consciously or not and whether by neglect or by active engagement. A decision to leave the portfolio as is, is still a portfolio-management decision.

Robert Cooper, Scott Edgett, and Elko Kleinschmidt (1999) published what they claimed to be the first extensive study of IPM in over 200 U.S. companies. They found that companies used a variety of portfolio-management methods but that companies who emphasized strategic approaches outperformed those who relied on financial methods.[284] The authors also offered the following definition of innovation portfolio management:

> Innovation portfolio management is a dynamic decision process, whereby a business's list of active new product (R&D) projects is constantly updated and revised. In this process, new projects are evaluated, selected, and prioritized; existing projects may be accelerated, killed, or deprioritized; and resources are allocated and reallocated to the active projects.[285]
>
> (Cooper, Edgett, and Kleinschmidt 1999, 335)

This subdiscipline of innovation management is also frequently called *Project Portfolio Management (PPM)* in the literature about R&D management. According to Menke (2013), there are two applications of PPM. The first, *strategic PPM*, is about "selecting the best set and mix of projects to deliver future benefits". And the second application of PPM is to "manage shared resources (people, facilities, and budget) during the execution of projects. This is sometimes *called pipeline management*" (Menke 2013, 34). Menke found a strong association between the presence of best-practice PPM processes and stock price performance of companies in the pharmaceutical industry.[286]

Other authors use the term *Innovation Project Portfolio Management* (IPPM). For example, Patrick Spieth and Martin Lerch (2014, 498) stress the "challenge of efficiently and effectively investing scarce resources in innovation projects to sustain or develop a firm's long-term competitive advantage and sustainable growth" and accordingly define IPPM as "a firm's dynamic capability to assess the challenge of evaluating, selecting, and prioritizing innovation projects."[287]

Whichever term you prefer, innovation portfolio management is about making choices that will determine the future of the business over the next few years or even the next decade. It entails both strategic (products, markets, technologies, etc.) and resource (financial, human, and capital assets) allocation choices. Mistakes made in portfolio management can have substantial negative impacts both upwards – strategic misalignment with the consequence of nonachievement of corporate goals – as well as downwards – resource misallocations causing project execution failures. Conversely, mastering portfolio management is essential to overall innovation success. A quantitative analysis of German companies by Christian Urhahn and Patrick Spieth (2014) found that portfolio management governance can indeed explain higher innovation outcomes.[288]

Another, shorter definition of innovation portfolio management by Kock and Gemünden (2016, 670) is that it is "a *dynamic decision-making process*, in which projects are evaluated and selected, and resources are allocated." The quality of portfolio decision-making is increased by having a clear innovation strategy, formal portfolio processes, frequently reassessing the portfolio, and fostering an organization climate in which risks can be openly communicated and discussed (Kock and Gemünden 2016).[289] The Kock-Gemünden definition includes initial project selection as part of the portfolio management process. Project evaluation and selection are obviously highly relevant in determining which projects end up in the portfolio in the first place. But these two processes are better seen as part of the innovation pipeline management process.

IPM is still a fairly new subdiscipline of innovation management. Anna Meifort (2016), who conducted a comprehensive review of IPM research, discerned four main perspectives (sometimes overlapping) to IPM in the literature:[290]

- The *optimization perspective,* which is concerned with making sure that the best projects are contained in the portfolio at any given point in time
- The *strategic perspective*, which regards IP as the central process for turning corporate strategic plans into action by allocating resources to projects in accordance with strategy
- The *decision-making perspective*, which considers IPM to be a dynamic decision-making process of how to allocate resources under uncertainty
- The *organizational perspective*, which recognizes that IPM involves several decision makers and interested parties with different goals and considerations across multiple organizational levels

Meifort concludes her review of innovation portfolio management with this synthesis:

> IPM is a complex decision-making process characterized by high uncertainty. It deals with constantly changing information about opportunities internal as well as external to the firm and with projects interrelated across space and time. Furthermore, it is embedded in the hierarchy of the organization and usually includes several organizational units.[291]
>
> (Meifort 2015, 265)

Note that IPM is "characterized by high uncertainty." Three major portfolio uncertainties that require managerial attention have been described:

> - *Uncertainty from the environment* due to factors external to the company that affect the portfolio.
> - *Uncertainty from organizational complexity* due to the parent organization's systems, structures and activities that affect the portfolio and include portfolio-level issues and inter-project dependencies.
> - *Uncertainty from single projects* due to changes, deviations and unexpected events that may take place within the portfolio at the single-project level and may have an effect at the portfolio level.[292]
>
> (Martinsuo, Korhonen, and Laine 2014, 733)

The Portfolio and Innovation Strategy

The innovation portfolio should reflect major elements of the innovation strategy, in particular, the type of innovator the firm wants to be (leading edge, fast follower, operational excellence, or cost leader), the types of innovation it will mostly be pursuing (product, service, process, etc.), and the degrees of innovation (incremental, next generation, radical/breakthrough) it will emphasize.

It is also possible to discern different styles of strategy among companies, which will result in the preference of certain types of innovation projects over other types. Much has been written about strategic styles, and many authors in academia and in the management consulting industry have come up with their lists and descriptions of strategy archetypes that seem to represent patterns of common strategic behavior observed in industry. In a popular example, Pierre Loewe, Peter Williamson, and Robert Chapman Wood (2001) propose the following "five styles of strategy":

> 1. *The Cauldron*. In this style, perhaps the most entrepreneurial and demanding, leaders catalyze the entrepreneurial energy of the entire management team, so the group repeatedly challenges everything about the organization. The team constantly rethinks its business models and rapidly creates new models for both existing and new businesses. This approach results in rapid change throughout the organization.
>
> 2. *The Spiral Staircase*. Here managers innovate so consistently and so often in their existing business that, over time, they repeatedly change its very nature. Just as a circular staircase takes you upward without much changing your latitude or longitude, a Spiral Staircase innovator rises dramatically in its chosen business while seeming to stay in the same place.
>
> 3. *The Fertile Field*. In this approach, managers focus on finding new uses for existing strategic assets and competencies, sowing them across a wide field that extends far beyond the company's existing operations.
>
> 4. *The PacMan*. In this model the company effectively outsources much strategy development and R&D to the marketplace, investing in startups and gobbling up those that prove themselves. Effective PacMan investors are not just gobbling up entrepreneurial startups to enjoy the fruits of their labors, however, but assembling coherent competencies for the future.
>
> 5. *The Explorer*. Here a company sets out work in a big, poorly understood field where it knows it will take labor for many years before seeing profits. It keeps its investments small at first, but achieves its goal through a series of relatively low-cost probes that progressively solve the problems that had prevented the innovation from happening.[293]
>
> (Loewe, Williamson, and Wood 2001, 115–116)

The astute reader may realize that simplifying strategies into a handful of styles or archetypes is just another way of dealing with complexity. None of these styles will be a perfect fit for any company and, therefore, should never be pursued slavishly. But they may, on occasion, provide a helpful framework for discussions, serving to compare and contrast different strategic options.

Portfolio Analysis and Rebalancing

In order to analyze the innovation portfolio, the first step is to make a list of all the relevant initiatives with some basic information about each, such as their start and end dates, their cost in dollar and human resource terms, their classification, and so on. While it seems obvious that organizations should have this information at hand, it is not all that common, and this step often takes a fair amount of effort. How to classify initiatives – whether by product line, business unit or technology – is also harder in practice than it seems in theory. But once the complete list of projects has been compiled and scrubbed so that the data is credible, the next step is usually to depict all the initiatives on a visual chart in a way that can facilitate a high-level strategic conversation. This chart is called the *Portfolio of Innovation Initiatives*, and it is typically constructed as a bubble chart.[xxxvii] This depiction allows a lot of data to be presented in an easy-to-read way that facilitates the portfolio management discussion. Bubble charts are particularly strong at portraying balance and proportionality.

There are many variations of portfolio bubble charts, but this is one of the most common (refer to Figure 8.1). It is easy, however, to change what the parameters depict to give a different perspective on the portfolio. Each initiative is represented by a bubble that has four parameters. The parameters and what they represent are:

- *The X and Y axes, respectively*. Here the X-axis represents the time horizons of expected completion – usually short, medium, and long term – with the exact time frames determined by the nature of the industry (e.g., shorter for CPG and consumer electronics, longer for heavy industry). These horizons are closely related to the three growth horizons (H1, H2, H3) that were introduced in Chapter 1. The Y-axis represents the uncertainty of success (or risk as some would call it) from low to high.[xxxviii] The X and Y axes can also be used to depict other parameters, such as the newness of the technology or market, if that would provide additional insight.
- *The size of the bubbles*. Here the size of the bubbles represents the magnitude of investment so that projects with large budgets have large bubbles and projects with small budgets have small budgets. The size of the bubble can also be used to represent another parameter such as the expected market size or future revenue of the particular innovation.
- *The color or shade of the bubble*. Here the shade is used to identify the business unit for which the innovation is being done. The bubble color can be used to signify other parameters such as product lines, technology types, strategic themes, or geographic focus.

This portfolio analysis tool is just as applicable to the public or nonprofit sector as to the private sector. It is only a matter of selecting the parameters most relevant to a particular agency or nonprofit.

xxxvii Microsoft Excel® has the necessary bubble-chart functionality.

xxxviii Some authors reverse this axis so it runs from high to low, which results in a mirror image reflected off the horizontal.

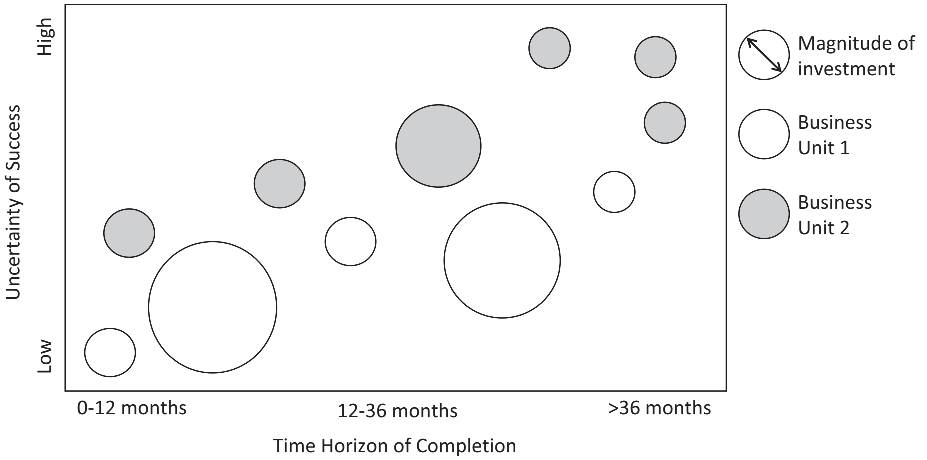

Figure 8.1: An Illustrative Portfolio of Innovation Initiatives.

It is advisable to create multiple types of portfolio bubble charts to provide different perspectives on the composition of the portfolio. The choice of parameters will depend on the company's strategy and where it believes strategic advantage and commercial success can be found through innovation. Different consultants and academic researchers are often proponents of a particular type of portfolio chart that fits their beliefs on how to succeed at innovation. For example, Juliana Mikkola (2001) advocates for constructing an R&D Project Portfolio Matrix with firm competitive advantage on the Y-axis and benefits to the customer on the X-axis, based on the rationale that the best projects ("stars") are those that score high on both attributes.[294] In another example, Bansi Nagji and Geoff Tuff (2012) advocate for an X-axis that represents the newness of the products and assets (from existing to increment to new) and a Y-axis representing the newness of the intended market from existing markets and customers to adjacent markets to new markets yet to be created.[295]

Much can be learned from looking at a portfolio bubble chart. Any such insights obviously need to be complemented and enhanced with other information about the organization's strategy, capabilities, and the details of individual initiatives.

Even without the benefit of any contextual information, much can still be inferred from the illustrative portfolio depicted in Figure 8.1:

– On the face of it, we can tell that the bulk of innovation resources are going to BU1, at least in the short to medium term.
– The bubble closest to the origin signifies a short-term, low-cost incremental innovation (hence the low uncertainty). This is likely being done to do an incremental upgrade to the offering.
– It is followed by a much bigger, but still low uncertainty innovation initiative that will be complete within 12 months. That profile would be consistent with a major new version or model update built with well-established knowhow.

- Another incremental project will follow it in the 12–18-month timeframe but with higher uncertainty, which probably means that some new technologies or processes will be involved.
- The other large BU1 bubble is probably a new generation of product based on some newer technologies, first to be mastered in the smaller project to the left of it.
- At the same time, smaller but higher uncertainty innovation initiatives are being pursued for BU2, with a cluster of three high-uncertainty low-budget projects only expected to yield results in three or more years. That is typical for more exploratory work, which implies that BU2 is the less mature business unit of the two.
- In fact, the chart would be consistent with BU1 being a cash-cow mature business getting most development funds (but for not particularly innovative upgrades to the product line), and BU2 being the smaller business with more potential for growth (but with technology or processes that still have to be mastered by the organization).

If this were a real situation, we would have had the context to know whether these educated guesses were true or not. If not, we would realize that the portfolio did not reflect the intended strategy and the situation and would need to be adjusted.

For reference, more details on the typical nature of the projects found in each of the horizons can be found in Table 8.1.

Table 8.1: Innovation by Growth Horizon.

	H1 Current Core	**H2 Emerging Opportunities**	**H3 Future Down the Road**
Time Horizon (depends on industry cycle time)	Short term (0–12 months)	Medium-term (1–3 years)	Long term (3+ years)
Innovation Type	Incremental innovation	Next generation innovation	Radical innovation
Purpose	Sustain and update current activities	The next evolution of the organization	Define the future of the organization
Uncertainty Level	Low	Medium	High
Operational Model	Core organization, processes & metrics	Adjusted processes & metrics	Exploratory or venture model
Capabilities	Existing	New capabilities that build on current	Completely new capabilities

There is a popular rule that resources (budget) should be distributed between H1, H2, and H3 in a 70:20:10 ratio, meaning that 70 percent should go to H1, 20 percent to H2, and 10 percent to H3. While 70:20:10 is a good reference point, there is no reason why it would be suitable for all organizations.[xxxix] A strategy of investing more in exploration could mean a 60:20:20 portfolio, or a major strategic pivot could necessitate a 50:30:20 portfolio. Ironically, in some organizations that lack a clear strategy, the strategy may be inferred from the portfolio, like we did above when discussing the illustrative portfolio in Figure 8.1. But of course, it is always best to start with laying out the strategy.

Strategy alignment is the most important quality of a good portfolio. But a close second, though often forgotten, quality is *resource sufficiency*. This is the principle that each initiative should be adequately funded and resourced for it to succeed. A portfolio may seem to be perfectly aligned with the strategy in terms of its overall ratios, while several of the initiatives in it may be under-resourced. Depriving projects of sufficient resources because the organization is trying to do too many of them is sometimes referred to as “spreading the peanut butter too thin.” However, there is some evidence that allocating resources to a broader range of innovation projects can raise revenue from new products, with the effect being more pronounced for companies creating novel products that are further from their knowledge core. This is likely because it is better to spread bets under conditions of high uncertainty (see Klingebiel and Rammer 2014).

A third quality is *diversification*, which some authors prefer to call *resource allocation breadth* in the context of IPM. Not all innovation projects or innovations will succeed. Diversification – just like in a portfolio of stock market investments – helps to reduce the overall volatility of the portfolio’s value. In probabilistic terms, diversification only works well when various investments are uncorrelated. In innovation terms, this means that diversification is weakened if several seemingly different innovation projects all rely on the same underlying technology. In a company with multiple business units, the portfolio will also be diversified through the presence of projects from each BU. Care should be taken not to blindly maintain historical ratios between BU innovation resourcing, but to proportionately favor BUs with higher growth potentials, as would hopefully already be reflected in the corporate strategy.

The principle of portfolio diversification has its origins in finance, in particular in the study of the microeconomics of capital markets. While doing his doctoral research at the University of Chicago, Harry Markowitz (1952) had the insight that because the dividend stream from any particular stock is uncertain, the investor had to be concerned with both the expected return and the risk of the stock portfolio as a whole. The risk (i.e., the variance of returns) of the total portfolio can be lowered by populating it with securities of which the dividends are mostly unrelated (i.e., have a low covariance).[296] In 1990, Markowitz was awarded the Nobel Memorial Prize in Economic Sciences for his work in this field. His insight has become a cornerstone of

xxxix Claims that the 70:20:10 rule is universally proven should be treated with great skepticism. It is hard to determine whether companies who might have gained from applying this rule, did so because of the particular ratios, or because they were more deliberate about innovation portfolio management than others.

investment-portfolio theory in the form of the *Capital Asset Pricing Model* (CAPM), and investors are routinely advised to diversify their portfolios of financial securities to reduce volatility.

In summary, the innovation portfolio should always reflect the current strategy, and each initiative in it should be adequately resourced. If not, the portfolio needs to be rebalanced and resources reallocated. The following process steps can be followed to rebalance the innovation portfolio of initiatives.

1. *Take stock:* Find and list all initiatives and projects that comprise the portfolio. Add up the costs and expected value (using whatever metrics are relevant for your organization).
2. *Classify:* Utilize a robust classification rubric that cannot easily be gamed* to classify projects in terms of incremental/adjacent/radical as well as riskiness, growth, or time horizon etc.
3. *Assess:* Determine whether the current portfolio achieves strategic goals and quantify the shortfalls.
4. *Weed:* Terminate zombie projects (i.e., projects that are not making progress and adding no value) and other projects that contribute little to the strategic goals or have a low probability of success. Perhaps the hardest part of this step is to kill seemingly successful projects because they no longer serve the organization's strategic goals.
5. *Reallocate*: Transfer resources to high-priority projects and initiatives.
6. *Check*: Identify any remaining portfolio gaps and ensure the mix reflects the strategy. Ensure all the projects that made it through the reallocation process are adequately resourced. If not, repeat the weed and reallocation steps.
7. *Initiate*: Fund new projects to fill any gaps with strategy not met by existing projects.

   *Proponents of particular projects will naturally try to get their projects classified into a category that is most likely to receive funding. For example, once it becomes clear that radical innovation projects will receive a larger share of the budget, attempts will be made to reclassify incremental innovation projects as radical. The organization needs to establish very clear classification criteria upfront to counter this behavior.

A major portfolio-rebalancing exercise takes substantial time and resources. It is usually not needed more than once a year, unless there is a significant strategic pivot that necessitates it. Depending on the duration of initiatives and the development cycle time of the industry, it may be more practical to do a major rebalancing exercise every other year. However, in between major rebalances, it is advisable to do more frequent lower-effort portfolio checkups to ensure that major misalignments are caught in time.

A persistent allocation and portfolio misalignment problem is that companies do not have portfolio compositions that reflect their strategic intent. This problem is most acute for companies who like to think of themselves as leading-edge (radical) innovators, but do not invest accordingly. Too often, self-styled leading-edge innovators overinvest in incremental-innovation project while underinvesting in radical innovation projects. An overemphasis on incremental projects is problematic for all companies, but particularly costly for companies who pursue a leading-edge strategy.

What proportion of the total portfolio budget should be reallocated during a major portfolio review is an interesting question. One can imagine that too little reallocation will not make enough of a difference, but that too much reallocation may be extremely disruptive. Indeed, research by McKinsey & Company (Chan et al. 2014) found that top-quartile innovators reallocated somewhere between 6 and 30 percent of their portfolios, while bottom-quartile innovators tended to have reallocations below 6 percent.[297] The sweet spot, thus, seems to be higher than 5 percent but lower than 30 percent.

All the projects and initiatives that form part of the portfolio were approved at some point in time, with multiyear projects typically being reapproved annually. If, upon review, the portfolio composition is found to be undesirable, the criteria for such approvals will need to be adjusted too, and in some cases the approval process itself may need to be strengthened. How innovation projects are approved is covered later in this chapter.

Decision-Making Biases

The current innovation portfolio of initiatives (PoI) is the collection of all currently active and approved future innovation projects and initiatives. It includes projects that have been recently approved as well as projects that have been approved a long time ago. It is the aggregate of all decisions made to approve and fund projects, to renew project approvals, and the failure to terminate projects that no longer serve a purpose. Therefore, to manage portfolio decision-making better requires an understanding of organizational decision-making.

The decision-making processes of any individual or organization are prone to multiple types of cognitive biases when making judgments in situations of uncertainty. These biases affect both which projects are initially approved or rejected, and whether projects continue to be part of the portfolio. Due to the pioneering work by Nobel laureates, Daniel Kahneman and Amos Tversky (1979), who created the new field of *behavioral economics,* we now have a much better understanding of cognitive biases that affect decision-making.[298]

The work of Kahneman and Tversky was a direct challenge to the classical assumptions of perfect human rationality in economic behavior, which have often been criticized as unrealistic. Behavioral economics integrates insights from psychology, neuroscience, and microeconomics in an attempt to come up with more realistic assumptions. It established the concept of *bounded rationality* based on the insight that humans take shortcuts that lead to suboptimal decisions. Many human decision-making errors can be traced back to such cognitive biases.

There is, by now, a plethora of named cognitive decision-making biases that can be divided into different categories. For example, see VisualCapitalist (2017) for an extensive listing of cognitive biases.[299] A few of the biases relevant to project and portfolio decision-making are summarized in Table 8.2.

Table 8.2: Some Cognitive Biases That Affect Portfolio Decision-Making.

Cognitive bias	Description of bias	Consequences
Overconfidence bias	Overestimating your own abilities	Underestimation of project cost, time, and execution risk
Sunk-cost fallacy	Inability to admit mistakes	Personal and organizational resistance to terminate failures, resulting in more waste
Confirmation bias	Selecting data that supports your established beliefs	Project estimates (cost/time/risk/value) skewed to belief rather than fact
Recency effect	Heavier reliance on more recent data	Risky estimates based on most recently available data
Anchoring effect	Locking in information available at the time of the decision	Leadership resistance to revision of flawed estimates
Motivational bias	Self-interest and peer pressure distorting judgment	Biased business cases, project selection and approval (hockey stick effect)

In his popular book, *Thinking Fast and Slow*, in which he explains behavioral economics to a general audience, Kahneman (2011) cautions that people assign much higher probabilities to the truth of their opinions than is warranted by facts.[300] Being aware of our potential cognitive biases is the first step in minimizing their deleterious effect on our decision-making. Training decision-makers on probability theory is a good second step. Other mitigation methods are inviting perspectives from different experts and allowing disagreements to surface, attempting to contradict key assumptions, and revising management incentives that may be reinforcing certain biases.

Even after all biases are addressed, mathematically optimizing a complex portfolio is not a trivial task. The number of combinations and permutations of possible projects can be staggering simply in terms of their start and end dates, and the types and amounts of resources to be allocated to them. Analyzing all potential portfolios and finding the optimal one that best matches the organization's strategic goals (e.g., revenues from new launches in a particular year) can require computations of enormous complexity that exceed the capabilities of spreadsheet applications. Fortunately, there are tailormade analytics solutions available for this purpose from specialist software developers such as Decision Lens. Due to the complexity of their portfolios, government agencies have also been looking at adopting algorithmic portfolio optimization methods; for example, see Mun (2020).[301] A further discussion of this advanced aspect of portfolio management is beyond the scope of this text.

One last aspect of innovation portfolio management that should be mentioned is the practice of estimating and aggregating the expected value of all projects in the portfolio, resulting in a single dollar figure of *expected portfolio value*. This practice is common for companies in the pharmaceutical or natural resources industries, but less so for companies in other industries. (For a discussion of R&D portfolio valuation in the pharmaceutical industry, see Girotra, Terwiesch, and Ulrich 2007.[302]) For companies seeking to maximize the expected values of their portfolios, that metric becomes a KPI of the quality of their portfolio as well as their portfolio management.

Project Selection

Innovation projects got into the portfolio because they were originally selected as new projects to pursue, and they presumably went through some sort of screening process to be approved. This means that a proper new project selection process that weeds out undesirable projects before they start is an essential component of an effective portfolio management regime.

A popular metric for the total value that a project is expected to contribute is Net Present Value (NPV), defined as the total of all discounted cash flows (negative and positive) arising from a project over its life. NPV incorporates investments and expenditures along with future expected profits in a single value in today's dollars which is arrived at by discounting values from future years with the weighted cost of capital. NPVs are, however, only meaningful if a project is far enough along to make accurate estimates for all these cash flows.

NPVs will be extremely unreliable for earlier-stage projects, or opportunities involving new technologies or markets, when any financial estimates are subject to large potential errors due to the high degree of uncertainty involved. NPVs are best not used at all to screen such opportunities or for R&D projects that have these characteristics. For that reason, most projects are best selected based on scoring models where potential projects are graded in a hybrid qualitative-quantitative scoring model, which takes into account multiple variables that are considered to be indicative of future value to the company. Each variable is typically scored using a numerical scale (say 1–5 or 1–10) that assigns a value based on a match with a description associated with each point on the scale.

Weights also need to be allocated to each of the variables (criteria) used to incorporate their relative importance. The maximum aggregate score obtained by multiplying each weight with the maximum possible score obtainable on the scale and adding these scores should ideally be a round number like 100. For example, if variables can be assigned a value between 1 and 10, then the weights for all the variables should add up to 10 to result in a maximum aggregate score out of 100.

This illustrative *six-factor scoring model* by Cooper, Edgett, and Kleinschmidt (2001)[303] illustrates factors that are often considered for project selection.

The model contains a fairly typical set of criteria found in such models:

Strategic Alignment:
- Degree to which project aligns with our strategy
- Strategic importance

Product/Competitive Advantage:
- Offers customers/users unique benefits
- Meets customer needs better
- Provides value for money for the customer/user

Market Attractiveness:
- Market size
- Market growth rate
- Competitive intensity in the market (high = low score)

Synergies (Leverages Our Core Competencies):
- Marketing synergies
- Technological synergies
- Operations/manufacturing synergies

Technical Feasibility:
- Size of technical gap (large = low score)
- Technical complexity (barriers to overcome) (many/high = low score)
- Degree of technical uncertainty (high = low score)

Risk versus Return:
- Expected profitability (magnitude: NPV)
- Return on investment (IRR)[xl]
- Payback period (years; many = low score)
- Certainty of return/profit estimates
- Low cost & fast to do

Each of the six factors would be assigned a number between 1 and 10 at review meetings to yield a total "Project Attractiveness Score" out 60. (Minimums can be assigned per factor as well as well.)

This process facilitates head-to-head comparisons of projects with totally different profiles without having to resort to a single financial metric such as NPV.

xl Internal rate of return, that is, a method of calculating an investment's financial rate of return.

While scorecard models are intended to have built-in flexibility to score projects with different scope from one another, a one-size-fits-all scorecard is seldom feasible. There may have to be a handful of different scorecard types that correspond with very different types of projects. This is an approach also advocated by Cooper and Edgett (2006), who suggest using different scorecards for difference classes of projects, such as new product, platforms and technology developments, improvements, modifications, and extensions, and customer requests.[304]

A crucially important element in project selection is the process followed to make these determinations within the organizational context. This is covered in the upcoming section on project management.

Innovation Project Management

At the beginning of this chapter, it was assumed that the reader is familiar with at least the basics of project management. The details of project management – which is a comprehensive discipline on its own – are out of scope for this book. This section is, therefore, limited to briefly pointing out some distinctive characteristics of innovation projects and the challenges of managing projects that contain a substantial amount of innovation activity.

It is entirely possible for a well-conceived innovation to fail due to execution problems. One of the most perplexing aspects of innovation failures is to determine whether they were the result of a good concept poorly executed or, alternatively, of a bad concept that, no matter how well it was executed, was always destined to fail. What the exact proportion is between these alternative explanations of failure is impossible to know with hindsight, but it can be safely assumed that a fair share of innovation projects would not have failed had they only been better managed. It is, therefore, important that innovation managers are well versed in the fundamentals of project management.

For the innovation project manager who wants to learn more, there are many good resources on project management available. The reader should consult those resources – some of which are listed at the end of this chapter – for further information.

The Project Management Institute (PMI) is the foremost proponent of project management as a discipline. It has over 600,000 members and 300 chapters worldwide.[305] PMI offers various project management certifications of which the PMP® (Project Management Professional) is its signature certification. PMI's foundational publication is the authoritative *A Guide to the Project Management Body of Knowledge* (2021), or *PMBOK® Guide* (2021) for short, which has been updated and extended (e.g., to cover software projects and agile techniques) from time to time and is in its seventh edition at the time of writing.[306]

Innovation project management, sometimes also referred to as new product development (NPD), is a well-trodden terrain its own right. Multiple publications and professional organizations make it their business to stay on top of the latest developments, set standards, and be a home for NPD professionals and practitioners.

The Product Development and Management Association (PDMA) is the main organization in the field of NPD. While it has expanded its scope to innovation more generally, it retains its original focus on product development and product management. PDMA publishes numerous publications on the topic of NPD and offers the New Product Development Professional (NPDP) certification to practitioners. PDMA also publishes the academic *Journal of Product Innovation*. The NPD equivalent of the PMBOK® is the *NPDP Certification Body of Knowledge* (BOK), currently in its second edition (PDMA 2020). It includes in-depth coverage of the product innovation process, product design & development tools, market research in product innovation, and product innovation management.[307] PDMA has extended its coverage to new topics and techniques such as design thinking.

In essence, project planning requires breaking down a project into all its constituent tasks with well-defined final as well as interim milestones to achieve. This is called a *Work Breakdown Structure* (WBS) and can be depicted by a tree with multiple branches. There are usually multiple levels of tasks. For example, building a new house starts with laying a foundation, framing the structure, and then running the plumbing lines, electrical wires, and ventilation ducts. Each of these can be broken down into many subtasks to be performed by different types of tradespeople. A more descriptive *Statement of Work* (SOW) typically accompanies the WBS and is usually included in contracts together with the WBS. Each task must be assigned a duration as well as a resource requirement; for example, "2 test engineers for 3 days."

Most tasks need to be performed in a sequence since many are dependent on the completion of others; for example, a house cannot be framed if the foundation has not yet been laid. Other tasks may be performed at the same time; for example, running the electric wires and plumbing pipes in the new house can be done together once the framing is finished. Understanding these dependencies is a very important part of good project management, particularly because not all task dependencies are always that obvious. If a dependency is missed during the planning stage, it can cause major delays later when work on the next tasks needs to stop to first allow it to be completed.

A *milestone* is always assigned a single point in time; that is, it has only one date associated with it. A task, as previously explained, always has duration, which means it has both a start date and an end date. Viewing project tasks and milestones against the timeline over which they are meant to be accomplished can be done by means of a Gantt chart[xli] – with horizontal bars for tasks and triangles for milestones. Lower-level tasks can be nested within higher-level tasks. All project management software tools (see below) provide this functionality, but a basic Gantt chart can easily be constructed using spreadsheet software.

xli The chart was invented as a production control tool in 1917 by Henry L. Gantt.

The *critical path* is the longest sequence of dependent tasks that must be finished on time to complete the entire project from beginning to end. A Gantt chart has the drawback that it can only be used to determine the critical path for a relatively simple project with only a few tasks and dependencies. On the Gantt chart, tasks that are dependent on the completion of others can be connected by lines and arranged to reflect these dependencies. This gets impractical and then impossible when the tasks increase to dozens and then hundreds, with multiple different types of dependencies.

The *Critical Path Method* (CPM) entails depicting tasks diagrammatically with connectors between them to indicate dependencies going forward. That makes it easy to show that one task is dependent on the completion of two or more other tasks. For any one task, the early start (ES) is the earliest date at which it can start given the tasks that precede it and their interconnections, and the early finish (ES) is the earliest date on which it can be finished. The late start (LS) is the latest an activity can start, and the late finish (LF) is the latest an activity can finish without delaying completion of the project. The *Program Evaluation and Review Technique* (PERT) is a similar method to CPM, pioneered by the U.S. Navy in the 1950s to deliver the Polaris submarine (a highly complex project) on time. The newer *Dynamic Progress Method* (DPM) uses simulation techniques that exploit modern computing power to overcome some of the drawbacks of CPM/PERT plans, which rely on overly simplistic assumptions. For example, in DPM, a task duration would be estimated by simulation based on parameters such as actual resource productivity rather than taken simply as a given input (White and Sholtes 2011).[308] An in-depth overview of DPM and other advanced project-optimization techniques is beyond the scope of this text.

The status of any task can be that it is not started, is fully completed, or is partially completed. This is expressed by a simple metric called *percentage completion*. The *earned value* (EV) of work done is a more sophisticated metric that gauges progress based on what proportion of the *budget at completion* (BAC), or *planned value* (PV) for a project has been realized. Putting completion status in dollars terms allow different cost variances to be calculated and analyzed. For instance, if a construction project is only 40 percent complete after 50 percent of the budget has already been spent, it will be highlighted by such an analysis, which is beyond the scope of this text but well covered in the project and cost accounting literature.

Many software vendors provide Project and Portfolio Management (PPM) solutions. Microsoft Project® is probably the best known and fairly easy to learn for most because of its familiarity to MS Office users. Then there are large enterprise solutions that are very powerful but require significantly more financial investment, and more time and effort to master. Examples of these are Primavera (by Oracle) and Planview. Lastly, there is the latest generation of SaaS solutions that pride themselves on their flexibility and quick learning curve. Examples of these are Smartsheet, Teamwork Projects, and Zoho. The latter category offers a range of PPM functionality from basic to sophisticated; the solutions with more basic

PPM functionality typically being Swiss-Army-knife type business solutions that include some non-PPM functionality along with basic PPM functionality.

Typical Innovation Project Management Pitfalls

"No battle plan survives first contact with the enemy," is a military saying[xlii] that entered business use to express the common observation that even the best-laid plans are imperfect and will need corrections and frequent adaptions after a project has started or customer feedback has been received.

There is also an adage in project management that out of the triangle of *performance, timeline*, and *cost*, you can only get two out of three. One of the three always has to be sacrificed, or at least subordinated, for the other two. If you fix performance and delivery timeline, there is no telling what the project would cost. If you fix the cost and the delivery time, there is no telling what performance you will get. And if you fix performance and cost, there is no telling how long it will take. Though imprecise, this adage reflects the pressures that uncertainty places on project execution.

The most common complaint with innovation projects (and other types of projects) is that they run late (i.e., behind schedule) and over budget. There are many reasons why an innovation project may be running late, and several of these may also contribute to overspending. Common root causes are:

- The project did not start on time, or it started but was under resourced for a stretch of time at the beginning with key staff joining late after being released from their previous assignments.
- Key resources were overcommitted, sharing too much of their time with other projects and being distracted by other responsibilities.
- The plan was always overoptimistic – tasks were allocated insufficient time to be completed and/or were under resourced as a result.
- There was a backlog for using the necessary facilities; for example, manufacturing or testing facilities.
- The technology was immature or harder to integrate than expected.
- The technical specification kept changing.
- It was harder than expected to scale up the product or service prior to its launch.
- External vendors or other stakeholders did not deliver or respond on time.

xlii It is a condensation of an observation originally made in 1871 by Prussian Field Marshal Helmuth von Moltke.

Senior executives may underestimate their own role in causing project delays. They are usually under the impression that they make the necessary management decisions more quickly than they actually do. But they forget that their limited availability results in them only engaging fully in a matter of days or even weeks after an issue arose that needed a decision, which means the decision is overdue by the time they are presented with it.

Doing project plans at a high level of detail, with highly granular task breakdowns and corresponding resource assignments, may seem like the most diligent approach. However, an overly detailed plan is more likely to be wrong as a whole, and is also prone to overestimating the work required. For example, a particular task may reasonably be estimated to take 10 days to complete. However, when it is broken down into four consecutive subtasks, an overcautious team may allocate 3 days each to those 4 subtasks, unnecessarily prolonging the task from 10 to 12 days. This type of planning also discourages the transfer of time savings made in one area of the project to another part of the project. The same is true for overdetailed resource allocation, which could discourage team members from helping one another when their own tasks are done.

In large organizations conducting many projects at the same time, total resource needs aggregated across all projects may show a huge hump at the present time and into the immediate future, with a sharp decline subsequently. For instance, in an organization with 100 engineers, the current demand may show as 150 engineers but three months out, only as 50 engineers. Early in my career, I once had an exasperated engineering executive remark on such a resource forecast: "I am not sure whether to hire or fire engineers!" The explanation for this anomaly is that in the present and near term there is an over-demand for personnel because several projects are running behind schedule or in danger of doing so, and the work that must be done is now well-understood, if overwhelming. Yet, three to six months out, the work has not been planned to that level of detail yet, and not all future projects are visible yet. That results in not all the resource needs being loaded in the system for the period farther out.

There is always a question as to what level of detail resources should be allocated to tasks. At one extreme, each task would have a precise resource need associated with it; for example, 0.5 (half) of a product designer for 3 days. On the other extreme, no human resource needs would be loaded against tasks, but the full innovation team would be assigned and expected to get all the work done. The former is typical for large complex organizations with multiple functional departments where project resources have to be internally contracted from their home functions; the latter is typical for a startup or a skunkworks type of environment with a small, dedicated team.

There are pros and cons to each model. The former helps functional departments plan how to assign their resources to projects and make sure the necessary staffing is available at the right times, but the complexity makes it hard to handle and the true resource demand is always going to diverge from the plan anyway.

The latter provides maximum flexibility but assumes that resources are fungible and can fluidly move across multiple tasks when they may not be. Usually, organizations pick some midway point between the two extremes; for instance, allocating resource needs using averages by month of the project. But that brings a new drawback, which is that persons assigned to a project for a particular month may either be over or underworked. There is no perfect resource-planning methodology, and the innovation project manager needs to be deliberate yet flexible at the same time, keeping tabs on what all the assigned resources are doing all the time, while being ready to rapidly adapt to new needs at hand. Successful innovation project managers also know how to maintain good relationships with the managers of the functional departments from which their team members come.

When task-completion percentage is tracked, innovation project managers should watch out for what I call the *80-percent-completion trap*. This happens when task completion is updated linearly every week from 0 to 80 percent, up to a point where it inexplicably gets stuck at 80 percent. This is an unwelcome surprise for the innovation project manager, who thought everything was proceeding to plan. The explanation for tasks getting stuck on 80 percent is overoptimistic progress reporting earlier on, together with an underestimation of what it will take to complete the hardest part of the task, which people are tempted to leave until the last. For example, a programmer may write a piece of software and report progress based on the number of lines of code written, but then find that the software does not function as intended and get stuck in a loop of debugging and rewriting the software. The 80-percent-completion trap can be avoided by asking more thoughtful questions on progress throughout, resisting the temptation to only gauge percentage completion based on work effort expended, and frontloading the hardest parts of the task wherever technically possible.

The Origin and Persistence of the Stage Gate® Model

While the term Stage-Gate® is in widespread use and considered to be generic, it is a registered trademark of Stage-Gate Inc.,[309] a company founded by Scott Edgett and Robert Cooper. Both were formerly professors at McMaster University in Canada. Cooper and Edgett popularized the idea of managing innovation projects in well-defined stages, with clearly demarcated gates that control advancement from one stage to the next. Both, but Cooper in particular, have been prolific authors on the topic of innovation management. Cooper (1990) originally proposed the Stage-Gate® Systems as a better, more organized way of managing new products in an article over three decades ago.[310] He presented his system as a solution to the problem that product firms were facing in reducing cycle time (i.e., time from the beginning of an NPD project to product launch) and increasing the success rate of new products.

Cooper used the metaphor of a production line with quality checks at each of the handoffs between work stages to argue that development should also be managed that way. In this sense, Cooper's system is the natural extension of Taylorism (see Chapter 4), from manufacturing to project management. Cooper also sold the process as a risk management process because he recognized that each successive stage of development is usually more expensive that the one preceding it, but that information becomes more readily available as the project advances. By controlling the entrance to the next stage at the gate, costly mistakes can, therefore, be avoided as long as the right criteria are applied. The gate in practice is a cross-functional meeting of all major internal stakeholders represented by senior managers known as *gatekeepers*. The input to the meeting is an assessment of the project from both a business and technical perspective, typically using a checklist of questions to be answered, which will vary by gate and stage. Cooper proposed a "Go/Kill/Hold/Recycle" decision as the output of the meeting.

A simple innovation process with four stages and five approval gates are shown in Figure 8.2.

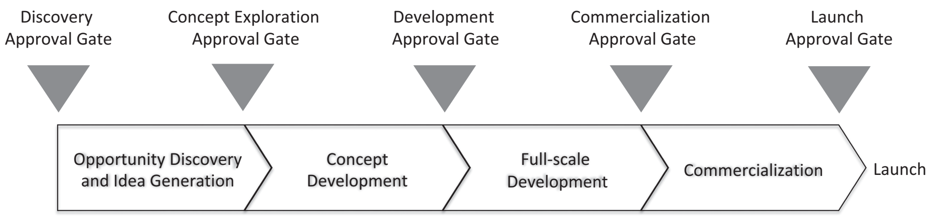

Figure 8.2: Illustrative Innovation Stages with Approval Gates.

In practice, companies typically have between four and seven stages. Usually, organizations also conduct one or more *Post-Implementation Reviews* to assess what went well and what did not, and to feed back what they have learned into lessons for the next project.

Formal stage-gate controls have been criticized for restricting learning during new product development, thereby depressing innovation. For example, a study by Rajesh Sethic and Zafar Iqbal (2008) found that strictly enforced evaluation criteria to maintain tight control over projects was associated with inflexibility, which led to learning failures. Learning failures, in turn, adversely affected the market performance of new products. This effect was particularly pronounced when firms operated in turbulent technological environments.[311] In other words, this model is not suitable for situations of high technological uncertainty. In contrast, the Lean Startup model is appropriate for high uncertainty and gives learning a prominent place through its Build-Measure-Learn approach (see Chapter 6).

Another concern is that the emphasis on reducing uncertainty associated with the stage-gate process may result in projects that could have succeeded getting killed. A study by Van Oorschot et al. (2010) found some evidence for this notion, but the authors concluded that relaxation of initial investment constraints can mitigate this risk. They also suggested that an initial focus on building the team rather than containing project running costs would be beneficial.[312]

In recent years, the popularity of agile methods (see Chapter 4), which spread from the software industry to other industries, has led Cooper to update his gate-based system into a hybrid model that can also be used in manufacturing, not just for software. Cooper's *Agile-Stage-Gate* hybrid model keeps the linear, consecutive ideation-to-launch stages from the original Stage-Gate® model, but inserts agile working methods within some or most of the Stage-Gate stages. Each hybrid stage is composed of consecutive time-boxed sprints (as per the agile method) that last a few weeks, each with a tangible result being the output of each sprint (Cooper and Sommer 2018).[313] The adaptivity added to the stage-and-gate system allows product development to begin even when it is not fully defined, and the product definition is then itself developed as part of the development process, comprising a number of iterative cycles that each include build, test, feedback, and revision steps (Cooper 2017).[314]

The popularity of open innovation has similarly led to proposals for the more formal integration of open innovation activities inside the stage-gate process. This entails adding appropriate open-innovation evaluation criteria into every gate review, and supplementing traditional activities in each stage with both inbound and outbound open-innovation activities that are appropriate for that stage. For example, ideas from inventors and startups can enrich the company's own during the definition stage while different models, such as out-licensing or selling technologies, can be considered during the commercialization stage (Grönlund, Sjodin, and Frishammar 2010).[315]

U.S. DOD Acquisition Phases

Cooper may have encoded and popularized the concept of an innovation project that is executed in consecutive phases with a review point (gate) separating each phase. However, this concept has much older origins in the field of military systems engineering, particularly as defined by the U.S. Department of Defense (DOD) in the 1970s and 1980s. For example, MIL-STD-1521 (1985), originally issued in 1975, (subsequently updated and superseded) outlines 10 reviews that could be performed on the development path of a system (U.S. Department of Defense 1985).[316] The first was the *System Requirements Review* (SRR) during concept exploration to make sure the system would meet operational requirements and to approve a preliminary program plan; the *System Design Review* (SDR) was held to check that the system under development was both adequate and cost effective to meet operational requirements (the analog of a technical and business review); the *Critical Design Review* (CDR) was conducted before releasing the design for fabrication, production, or coding (as the case may be for hardware or software) to ensure that the detailed product specification met the original requirements and that the system design was mature enough to be built, and so on.

The current standard for technical reviews and audits to be performed throughout the acquisition life cycle for the U.S. DOD and other defense agencies is administered by the IEEE Standards Association and titled *IEEE 15288.2-2014 – IEEE Standard for Technical Reviews and Audits on Defense Programs* (IEEE 2015).[317]

The current international standard for systems engineering is ISO/IEC/IEEE 15288:2015 – *Systems and Software Engineering – System Life Cycle Processes* (ISO 2015).[318] It describes the lifecycle of systems created by humans and sets out the processes for managing the system life cycle.

MITRE, a not-for-profit sponsored by the U.S. government that operates several federally funded research and development centers (FFRDCs), provides an online *Systems Engineering Guide* (MITRE 2022) that also reviews the history and evolution of systems engineering.[319]

U.S. DOD Instruction 5000.85 (2020, 10), titled *Major Capability Acquisition*, lays out the currently recognized phases, milestones and major decision points for large acquisition projects, as can be seen in Figure 8.3.[320]

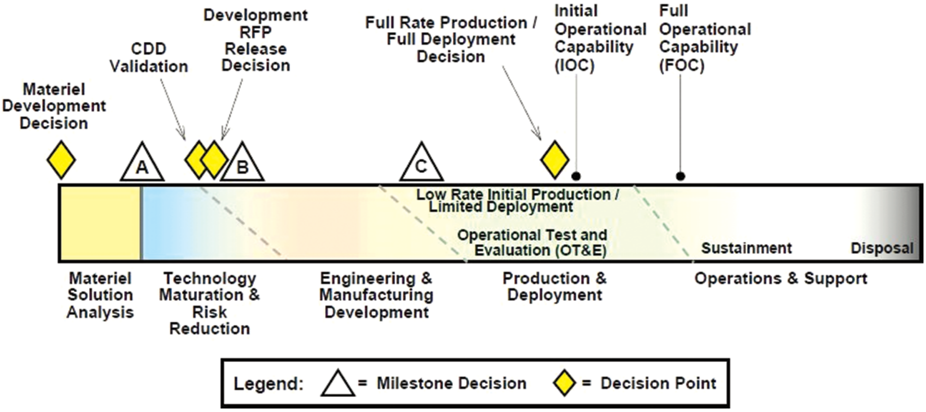

Figure 8.3: U.S. Department of Defense Acquisition Phases.
Source: DOD Instruction 5000.85 Major Capability Acquisition (2020), U.S. Department of Defense.

The major decision points (analogous to Cooper's gates) are depicted by the various triangle or diamond symbols. There are five major phases, from Material Solution Analysis to Operations and Support.

Chapter Summary

- Innovation systems are complex systems because they have emergent properties that occur at higher levels, but which are not present at lower levels. Human brains cannot manage complexity without using special techniques and frameworks.
- Innovation portfolio management is a dynamic decision-making process, subject to uncertainty, whereby an organization's collection of innovation projects is constantly updated and revised.
- The innovation portfolio must reflect the current innovation strategy of the organization. If not, it should be updated and rebalanced. The portfolio of initiatives can be visually represented by a bubble chart where the parameters of the chart are selected to reflect the most important strategic dimensions.
- The portfolio decision-making process is particularly susceptible to cognitive biases. Understanding and mitigating the most common biases will improve the quality of the decision-making process and thereby, the quality of the portfolio.
- When selecting and approving innovation projects, it is best to use holistic scoring models that take into account multiple variables that are indicative of the future value to the company.
- Innovation project management is based on standard project management principles but is subject to several pitfalls due to the more uncertain nature of innovation projects.
- Some form of stage-gate® model – a sequential, linear, multi-stage development path with decision-making gates between stages – is widely used for innovation projects in both the private and public sector. However, the model does not work well under conditions of high uncertainty where the Lean Start-up model should be preferred.

Suggested Exercises and Assignments

- Make a rough estimate of how the innovation portfolio of a selected company or agency is divided between H1, H2, and H3 projects. Compare this portfolio composition with the stated mission and/or strategy of the organization. Discuss whether and how the portfolio needs to be rebalanced to align with the strategy.

- Which cognitive biases or distortions underpin typical roadblocks to approving radical innovation projects in government? Recommend concrete actions for mitigating these biases.
- Do a high-level analysis of a few recently completed projects from a selected organization. Consider whether there is a pattern of common issues (e.g., late completion, overspending) between these projects. Discuss what the root causes are for these issues and what changes to project selection and management are needed to avoid their recurrence on future projects

Recommended Further Reading

Cooper, Robert G., Scott J. Edgett, and Elko J. Kleinschmidt. 1998. *Portfolio Management for New Products*. Reading, MA: Addison-Wesley.

Kerzner, Harold. 2017. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 12th Edition*. Chichester, West Sussex, UK: Wiley.

Project Management Institute (PMI). 2021. *The Standard for Project Management and a Guide to the Project Management Body of Knowledge (PMBOK® Guide), 7th Edition*. Newtown Square, PA: Project Management Institute, Inc.

Chapter 9
Private Financing of Innovation

Innovation projects need resources, and therefore financing, if they are to yield their intended value. In established organizations, innovation projects must meet specific criteria to proceed and use the organization's resources. The typical approval phases for that were discussed in the previous chapter.

This chapter focusses mostly on the private financing of innovation in the form of new ventures, in particular startups, but the principles of venture financing amidst uncertainty that are introduced in this chapter have much wider applicability. (The financing of innovation projects in established corporations is assumed to form part of the project approval and portfolio decision processes described in Chapter 8 while the public financing of innovation will be covered in Chapter 10.)

Startups are new organizations created to develop and bring innovations (usually one initially) to market. Startups at inception do not have existing resources and capital to draw on. They have to be explicitly funded at each step of the way. However, there is significant uncertainty about the innovation outcome, and the trial-and-error nature of the innovation process will inevitably lead to some waste. This requires suitable finance models and investors (private or public) who are tolerant of uncertain outcomes and waste.

The chapter will, accordingly, start with a Schumpeterian perspective on entrepreneurial waste. This will be followed by a deeper discussion of the nature of uncertainty (a subtheme throughout this book). The major types of uncertainty that affect innovation will be defined, and their investment implications explained.

The main venture capital (VC) stages and terms will be introduced, followed by an overview of recent trends in venture financing. The funding landscape will be completed with an overview of the main funding sources other than venture capital. The evolution of VC funding and concerns about its industry concentration, lack of diversity, and potential judgment biases are discussed. The chapter concludes with a brief overview of corporate venture financing.

Innovation, Entrepreneurs, and Waste

Because of the risks and uncertainties inherent in the process of innovation, waste is unavoidable, both waste in terms of financial resources (funds) invested, and waste in terms of the opportunity costs of scarce resources that could have been deployed on a perhaps more successful venture. Waste is the price we pay for learning and for reducing uncertainty during the innovation and research processes.

The willingness to finance potentially (and even probably) wasteful ventures is a crucial building block of an economic system favorable to innovation. Schumpeter

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recognized that the *financing* of innovation is just as much a critical part of the capitalist economy as innovation itself. In fact, Schumpeter (1939) made it explicit in his own definition of capitalism:

> We have to define that word which good economists always try to avoid: capitalism is that form of private property economy in which innovations are carried out by means of borrowed money. Most of the features . . . of capitalism would be absent from the economic and . . . cultural process of a society without credit creation.[321] (Schumpeter 1939, 223)

Financiers, of course, are profit-seekers themselves and will only lend or invest money under the expectation that they will make it a return on it commensurate with the risk of the borrower defaulting. Unlike bank lenders, venture capitalists are willing to write off the money invested in a majority of their investments as long as a small number of those investments make up for it by yielding them spectacular returns. Schumpeter seemed to anticipate this arrangement between the entrepreneur and the venture capitalist when he wrote:

> Risk bearing is no part of the entrepreneurial function. It is the capitalist who bears the risk. The entrepreneur does so only to the extent to which, besides being an entrepreneur, he is also a capitalist but qua entrepreneur he loses other people's money.[322] (Schumpeter 1939, 255)

That the entrepreneur loses other people's money is equally true whether the entrepreneur is heading up a startup, an executive in a large corporation, or a manager in a government agency. In the case of the startup, the person's money being lost may be a venture capitalist or angel investor, and in the case of the corporation, it is the shareholders' money. (Schumpeter predicted an end state of capitalism in which most innovation would be performed inside large corporations.) In the case of a public-sector entrepreneur, any money lost on a failed venture is to the account of the taxpayer.

Both R&D and product innovation are inherently wasteful processes because success is never guaranteed. This creates the all-important question of who should be paying for these activities at each stage of the process. And so, the assessment of the risk and uncertainty of such endeavors is inextricably connected to the type of financing they will receive. Neither of these activities can be collateralized like other business investments for which financing is sought. For example, farming is also a risky activity, but at least a farm purchase can be financed with a mortgage using the farm as collateral; and the same is true for a factory. R&D and innovation cannot be collateralized because they have so little residual value when not successful, unlike a farm or piece of capital equipment.

An understanding of the path of scientific progress all the way up to commercial innovation is needed for categorizing and assessing the different kinds of risks and uncertainties along the way. The roles played by the public sector and private sector actors, such as venture capitalists, in funding innovation along each step of the way will depend on this assessment. As will be shown, the highest level of risk and uncertainty, including that which is wholly unknowable, is often financeable only by the state because no rational private-sector entity would be willing to underwrite it. This brings about an interplay between public and private financing, which has brought us the technological and industrial revolutions driven by transformative information and communication technologies introduced over the last few decades.

A Typology of Uncertainty

Investing financial and other scarce resources in a venture with a future that is not predetermined is at the very heart of entrepreneurial activity. But the terminology we use to describe the extent to which any particular future outcome may be different from our expectations is important if we are to gain a better understanding of our exposure to a failed investment or venture. Precision of language matters here as our course of action – whether private or public – is strongly influenced by our framing of the challenge at hand. In fact, the respective roles of the public versus the private sector in financing innovation may well depend on an assessment of the levels of risk and uncertainty that applies to each particular area of research, development, and technological innovation.

The early 20th century American economist Frank Knight offered a useful distinction between *risk* and *uncertainty*:

> The practical difference between the two categories, risk and uncertainty, is that in the former the distribution of the outcome in a group of instances is known . . . . While in the case of uncertainty that is not true, the reason being in general that it is impossible to form a group of instances, because the situation dealt with is in a high degree unique.[323]

Thus, *risk* is both measurable and quantifiable with a known probability distribution of outcomes like the outcome of a turn of a roulette wheel, actuarial mortality in a population group, or credit default risk for a particular debt instrument. Knowledgeable private actors are well equipped to handle such risks. However, *uncertainty* can neither be measured nor quantified. Uncertainty is, therefore, best handled at the highest collective level, which is that of the nation state. Uncertainty could imply adverse outcomes, such as a town being wiped out by a natural disaster; or it could be a highly beneficial event, like a medical or other breakthrough, such as finding a cure for cancer, or discovering antigravity that allows vehicles to float like they do in sci-fi movies. Big scientific discoveries are often made serendipitously, which fits the definition of uncertainty. The return for an investment in such discoveries is simply too uncertain for private-sector investors intent on making a profit. Knight's definition of uncertainty is called *Knightian uncertainty* by some economists.

In Knight's view, entrepreneurs have to face uncertain outcomes. In that sense, so-called entrepreneurial risk – the risks that entrepreneurs take with their time, career, and funds – is better classified as an uncertain venture, rather than a risky venture.

More recently, Harvard economist Richard Zeckhauser (2006) built on Knight's definitions of risk and uncertainty, but added a third concept, *ignorance*, to the far end of the spectrum, which starts with certainty (omitted below) followed by *risk* and *uncertainty*, and then by *ignorance*. Ignorance is when we cannot even fathom what the future states of the world may be: "The identity of possible future states of the world as well as their probabilities are unknown and unknowable" (Zeckhauser 2006, 2).[324]

Thus, Zeckhauser's typology of risk shown in Table 9.1 recognizes three different investment environments that map to three different types of knowledge of the future states of the world. The first, "risk," is where the probabilities are known, and the distributions of returns are known too. The second, "uncertainty", is where the probabilities of future states are unknown even though the states can be defined, and the distributions of returns can at least be conjectured. The third, "ignorance," is where the future states of the world themselves are unknown, and distributions can only be guessed. The latter is reminiscent of former U.S. Secretary of Defense, Donald Rumsfeld's infamous phrase "unknown unknowns" when describing the situation during the leadup to the second Iraq war (Rumsfeld 2002).[325]

Table 9.1: Zeckhauser's Escalating Challenges to Effective Investing.

	Knowledge of the states of the world	Investment environment	Skills needed
Risk	Probabilities known	Distributions of returns known	Portfolio optimization
Uncertainty	Probabilities unknown	Distributions of returns conjectured	Portfolio optimization Decision theory
Ignorance*	States of the world unknown	Distributions of returns conjectured, often from deductions about other's behavior. Complementary skills often rewarded alongside investment	Portfolio optimization Decision theory Complementary skills (ideal) Strategic inference

Source: Adapted from Zeckhauser (2006)[326]
*What Zeckhauser called ignorance, several other authors prefer to call *radical uncertainty*. Admitting ignorance is hard, and radical uncertainty seems to be the preferred euphemism for ignorance.

Regardless of what it is called, radical uncertainty presents unique challenges if looked at from a downside perspective. But it also offers unique opportunities if looked at from an upside perspective – sometimes innovations can exceed the wildest expectations of their originators.

In a paper summarizing the argument for his seminal *General Theory* (Keynes 1936),[327] the famous economist John Maynard Keynes (1937) offered this often-quoted definition of uncertainty:

> By "uncertain" knowledge . . . I do not mean merely to distinguish what is known from what is merely probable . . . . The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence, or the obsolescence of a new invention, or the position of private wealth owners in the social system in 1970. About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know.[328] (Keynes 1937, 213–214)

Keynes's concept of uncertainty about future states, as expressed in his *General Theory*, is consistent with Knight's to a degree, but also seems close to Zeckhauser's concept of ignorance. Perhaps Keynes tried to straddle both Zeckhauser's concepts of uncertainty and ignorance (radical uncertainty). To be consistent, Zeckhauser's definitions will be used from here on, but ignorance will be called *radical uncertainty*. The three states are thus: risk, uncertainty, and radical uncertainty, as defined in Table 9.1.

There is another dimension to uncertainty, and that is the time horizon over which it is operative. Jose Maria Barrero, Nicholas Bloom, and Ian Wright (2016) surveyed over 4,000 firms to examine the effects of long-run uncertainty versus short-run uncertainty. They found that R&D and investment are more sensitive to long-run uncertainty, suggesting that long-run policy uncertainty will be most damaging to economic growth by reducing R&D and investment.[329]

When discussing creativity in Chapter 4, it was explained that there is a deep underlying unease in organizations with the uncertainty associated with creativity, even as lip service is dutifully paid to creativity and innovation. People either avoid uncertainty altogether or they downplay its potential impact, with the consequence that they are not prepared for uncertainty's negative consequences, nor for exploiting the upside opportunities it may bring. The widely used stage-and-gate model of sequenced development (see Chapter 8) fails under conditions of extreme uncertainty, such as when the technology and the market are unproven. The model's Achilles heel is allowing the accumulation of large costs prior to adequately resolving major uncertainties. In contrast, more flexible innovation techniques, such as the Lean Startup (see Chapter 6), tackle radical uncertainty head on, and are therefore more suitable when innovating under conditions of high or radical uncertainty.

In a startup environment, it is acknowledged (almost expected) that the first innovation attempt is likely to fail and that multiple pivots will be needed. Successful startups manage to pivot to a viable offering before they run out of money. Startups that fail run out of money before they can pivot to a viable offering. This fact inextricably links the management of innovation uncertainty to the financing method of innovation.

On the one hand, the innovation process has to be improved and accelerated (mainly through early and fast experimentation) to yield a viable offering before running out of money. On the other hand, it is crucially important for the innovator to have sufficient cash on hand to finance the innovation through multiple pivot points. Bill Janeway, who has had a productive dual career as a venture capitalist and academic, makes the salient point that "access to cash in case of crisis is the only hedge against ontological uncertainty" (Janeway 2018, 77).[330] And so, early experimentation and sufficient funds to sustain the trial-and-error process of innovation are the two main ways for dealing with radical uncertainty in an entrepreneurial environment.

Entrepreneurship involves highly uncertain returns for the entrepreneur with a wide dispersion of outcomes. Robert Hall and Susan Howard (2010) studied the historical cash rewards of VC-backed entrepreneurs over a period of 20 years, comparing it to what they would have received from risk-free salaried jobs. The standard payoff for a VC-backed entrepreneur is a below-market salary and a share of the equity which may pay out if the company goes public or is acquired. They found that the typical VC-backed entrepreneur receives $5.8 million in exit cash but that three quarters of entrepreneurs receive nothing at exit, while a few lucky ones receive over a billion dollars.[331]

Startup Financing Stages

Entrepreneurs who start new ventures from scratch need funding. A small amount of startup funding may be obtained from personal or small business loans, but given the high mortality rates of startups, bank loans are generally not a feasible option. Initial funding typically comes from founders and their family and friends. Next up (at a slightly later stage) are *angel investors* – rich individuals who were often successful entrepreneurs themselves and may provide startup funds (and often advice too) in return for an ownership stake. But eventually, the growing venture needs more funding than individuals can provide.

Venture capital (VC) firms take in money from multiple investors, pool it, and then use it to fund startup companies with high-growth potential. In exchange for their investment, VC firms take an equity (ownership stake) in the company. (VCs also charge their investors an annual management fee, usually 2–2.5 percent of funds invested.) VCs typically do not take more than 50 percent of the equity of a startup, and they spread out their risks by investing in multiple startups. A small VC firm, typically with total investment funds of under $50 million is also called a *microfund. High-net-worth family offices* – private offices that exist to invest the funds of very wealthy families – also invest in startups. Such an office acts like a family-funded and owned VC.

A startup's presentation of its value proposition and business model to convince a VC to invest in it is called a *pitch*.[xliii] Before making an investment, VCs will consider the appeal and uniqueness of the offering of the startup, along with its commercial growth potential and the strength of the management team. When the VC is convinced by a pitch, it will invest funds in the startup. This event is called a *deal*.

A VC holds its investment in the startup, often increasing it as the growing company requires more capital (each new injection of funds usually requires a new pitch to the VC), until a capital event called the *exit*. At the exit, the VC liquidates its investment in the startup (hopefully at a substantial capital gain) as new owners take over. This can happen when the now-mature startup lists its common stock on a stock exchange for the first time, an event called an *Initial Public Offering (IPO)*. Alternatively, the startup may be acquired by a large company, or it may merge in some form with an existing company. An alternative to an IPO is the *Special Purpose Acquisition Vehicle (SPAC)*, where the exit entails the startup merging with an empty shell of a company that is already listed on a stock exchange, which has the supposed advantage of saving conventional IPO costs and accelerating the exit. *SPAC IPOs* have gained popularity in recent years.

VC deals are classified in terms of the stage in which the investment is made, with each stage corresponding to the maturity of the startup in which they are made. Table 9.2 describes the main VC stages. The *Pre-Seed Stage* is normally classified as a stage preceding the five main stages. This stage is too early for VCs to consider funding the venture, and the founder will first be expected to build out some prototype that can be used to assess the viability of the concept. The last stage, the *Mezzanine Stage,* is concluded by the exit. As a general rule, the amounts of funding required and invested by VCs will increase by stage, as more funding is needed to scale up the fledgling business.

When looking at reported numbers about the VC industry, it is important to distinguish between the following terms:

- *funds raised* (also called *funds collected*) by VCs from investors
- *deal count* (i.e., the number of investments done)
- *deal value* (i.e., the value of funds' investments)
- *number of exits* (often broken down into number of IPOs or SPAC IPOs)
- *exit value* (i.e., the money received when selling the VCs' stakes in companies)

xliii Templates for pitch decks can easily be found online, along with examples of pitch-deck formats preferred by big VC companies and actual pitch decks for well-known companies such as AirBnB and Facebook.

Table 9.2: Venture Capital Stages for Startups.

	0. Pre-seed	1. Seed	2. Series A	3. Series B	4. Series C	5. Mezzanine
Main activities	– Business concept development – Partnership agreements – IP (patent or copyright) acquisition – Pitch deck development	– Creating a product or prototype – Getting the business running – Fundraising	– Market and industry research – Business plan writing – Marketing and advertising – Revenue generation – Scale-up plans	– Expanding customers – Establishing a viable product or service – Scaling production	– Building new products and markets – Establishing a strong customer base – Acquiring other companies	– Being acquired by another company or SPAC – Remaining private using VC funds – Making an IPO
Main funding sources (i.e., typical investors)	– Founder – Friends and family – Early-stage funds (Micro VCs)	– Founder – Friends and family – Angel investors – Early VC	– Accelerators – Super angel investors – VCs	– VCs – Late-stage VCs	– Late-stage VCs – Private equity – Hedge funds – Banks – Corporate VC funds – Family offices	– Private equity firms – Hedge funds
Examples of funders	– Seedcamp – K9 Ventures – First Round	– Techstars – 500 Startups – Y Combinator – AngelPad – Speedinvest	– IDG Capital – New Enterprise Associates – Plug and Play – SOSV	– Khosla Ventures – GV – NEA	– Accel – Sequoia Capital – Founders Fund – Lightspeed Venture Partners	

Source: Adapted from Fowler (2022).[332]

Venture Capital Trends

According to Pitchbook (2022, 3), U.S. VC-backed companies collected nearly $330 billion in investment funds in 2021 – a record, and roughly double the previous record of $166.6 billion raised in 2020.[xliv] There was a total number of 17,054 deals. In 2021, more than $774 billion in annual exit value was created by VC-backed companies that either went public or were acquired. Early-stage VC deal activity in 2021 nearly doubled the prior record and eclipsed $80 billion for the first time ever.[333]

VC investing measured both in the number of deals and the deal value have risen substantially over the last 15 years, as can be seen in Figure 9.1. Between 2020 and 2021, deal value has nearly doubled.

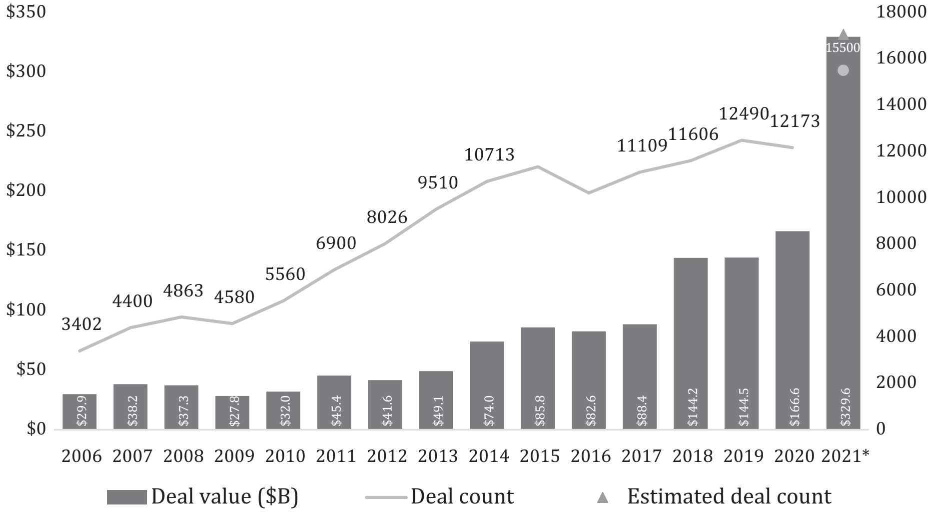


Figure 9.1: U.S. Venture Capital Deal Activity.
Source: PitchBook data (2022b).[334]

The size of U.S. angel and seed deals have also increased substantially over the last decade. In 2011, the vast majority of such deals were below $1 million. But in 2021, the majority of these deals were above $1 million, with a significant proportion over $5 million. In the last few years, angel and seed deals were roughly 40 percent of the total of all VC deals, with early and late VC deals splitting the remainder with about 30 percent of deals in each (Pitchbook 2022, 8).[335]

xliv To protect the economy from the COVID-19 pandemic, the U.S. (and many other) governments pumped massive amounts of money into the system through both fiscal and monetary stimulus. With rock-bottom interest rates and a record-high stock market, many investors were looking for alternative places to get a return on their funds.

As can be seen in Figure 9.2, a plurality of VC deals (37 percent) is in the software industry, but consumer and commercial products and services also get a fair share of deals (28 percent combined). Next comes the life-sciences industry, with a significant total of deals (21 percent) between the three categories of HC (healthcare): devices, services, and pharma and biotech deals.

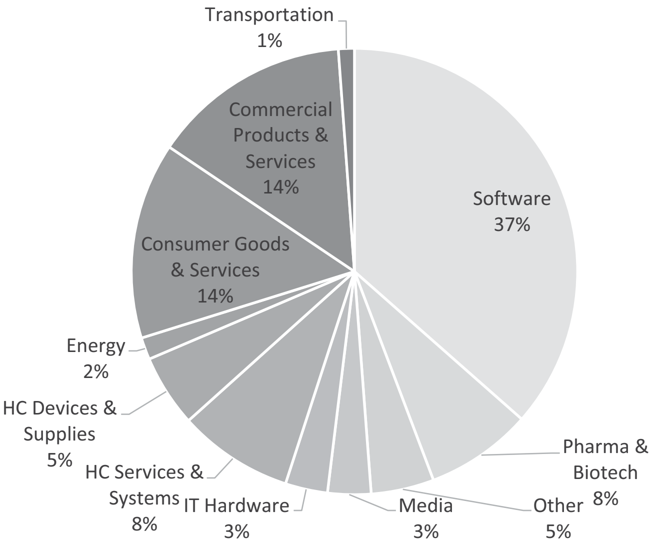


Figure 9.2: U.S. VC Deal Activity, Percentage of Number of Deals by Sector (2021).
Source: Analysis of PitchBook data (2022b).[336]

The year 2021 was also the biggest year in terms of *global* venture funding, reaching a record of $621 billion, more than doubling the 2020 total. The year saw a record number of unicorns born, and the total number of unicorns existing by the end of the year was also a record. (A unicorn is a startup valued at over $1 billion.) While the United States led as usual, this growth was seen over all regions, signifying the globalization of innovation capital. The total number of unicorns rose to 959 in 2021, due to a staggering number of unicorn births. Forty-four of the unicorns were classified as decacorns, meaning they had valuations exceeding $10 billion. There were also a record number of 1,556 mega-rounds (over $100 million) of financing in 2021, which (while only being one in 20 of every deal globally) accounted for 59 percent of all funding dollars. While the United States led in total funding, Asia led in the total number of deals. In the final quarter of 2021, VCs kept leading deal shares at 30 percent, followed by corporations at 11 percent, asset/investment management at 10 percent, angel at 9 percent, CVC (corporate venture capital) and private equity each at 7 percent, incubators/accelerators at 4 percent, and all others at 21 percent (CBInsights 2022a).[337]

Other Private Sources of Financing

In recent years, an increasing number of nontraditional actors have been attracted into the VC space:

Corporate Venture Capital (CVC) is corporate money directly invested in external startup companies, either through the acquisition of equity stakes, like conventional VCs, or through joint venture (JV) agreements. CVCs are the investment arms of established corporations who desire to invest corporate capital in startups, often in fields related to the corporation's business, or in new areas in which the corporation is considering expanding into. According to CBInsights (2022b, 7), global CVC-backed venture funding more than doubled in 2021 to reach a record $169.3 billion in 2021. The United States alone attracted $86.9 billion of the total, including four rounds of CVC funding rounds in excess of $1 billion each.[338]

Private Equity (PE)[xlv] is similar to VCs in the sense that private funds are invested by the PE firm by pooling the funds of multiple high-net-worth investors, and investing them in companies with the intention of exiting later and making a profit on the investment. The investment is of a direct and private nature, and involves taking an equity (ownership) stake. But PE firms have traditionally invested in mature private companies that are already well established, and the PE space tends to be dominated by large institutional investors. Therefore, PE investment in startups is focused on the fourth or fifth stages. Unlike VCs, PE firms usually buy 100 percent of their targets, thus ensuring full control. They usually invest over $100 million in a single company and tend to concentrate their holdings in a small portfolio of companies. PE firms buy businesses that they believe they can improve and sell at a profit, in contrast to VC firms that invest in fledging companies and help them grow up. While VCs usually focus on technology industries, PE firms will buy companies in any industry. For these reasons, the total deal value of PE exceeds VC deal value. According to PitchBook (2022c), the total PE deal value in 2021 was $1.2 trillion.[339]

Sovereign wealth funds (SWFs) are investment funds that are directly owned by a nation state. These funds are usually operated by nation states that run frequent budget surpluses and desire to invest the excess funds at higher returns than the prevailing bank interest rate offered by their central banks. An example of a nation with multiple sovereign wealth funds is the United Arab Emirates (UAE), which generates much of its revenue from oil exports and wishes to diversify away from oil-based returns. SWFs are typically very large, with assets in the billions of dollars. Other countries

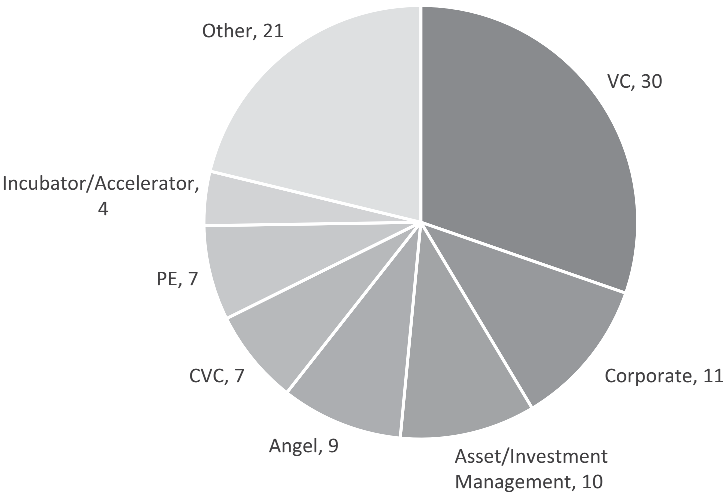
xlv Some authors classify venture capital firms as a subcategory of private-equity firms, which is technically correct. The other private-equity firms are called *buyout firms*, which is the subcategory referred to in this bullet, reflecting common usage of the term private equity to only refer to buyout firms.

with large surpluses that run SWFs include China and Norway. At the beginning of 2022, the world's top 10 SWFs managed assets in excess of $7.4 trillion.[340]

Hedge funds are investment partnerships with financial portfolios managed by professional fund managers. The investors (limited partners) pool money into the fund for investment by the fund manager, who typically has wide latitude in choosing investments within the fund's stated strategy. As per its name, a hedge fund has as its main purpose to maximize returns while minimizing risks. Hedge funds have not traditionally invested in startups, but now sometimes invest in the fourth or fifth stages. According to PitchBook (2022, 25), $253.5 billion in 2021 deal value was associated with such nontraditional investors.[341]

In summary, Table 9.3 provides an overview of the relative contributions to venture funding globally from different types of investors.

Table 9.3: Global Investor Deal Share (percent), Q4, 2021.



Source: Analysis of data from CBInsights (2022c).[342]

The Evolution of the VC Environment

Martin Kenney and John Zysman (2018) from the University of California describe the evolution of the current VC environment since the dot.com crash of 2000. This evolution influenced how new firms were formed as well as how many exited through IPOs. The *technological enablers* were the decreased cost, increased speed, and ease of market entry due to availability of open-source software, digital platforms, and cloud computing. These enabled a strategic change with a proliferation of startups seeking to disrupt incumbent firms in a wide variety of business sectors. The eased market entry was accompanied by a proliferation of private funding sources willing to advance capital to young unlisted firms. These sources now include crowd-funding websites, angels, accelerators, microventure capitalists, traditional venture capitalists, and lately mutual funds, sovereign wealth funds, and private equity funds. The enormous amounts of money and diversity of funding available from these investors led to a decline in the proportion of traditional exits through IPOs. There was a large increase in the last decade of the number of so-called *unicorns* – VC-backed private firms with valuations exceeding $1 billion. The ease of new firm formation and the large amounts of capital available mean that new firms can afford to run massive losses for long periods in an effort to dislodge incumbents or beat other well-funded startups. The result has been remarkable turmoil in many formerly stable industrial sectors, as the new entrants fueled by capital investments undercut incumbents on price (Kenney and Zysman 2018).[343]

A parallel evolution has occurred in early-stage VC financing, particularly for software and service startups, away from more traditional active VC governance and larger investment amounts to a so-called *spray-and-pray approach*. With the spray-and-pray approach, VC investors will provide both limited funding and limited governance to a larger number of startups, as well as an increased number of investment rounds. This change was brought about by technological improvements – most notably cloud computing that allows hardware that previously needed to be bought and installed by the startup to be rented, along with free open-sourced software. These improvements made market entry easier (Kenney and Zysman 2019)[344] and also served to reduce startup costs while accelerating experimentation cycles (Ewens, Nanda, and Rhodes-Kropf 2018).[345]

Traditionally, the startup CEO receives little or no compensation until a tangible, marketable product is available. After that milestone, CEOs usually receive a substantial salary and bonus tied to growth, more in line with the compensation package of non-founder CEOs at comparable-size firms. Research by Michael Ewens, Ramana Nanda, and Christopher Stanton (2020) suggests that the product-market-fit milestone represents a major shift in the life cycle of the firm because it is also a transition point where the talent in the venture is not replaceable (synonymous with the firm) to where the human capital is more replaceable. However, the vast majority of startups fail altogether or do not achieve a product market fit within three years, highlighting the professional risk that founders who leave jobs to start a new business are exposed to.[346]

Venture capital is associated with some of today's most famous high-growth firms. Alphabet, Apple, Amazon, Facebook (Meta), and Microsoft in the United States, and Alibaba and Tencent in China were all VC backed prior to their IPOs. Josh Lerner and Ramana Nanda (2020) point out that nearly half of entrepreneurial companies that eventually list publicly were VC backed. While the VC model has obvious strengths in furthering innovation – particularly its strong governance implemented by staged financing and the active involvement of venture capitalists in their portfolio companies – Lerner and Nanda (2020) point out its most-concerning limitations:

1. the very narrow band of technological innovations that fit the requirements of institutional venture capital investors
2. the relatively small number of venture capital investors who hold, and shape the direction of, a substantial fraction of capital that is deployed into financing radical technological change
3. the relaxation in recent years of the intense emphasis on corporate governance by venture capital firms[347]

(Lerner and Nada 2020, 235)

The first concern was illustrated earlier by the narrow industry mix of VC investments. The second concern is illustrated by an analysis of the partner profiles of the 50 largest VC firms, which shows a clear lack of diversity. Of 416 partners, 82 percent were male, 69 percent were in the San Francisco Bay area, 59 percent attended one of the top universities, 12 percent have an MBA from Harvard, and 9 percent have an MBA from Stanford (Lerner and Nanda 2020, 250–251)[348] The third concern was alluded to above in the discussion of the evolution to the so-called spray-and-pray approach.

There is always a question as to how good the judgments of venture capitalists are on new ventures that are presented (pitched) to them. Anecdotal stories abound of VCs who rejected startups who later became spectacularly successful. Some VCs are quite honest about their past misjudgments and show a sense of humor about it. For example, Bessemer Venture Partners (2022) maintain a webpage, titled "The Anti-Portfolio. Honoring the Companies We Missed."[349] This page contains big names such Airbnb, Apple, eBay, PayPal, Tesla, and Zoom – all turned down at some point by this VC firm.

Erin Scott, Pian Shu, Roman Lubynsky (2020) performed a systematic examination of the predictive quality of venture evaluation. They asked a panel of 251 experienced entrepreneurs, investors, and executives to read succinct summaries of 537 ventures in high-growth industries without meeting the startup founders or disclosing the valuations of the startups to them, and to evaluate the commercial viability of these startups based on what they read. (The panel was selected from experienced startup mentors from the Massachusetts Institute of Technology (MIT) Venture Mentoring Service, a free educational service that provides advice and mentorship to aspiring MIT-affiliated entrepreneurs.) The venture's subsequent commercialization success was used as a proxy for actual venture quality. The researchers found that these experts were able to make good judgments on the quality of many of these ventures. But the experts could only make judgments for ventures in computer hardware, energy, life sciences, and medical devices sectors. They could not do so for ventures in the consumer products, consumer web and mobile, and enterprise software sectors (Scott, Shu, and Lubynsky 2020).[350]

Governments also provide startup funding in the form of either loan financing or grants. (In free market-oriented countries such as the United States, the government is usually reluctant to take an equity stake in a private company.) Public-sector financing of innovation and R&D, as well as the philosophies that influence it and policies that govern it, is the topic of Chapter 10.

Corporate Innovation Funding Sources

Most of the preceding discussion on innovation financing was about venture investing in startups. However, there is much innovation activity inside established corporations, which is financed by some combination of shareholder equity or corporate debt funding, client contracts, and government contracts or grants. Corporations also finance innovation activities external to their organization; for example, at startups, partner organizations, universities, or industry consortia. Various open-innovation models were covered in Chapter 5.

Even internal corporate funding for innovation can be differentiated based on source; for example, whether it comes from a central corporate fund, or whether it comes from a business unit or another internal corporate organization, such as a special innovation organization. (For a discussion of the latter, see Chapter 4.)

There is a good reason that only very large corporations can afford to fund their own basic research: The outcome of any single basic-research project is extremely uncertain, and the potential commercial usefulness of its findings is even more doubtful. For a private company, it, therefore, only makes sense to conduct basic research if it can afford to sponsor many such projects, in the hope that some of the projects in its portfolio may pay off handsomely. Nobel laureate Kenneth Arrow (1962) articulated this truth as follows:

> The only way, within the private enterprise system, to minimize this problem is the conduct of research by large corporations with many projects going on, each small in scale compared with the net revenue of the corporation. Then the corporation acts as its own insurance company.[351]
>
> (Arrow 1962, 616)

Today, America's five biggest tech companies are spending enormous amounts on R&D in an effort to maintain their future competitiveness. The so-called Big Five (Alphabet, Amazon, Apple, Meta, and Microsoft) spent a combined amount of $149bn in 2021, roughly a quarter of total U.S. R&D spending,[xlvi] according to a calculation by *The Economist* (2022).[352] These modern giants have taken over the mantle from the

xlvi Some of the Big Five's R&D spending is not spent domestically, making such a comparison imprecise.

large corporate labs of the past, such as IBM, AT&T/Bell, and Xerox. (The contribution of the platform business model to their rise was discussed in Chapter 6.)

Monopolies are, however, a double-edged sword as far as innovation investment is concerned. As pointed out in Chapter 1, a primary incentive to innovate comes from competition, which makes innovation essential for continued product differentiation. As companies grow larger, they can afford to pay for more R&D, but their incentive to innovate may diminish as their market power increases. Kenneth Arrow (1962) articulated this tension as follows:

> We expect a free enterprise economy to underinvest in invention and research (as compared with an ideal) because it is risky, because the product can be appropriated only to a limited extent, and because of increasing returns in use. This underinvestment will be greater for more basic research. Further, to the extent that a firm succeeds in engrossing the economic value of its inventive activity, there will be an underutilization of that information as compared with an ideal allocation.[353] (Arrow 1962, 619)

The shortfall in investment in R&D and innovation by the private sector, provides a rationale for public-sector involvement, which is the subject of Chapter 10.

Chapter Summary

- The trial-and-error nature of innovation in the pursuit of value makes some waste unavoidable. Profit-seeking financiers, who are willing to finance entrepreneurs and tolerate losses in the process, are essential to innovation happening within the capitalist system.
- Startups operate under conditions of radical uncertainty, which in most cases will require multiple pivots before a successful business emerges. Adequate capital is needed to finance these pivots.
- Venture capitalists (VCs) receive funds from multiple sources and invest them in a portfolio of startups, with only a minority expected to succeed. The total funds invested by VCs have sharply increased in recent years.
- There are multiple VC rounds with the size of the investment increasing with each stage. Deals happen when VCs invest in startups. Exits are when they liquidate their investment, hopefully at a profit.
- There are concerns about the narrow range of industries preferred by VCs, as well as the lack of diversity of VC decisionmakers.
- Other significant sources of startup funding are corporate venture capital (CVC), private equity (PE), sovereign wealth funds (SWFs), and hedge funds.
- The digital behemoths have become major investors in startups, while also investing large amounts on inhouse R&D and innovation.

Suggested Exercises and Assignments

- Watch an episode of the reality-TV series, *Shark Tank* (*Dragon's Den*). Critique the pitches made by the founders and discuss whether you agree with the deals offered or not offered to them. Debate whether you would have accepted the deal if you were in the founder's shoes.
- Select and analyze a unicorn (a startup valued over $1 billion) by obtaining news articles, press releases, and corporate documents such as pitch decks in the public domain. Map out the rounds of funding it has received so far, and what it was valued at each funding round. Identify the major innovation challenges it still has to overcome, and which seem most uncertain. Debate whether it is over- or undervalued based on the value of its offering, its market position, and ability to scale up in the future.
- Pick an industry of interest and analyze recent deal and exit data for it, using free data available from Pitchbook. Discuss whether the VC investment trends truly reflect the opportunities for value creation in that industry, and whether VCs may be over or underestimating the potential value of companies in the industry.

Recommended Further Reading

Janeway, William H. 2018. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, UK: Cambridge University Press.
Gertner, Jon. 2012. *The Idea Factory: Bell Labs and the Great Age of American Innovation*. New York: Penguin Press.
Lamoreaux, Naomi R., and Kenneth Lee Sokoloff. 2007. *Financing Innovation in the United States, 1870 to the Present*. Cambridge, MA: MIT Press.
Lerner, Josh, and Ramana Nanda. 2020. "Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn." *Journal of Economic Perspectives*, 34 (3): 237–261.
Perez, Carlota. 2002. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham, UK: E. Elgar Pub.
Ramsinghani, Mahendra. 2021. *The Business of Venture Capital: The Art of Raising a Fund, Structuring Investments, Portfolio Management, and Exits*. Third edition. Hoboken, NJ: Wiley.

Recommended Data Sources

The National Venture Capital Association (NVCA 2022)[354] is the industry association for the U. S. venture-capital community. Its annual *NVCA Yearbook* is the definitive source for trends and analyses of VC activity in the United States from the past year. The *Yearbook* also contains historical data and information on VC activity.

For data sourcing, the NVCA partners with PitchBook (Pitchbook 2022),[355] a company that specializes in capturing data on startup funding and deal activity. PitchBook covers the spectrum of VC, PE, and M&A activity. PitchBook covers and captures private investment data like Bloomberg captures data on trading and investment in public companies. As such, it is the primary source for this data in the United States and is widely referenced. PitchBook also issues its own (usually free) quarterly reports on VC-activity.

CBInsights, a research company, extensively covers global venture trends. Some of its reports and data are made available for free to nonsubscribers. For example, it maintains an online tracker, "The Complete List of Unicorn Companies," (CBInsights 2022)[356] of unicorn companies worldwide, and it publishes an annual *State of Venture* report with accompanying downloadable data (CBInsights 2021).[357]

Chapter 10
Public Financing of R&D and Innovation

The public financing of R&D and innovation is often rationalized on the basis that government must step in when the market underinvests in R&D and innovation that will benefit the nation. Public funds are dispensed through particular agencies that tend to finance scientific research, technological development, and innovations that comport with their respective missions. The government may also wish to generally support innovation by taking on the role of a venture capitalist.

The chapter starts with an exploration of the Linear Model of Innovation and its influence on government support for basic and applied research. A critique of the Linear Model is followed by the introduction of Pasteur's Quadrant, an alternative two-dimensional model that acknowledges different starting points for basic research. The history of U.S. government support for R&D in the post-WWII era is briefly reviewed, with reference to the various economic philosophies that influenced it.

The U.S. government's venture funding programs for small businesses and startups are introduced, along with a discussion of where the uncertainty tolerances of the public sector versus private sector differ, and how that can explain the government's complementary role in financing innovation.

A deeper discussion on the economics of research explains what the public sector tries to achieve when financing R&D. Trends of actual U.S. government versus private spending are presented, and the major allocations of current federal R&D budgets are shown by agency. The largest allocation, defense-related R&D, is briefly discussed in its historical context, with specific reference to how defense R&D spending stimulates private-sector innovation. The chapter concludes with a short overview of intramural government R&D.

The Linear Model of Innovation

How we frame the innovation process and classify its major different steps is not only of theoretical importance. It determines which parts of invention and innovation get funded and by whom. The model of innovation we adhere to will influence which parts of R&D and innovation are funded by the state and which by the private sector. It will influence what we consider to be the most appropriate handover points between the main actors. And it will influence the roles that we see private companies, universities, and the public sector play and how they interact with one another.

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The *Linear Model of Innovation*[xlvii] is so widely ingrained in our assumptions on how technology-based innovation happens – and maybe too easily accepted – that it feels almost trite to describe it here. According to this model, innovation starts with basic research, proceeds to applied research, on to development, and finally to production and diffusion:

Basic Research → Applied Research → Development → Production → Diffusion

Even with this simple linear model, the impetus for the innovation is not definitive, and the causality not always obvious. *Technology-push innovation* start with a groundbreaking new technology for which applications are then found. The laser is a classic example of that. On the other hand, an industry's need for a particular solution may necessitate research to solve a technological challenge. This is called *market-pull innovation.* The space program developed many new breakthrough technologies because they were required to go to the moon. The typical causality can differ and vary by industry; for example, the mobile-phone industry is mostly technology push and the apparel industry is mostly market pull. But when the breakthrough new textile Gore-Tex was introduced, that was technology push in the apparel industry. And when mobile phone makers eliminate certain functions because they are no longer desired by consumers and rush other new functions to market because they are desired instead; that is market pull in the mobile phone industry.

Benoît Godin (2006)[358] traced the history of the Linear Model to Vannevar Bush's seminal 1945 report, *Science – The Endless Frontier.* The report on how to conduct research in the United States in peacetime, was commissioned by President Roosevelt and delivered to President Truman. Bush was the director of the Office of Scientific Research and Development (OSRD) during the World War II and the most influential wartime scientist in the United States. Bush defined *basic research* as the term we understand today; that is, as a search for scientific knowledge without having an application for the knowledge in mind:

> Basic research is performed without thought of practical ends. It results in general knowledge and an understanding of nature and its laws. This general knowledge provides the means of answering a large number of important practical problems, though it may not give a complete specific answer to any one of them. The function of applied research is to provide such complete answers. The scientist doing basic research may not be at all interested in the practical applications of his work, yet the further progress of industrial development would eventually stagnate if basic scientific research were long neglected.[359] (Bush 1945, 79–80)

The Bush report proposed the government's and industry's respective roles in sponsoring research. The report was the product of work by four large committees, each comprised of academics and industry leaders. Bush provided an interpretative

xlvii The linear model evolved from prior research by Maclaurin, as explained in Chapter 2.

summary of the recommendations, mostly keeping the ones he liked and dropping the ones he did not. It was a political document, representing particular policy choices for scientific research and development in the postwar era.

Daniel Kevles (1977) provides the historical context for Bush's report and how it was preceded by an intense, political, and sometime acrimonious debate that already started during the war about how the U.S. federal government should advance science for the general welfare during peacetime.[360] During the war years, there were concerns about the dominant role that big business in alliance with a few leading universities was playing in defense research. Numerous universities and individuals had offered their assist to the war effort, but most were politely rebuffed. The concentration of industrial researchers was already high before the war, with two-thirds being employed in less than 10 percent of all industrial laboratories. The government's contract policy during the war increased this concentration with two thirds of all public R&D funds going to only 68 corporations by the end of the war. And over 90 percent of these contracts gave industrial contractors the patent rights to the fruit of public-funded research. The patent concentration was a big concern from a competition-policy perspective as well. The reliance of universities on corporations for research funding was another major concern.

Definitions of R&D

A clear line can be drawn from Vannevar Bush to the Linear Model and associated definitions currently in use by the U.S. government. Indeed, the Linear Model and its terminology have been very influential since 1945 in framing how we think especially about the R&D part of the innovation process, not just in the United States but worldwide. The OECD's *Frascati Manual 2015,* which is the latest version of this authoritative international methodology for collecting and using R&D statistics, defines R&D broadly as follows:

> Research and experimental development (R&D) comprise creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge.[361] (OECD 2015, 44)

Accordingly, there are five criteria for an activity to be classified as R&D. It must be *novel, creative, uncertain, systematic, and transferable and/or reproducible.* R&D is an umbrella term that comprises three distinct activities – *basic research, applied research*, and *experimental development* that are, respectively, defined as follows in the *Frascati Manual*:

- *Basic research* is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view.
- *Applied research* is original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective.
- *Experimental development* is systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes.[362]

(OECD 2015, 51–52)

The Frascati Manual also stresses that experimental development should not be confused with product development:

> Experimental development is just one possible stage in the product development process: that stage when generic knowledge is actually tested for the specific applications needed to bring such a process to a successful end. During the experimental development stage new knowledge is generated, and that stage comes to an end when the R&D criteria (novel, uncertain, creative, systematic, and transferable and/or reproducible) no longer apply.[363] (OECD 2015, 45)

Currently, the U.S. federal government uses the following definitions *of Basic Research, Applied Research* and *Experimental Development*:

> *Basic Research.* Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts. Basic research may include activities with broad or general applications in mind, such as the study of how plant genomes change, but should exclude research directed toward a specific application or requirement, such as the optimization of the genome of a specific crop species.
>
> *Applied Research.* Original investigation undertaken in order to acquire new knowledge. Applied research is, however, directed primarily toward a specific practical aim or objective.
>
> *Experimental Development.* Creative and systematic work, drawing on knowledge gained from research and practical experience, which is directed at producing new products or processes or improving existing products or processes. Like research, experimental development will result in gaining additional knowledge.[364] (OMB 2021, 3–84)

The U.S. Department of Defense (DOD) uses similar definitions for basic and applied research, but expands on the definition of experimental development. The DOD uses *Advanced Technology Development* instead of Experimental Development, and has an additional technology stage before full-scale *Systems Development*, namely *Advanced Component Development and Prototypes*. Relevant extracts from the DOD (2004) definitions are:

> *Advanced Technology Development (ATD).* This budget activity includes development of subsystems and components and efforts to integrate subsystems and components into system prototypes for field experiments and/or tests in a simulated environment. The results of this type of effort are proof of technological feasibility and assessment of subsystem and component operability and producibility rather than the development of hardware for service use.[365]
>
> (DOD 2017, 5–4)

> *Advanced Component Development and Prototypes (ACD&P).* Efforts necessary to evaluate integrated technologies, representative modes, or prototype systems in a high fidelity and realistic operating environment are funded in this budget activity. The ACD&P phase includes system specific efforts that help expedite technology transition from the laboratory to operational use. Emphasis is on proving component and subsystem maturity prior to integration in major and complex systems and may involve risk reduction initiatives.[366] (DOD 2017, 5–5)

One of the main reasons that the Linear Model of Innovation is so well entrenched is because data, especially internationally comparative data, on innovation are routinely captured according to the Linear Model as codified within the Frascati Manuel. But the Linear Model is not necessarily the best, or only, representation of reality. While the Linear Model has been expanded by some authors in an attempt to incorporate both technology-push and market-pull mechanisms, many modern authors now consider it as having outlived its purpose as an explanatory model of how technological innovation changes the economy with models such as the Triple Helix (see Chapter 11) supplanting it.

Within the linear model, there have been different opinions as to the extent that government should emphasize funding of basic research over applied research. In the early 1970s, Lord Victor Rothschild conducted an investigation of U.K. innovation policy for Margaret Thatcher, who was Minister of Education at the time. Rothschild drew a clear line between basic and applied research and advised that applied science funds should be transferred from research councils to government departments. The idea was that applied R&D (i.e., R&D with a practical application) must be directed by the customer, the ultimate user of the application. This is called the customer/contractor model with the contractor being the organization who performs the applied research. This was motivated by the belief that research scientists are not as well qualified to decide what the nation's needs and priorities are as those responsible for ensuring that those needs are met. According to Parker (2015), the main benefit of this approach was that it brought much more accountability to publicly funded research, but it pushed academia into a defensive mode and made it harder for the government to engage expertise. All attention was focused on what was in the contract. The recommendations of the 1971 *Rothschild Report* on government-funded R&D were mostly adopted by the government and subsequently implemented.[367]

Evolutionary economics (see Chapter 3), which holds that technological progress and innovation are evolutionary processes, has been influential in shaping the role of government support for R&D. Richard Nelson (2006) explains the reasons for his belief that technological progress is evolutionary as follows:

> First, at any time there generally is a wide variety of efforts going on to improve prevailing technology or to supersede it with something radically better. These efforts generally are in competition with each other and with prevailing practice. The variety reflects differences in judgments about what prospects are most promising. The winners and losers in this competition are to a considerable extent determined by an ex post selection process.

> Second, today's efforts to advance a technology to a considerable extent are informed by and take off from the successes and failures of earlier efforts. Although there are occasional major leaps that radically transform best practice, for the most part technological advance is cumulative.
>
> Third, the advanced technologies of any era almost always are the result of the work of many inventors and developers. Technological advance is a collective, cumulative, and evolutionary process.[368] (Nelson 2006, 906)

Nelson (2006, 906) points out that technological advance being an evolutionary process in no way suggests a hands-off approach for those who wish to advance it.[369] On the contrary, guidance is needed because a strong body of scientific understanding of new technologies enlarges the space that an inventor or innovator can clearly see and then make informed decisions on what paths to pursue. A body of strong science helps innovators and researchers to design more productive experiments that will reduce uncertainty, thus, furthering the invention and innovation processes.

Pasteur's Quadrant

Donald Stokes (1997) made a notable critique of the Linear Model of Innovation and of the clear line drawn by Rothschild between basic and applied research. Stokes discerned a more complex two-dimensional relationship between basic and applied research rather than the linear continuum from basic to applied research, as assumed in the Vannevar Bush-model that prevailed after the Second World War.[370] Stokes acknowledges that some basic research may be conducted absent of any potential uses in mind, such as Niels Bohr's research on the structure and inner workings of the atom. Also, some applied research may be entirely application-focused – such as Edison's inventions. (Edison was famously uninterested in basic science, only in what commercial applications he could develop.) However, there are many examples of cases in which basic research is conducted with an application or use already in mind. The Manhattan Project to develop the atomic bomb that ended the Second World War is one prominent example of the latter. A more peaceful example is the work conducted by Louis Pasteur, who pursued basic research into the nature of bacteria-borne diseases to develop countermeasures against these diseases. In his eponymous book expounding this argument, Stokes offers a 2x2 matrix (see Figure 10.1) with the vertical axis showing whether the research is conducted to obtain a fundamental understanding (i.e., pure basic research) and a horizontal axis showing whether an application is already being considered. *Pasteur's Quadrant* in the top right represents research that is both conducted to obtain a fundamental understanding and to support an application, such as was the case in both examples above.

Basic research is often not application-blind, as was indeed the case for Louis Pasteur. In today's technology-rich world, this even truer than at the time of Pasteur. Nathan Rosenberg (1996) argues that many of the most challenging scientific puzzles have been illuminated or created when new technologies were used, and their workings needed to be better explained.[371]

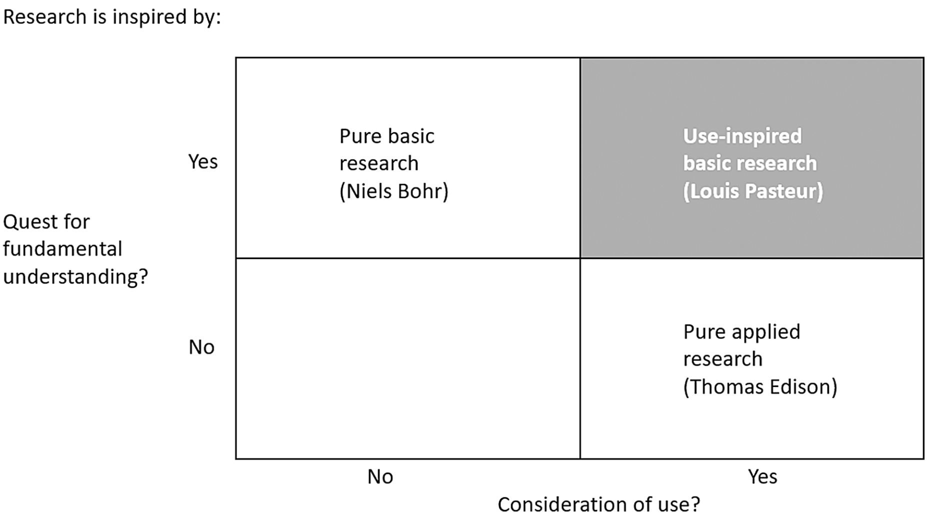

Figure 10.1: Pasteur's Quadrant.
Source: Adapted from Stokes (1997).[372]

A Brief History of U.S. Government Support for Innovation

The Linear Model of Innovation has been the prevailing post-WWII model to depict the course of technological innovation. According to this model, innovation starts with basic research, then adds applied research and development, and ends with production and diffusion. Its simplicity has made it a very influential model, and its stages are reflected in how most governments define public-spending programs on innovation and capture innovation statistics (Godin 2006).[373] For example, the authoritative *Oslo Manual* (OECD 2015),[374] which is the OECD guideline for collecting and reporting national-level innovation data across member countries, still employs these terms in one form or another.

Aside from what types of industrial innovations governments should directly support (e.g., pharmaceutical, clean energy, etc.), the policy debate concerning public spending on innovation largely centers on which of the categories of innovation (basic research, applied research, etc.) the government should support and by how much, and which are best left to the private sector. The answers to this question differ depending on the exigencies of the situation (e.g., wars, pandemics, unemployment, climate disasters) and the relevant mission at hand, as well as the economic philosophies adhered to by the policymakers. (Refer to Chapter 3 for an overview of the relevant economic schools of thought).

The neoclassical case for public-sector financing of basic research, as originally articulated by Kenneth Arrow (1962), is based on the belief that knowledge resulting from basic research is a public good.[375] If knowledge is indeed a public good – meaning that it is both *nonrival* in consumption, because the same knowledge can be used by an unlimited number of actors; and *nonexcludable*, when the knowledge is in the public domain – then private-sector firms might underinvest in research, implying that knowledge is also a positive (beneficial) externality. This will happen when firms perceive that at least some of the research they do to gain a competitive advantage will eventually become accessible to competitors, or they may wait for competitors to do the research. From the point of view of the government, that is a market failure that needs to be corrected by public financing, in particular for innovations that have significant positive externalities such as national defense, public health, or environmental improvements. Market failures provide a rationale for government intervention within the neoclassical paradigm. Within the linear model, the further one moves upstream, the more uncertain the outcomes, which make private investment harder. In particular, market failures provide a rationalization for government intervention in basic research, for which the return cannot be known with any certainty in advance for private entities to make rational investment decisions.

Increasing returns to scale which suggest a natural monopoly is a classical reason for the existence of a market failure. There are additional market failures that could justify government intervention within the neoclassical paradigm. For example, some investments are *indivisible* and need very large upfront financing. Other market failures may come from *information asymmetries*, where private financing is inadequate due to the high uncertainty of technical success. Particularly in emerging markets, there may be *missing capabilities*, such as technical and management skills, and markets may be underdeveloped (Nelson 1959).[376]

In summary, the neoclassical case for government support of innovation is based on exception, only justifying public spending when clear market failures exist that require government intervention. It avoids an active *industrial policy*, where the government chooses important industries that it considers worth supporting over the long run in order to build out its economy. Yet the latter is the approach followed by China in the last few decades, and earlier by South Korea and Japan.

The history of U.S. government support for innovation during and after the Second World War is instructive of the effect of different philosophies. The U.S. Office of Scientific Research and Development (OSRD), headed by Vannevar Bush during World War II, followed what was called a “connected-science approach” that effectively meant that the government commanded and funded the entire innovation process from basic research to production, with participation from universities and private industry. This was most notable in the case of the Manhattan Project, which resulted in the first nuclear bombs. At the start of the war, the basic nuclear science still had to be resolved, but by the end, the bombs were in production and put into action. (This is another example of Pasteur's Quadrant.) The same approach was used for other technologies considered crucial for the war effort such as radar, computers, rockets, and explosives (Freeman 1995).[377]

However, once the war ended, the United States abandoned the connected-science approach and only directed public financing to basic research, often conducted at multiple new science agencies founded by the government for this purpose, such as the National Institutes of Health, or federally funded universities. Everything changed when the Soviet Union unexpectedly launched Sputnik, the first man-made satellite, in 1957. Large space and military programs were immediately created by the United States to compete with the Soviet Union. Public spending on R&D rose sharply to about 2 percent of GDP. But most importantly, the connected-science model was revived in the founding of the National Aeronautical and Space Administration (NASA) to compete with the Soviets in space, and the Defense Advanced Research Projects Agency (DARPA) to compete with the Soviets in military technology. Both agencies were founded in 1958, the very year after Sputnik was launched (Bonvillian 2014).[378]

In later decades, the focus of public policy also shifted from promoting pure R&D to industrial R&D and innovation more broadly. This was the result of an increased recognition (largely as a result of Japanese industrial competition) of the importance of incremental innovations coming from shop-floor technicians and industrial engineers, and a newly gained appreciation of product-improvement sources such as market feedback, suppliers, and sub-contractors. The social, technical, and economic linkages in the system, and particularly efficiency incentives are also considered to be significant (Freeman, 1995).[379]

Small-Business and Startup Funding

The importance of small businesses to job creation and public interest in small-business promotion came to the fore during the Reagan era, when government itself was viewed with great skepticism. In the United States, the promotion of small-business innovation to achieve economic growth was institutionalized in several new agencies with spending mandates, most notably the seed-funding Small Business Innovation Research (SBIR) program founded in 1982, the Manufacturing Extension Partnership (MEP) founded in 1988, and the Small Business Technology Transfer (STTR) program founded in 1992. A Department of Energy agency to drive innovation related to alternative energy sources, the Advanced Research Projects Agency–Energy (ARPA-E), based on the connected-science model exemplified by DARPA, was founded in 2009 (Freeman 1995).[380]

The existence of the above-mentioned programs, particularly SBIR and STTR, means that the U.S. federal government is in the business of funding small businesses and startups that are innovating technologies or products. This is in addition to the government's ongoing funding of basic and applied research, which typically happens at established and larger companies, and at universities or government labs. SBIR and STTR funding amounts are substantial, with Fiscal Year 2019 obligations totaling $3.29 billion for SBIR and $429.3 million for STTR (SBA 2021, 1).[381] The financing for both programs is allocated via participating agencies; 11 agencies in the case of SBIR, and five agencies in the case of STTR (who also participate in SBIR). The five agencies participating in both programs are the DOD, DOE, HHS, NASA, and NSF. SBIR/STTR programs are structured in three phases:

1. *Phase I: Feasibility-Related Experimental Study or Theoretical Research/Research and Development*. Awards range from $100,000 to $250,000 for a 6 to 12-month period
2. *Phase II: Continued Research/Research and Development Effort*. Awards range from $750,000 to $1,650,000 for a two-year period
3. *Phase III: Commercialization Effort*. This phase entails work that derives from, extends, or completes work from Phases I and II, but is funded by sources other than the SBIR/STTR Programs[382] (SBA 2021, 7–8).[383]

Geoff Orazem and I (2021) have recently weighed in on the question What are the major differences between the private and public sectors respective to innovation financing? In our opinion, they are generally speed and risk (more precisely called "uncertainty" as explained the previous chapter) tolerance. That is not to say the one actor is more or less uncertainty-tolerant overall, but that the *types of uncertainty* each will be comfortable with can be quite different. Private companies generally innovate faster, but often prefer leveraging proven technologies that can deliver revenue and other commercial benefits quickly. The public sector usually moves more slowly, but is willing to take on much higher technology uncertainty and invest in long-term research that could take decades to mature.[384]

Another question is: How does government funding complement private funding at different points in the timeline? The differences in uncertainty tolerance and expected return time frames (speed) are largely reflected in the time horizons that public and private sectors require to see a return on their investment. Figure 10.2 is an illustration of the time lag between investment and expected returns for various types of public and private sector programs.

Table 10.1 is a comparison of some of the main differences between public and private sector innovation of startups and other new ventures, with specific reference to the SBIR and STTR government programs.

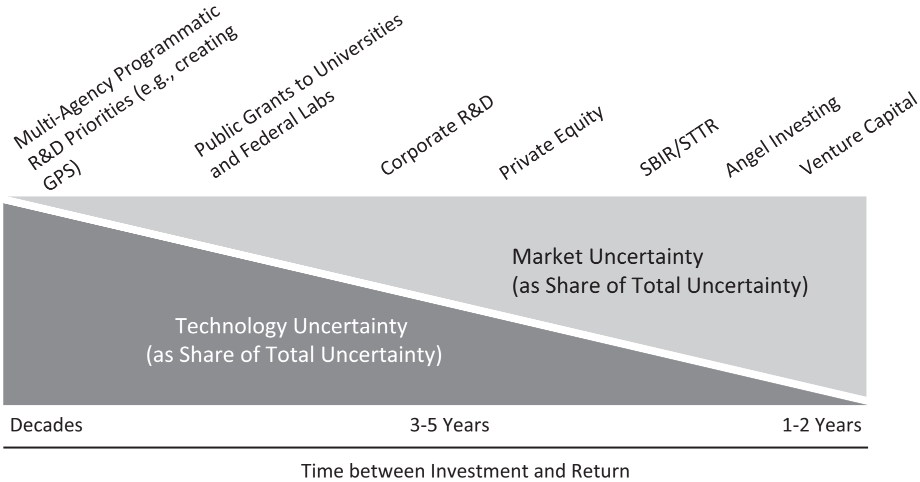

Figure 10.2: Typical Time Lag from Funding to Return for Various Public and Private Programs. Source: Based on Orazem and Van Biljon (2021, 57).[385]

Table 10.1: Comparison Between U.S. Public and Private Sector Startup Funding.

	Public Sector	Private Sector
Innovation's purpose & goals	To better deliver on a public mission To create/incubate a new sector or industry for the country	To increase revenue, decrease cost, and, thereby, drive returns for investors Shareholder returns may be supplemented by Environmental, Social, and Governance (ESG) considerations
Who typically gets funded	Small group of universities, large labs, repeat Small Business Innovation Research (SBIR) winners, and large private companies that focus on public R&D projects	*Start-ups:* Theoretically, everyone with an idea, though in practice, women and minority founders struggle *Established firms:* Usually only designated managers who are authorized to apply for approval
What gets funded	Mission-oriented technology	B2B and B2C[xlviii] product companies. For example, social media products, consumer products, cyber security products

xlviii Business-to-business (B2B) and business-to-consumer (B2C).

Table 10.1 (continued)

	Public Sector	**Private Sector**
Source of funds	Taxpayers	Private investors who expect returns
End-user/funder alignment	The end user for the innovation, and the funder of the innovation tend to be different people in different parts of the organization who don't communicate	Company innovation teams tend to be well-connected to the end user External innovation teams (venture capitalists [VCs]) spend significant time understanding the market and end users
Funding Process	*When:* SBIR and STTR (the principal programs targeting early-stage founders) have annual "solicitation windows," and if an innovator misses the window, they may have to wait a year or more to compete for funding Funds generally lost if not used during fiscal year *Finance sequencing:* Set funding rounds	*When:* Rolling investment rounds for startup with annual and quarterly budget cycles for established firms Unused funds automatically available in next fiscal year *Finance sequencing:* Size and volume of startup funding rounds tailored to the investor and inventor's needs
Risk Tolerance of Investors	– Open to long term investments in high-risk technologies – Do not care about commercial risk (they aren't trying to profit) – Expect to see a strong track record	– Want little-to-no technical risk that could delay fielding – Open to some commercial risk if it's quantifiable – Open to first-time startup founders
Compensating investors for the risk they are taking with their money	– The government can better deliver on its mission – National security and prosperity, economic growth	– *Corporate innovation:* Increased profitability thanks to the innovation – *VC:* Equity in investees
Decision process	In the SBIR/STTR program, applicants have one opportunity to submit a proposal per cycle and the government makes one decision whether to fund (black box review process)	Startups have multiple rounds of pitching, reviews, and revisions Established firms have formal phase-gate approval processes to authorize funding for different project stages.
Oversight	Highly regulated with oversight from many internal and external groups (due to investment of taxpayer dollars in technologies that can affect millions of people)	As loose or regulated as shareholders and investors choose, subject to external constraints such as stock exchange rules, corporate law, and antitrust considerations.

Source: Orazem and Van Biljon (2021, 59).[386]

The Economics of Research

Experimentation to reduce uncertainty is so at the core of entrepreneurship that some authors even define entrepreneurship in those terms. According to Kerr, Nanda, and Rhodes-Kropf (2014), "Entrepreneurship is fundamentally about experimentation because the knowledge required to be successful cannot be known in advance or deduced from some set of first principles."[387]

The cost of experimentation is the price paid for resolving the uncertainty. Technological changes have lowered experimentation costs, particularly in industries that benefited from the application of ICT technologies such as the internet, cellphones, open-sourced software, and cloud computing. Furthermore, these changes also obviate high-cost capital investments in servers and hardware, with software firms being able to rent whatever capacity they need. This has reduced a major traditional barrier to entry. With smaller amounts of funding needed, funding sources have proliferated, including crowdfunding platforms that are very easy to access. Another driver of cheaper experimentation is the Lean Startup methodology (see Chapter 6), which is now in widespread use. The Minimal Viable Product (MVP) approach at the heart of the Lean Startup emphasizes doing fast and cheap experiments to validate assumptions. An often-overlooked part of containing experimentation cost is the ability to terminate failed or failing projects. This is harder to do for established corporations than for VC-backed startups, where VCs brutally cut off funding once failure is clear.[388]

When a firm conducts R&D, it is almost inevitable that at least some of the knowledge created will enter the public domain where it will get picked up by other firms (sometimes its direct competitors) who will use that knowledge or technology for their benefit. Such *R&D spillovers,* also called *technology or knowledge spillovers,* have been a hotly debated and are a much-studied topic. In economic terms, an R&D spillover is a *positive externality*, which benefits society. However, as firms who perform R&D know in advance that rivals will likely benefit from their knowledge creation, it may discourage them from spending on R&D, at least to some extent. This creates the policy concern that spillovers may diminish the desire of firms to engage in R&D, thereby causing underinvestment in R&D. Economists call this the *divergence between private and public returns to R&D*. Since policymakers are concerned with maximizing public returns from R&D, they have to be concerned with the divergence because lower private returns to R&D will cause underinvestment in R&D. The presence of knowledge spillovers is often given as a justification for providing strong property rights (in particular, patents) to inventors in order to increase the private return to inventing.

Economists typically use three methods to estimate the magnitude of knowledge spillovers: case studies, a production-function approach, and patent-count research. An estimate based on a meta study of three decades of such data suggests that the social returns from spillovers are around 60 percent, while the private returns are around 15 percent, which makes a strong case for public research subsidies (Bloom, Van Reenen, and Williams 2019).[389]

There is another type of spillover, which is associated with what is called the *product market rivalry effect of R&D*. Such *product-market spillovers* happen when an innovating firm steals market shares from others without generating a social benefit. For example, a pharmaceutical firm may spend billions developing a drug that is only incrementally better than the drug of a rival firm. That may allow it to capture almost the entire market with massive benefits to its shareholders, yet its drug has only marginal additional benefit for society (Bloom, Van Reenen, and Williams 2019).[390] This type of spillover is associated with patent races where the first to patent a new technology gets the right to use it in its products and thus, gain a competitive advantage on its competition. Whereas the first type of spillover benefits rival companies, the second has a negative effect on a rival firm's value. Econometric studies that attempt to assess the R&D spillover effect have been complicated by the presence of both these positive and negative spillovers (Lucking, Bloom, and Van Reenen 2018).[391] It should also be noted that while the presence of knowledge spillovers can be used to justify strong patent regimes, product-market spillovers create an argument against strong patent regimes.

Fleming et al. (2019) have drawn attention to the extent to which government spending on basic research in the United States has replaced industry spending on basic research. Acknowledging that in today's knowledge economy innovation increasingly relies on scientific knowledge, the authors studied the linkages between patents and their funding sources to answer the question: If corporations are funding less basic research themselves, where do they find the ideas and knowledge to fuel their innovation? They found that the total proportion of U.S. patents relying on federal funding has sharply risen from about 10 percent in 1975 to about 30 percent in 2011, after which it plateaued to 2017 (the last year of data in the study).[392]

It is not only U.S. patentees who rely more on U.S. federally funded research, but also non-U.S. patentees – about 12 percent of foreign inventors relied on federally supported research in 2017. Startups are even more dependent on government research than established corporations: Federally supported research was cited in 34.6 percent of the 121,765 patents awarded to VC-backed companies from 1976 to 2016 compared to all corporate patents over this period, of which 21.7 percent relied on federally supported research (Fleming et al. 2019).[393]

Investing in R&D is quite different from other business investment. About half or more of R&D spending is on the salaries of highly educated scientists and engineers. They create an intangible asset which adds to the firm's knowledge base, in the hope that future profits may be generated from this knowledge. Much of the knowledge created is tacit, meaning that it is embedded in the firm's human capital. If these employees leave, it is lost with them. Firms try and smooth out their R&D spending over time so as not to lay off knowledge workers. A second major feature of R&D investment is the level of uncertainty associated with its product, an uncertainty which is at its highest at the beginning of a project. Startups and small firms in R&D intensive industries face a higher cost of capital than their larger competitors or comparable firms in other industries. The VC industry seems to be positioned where it is to cater to these types of startups (Hall and Lerner 2010).[394]

When the government buys R&D services with taxpayer dollars, there is sometimes a concern that given that there are limited R&D resources in a particular country, the government's spending on R&D may lead to the *crowding out* of private sector R&D, which some may consider to be more reliable. On the other hand, government spending on R&D may also provide a foundation for private sector R&D to be conducted upon and would serve to increase private sector R&D, which is *crowding in*. The question as to which effect – crowding out or crowding in – prevails is particularly relevant for defense-related R&D, given that such spending regularly dwarfs other direct government spending on R&D and innovation. Added to the regular crowding-out concern, there is then a further concern that defense spending may be crowding out civilian R&D spending, and that a country may forgo national productivity and economic growth as a result.[xlviv]

Enrico Moretti, Claudia Steinwender, and John Van Reenen (2020) did a major study of defense R&D spillovers in the United States and other OECD countries. They found that the evidence supported the crowding-in effect rather than the crowding-out effect: "On average, a 10% increase in government-financed R&D generates a 5% to 6% additional increase in privately funded R&D." In addition, they found evidence of international spillovers, meaning that government-funded R&D in a particular industry and country raises private R&D in the same industry in another country. Furthermore, increases in private R&D that were induced by increases in defense R&D led to productivity gains in the private sector.[395]

Three decades ago, Richard Nelson and Gavin Wright (1992) explored the trajectory of post-WWII U.S. per capita income and productivity (output per manhour) across a wide range of industries in order to examine the *convergence* of these metrics for the United States with those of other advanced industrialized nations.[396] The modern study of convergence is closely related to finding answers to historical questions such as why Britain was ahead in the First Industrial Revolution, and how America and the Continent caught up, as well as current questions on why some countries take and hold onto their lead in certain key modern industries. From a long-cycle perspective (see Chapter 2), the question is whether convergence is a long-term trend or whether leadership positions abruptly change at certain times, and formerly lagging nations take over as the new leaders. Nelson and Wright (1992) concluded that the postwar American lead could be attributed first to its strength in mass-production industries built on resource abundance and large domestic market size; and second, to investments in higher education and R&D, which far surpassed the levels of other countries at the time. It was not until Japan

xlviv This is a manifestation of the old guns-versus-butter tradeoff.

and the European nations made similar large investments in scientific and engineering education and in R&D that they were able to catch up.[397]

U.S. Government Investment in R&D

As was explained in Chapter 7, R&D intensity for a private company is a metric obtained by dividing total R&D expenditures by total revenues for any particular year. R&D intensity at a national level is calculated by dividing total national R&D expenditure – called Gross Domestic Expenditure on R&D (GERD) – by the country's GDP (gross domestic product). *National R&D intensity* provides an indication of the overall investment a nation is making in R&D and, by association, in innovation. Since national GDP numbers are widely available, R&D intensity can be calculated provided that a nation captures and publishes data on domestic R&D expenditures by public and private organizations. The OECD's Directorate for Science, Technology, and Innovation aggregates available national R&D intensity data, allowing national comparisons. Figure 10.3 shows R&D intensity in 2020 for selected countries, and the European Union (EU27) as a group. As can be seen, the United States spent just under 3.5 percent of GDP on R&D funded by all sources, which puts it below Israel, South Korea, and Sweden, but above Japan, Germany and China.

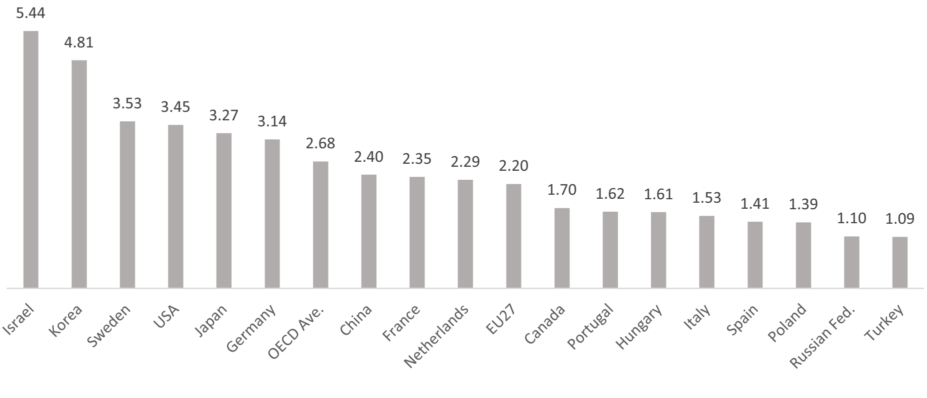

Figure 10.3: Country R&D Intensity (2020).
Source: OECD (2022).[398]

Given the relative size of its economy to other nations, the United States has funded the lion's share of global R&D in the years post World War II. At one point it was funding as much of 69 percent of post- World War II R&D (Office of Technology Policy 1997).[399] Though not as dominant as before, the United States is still the largest single spender on R&D.

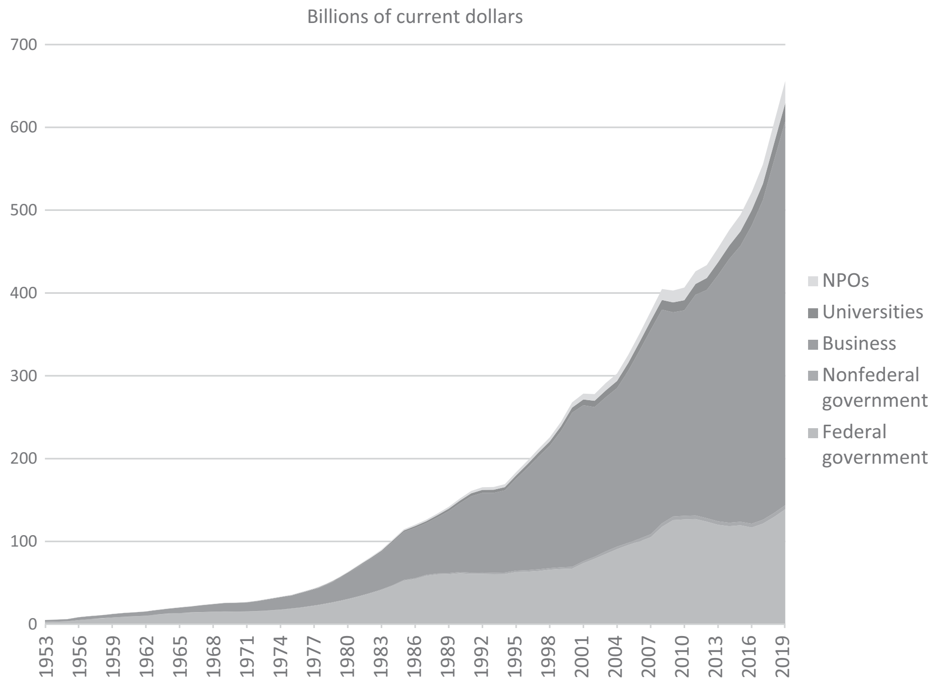

Figure 10.4: U.S. R&D Expenditures by Source of Funding: 1955–2019.
Source: Analysis of National Center for Science and Engineering Statistics (2021) data.[400]

In the United States, R&D is funded and performed by the federal government, state governments, businesses, universities, and nonprofit organizations (NPOs) (refer to Figure 10.4). Total U.S. R&D expenditures were $656 billion in 2019. Together, the U.S. federal government and business were responsible for well over 90 percent of all R&D expenditures. In 2019, government spent $139 billion and business $464 billion on R&D. That business now funds far more R&D than government in the United States is a major reversal of roles compared to the first three decades after the end of World War II, when government funding dominated. While there was a sharp decline in government R&D spending in the 1970s amidst a slow but steady rise in business R&D, it was only in 1980 that business R&D spending exceeded U.S. government R&D spending as can be seen in Figure 10.4.

Figure 10.5 shows that the importance of business spending on R&D has increased as the federal government's relative contribution has sharply decreased from its heydays in the 1960s during the Cold War and the Apollo space program. In 2019, the U.S. federal government spent only 0.65 percent of GDP on R&D as opposed to 1.86 percent of GDP during its peak in 1964. Business has stepped in, with R&D expenditures rising from 0.58 percent in 1953 to 2.16 percent in 2019.

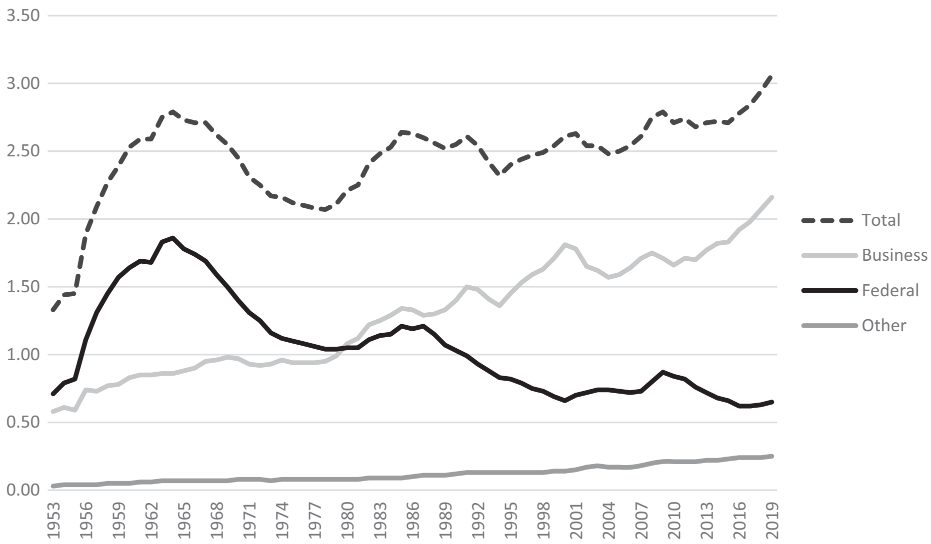

Figure 10.5: U.S. R&D Spending by Funding Source as Percent of GDP.
Source: Analysis of National Center for Science and Engineering Statistics (2021) data.[401]

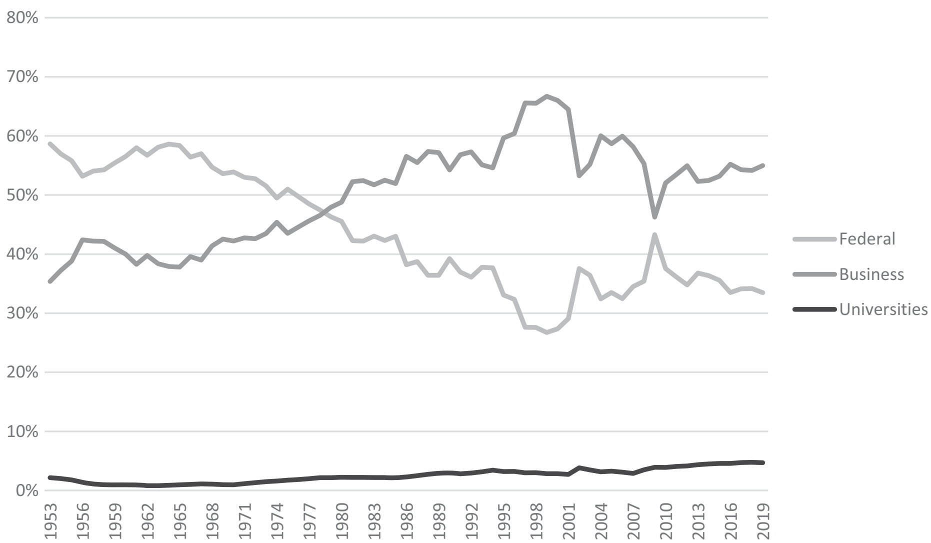

Figure 10.6: Share of U.S. Applied Research Funding.
Source: Analysis of National Center for Science and Engineering Statistics (2021) data.[402]

A major trend obscured by the total expenditure numbers becomes apparent when only the funding directed at applied research is examined. As can be seen in Figure 10.6, the government contributed a majority of the applied-research funding

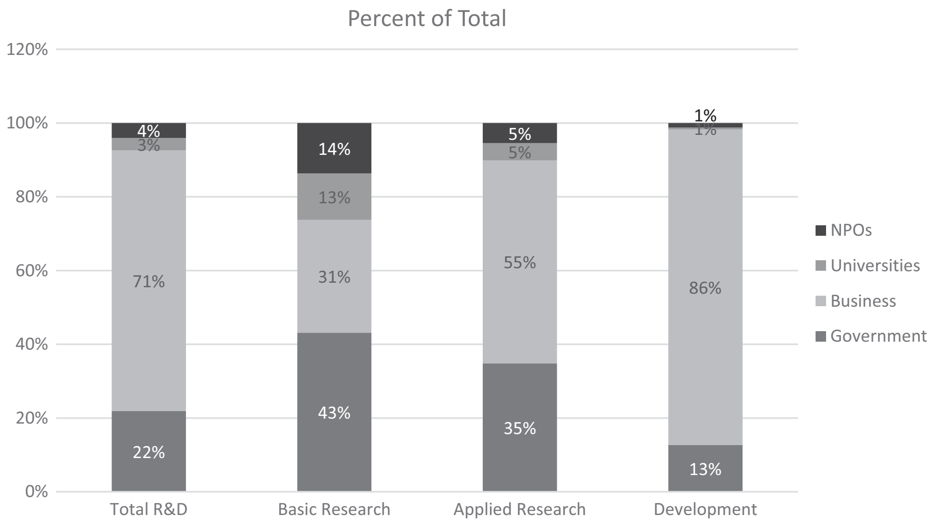

Figure 10.7: U.S. R&D Funding by Type and Source.
Source: Van Biljon analysis of National Center for Science and Engineering Statistics (2021) data.[403]

prior to the late 1970s, but subsequently, business has been spending more on applied research. This is consistent with the neoclassical philosophy of the government stepping in to correct market failures and funding primarily early research while leaving the rest to the private sector However, it is criticized by those pushing for a more activist, mission-oriented role for government, which includes seeing research through to fruition. The latter viewpoint will be further illuminated in Chapter 12.

As can be seen in Figure 10.7, the government still funds the plurality (43 percent) of basic research and 35 percent of applied research, while business funds 55 percent of applied research. Business funds 86 percent of development, with the government only funding 13 percent. In total, the U.S. government now only funds 22 percent of all R&D, with business funding 71 percent, and universities and NPOs funding 3 percent and 4 percent, respectively.

The largest agency R&D budgets and the respective budgets for basic research, applied research, and experimental development can be seen in Table 10.2. The total R&D outlay of the U.S. federal government was nearly $151 billion in its 2020 financial year.

In overview, defense and aerospace (NASA) consume half the federal R&D budget, with health-related research (mostly into pharmaceuticals and biotechnology) taking more than a quarter of the budget. The departments and agencies receiving the lion's share (93 percent combined) of U.S. federal R&D funding are:

– The *Department of Defense* with $62.5 billion or 41 percent of the total. It is noteworthy that most of this funding is going to experimental development of future defense products and systems, even though the basic and applied research budgets are large in dollar terms.

Table 10.2: U.S. Federal Obligations for R&D by Agency and Type of R&D: FY 2020 Preliminary.

	Percent of total	Total R&D	Basic research	Applied research	Experimental development
Department of Defense	41%	62,461	2,565	5,900	53,996
Department of Health and Human Services	28%	41,562	20,477	20,266	819
Department of Energy	11%	16,136	5,483	7,199	3,454
National Aeronautics and Space Administration (NASA)	9%	13,400	5,260	2,356	5,785
National Science Foundation	4%	6,157	5,342	814	–
Department of Agriculture	2%	2,904	1,183	1,506	215
Department of Commerce	1%	1,622	262	1,109	251
Department of Veterans Affairs	1%	1,603	669	902	32
Other agencies	3%	5,040	515	3,455	1,069
TOTAL	100%	150,885	41,755	43,507	65,622

Source: National Center for Science and Engineering Statistics (2021).[404]

- The *Department of Health and Human Services* with $41.6 billion 28 percent of the total. The National Institutes of Health (NIH) receive $39.3 billion of this amount for medical research, including pharmaceuticals and biotechnology.
- The *Department of Energy* with $16.0 billion or 11 percent of the total. $6.3 billion goes to the National Nuclear Safety Administration, $5.3 billion to Office of Science (which sponsors basic research in physics, supercomputers, and other cutting-edge areas) and $2.6 billion to Energy Efficiency and Renewable Energy R&D.
- The *National Aeronautics and Space Administration* (NASA) with $13.4 billion or 9 percent of the total.
- The *National Science Foundation* (NSF) with $6.2 billion or 4 percent of the total. The NSF supports fundamental research in all nonmedical fields (medical research being covered by the NIH).

The Influence of Defense R&D Spending

Throughout history, defense procurement has had a major influence on technological development. A recent book by Stanford University historian Priya Satia titled *Empire of Guns: The Violent Making of the Industrial Revolution* (2020), details the contribution of the British gun industry to the Industrial Revolution in Britain in the 18th century. Satia tells the story of how a family-owned firearm manufacturer in the city of Birmingham became the biggest gunmaker in Britain. By the late 17th century, British gun makers could make tens of thousands of guns per year. By 1815, they could make millions. This scaling up of manufacturing was directly enabled by a state who was willing to tinker with firearm designs and compromise features for a design that could be more easily mass-produced. The state also provided funds to overcome any supply-chain bottlenecks by training more workers. Starting in 1688 with the launch of the Nine Years' War and stretching through the end of the Napoleonic Wars in 1815, Great Britain was engaged in a state of near-constant warfare. The state would purchase not just guns, but cannons, uniforms, and other military equipment. This greatly stimulated private-sector innovation and financed industry expansion during the early Industrial Revolution.[405]

The prominence of defense-related R&D has been a major characteristic of the post-World War II era, particularly in the United States. Much has been written on a case or technology basis on military R&D leading to innovation, with examples such as the GPS and the internet among many. Taking a more systematic view, David Mowery (2010) suggests three main mechanisms whereby defense spending on R&D furthers private innovation:

1. *New bodies of scientific engineering knowledge* – mainly generated by basic and applied research – are created that can support both defense and civilian applications. In addition, such spending may create and expand institutions that train scientists and engineers who go on to innovate in the civilian world.
2. *Spinoffs* where defense-related programs create technologies with application in both defense and civilian-related uses. These are also called *dual-use technologies*.
3. *Procurement* in the form of substantial defense purchases of new technologies, which benefits the development of such technologies and creates an initial market for them. Having the government as a lead customer ordering substantial quantities also reduces the prices of new technology products while increasing their reliability and functionality.[406]

At the U.S. Department of Defense, the Deputy Assistant Secretary for Industrial Policy is responsible for the health and viability of the *Defense Industrial Base* as it relates to supporting national-security objectives. The Industrial Policy organization within DOD provides reports, conducts meetings, and shares assessments with Congress in an effort to inform legislation and policy related to the Defense Industrial Base.

Since 1994, the DOD's Industrial Base Policy Office (2022) compiles an Annual Report to Congress (as required by Title 10, U.S.C., section 2504), which summarizes the Department's industrial capabilities-related guidance, assessments, and mitigation actions. This annual report, titled *Annual Industrial Capabilities Report*, is available for public download. Each report summarizes Department of Defense industrial capabilities-related guidance, assessments, and actions initiated during the prior year and as they existed at the close of that year.[407]

Intramural Innovation by the U.S. Government

While most of the federal government's budget and focus is focused on extramural innovation by industry, academia, and other nongovernment organizations as previously discussed, there is also a substantial intramural amount of innovation happening inside the government. Joshua Bruce and John de Figueiredo (2020) point out that the U.S. federal government innovates along four dimensions, of which only the last two are not found in the private sector but are unique to government:

1. *Technological innovation*. These innovations contain "technically new and novel inventions and improvements that are consistent with the broader economics literature on technical change."
2. *Organizational innovation.* These are innovations that improve how government operates and is organized, often with the result of greater administrative efficiency.
3. *Regulatory innovation.* The federal government is responsible for defining and administering the laws of the country through a regulatory apparatus. "Regulatory innovations include the process of making rules and regulations, enforcing those regulations, and adjudicating these regulations. The government is continually evolving the rule-making process, within the rubric of the Administrative Procedures Act of 1946."
4. *Policy innovation.* These comprise new types of regulatory policies and frameworks implemented by the administrative state to achieve desired social welfare and policy objectives. Examples of policy innovations include the cap-and-trade program to combat pollution, and spectrum auctions to allocate broadcast rights over electromagnetic frequency ranges to the private sector.[408]

During 2020, the U.S. federal government employed 4.3 million full-time equivalent (FTE) workers, just under 4 percent of the total U.S. FTE workforce. About half these employees are in the military (1.4 million) and Post Office (585,000) combined. The other half are mostly civilians working within executive branch agencies. (Approximately 70% of these federal employees are on the General Schedule (GS) pay plan, which has 15 major levels called grades. The higher the grade level, the higher the skill level and the more senior the employee is.) The number of scientists in the government rose from 155,000 in 1980 to just under 200,000 by 2014 and has been fairly stable since. About half the scientists worked for the DOD, with NASA having the highest concentration of scientists. An analysis by Bruce and De Figueiredo (2020) found that about 87,000 of all government scientists were engaged in R&D-focused work while 26,000 were engaged in R&D-adjacent activities. Scientists were classified as being in an *R&D-focused position* if their primary job was to do research, development, testing and evaluation, or data analysis. Scientists were classified as being in an *R&D-adjacent position* if they engaged primarily in R&D grant administration, scientific and technical information processing/dissemination, or the management of science. The DOD has the largest share of federal R&D scientists; NASA, HHS, USDA, and DOE have substantial numbers of R&D-focused scientists.

Attempts were made by Bruce and De Figueiredo (2020) to assess the output of intramural federal government innovation activities. They found that both inputs (number of scientists as well as budgets) are heavily weighted toward three agencies: the DOD, NASA, and DOE. As a result, output measures such as patents were also heavily weighted toward these agencies, in particular because the scientific disciplines involved – engineering, physical sciences and some life sciences – result in more patentable results. A patent analysis will tend to undercount innovation outputs by agencies more engaged in data analytics, social science, mathematics, and other parts of life science. In terms of quality, government patents tend to be less cited than those of private company patents, but are slightly more original. Other metrics that could be used for government innovation output are:

- Number of academic publications by government scientists
- Innovation prizes awarded by agencies to their own researchers, as well as third-party prizes such as the Ash Center prizes for innovativeness in government
- Innovations where the government is a lead user; for example, NASA's use of novel rocket propulsion or life-sustaining technologies[409]

Chapter Summary

- The Linear Model of Innovation sees innovation as a sequential linear process that starts with basic research, followed by applied research, development, and finally production and diffusion. Government and international definitions of R&D and innovation tend to follow this model.
- However, the causality from basic research to applications may be reversed when a desired application is the driver for initiating basic research. This case is called Pasteur's Quadrant.
- The neoclassical case for government support of innovation is based on exception, only justifying public spending when clear market failures exist that require government intervention. This usually only provides a rationale for government supporting basic research.
- During WWII, the U.S. government directly supported applied research and development as well. This integrated model was revived for defense and space R&D due to the Cold War, with the result that the lion's share of U.S. government spending on innovation since then has been defense related.
- When private firms perform research, knowledge spillovers, that mean that their research can be used by others, inhibit their willingness to spend on research. This creates a rationale for government subsidizing research that would benefit society at large.

– Most U.S. R&D is paid for by either the federal government or business, with public spending concentrated in basic research and private spending concentrated in applied research and downstream innovation.
– The departments of Defense, Health and Human Services, and Energy together account for 80 percent of government R&D spending.
– Private-sector spinoffs from government spending can be significant, both in terms of new technologies and industry-capability building.
– The U.S. government also performs intramural research, employing about 200,000 scientists with 87,000 focused on R&D work.

Suggested Exercises and Assignments

– Find and discuss recent cases that fall into Pasteur's Quadrant. Describe what the need was, and what basic research had to be done before applications could be developed.
– Analyze the trends in R&D expenditure by a particular agency based on publicly available data. Construct a rough portfolio-of-initiatives bubble chart (see Chapter 8) for the agency's R&D initiatives. Discern the focus and priorities of the agency's R&D expenditure. Discuss whether these are consistent with the agency's stated mission.
– Find a novel example of a public-spending program intended to induce private-sector innovation. (Avoid picking DARPA or another obvious example.) Summarize the program in half a page, with appropriate references. Share and discuss in class. Comment on whether the program is succeeding in its goals, and how.

Recommended Further Reading

Block, Fred L., and Matthew R. Keller. 2011. *State of Innovation: The U.S. Government's Role in Technology Development*. Boulder, CO: Paradigm Publishers.

Cornell University, INSEAD, and WIPO. 2020. *The Global Innovation Index 2020: Who Will Finance Innovation?* Ithaca, Fontainebleau, and Geneva. Available at https://www.wipo.int/global_innovation_index/en/2020/.

Hall, Bronwyn H, and Josh Lerner. 2020. "The Financing of R&D and Innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation Vol. 1*: 609–639. Amsterdam: Elsevier https://doi.org/10.1016/S0169-7218(10)01014-2.

Janeway, William H. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, United Kingdom: Cambridge University Press, 2018.

Recommended Data Sources

The Organization for Economic Cooperation and Development (OECD) publishes an annual report, *Gross Domestic Spending on R&D*, for 46 countries as well as the EU27 and the OECD aggregate.[410]

The *World Intellectual Property Organization* (WIPO) publishes an annual report, *the Global Innovation Index* (WIPO 2021), that contains the economic profiles of over 130 countries, their ranking on a global level, data on patents, R&D expenditure, and various other measures of technological progress as well as the latest global innovation trends.[411] The report usually has a yearspecific thematic subtitle.

Chapter 11
National Innovation

An understanding of the national landscape that innovation is conducted in, as well as an appreciation for the roles of the main types of actors and their most important interactions, are prerequisites for crafting an effective innovation policy. The major frameworks that are used to model this landscape and the interactions between the main actors are, therefore, introduced in this chapter. The specifics of innovation policy and the instruments available to execute it will follow in Chapter 12, along with a discussion of the present-day challenges around innovation policy.

This chapter accordingly introduces innovation policy and its purpose, starting with the typical types of innovation policy. It proceeds to expound the concept of a National Innovation System what the constituent elements of such a system are. The connection between economic development and an expanded National Innovation System is explored, and the concepts of national innovative capacity and economic complexity are introduced. The Triple Helix Model is introduced, along with a discussion of how universities, government, and industry acting in concert produce knowledge and further innovation. Further extensions of the Triple Helix, as well as Mode 2 and Mode 3 knowledge production, are also explained.

Introduction to Innovation Policy

Since the late 1990s, there has been a rapid increase in policymaker interest in innovation policy, as was noted by Jakob Edler and Jan Fagerberg (2017).[412] Part of this may be explained by changes in what is understood by the term "innovation"; as its meaning has broadened, so has the scope of innovation policy. Schumpeter's distinction between invention and innovation is ever relevant, as it emphasizes that innovation employs pre-existing elements obtained from invention. Schumpeter's insight was that ideas (and invented technologies) are only consequential for our economic and social system if they are fully exploited and implemented at scale. Edler and Fagerberg (2017) distinguish three types of innovation policy:

- *Mission-oriented policies* that aim to provide solutions that can be implemented in practice to specific challenges on the political agenda. In order to design and implement effective policies, policymakers have to take all phases of the innovation process into account. Defense-solution policies are an obvious example that date back from World War II and earlier. A new modern-day mission would be innovation policy to combat global warming.
- *Invention-oriented policies* are more narrowly focused on the R&D phase; that is, the invention phase in Schumpeterian terms. Government spending on basic science and research post World-War II fall in this category, which long stood

https://doi.org/10.1515/9783110711066-011

on its own but today we would fit in under the umbrella of innovation policy. These policies were justified by neoclassical economists as needed to overcome market failures (the failure of the private sector to sufficiently invest in R&D on its own) as the economic gains would not be fully appropriate by companies who made the investment.
- *System-oriented policies* are concerned with system-level features at the level of national innovation – whether it be interaction between different parts of the system, the need for improving some vital components of the system, or the capabilities of the actors. The National Innovation System (NIS) approach and its adoption by national governments and the OECD for policy design and international comparison are directly associated with such policies. The innovation system literature draws on evolutionary economics (see Chapter 12).[413]

Innovation policy is also sometimes called *Science, Technology, and Innovation (STI) policy* to emphasize the R&D and technology elements included in the policy. Johan Schot and W. Edward Steinmueller (2018) have proposed three frames of STI policy, with two frames coming from the historical context and a third contemporary frame:
- The first frame is the Post-World War II government support for science and R&D to compensate for insufficient private sector investment, with the ultimate aim of driving economic growth.
- The second frame, which emerged during the 1980s amid a fast-globalizing world, was that of competitiveness, and the role that national innovation systems could play in knowledge creation and commercialization. STI policy was utilized to foster linkages and networks, to build clusters, and to promote entrepreneurship.
- The third frame is about dealing with our contemporary social and environmental challenges, and the need for transformation of the socio-technical system as conceptualized within the sustainability transition field.[414]

There are increasingly voices calling for innovation or STI policies to prioritize the third frame, as will be discussed toward the end of this chapter.

The study of Science, Technology, and Innovation Policy (STI) is somewhat confusingly called *Science Policy and Innovation Studies (SPIS)* by some researchers, such as Ben Martin (2012).[415] Being an evolving and multidisciplinary field, the scope of innovation policy studies is not easy to pin down. *Research Policy* by Elsevier claims to be the leading academic journal[li] dedicated to the field of innovation studies, and its definition is probably as authoritative as it gets:

li Other leading journals in the field are *R&D Management* and *Technovation*.

> Research Policy (RP) is a multi-disciplinary journal devoted to analyzing, understanding and effectively responding to the economic, policy, management, organizational, environmental and other challenges posed by innovation, technology, R&D and science. This includes a number of related activities concerned with the creation of knowledge (through research), the diffusion and acquisition of knowledge (e.g., through organizational learning), and its exploitation in the form of new or improved products, processes or services.[416] (Elsevier 2022)

Even the name of journal, "Research Policy," and its present subtitle, "Policy, Management and Economic Studies of Science, Technology and Innovation," suggest the evolution of this field from the original study of research policy to the study of innovation policy, with science and technology included in the scope.

Since the 1990s, the term innovation policy has been assumed by many to include the elements or science and technology, as well as the activities of research and development. For brevity, I will use the term *innovation policy* with the understanding that it includes all these elements, only elaborating on it when it is necessary to make distinctions.

Origins of the National System of Innovation

The core idea behind a National System of Innovation (NSI), as it is usually called in Europe, or a National Innovation System (NIS),[lii] as it is better known in the United States, is that there are important interactions between various economic and knowledge activities and actors that need to be managed or at least coordinated by the state if the nation is to achieve its full innovation potential. Luc Soete, Bart Verspagen, and Bas Ter Wheel (2010) define the concept of a National System of Innovation more comprehensively as follows:

> The *systems of innovation approach* spells out quite explicitly the importance of the 'systemic' interactions between the various components of inventions, research, technical change, learning, and innovation; the national systems of innovation brings to the forefront the central role of the state as coordinating agent. Its particular attractiveness to policymakers lays in the explicit recognition of the need for complementary policies, drawing attention to weaknesses in the system, while highlighting the national setting of most of those institutions.[417]
> (Soete, Verspagen, and Ter Wheel 2010, 1162)

A more succinct definition was offered earlier by Christopher Freeman (1987): A national innovation system is "the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies."[418]

The theory of National Systems of Innovation was developed in the 1980s and 1990s by Christopher Freeman,[419] Bengt-Åke Lundvall,[420] and Richard Nelson.[421] Freeman (1995) later credited Lundvall as being the first person to use the term.[422]

lii This is the term preferred in this book.

Freeman (1987) himself made a seminal contribution to the new field with his analysis of the Japanese innovation system.[423] Because of Japan's economic strength in the 1980s, there was much discussion at the time about Japan's unapologetic and seemingly highly successful use of a robust industrial policy to achieve dominance in several industries, as opposed to the United States and United Kingdom, who professed to follow hands-off free-market policies. In Japan, the Ministry of International Trade and Industry (MITI) had a prominent policy role in engineering the rapid catch-up of the Japanese economy after it was shattered during World War II (Johnson 1982).[424] Another important feature was the role of corporate R&D in Japan. A third feature was the emphasis on human-capital development. The conglomerate structure of Japanese industries that made large firms able to internalize externalities was another subject of interest.[425] Initial claims that Japan's success could be attributed to copying foreign technology were debunked when Japanese products and processes outperformed those from America and Europe. In fact, Japanese R&D had surpassed U.S. R&D as a proportion of civil industrial output. While U.S. R&D was heavily weighted toward defense, Japanese R&D was highly concentrated in the fastest growing civil industries such as electronics. Freeman (1995) also contrasts the Japanese system with that of the Soviet Union, where the state exercised complete control:

> Thus, whereas the integration of R&D, production, and technology imports at firm level was the strongest feature of the Japanese system, it was very weak in the Soviet Union except in the aircraft industry and other defence sectors. Finally, the [user-product] linkages which were so important in most other industrial countries were very weak or almost nonexistent in some areas in the Soviet Union.[426] (Freeman 1995, 12)

The above comparison illustrates the usefulness of the NIS approach not only in framing a country-level discussion on innovation policy, but also to facilitate international comparisons. According to Lundvall (2016), the main differences between nations will be reflected in the following areas and parameters:
- Internal organization of firms
- Inter-firm relationships
- Role of the public sector
- R&D intensity and R&D organization
- Institutional set-up of the financial sector[427]

Writing on the U.S. NIS, Robert Atkinson (2014) suggests a triangular conceptualization of an NIS:

> One way to conceptually organize all the factors determining innovation in a nation is to think of an innovation success triangle, with business environment factors along one side of the triangle, the trade, tax and regulatory environment along another, and the innovation policy environment along the third. Success requires correctly structuring all three sides of the innovation triangle.[428] (Atikinson 2014, 2)

Any study of national systems of innovation will include a historical, as well as a comparative, perspective to understand how nations have achieve success in the past, and whether there was a common set of policies associated with success. In 1791, the first U.S. Treasury Secretary, and founding father, Alexander Hamilton presented Congress with his *Report on the Subject of Manufactures*.[429] In the report, Hamilton commented on the economic principles of England and France and made recommendations to encourage the growth of the U.S. manufacturing industry to serve the larger goal of securing independence for the new country. The young United States was mainly an agricultural nation at the time, relying on imports of manufactured goods coming primarily from its former colonial master, Britain. The report is best known for Hamilton's argument for the need of protection of *infant industries* ("infant manufactures" as Hamilton called them) by means of import tariffs ("bounties") and industry subsidies paid for by collecting tariffs. His argument was that the U.S. industry would eventually be able to compete with British industry if given enough initial shelter to build up experience and become profitable and self-sustaining. The *infant-industry doctrine* has intuitive appeal, but it has also been contentious mainly because it is not clear when such protections can ever be lifted.

The 19th century German-American economist Friedrich List was probably the first to fully articulate the concept of a national system of innovation in his book titled, *The National System of Political Economy* (1842),[liii] which could just as well have been titled, "The National System of Innovation," given its contents. List had spent time in America where he got introduced to the ideas of an industrial policy to protect infant industries, as proposed by Alexander Hamilton. List was also skeptical of the notion of unfettered free trade, particularly from the point of view of a still-industrializing country. At the time, Great Britain was the most industrialized country, and both the United States and List's native Germany were keen to catch up to her. List studied Great Britain's history of industrialization, noting how she had imported and accumulated knowledge and expertise from all over the world, including skilled immigrants. Britain also maintained tariffs against certain imports to protect her own manufacturing industry, and she prevented the export of key machine-tool technology. The British system was set up to allow easy imports of all factors of production – commodities and people – with dominant naval power securing the sea routes for both exports and imports, and the conquest of overseas territories extending Britain's naval and trade reach.[430]

Most importantly, List recognized the dependence of manufacturing business on physics, chemistry, mathematics, the art of design etc. and how progress in the sciences would be leveraged by multiple industries, as these advances allowed processes to be improved and altered. List recognized the crucial role of systemic

liii Originally published in German under the title, *Das Nationale System der Politischen Ökonomie*.

interactions between sciences, technology, and accumulated knowledge and skills in the growth of a national economy:

> The present state of the nations is the result of the accumulation of all discoveries, inventions, improvements, perfections and exertions of all generations which have lived before us: they form the intellectual capital of the present human race, and every separate nation is productive only in the proportion in which it has known how to appropriate those attainments of former generations and to increase them by its own acquirements.[431] (List 1841, 113)

In essence, the modern NIS concept is based on an innovation-systems theory that recognizes two important types of interactions. First, what looks like innovation at the aggregate level is the result of interactions of many actors at the lower levels. Second, many of these interactions are governed not only by market forces, but by nonmarket institutions (Soete, Verspagen, and Ter Weel 2010).[432]

The United States was quite successful in its attempts to catch up to Great Britain, and Friedrich List had absorbed much from his residence in America and from Hamilton's report, which left a big impression on him. Eventually, List returned to Germany (which was not yet a unitary state at that time) and advised Prussia on her mission to industrialize and catch up to Great Britain. For underdeveloped countries, List emphasized the crucial importance of technology accumulation through two methods: *technology imports* to enhance local activities and *interventionist policies* to foster strategic infant industries. This strategy required direct government action. It was only the government who could afford to send officials on learning tours to countries such as Britain and the United States and pay students to study abroad. It was only the government who could build up an education system to introduce and diffuse new techniques throughout the economy. Due to the advocacy of List and others, Germany developed world-class technical education and training systems. List's model proved highly successful in Germany, and in its essence was followed in the 20th century by countries such as Japan, Korea, and China. In another historical twist, List had argued for the creation of a German customs union, which eventually led to Germany becoming a country (Freeman, 1995).[433]

The idea of having an inhouse corporate R&D department was pioneered in the chemical industry in Germany circa 1870, and soon adopted by Edison in the U.S. electrical industry with his Menlo Park Lab in 1876. Corporate R&D remained dominant in the United States until World War II necessitated the government's involvement through the connected-sciences approach, which was not only used for the Manhattan Project (nuclear bomb) but also for developing radar, computers, rockets, and explosives These successes of R&D in aiding the war effort made R&D to be seen as the source of innovation in the immediate postwar period (Freeman, 1995).[434]

The Modern National Innovation System

The notion of a national system of innovation was adopted in Europe, particularly by Sweden, Finland and the Netherlands. Supranational organizations such as the OECD, the European Commission, the United Nations Conference on Trade and Development (UNCTAD),[liv] the World Bank, and the International Monetary Fund (IMF) have also recognized the NIS in one form or another. The main policy implications are that the NIS is a departure from the narrow traditional market-failure role of government where every policy has to be justified by the identification of some market failure and an argument that the intervention is merited. In the systems view of innovation, markets are not relied upon to achieve an optimal state; instead, nonmarket institutions are an important driver of such outcomes. The innovation systems approach is also dynamic, not aligning policy to achieve an optimal outcome that is considered elusive, but subject to continuous adjustment, just like innovation itself. The major implications are, first, that there is a broader justification for the use of policy instruments; for example, to stimulate the distribution of knowledge and improve coordination between actors; and second, that the government is itself an integral part of the system. Innovation-systems policy includes all instruments that are traditionally part of science and technology policy, but adds education policy. Industrial policies and regional policies are other important components of innovation-systems policies (Soete et al. 2010).[435]

Lundvall (2016) proposes that the performance metrics of a national innovation system "should reflect the efficiency and effectiveness in producing, diffusing and exploiting economically useful knowledge." Lundvall's approach is centered on the innovation system as a dynamic social and learning system. (The strategic role of learning and knowledge in the system makes it an evolutionary concept). It has, however, been very hard to come up with suitable metrics that can reasonably be captured. Lundvall acknowledges that neither R&D intensity, nor metrics such as patent count, proportion of new product in sales, or proportion of high-tech products exported are sufficient in their own right, but that they could be combined for a more satisfactory assessment of the performance of a national system.[436]

While acknowledging that there is no national coordinated policy system in the United States, Atkinson (2014) discerns the main elements comprising the U.S. NIS as tabulated in Table 11.1. The three column headings can also be thought of as sides of a national-innovation triangle.

While some nations such as Japan and many nations in Europe have strong innovation policy systems, they also suffer from more restrictive regulatory and more limited business environments compared to the United States. The United States

liv A United Nations agency that assists developing countries with trade, investment, finance, and technology to foster inclusive and sustainable development.

Table 11.1: Elements of the U.S. National Innovation System.

Business Environment	**Trade, Tax, and Regulatory Environment**	**Innovation Policy Environment**
Business Financing System – Venture and Risk Capital – Firm Finance (Debt and Equity)	Regulatory Environment – Industry Structure and the Nature of Competition – Regulatory System for Entrepreneurship – Role and Form of Regulation – Transparency and Rule of Law	Research and Technology – Support for Research in Universities and Research Labs/Research Institutes – Federal Labs – University Research – Technology Transfer Systems – Support for Research in Business
Cultural Factors – Nature of Customer Demand – Risk Taking and Entrepreneurship – Attitudes Toward Science and Technology – Collaborative Culture – Time Horizon and Willingness to Invest in the Future	Tax, Trade, and Economic Policy – Macroeconomic Environment – Tax Policy – Trade Policy – Intellectual Property – Standards	Systems of Knowledge Flows – Innovation Clusters – Industry Collaboration Systems (with academia and research institutes) – Acquiring Foreign Technology and Exporting U.S. Technology – Technology Diffusion and Adoption
		Human Capital System – Education/Training (K–12) – Higher Education – Skill/Technical Training – Immigration Policy

Source: Based on Atkinson (2014).[437]

generally has a good business and regulatory environment, but a weaker policy environment. No nation scores perfectly on all elements.

A stronger NIS is likely to attract more entrepreneurs, who tend to vote with their feet. A recent investigation by Annamaria Conti and Jorge A. Guzman (2019) on what benefits Israeli entrepreneurs derive from migrating to the United States has found that the U.S. entrepreneurial ecosystem has advantages over other innovative economies from several sources that can provide sizeable advantages to startups. In particular, these are the availability of investors (which facilitates fundraising), large consumer markets (which facilitate sales growth), and large acquisitions markets (which facilitate exit strategies).[438]

Too often innovators fail to enjoy significant economic returns from a good innovation, even as their customers, imitators and other industry participants benefit.

David Teece (1986) demonstrated that when imitation of an innovation is easy to do, markets do not work well, and the profits from such an innovation may go the owners of certain complementary assets, rather than to the developers of the intellectual property.[lv] Innovation firms who do not have manufacturing, supply chain, and market distribution capacities may die as others take over the production of the innovation. This implies that the boundaries of the firm are an important strategic variable for innovating firms and the ownership of complementary assets may determine who wins or loses from innovation. Imitators can often outperform innovators if they are better positioned in terms of complementary assets. The implication for public policy is that the promotion of innovation should not only focus on R&D, but also on the establishment of complementary assets and underlying infrastructure. This includes removing barriers to the development of complementary assets. Tariffs and trade restrictions, in particular, need to be adjusted so they do not harm innovators while protecting imitators.[439]

National Innovative Capacity and Patenting Activity

Jeffrey Furman, Michael Porter, and Scott Stern (2002) have proposed a concept they call *national innovative capacity*, which is "the ability of a countryas – as both a political and economic entity – to produce and commercialize a flow of new-to-the-world technologies over the long term." The concept draws on Romer's endogenous growth theory (refer to Chapter 2), the literature on national innovation systems (refer to Chapter 11), and Michael Porter's cluster-based theory on national industrial competitive advantage – for the latter, see Porter (1990).[440] Taken together, these perspectives suggest that:

1. National innovative capacity depends on the presence of a strong common innovation infrastructure or cross-cutting factors which contribute broadly to innovativeness throughout the economy
2. A country's innovative capacity depends on the more specific innovation environments in a country's industrial clusters
3. National innovative capacity depends on the strength of linkages between the common innovation infrastructure and specific clusters[441]

Furman et al. (2002) then used this concept to analyze a dataset of patenting activity for 17 OECD countries between 1973 and 1996. The results suggested that public policy plays an important role in shaping a country's national innovative capacity. Public policy can increase the level of R&D resources available as well as shape

lv Economists use the term *appropriability* for the capacity of a firm to retain the added value it generates for its own benefit. This situation is an example of a lack of appropriability, because the innovator is unable to appropriate all the benefits.

human capital investment and innovation incentives. Furthermore, they could discern a convergence in innovative capacity across the OECD.[442]

Patent data are often used to track and compare the level of innovative activity in a country, since patent data are much easier to obtain than to quantify other aspects of innovation. However, patent data will only capture a fraction of innovative activity, that which leads to patents. Inventors and innovators who have devised a novel product or solution have three ways of taking advantage of their intellectual property before others do: First, they can take out a patent, which will require disclosure of the invention in return for a temporary monopoly right to use it. Second, they can keep it as a *trade secret*, which will provide them protection as long as they can keep a secret. The most famous trade secret is probably the recipe for Coca-Cola, which is locked in a vault and has been successfully protected for well over a century. The third way is to simply take advantage of the lead time enjoyed by the originator, get the innovation to market before everyone else, and ramp up production and distribution fast enough to build a strong market share.

The extent to which patent laws encourage innovation or not has been a topic of much research and debate. According to a review of research by Petra Moser (2013), the majority of innovations in countries with patent laws have historically occurred outside the patent system. And countries without patent laws produced as many innovations as countries without patent laws during at least some time periods. Secrecy was the main alternative mechanism used to protect intellectual property. In some industries secrecy is more effective and in these, inventors historically used less patents. On the other hand, advances in scientific analysis reduced the effectiveness of secrecy and have made inventors more dependent on patents. The implication for innovation policy as it is related to patent laws is that polices that strengthen patents to spur innovation will fail to encourage much innovation if a substantial share of innovation occurs outside the patent system. Moser (2013) concludes that the weight of historical evidence on patents that grant strong intellectual property rights to early inventors may discourage innovation. Instead, policies that encourage the diffusion of ideas and adjust patent laws to facilitate easier entry and encourage competition may be more effective at promoting innovation.[443]

Economic Development and the Expanded NIS

An analysis by Jan Fagerberg and Martin Srholec (2008) of the role of innovation capabilities in economic development across 115 counties between 1992 and 2004 has identified four NIS capabilities that can explain large differences in economic development. These are:

- The development of the innovation system. Countries who have improved their innovation systems so that they were functioning well have been more successful in catching up in GDP growth.

- The quality of "governance." A well-functioning innovation system is necessary, but not sufficient. Good governance is critical to realize the desired economic results
- The character of the "political system." There is no evidence that the adoption of a Western-style political system is more conducive to growth, and it may be the opposite way around for poorer countries, as the examples of China and Vietnam as well as pre-democratic (South) Korea suggest.
- The degree of "openness" to trade and foreign direct investment. There is little evidence that openness to trade is correlated with economic growth. Poorer countries with less absorptive capacity are much less likely than richer countries to benefit from direct foreign investment.[444]

In their report, *The Innovation Paradox* (2017), World Bank economists Xavier Cirera and William Maloney argue that developing countries are foregoing huge productivity gains that could be achieved by investing more in innovation and technology catchup. The report, Volume 1 in the *World Bank Productivity Project*, validates Schumpeter's belief that the potential productivity gains of adopting new technologies are substantial, showcasing very high rates of return to innovation in advanced countries and implying social rates of return to R&D far above private rates of return. The authors propose expanding the concept of the National Innovation System to incorporate EFI (equitable growth, finance, and institutions) since missing complements and failed markets are a much larger problem in developing countries. See Figure 11.1. For example, firm capabilities are critical complementary factors and deserve a lot of attention, particularly management quality, and a sequential policy mix is required to build firm capabilities step by step.[445]

The relatively new concept of *economic complexity* has been developed by César Hidalgo and Ricardo Hausmann (2009) to provide a novel view of economic growth and development based on trade data. The theory has three parts:

- First, that it is possible to quantify the complexity of a country's economy by examining its export composition
- Second, that this measure of complexity is correlated with a country's income level
- Third, that future growth can be predicted based on the deviation of current complexity from the current income level[446]

The implication is that economic development efforts should focus on creating and improving the conditions conducive to greater complexity to generate sustained growth (Hidalgo and Hausman, 2009).[447] The link between economic complexity and economic growth has been found compelling by many academic researchers and has attracted much subsequent research. The concept of economic complexity and its analytical framework have caught on with institutions such as the European Commission, the World Bank, the OECD, and the World Economic Forum (WEF). Economic

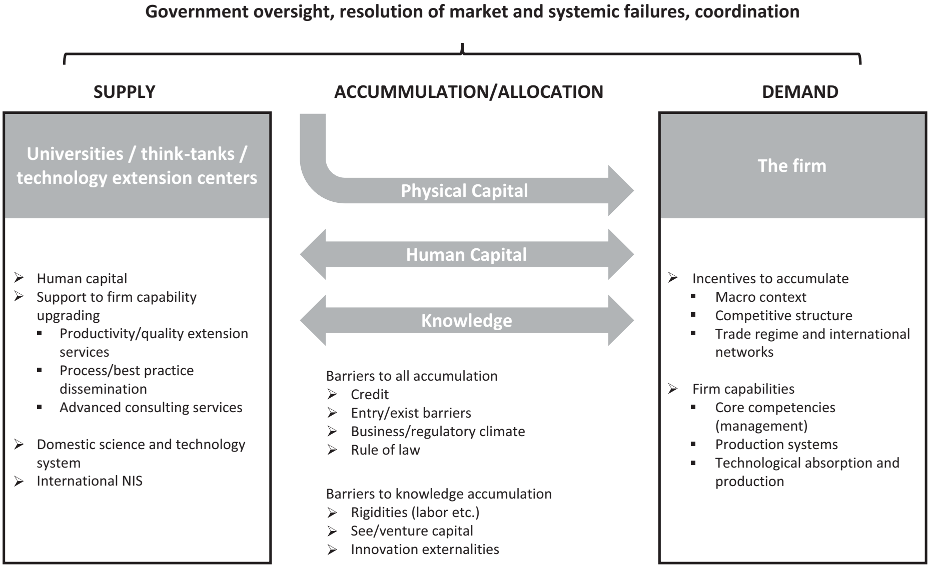

Figure 11.1: The Expanded National Innovation System.
Source*:* Reproduced from Cirera and Maloney, World Bank (2018).[448] Creative Commons Attribution CC BY 3.0 IGO.

complexity has also been found helpful in inequality research, as low economic complexity has been found to be a significant predictor of inequality (Hartmann et al. 2017).[449]

In a recent overview, Balland et al. (2022) point out that economic complexity is strongly linked with knowledge in the modern economy. According to them, productive knowledge takes three forms:
1. *Embodied knowledge* in tools and materials or artifacts
2. *Codified knowledge* in books, formulas, algorithms and how-to-do manuals
3. *Tacit knowledge* or know-how in brains[450]

The division of tacit knowledge between individuals is a form of specialization, where specialization allows the whole of society to know more, and do more, because individuals know different things. Specialization among individuals allow firms, cities, and countries to diversify. Societies with specialized individuals have access to a greater degree of knowledge and are, therefore, more diversified. Such a society of highly specialized individuals is more likely to innovate by combining ideas into new technologies. Statistically, the number of possible combinations will grow exponentially with the variety of elements available to combine. The converse is also true, which may be a big cause of income divergence between nations. Developed countries are more diversified and more complex, able to produce products and services that require a greater variety of knowledge. Thus, the policy implications are for countries and regions to increase their levels of specialization into more complex economic activities (Balland et al. 2022).[451]

Economic complexity rankings for countries and comprehensive country databases can currently be found at two major sources:

– The *Atlas of Economic Complexity* maintained by the Growth Lab of Harvard University (2022)[451]
– The *Observatory of Economic Complexity* (OEC 2022).[453] The OEC is now a for-profit data service, but it originated from postgraduate work by Alex Simoes at MIT, supervised by Professor Hidalgo (Simoes and Hidalgo 2011).[454]

The concept of economic complexity has further underlined the importance of knowledge development and specialization in order for a country to be competitive in the modern global economy. The Triple-Helix Model in the next section was conceived to better visualize how the modern knowledge society operates, and what its implications are for innovation policy.

Universities and the Triple-Helix Model

Since at least the 19th century, the accepted missions of academia have been teaching and research. During the late 19th and early to mid-20th century industrial laboratories employed many of the graduates as industry become more reliant on scientific research, both basic and applied. However, the large industrial laboratories declined during the last few decades of the 20th century. To fill the void left by these laboratories, a recent third mission for universities has become apparent, which is more directly contributing to economic development through technology-transfer to industry. Universities in the United States and around the world are currently in various stages of pursuing this new mission. The recognized impetus for it has been the decline in defense spending in the West after the end of the Cold War in the early 1990s (Etzkowitz and Leydesdorff 2000).[455]

> The common objective is to realize an innovative environment consisting of university spin-off firms, tri-lateral initiatives for knowledge based economic development, and strategic alliances among firms large and small, operating in different areas, and with different levels of technology, government laboratories, and academic research groups.[456]
>
> (Etzkowitz and Leydesdorff 2000, 112)

Originally proposed by Henry Etzkowitz and Loet Leydesdorff (1995), the *Triple Helix Model of Innovation* model attempts to visualize[lvi] a complex interaction process whereby the main three actors – government, universities, and industry – collaborate continually

lvi The intertwined double-helix structure of DNA is the inspiration for this visual metaphor.

in a way that is both intertwined with one another and influences one another.[457] The Triple Helix depicts government, industry, and universities as three relatively independent spheres that impact one another dynamically. It is modeled as a helix because these spheres overlap and interact continuously, with the respective strands reinforcing one another on the way up. (That is why it is depicted as a helix instead of a static Venn-diagram of three overlapping spheres.) A simplified, flat representation of the Triple Helix with the relationships between the three actors can be seen in Figure 11.2.

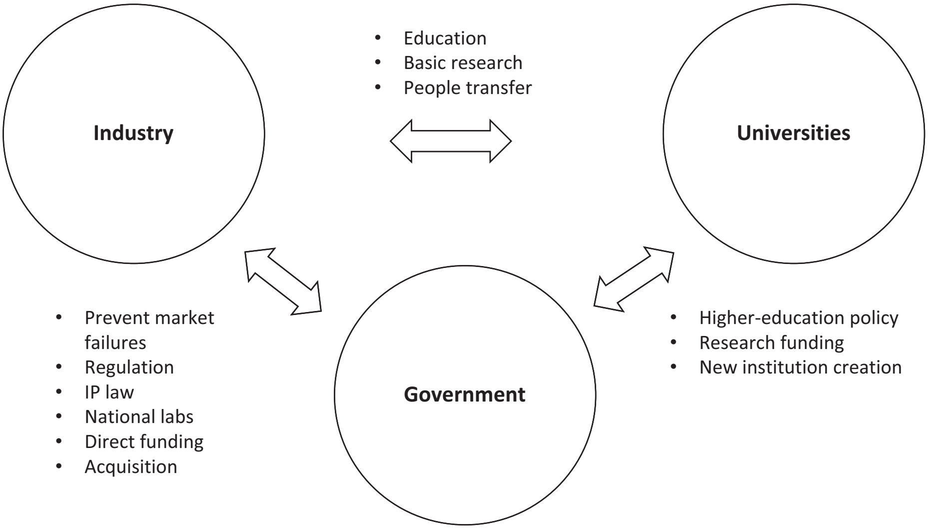

Figure 11.2: The Triple Helix of University-Industry-Government Relations.
Source*:* Inspired by the concept proposed by Leydesdorff and Ekzkowitz (1998).[458]

The *Triple-Helix Model* is intended to visualize how the modern knowledge society operates with economic transformations originating from constant progress in science and technology. As such, it is consistent with the evolutionary-economics philosophy (see Chapter 2). It is also an institutional model that reflects the triangular nature of innovation spending, policies, and the sharing of innovation activities between the government, private industry, and universities. As such, it is a key aspect of any national or multinational innovation policy. Government higher-education policy, researching funding, and the creation of new academic institutions largely determine the role of universities in national innovation. On their part, universities perform basic research and educate the people who go to work in industry, while professionals with industry experience come back to take on academic roles. Government regulations in general, competition policy in particular, and other laws such as intellectual property laws circumscribe the environment in which private firms innovate and operate. Public spending on innovation in the private sector is intended to address market failures

and/or promote industrial policy depending on the paradigm followed by the government of the day (Etzkowitz and Leydesdorff, 1995).
Since each actor has a relationship with each of the other, their respective roles can be discerned as follows:

– *Government and industry*. Government steps in to correct market failures and regulates industry to mitigate excesses. Government also provides the legal framework, particularly in terms of intellectual property law, to give protection to researchers and innovators, and provides an orderly market for the buying and selling of knowledge. The government can also directly influence industry innovation by sponsoring national laboratories, funding research and some forms of innovation, and by acquiring (purchasing) innovations from private firms.
– *Government and universities*. Universities are regulated, shaped, and often funded through government education policies. Governments can also create new universities, such as the U.S. land-grant universities. Specific funding for research from government agencies enable and influence the basic research that universities perform.
– *Industry and universities*. Universities educate new scientists and engineers who go on to work in business. The universities also perform basic research that business can use a starting point to further develop technologies. And experienced practitioners from business return to permanent or temporary teaching roles at universities to transfer their expertise to the next generation.

The Triple Helix is an alternative model to the older Linear Model of Innovation. It is a nonlinear model that extends the Linear Model by taking (nonlinear) interactive and recursive terms into account. These nonlinear terms change the causal relationships between inputs and outputs. It is also transformative within each of the spheres, as ". . . both the innovator and the innovated system are expected to be changed by the innovation." The driving force of the interactions is the "expectation of profits," which may mean different things to the various actors.[459]

The Triple Helix Association (THA)[460] is a nonprofit association that exists "to advance the scientific knowledge and practical achievements related to all aspects of the interaction between academy-industry-government (Triple Helix) for fostering research, innovation, economic competitiveness and growth."[461] THA holds conferences and symposia, issues THA awards for excellence to researchers, practitioners, and policymakers, and generally provides a network for researchers to cooperate. Its publication, the *Triple Helix Journal*, publishes research papers related to the topic.

Henry Ekzkowitz (2008) points out that it is possible to arrive at the Triple Helix by different routes. A *statist model* of societal organization is when the government is the dominant institutional sphere with industry and academia subordinate parts of the state. The former Soviet Union, France, and several Latin American countries exemplify the statist model. Its opposite, the *laissez-faire society*, has separation between the institutional spheres. Skepticism of government implies that it is best for these spheres to operate with connections that are not too close. In reality, however, the spheres operate more closely together than the ideology would imply. This is the case for countries such as the United States and United Kingdom.[462] The coming-together of these spheres in a triple helix is the logical end of a historical process of societal development across the last few centuries, as Ekzkowitz states in his book on the Triple Helix:

> The growth of science-based technology, from the 17th century, intersecting with the emergence of independent institutional spheres in the 18th century, founded a new dynamics of innovation. These two dimensions came together in the creation of the research university in the 19th century, incorporating experimental science. The teaching laboratory was invented, scaling up the integration of research and teaching, including research with practical implications, as the university gained autonomy from other social spheres. These twin developments augured the transition from a society based on vertical stratification in the premodern era to one increasingly based on horizontal relationships among institutional spheres.[463]
>
> (Etzkowitz 2008, 14)

Modes 2 and 3, and the Production of Knowledge

Mode 2, a new paradigm for producing scientific advances and innovation based on the notion of socially distributed knowledge, was introduced in an influential book by Michael Gibbons et al. (1994), *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Mode 2 was defined by deliberate contrast with *Mode 1*, the old paradigm of scientific discovery through experimentation, which is also closely associated with the Linear Model. Mode 1 is so-called “traditional knowledge” that is generated within a specific discipline and primarily in an academic context. Mode 2 represents knowledge generated outside of universities in the broader, transdisciplinary social and economic context. The transition from Mode 1 to Mode 2 has been enabled by the expansion of higher education to a much larger proportion of the population in the last few decades. As a result, there was a surplus of highly skilled graduates who could not be absorbed by universities. These people found work in private industries or even started their own enterprises, consultancies, or think-tanks. The result is new knowledge proliferating from multiple sources outside of universities, who no longer have a monopoly on research. Unlike peer review, which serves as a quality test of new knowledge in an academic setting, Mode 2 knowledge is mostly tested by success in the competitive market.[464]

Three of the authors of *The New Production of Knowledge* published a paper to further clarify and expand their Mode 2 proposition (Nowotny, Scott, and Gibbons

2003).[465] They point out that the transformation of the research process is due to three significant trends:

– *The increasing desire to steer research priorities*. This can be seen at the supranational level (e.g., the European Union), the national level, and at the system level (with research councils adopting more top-down research priorities).
– *The commercialization of research*. With the decline in the adequacy of public funding, researchers turn to alternative sources. Also, universities have become increasingly aware of the value of the intellectual property generated by their research, and desire to exploit (monetize) it themselves. This creates questions about who owns the intellectual property of research paid for by another party, and it diminishes the ideal of science as a public good. If the IP is valuable, confidentiality becomes a consideration as well as a reluctance to give it away through open publication.
– *The accountability of science*. Efforts are made by government funding agencies to evaluate the effectiveness of research they paid for and assess the quality of the output. This creates concerns about gameplaying by researchers, distortions of the assessments themselves (e.g., they may not recognize cross-functional research), and the incentives created for researchers to go for industry-style production – making it safer to deliver predictable and measurable results rather than groundbreaking research.[466]

(Nowotny, Scott, and Gibbons 2003, 181–184)

The Linear Model of Innovation could only represent either technology-push or market-pull innovation. However, nonlinear models of innovation in the evolutionary school allow for nonlinear dynamics that include the simultaneous evolution of technologies and institutions. The modern digital age is an example of a group of technologies that pushed forward innovations and new applications; however, the current situation is more complex, with firms and agencies learning how to reorganize these powerful new technologies and master demanding applications that best fit their new incarnations. Etzkowtiz and Leydesdorff (1995) call this phenomenon the *co-evolution* of technologies and institutions.[467]

Elias Carayannis and David Campbell (2009) have proposed *Mode 3* and the *Quadruple Helix* as the respective expansions of Mode 2 and the Triple Helix. Mode 3 is a system consisting of *innovation networks* and *knowledge clusters*. The *Mode 3 Innovation Ecosystem* is seen as the nexus of an emerging 21st-century innovation ecosystem in which people, culture, and technology form the essential building blocks.[468] In this nexus these different parts:

> meet and interact to catalyse creativity, trigger invention and accelerate innovation across scientific and technological disciplines, public and private sectors (government, university, industry and non-governmental knowledge production, utilisation and renewal entities) and in a top-down, policy-driven as well as bottom-up, entrepreneurship-empowered fashion.[469]
>
> (Carayannis and Campbell 2009, 202–203)

The fourth helix in the Carayannis-Campbell model, added to the existing three in the Triple Helix, is the *media-based and culture-based public*. Innovation policies have to acknowledge the important role that the public plays in achieving policy objectives. The Quadruple Helix, therefore, acknowledges the role that the media system plays in constructing and communicating the "public reality" that the public is also influenced by culture and values. As such, knowledge and innovation must reflect the dynamics of the so-called *media-based democracy*.[470]

The Triple Helix emphasizes knowledge production and innovation in the economy and is, therefore, compatible with the knowledge economy. The Quadruple Helix goes beyond that to include the perspective of the knowledge society and of knowledge democracy for knowledge production and innovation. The Quadruple Helix is compatible with environmental sustainability because the sustainable development of a knowledge economy requires a coevolution with the knowledge society. Thus, the necessary socioecological transition of society and economy can be contained within the Quadruple Helix (Carayannis et al., 2012).[471]

Other authors have added other dimensions such as globalization to extend the model. And Brundin et al. (2008) have suggested including the entrepreneur in the developmental context.[472] In response, Leydesdorff (2012), one of the originators of the Triple Helix, proposes that an *N-tuple* of helices (even 20+) may be envisioned as necessary to extend the model to incorporate any other dimensions.[473]

Chapter Summary

- There are three primary types of innovation policy: mission-oriented, invention-oriented, and system-oriented.
- The National Innovation System (NIS) comprises the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies.
- In the 19th century, Friedrich List recognized the dependence of the manufacturing industry on progress in multiple industries, and the crucial role of systemic interactions between sciences, technology, and accumulated knowledge and skills in the growth of a national economy.
- The dimensions of the U.S. NIS are: the business environment; the trade, tax, and regulatory environment; and the innovation policy environment. The expanded NIS can also be thought of as a knowledge system having a supply (universities) and demand (private business) side, with allocation and accumulation of human, physical and knowledge capital between the two sides. The government's role is to oversee and coordinate these interactions, correcting for market failures.
- Economic complexity is a new term that measures the complexity of a country's exports. It is believed to be correlated with national income growth, with the implication that developing countries need to diversify their economies.
- The Triple-Helix Model of Innovation emphasizes the central role of academia alongside government and industry within a modern knowledge society. It focuses

on the importance of the relationships between each of the three parties for fostering research, innovation, economic competitiveness, and income growth.
- Mode 1 is the traditional paradigm of scientific discovery through experimentation. It is associated with the Linear Model. Mode 2 is a new paradigm for producing scientific advances and innovation based on the notion of socially distributed knowledge, which emphasizes knowledge creation outside universities. It is associated with the Triple Helix Model.
- Mode 3 and the Quadruple Helix are the respective expansions of Mode 2 and the Triple Helix. Mode 3 is visualized as an ecosystem consisting of innovation networks and knowledge clusters.

Suggested Exercises and Assignments

- Research and write a paper that compares and contrasts the current national innovation systems of two countries with each other. Comment on the relative strengths and weaknesses of each. Make recommendations to one of the countries on how it can strengthen its innovation system by adopting some of the strengths of the other.
- Choose one industry cluster in a particular country and analyze it using the Quadruple Helix framework. Identify the most important sources of knowledge creation and the most important conduits of knowledge exchange. Make recommendations on innovation and industrial policies that would strengthen this industry cluster.
- Analyze patent data to study and predict the trajectory of technological progress in a selected technological-intensive industry (e.g., battery technology, genomics, quantum computing). Identify the top universities and companies, respectively, that seem to be the leading generators of technological knowledge. Make predictions on which companies and countries, respectively, are best positioned to become dominant in the field.

Recommended for Further Reading

Atkinson, Robert D., *Understanding the U.S. National Innovation System*. The Information Technology & Innovation Foundation (ITIF), June 2014, Available at SSRN: https://ssrn.com/abstract=3079822orhttp://dx.doi.org/10.2139/ssrn.3079822

Etzkowitz, Henry, and Chunyan Zhou. 2017. *The Triple Helix: University–Industry–Government Innovation and Entrepreneurship*. Routledge.

Jaffe, Adam B., and Manuel. Trajtenberg. 2002. *Patents, Citations, and Innovations: A Window on the Knowledge Economy*. Cambridge, MA: MIT Press.

Lundvall, Bengt-Åke, ed. *National Systems of Innovation: Toward a Theory of Innovation and Interactive Learning*. Vol. 2. Anthem Press, 2010.
Nelson, Richard R. *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press, 1993.
UNESCO. 2021. *UNESCO Science Report: The Race Against Time for Smarter Development*. S. Schneegans, Susan, Jake Lewis, Tiffany Straza, eds., UNESCO Publishing: Paris. Available at https://unesdoc.unesco.org/ark:/48223/pf0000377433.locale=en.

Chapter 12
Innovation Policy Tools and Challenges

In order to craft effective innovation policies, policymakers need to understand the full range of tools at their disposal, as well as what the evidence is about the effectiveness of particular tools. In addition, policymakers need to understand the types of policies they can pursue; how these policies are grounded in beliefs about economic growth, mission goals; and how innovation actually happens in private industry. Building on the frameworks of national innovation introduced in the previous chapter, as well as topics covered in earlier chapters, this chapter accordingly reviews the policy tools that governments have at their disposal to further national innovation and execute their missions.

The main tools of innovation policy are introduced together with the extent of their respective impacts in terms of net benefits, time frame of impact, and effect on inequality. Innovation policy tools are also classified in terms of their demand or supply orientation and the typical goals associated with each. Policy options to support the commercialization of technologies after the completion of basic research are discussed with specific reference to the U.S. Bayh-Dole Act.

The rationale for government support for innovation is revisited in a discussion of policy innovations in the United States that have given the public sector a more important role in innovation. The history of U.S. government support for innovation during, and subsequently to, World War II is related to illustrate the perennial tensions between a desire for a limited state role in innovation versus the exigencies of national security and associated missions, such as the space program and national health. Finally, the main critiques of the current status quo, and the arguments made for change by prominent voices, are related.

The Tools and Instruments of Innovation Policy

Nicholas Bloom, John Van Reenen, and Heidi Williams (2019) reviewed the typical innovation policy tools used by governments around the world, and assessed their effectiveness based on the available evidence in the literature (refer to Table 12.1).[474]

The main policy levers for promoting innovation are tax policies that favor R&D, government research grants, policies to increase the supply of human capital for innovation through training and immigration, intellectual property policies, and policies intended to promote competition:

R&D grants. Governments can sponsor R&D projects in the private industry directly by providing grants to universities and even private companies based on certain criteria, often as part of thematic R&D programs within government agencies. Direct grants can easily target the type of research that the government wants to

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Table 12.1: Innovation Policy Tool Evaluation.

Policy	**Net benefit Assessed magnitude: * low ** medium *** high**	**Time frame of impact Short, medium, or long (S/M/L) run**	**Effect on inequality ↑ up ↓ down**	**Quality of evidence Low, medium, or high (L/M/H)**	**Conclusiveness of evidence Low, medium, or high (L/M/H)**
Direct R&D grants	**	M	↑	M	M
R&D tax credits	***	S	↑	H	H
Patent box	Negative	NA	↑	M	M
University incentives	*	M	↑	M	L
STEM supply from universities	**	L	↓	M	M
Skilled[lvi] immigration	***	S-M	↓	H	H
Trade and competition	***	M	↑	H	M
Intellectual property reform	Unknown	M	↑	M	L
Mission-oriented policies	*	M	↑	L	L

Source: Adapted from Bloom, Van Reenen, and Williams (2019, 180).[475]

favor, for example, by giving money to universities for particular basic research. Governments can also fund their own R&D labs.

R&D tax credits. Most OECD countries provide some form of favorable tax treatment to R&D. While ordinary R&D expenditures are already tax deductible to a high degree, additional deductions (e.g., 150 percent) are frequently used to encourage R&D even more.

Patent boxes. These are special tax regimes that apply lower tax rates to revenues that come from patents versus revenues from general commercial sources. The problem with patent boxes is that they encourage "tax shopping" as firms – particularly multinational firms – shift their patent royalties around different tax jurisdictions and manipulate the stated revenue from patents to get the most favorable treatment, thus distorting the tax system.

Human capital supply. One part of such a policy would *STEM supply from universities* to encourage the founding and expansion of universities who train future workers in

lvi Science, technology, engineering, and mathematics studies.

science, technology, engineering, and mathematics (STEM). The other part of such a policy would *skilled migration* to encourage immigration of STEM workers. Another policy could reduce the barriers that exist to people from disadvantaged groups becoming inventors and innovators through, for example, improving school quality and providing mentors.

Trade and competition. Competition can spur companies to innovate to protect and gain new markets for their products. The moment the competition catches up to a product, it becomes less differentiated, profits fall, and the company is forced to innovate again. Open-trade policies increase the market size, and enable companies to spread the fixed costs of their innovation over a larger market. Trade also improves the quality and cost of inputs to innovation and aids the faster diffusion of knowledge.

Intellectual property (IP) reform. IP includes patents, copyrights, and trademarks, the most relevant for invention and innovation being patents. A patent grants a limited-time property right (effectively a monopoly) to an inventor to exclude others from making, using, selling, or otherwise profiting from their invention (unless they pay the patent holder an agreed license fee). A patent is granted in exchange for a full disclosure of the invention, so it can later be easily copied once the patent has expired. The U.S. Patent and Trademark Office (USPTO) awards patents to inventions that are novel, non-obvious and useful, and which are properly disclosed by the applicant.

Mission-oriented policies, sometimes referred to as *moonshots.* Such policies take their inspiration from the success of the R&D and innovation efforts during the Second World War and the Apollo moon program of the 1960s (hence the term, “moonshot”). The space program administered by NASA and Defense R&D through DARPA (the Defense Advanced Research Projects Agency) still uses mission-oriented policies as a matter of course. These models have been expanded to the Department of Energy (DARPA-E), and the Department of Homeland Security (IARPA). Many economists remain skeptical of such highly sector-focused policies out of concern that political decision-making may lead to firms engaging in lobbying and regulatory capture, rather than pursuing the most socially beneficial work. However, some moonshots may be justified in themselves, such as the mission to cure cancer, or the quest to find alternative energy technologies to prevent a climate disaster.

Public-Procurement Policies. While this policy tool was not included in Table 12.1, it is an important addition. The total public-procurement budget of most countries is multiple times the size of the innovation and R&D budget. An analysis by the OECD (Appelt and Galindo-Rueda 2016) has highlighted the extent to which public procurement, defined as the purchase by governments and state-owned enterprises of good and services, can support innovation. An analysis of data from 2010 to 2012 gathered from a range of EU and some other OECD countries found that 14 to 36 percent of companies reported undertaking an innovation activity as part of a public-procurement contracts, particularly introducing new products. It was also found that companies with public-procurement contracts were significantly more likely to have innovated than those without such contracts. Similarly, for U.S. companies, there was a positive correlation between R&D expenses and having received a U.S. government contract in the previous period. R&D expenses increased by 0.2 percent for every 10 percent increase of such past obligations. This R&D activity also eventually leads to patents, as the number of patent applications filed with the U.S. Patent and Trademark Office (USPTO) are positively correlated with R&D activity.[476]

The Defense Advanced Research Projects Agency (DARPA) was established in 1958 as an R&D agency within the U.S. DOD has always had an ambitious innovation model through which it pursues mission-oriented, high-risk/high-reward breakthrough innovations. The model positions DARPA as a public-sector intermediary between scientific researchers and industry and entails the development and implementation of technologies that support the DOD's mission areas. This is also sometimes called mission innovation, and it is much more activist than typical U.S. government R&D agencies, which do not pursue technologies that are oriented in advance to particular missions. DARPA has two younger clones, the Advanced Research Projects Agency-Energy (ARPA-E) formed within the Department of Energy (DOE) in 2009 and the Intelligence Advanced Research Projects Agency (IARPA), formed within the Office of the Director of National Intelligence in 2007. IARPA is most akin to DARPA, while ARPA-E attempts to be involved in upstream innovation, though it is housed inside the DOE, which has generally been following a more traditional R&D sponsorship model (Bonvillian, 2018).[477]

Public-procurement programs can be used to drive private-sector innovation through procurement contracts with innovation as their primary scope (such as DARPA above), or by incorporating innovation incentives into contracts for any other products or services (such as Medicare Advantage below).

Medicare is a federally funded U.S. health-insurance program for people age 65 or older (or with certain disabilities). *Medicare Advantage* plans offer eligible beneficiaries the option of obtaining their Medicare benefits through Medicare-approved private health insurers who compete with one another. Medicare Advantage plans cover items and services in addition to those covered by original Medicare, such as vision, hearing, and dental services, but all plans must follow Medicare's rules.[478] The Medicare program is overseen by the Centers for Medicare & Medicaid Services (CMS),[479] which is part of HHS. CMS created the *Five-Star Quality Rating System* to help beneficiaries compare Medicare Advantage plans. It releases new star ratings ahead of every annual open-enrollment period, when all beneficiaries have the option to switch plans (CMS 2021).[480]

The Medicare Advantage program is a public-procurement program as the U.S. government pays private insurers per-capita payments based on the bids that they have made to Medicare. Plans also receive substantial additional payments called *quality bonuses* based on their published star ratings. In 2021, quality-bonus payments to plans totaled $11.6 billion.[481] Higher-rated plans receive additional rebates that allow them to offer enhanced benefits, thereby increasing their attractiveness to beneficiaries. Every year, Medicare Medicare raises the ratings benchmarks to drive ongoing service improvements. In summary, Medicare runs an innovative public-procurement program that promotes customer satisfaction, service innovation, and quality improvements through major commercial performance incentives: the ability to attract customers with better ratings, and large bonus payments from the federal government.

Edler and Fagerberg (2017) offer a slightly different taxonomy of innovation policy instruments, differentiating between supply and demand policies and which goals

Table 12.2: Taxonomy of Innovation Policy Instruments.

Innovation Policy Tool	**Orientation Supply or Demand, or Both**	**Goals Relevance: Major ***, Moderate **, Minor ***						
		Increase R&D	**Skills**	**Access to expertise**	**Improve systemic capability, complementarity**	**Enhance demand for innovation**	**Improve framework**	**Improve discourse**
Fiscal initiatives for R&D	Supply	***	*					
Direct support to firm R&D and innovation	Supply	***						
Policies for training and skills	Supply		***					
Entrepreneurship policy	Supply			***				
Technical services and advice	Supply			***				
Cluster policy	Supply				***			
Policies to support collaboration	Supply	*		*	***			
Innovation network policies	Supply				***			
Private demand for innovation	Demand					***		
Public procurement policies	Demand	**				***		
Pre-commercial procurement	Both	**				***		
Innovation inducement prizes	Both	**				**		
Standards	Both					*	***	
Regulation	Both					*	***	
Technology foresight	Both							***

Source: Adapted from Edler and Fagerberg (2017, 12).[482]

they are best suited to achieve (see Table 12.2).[483] (They do include procurement in their list.) The policies, whether they are *supply- or demand-oriented* or both as well as the relevance of the policy to major goals (such as increased R&D and improved capabilities, are also considered.

The *EC-OECD STIP-Compass* is a dashboard maintained by the OECD (2022) and European Commission that provides access to an international database of public financial-support policies for business R&D and innovation. As of writing, the database contains nearly 700 policy initiatives from all over the world, and it supports searches and downloading of data for further analysis.[484]

The Valley of Death

Most economic growth in industrial economies is powered by incremental improvements in existing products, services, and processes, made by private firms motivated by market pressures. Such incremental innovations are mostly or entirely financed by private investment and are based on incremental technological improvements. Radical technological change happens when science-based inventions are turned into commercially viable innovations. (Note that the terms invention and innovation are used here in their Schumpeterian meaning.) An understanding of the transition from invention to innovation is important, as it relates directly to the conversion of a nation's research assets into its economic assets (Auerswald and Branscomb 2003).[485]

The so-called *Valley of Death* during the early stages of innovation describes the perilous transition between original scientific research and the commercialization of associated technologies. At this point, there is uncertainty both about what a new technology can do and the future market demand for it (Ellwood, Williams, and Egan 2022).[486] A substantial amount of time elapses before a promising R&D breakthrough that gives birth to a new technology will materialize in a new product, and many (if not most) such innovations fail. For example, in the pharmaceutical industry, innovation from an R&D project can take up to 17 years from beginning to end with only 1 in 10,000 new compounds succeeding, which is a success rate of only 0.01 percent (Mazzucato 2015, 65).[487]

The handover process between invention, which may entail government-sponsored research, and innovation, which is expected to be a private-sector activity, means that there is not only technology and market uncertainty to be overcome but also uncertainty about who should pay for the next stage of invention. Many promising technologies may be left for dead in the Valley of Death because they were not developed far enough for the private sector to pick them up and commercialize them.

The magnitude of the Valley-of-Death problem is illustrated by Greg Satell (2016) in his telling of the story of penicillin, and how long it took for this life-saving antibiotic to make it to the market where it could cure people:

> As many people know, Alexander Fleming originally discovered the miracle cure in 1928, when his bacteria culture was contaminated by a mold. What most people don't realize is that his findings sat in an obscure medical journal for a full decade before anyone noticed them. In fact, penicillin wasn't deployed until 1943, when the U.S. military used it to cure soldiers in World War II. And it wasn't until 1945 – nearly two decades after the initial discovery – that penicillin was made available to the general public. In the interim, researchers needed to figure out how to isolate the penicillin compound, make it stable, and produce it in large quantities.
>
> (Satell 2016)[489]

A recent NBER study (Arora et al. 2019) of major changes in the American innovation ecosystem over the past three decades noted a growing division of labor between universities that focus on research and large corporations that focus on development. The concern is that universities create knowledge in forms that cannot easily be turned into new goods and services by companies, especially as large companies themselves withdraw from research. "Small firms and university technology transfer offices cannot fully substitute for corporate research, which integrated multiple disciplines and components at the scale required to solve significant technical problems." While the division of innovative labor ostensibly raised the volume of science produced by universities, it may have also impeded, or at least slowed, the transformation of that knowledge into innovations in the form of novel products and processes.[490]

In practical terms, tens of thousands of papers are published each year by academic researchers. Any of these papers may hold the key to a blockbuster, welfare-increasing new product or technology like penicillin. But how do private firms become aware of such a promising new technology, and what proof would be required to justify spending millions of dollars of shareholder money on a new idea that only exists in a paper? Another issue is that private-industry inventions must be patented for the certainty of property rights that can justify the expenditure on commercializing the invention.

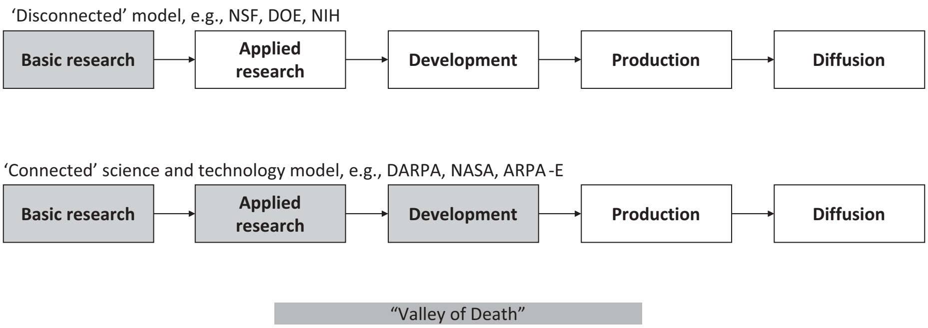

Figure 12.1: Alternative U.S. Government R&D Funding Models.
Source: Based on the discussion by Bonvillian (2014).[488]

R&D financing, such as DARPA and ARPA-E, based on the connected-science model pioneered in World War II are by nature designed to bridge the Valley of Death because they fund R&D through the applied research stage and into development. The disconnected model, where the agency only funds basic research, is also typically followed by agencies such as the NSF and the NIH, and also by the DOE, with the exception of its ARPA-E program, which emulated DARPA. See Figure 12.1.

The Bayh-Dole Act

Since so much basic research happens at universities, policymakers would like to ensure that valuable university research gets commercialized. The Bayh-Dole[lvii] Act of 1980[491] is U.S. legislation that gives colleges, universities and nonprofits the potential rights to intellectual property generated from federally funded research. Prior to the Act, patents for inventions made under contract to the federal government had to be assigned to the government. As a result, the U.S. government had accumulated thousands of such patents, but only a small percentage was ever put to good use. The idea behind the Bayh-Dole Act was to unlock the value of such intellectual property, allowing nongovernment entities to commercialize it for the benefit of the nation and economic growth. If universities owned the patents to their federally funded inventions – it was reasoned – they would have a direct financial incentive to pursue commercialization of research themselves of with corporate partners.

It took a while for the Bayh-Dole Act (BDA) to have its desired impact, as it required a culture change on the side of universities and professors. By the 2000s, a new generation of university presidents started pushing their researchers to commercialize their inventions. For example, Purdue University and other universities in Indiana partnered with venture funds to finance startups which eventually proliferated; in many such startups, professors hold equity stakes (Schoettle 2020).[492] In another example, Emory University received $525 million in 2005 for the rights to the anti-HIV drug, Emtriva, which was invented by three faculty members with government funding. This was believed to be the largest known intellectual property deal involving an American university. The BDA enabled this IP transaction for the university, who promised to reinvest the proceeds in further research that could be commercialized (Gotkin 2012).[493]

The process by which knowledge is transferred from universities to industry and other stakeholders has become known as *University Technology Transfer (UTT)*. The complexity of the UTT process results in Quadruple-Helix Models as *societal innovation* is added to the Triple Helix of government, universities and industry. If Mode 1 was the transfer of university knowledge to society in the form of education, and Mode 2 was the transfer of knowledge from universities to industry for commercialization, then Mode 3 is the transfer of university knowledge to communities across all sectors (Miller, McAdam, and McAdam 2018).[494]

lvii Named after its two co-sponsors, then Sens. Birch Bayh, D-Indiana, and Bob Dole, R-Kansas.

In the decades since 1980 when the BDA was passed, researchers have attempted to assess its effect. Loet Leydesdorff and Martin Meyer (2010) distinguish three periods: an initial period from 1980 to 1999 marked by an increase in university patenting, a period of relative decline from 1999 to the late 2000s, and a third period marked by linear increases driven in large part by non-U.S. universities doing high-tech patenting in the United States.[495]

Newer models of research, particular in the biomedical field have industry, universities, government agencies and other research funders cooperate at the start of a research project. Large pharmaceutical companies are funding research institutes closely affiliated with major research universities. The concept of public-funded centers of excellence hosted by prestigious universities has been adopted in the United States and several countries. Universities are sometimes taking drug development further downstream by means of their own spinout companies that can attract venture capital (Hudson and Khazragui 2013).[496]

Joel Gotkin (2012) has assessed the success and shortfalls of the BDA. The perceived successes are first that the BDA created a single and uniform policy that agencies and academic contracts have to abide by. This reduces confusion and benefits the technology-transfer process. Second is that BDA satisfies private industry's requirement for certainty of property rights before investing. Third is the emergency of the biotechnology field as the major share of university patents are related to biomedical research – which also happens to be mostly publicly funded.[497]

The perceived shortfalls are first a skepticism that BDA drove increases in university patents as these were already rising pre BDA; second that BDA undermines the flow of biomedical research because it incentivizes early patenting of so-called upstream discoveries, which unreasonably raises the price of research downstream for another entity that may take the discovery further to benefit the public; third that it distorts research priorities by redirecting academic resources away from basic research to more commercially viable research; and last that it creates a *tragedy of the anticommons*. The tragedy of the commons is that there is no incentive to conserve a common resource which will be overused, such as a public grazing ground. The tragedy of the anticommons is the converse – meaning that if there are multiple owners, each has the right to exclude others from a scarce resource. Thus, patented technologies are underused and not commercialized. The cost of transacting patents is high, particularly in the biotechnology field where future discoveries frequently build on past discoveries. Some commentators argue that BDA exacerbates the anticommons problem because it encourages early-stage patenting of discoveries, which would have stayed longer in the public domain had it not been for the Act (Gotkin 2012).[498]

Albert Link, Robert Danziger, and John Scott (2018) also came to findings counterintuitive to the intention of the BDA, in response to other researchers (e.g., Nicholas Bloom 2017) who had pointed out declining productivity in biomedical research. Link, Danziger, and Scott found that firms that received SBIR-funding and partnered with a university were – compared with similar firms that did not partner with a university –

"less likely to commercialize their technology, less likely to retain employees who were hired to help with the funded project, and less likely to realize employment growth beyond what would have been predicted in the absence of the award." They believe the BDA is to blame as it distorts the innovation, generating IP conflicts between universities over precedence, and restricting the use of knowledge by both industry and academic researchers. This tension was exemplified by the competing claims of the University of California, Berkeley, and the Massachusetts Institute of Technology for patents on the CRISPR-Cas9 genome-editing system. In addition, there have been patent infringement lawsuits between universities and industry over the alleged unauthorized use of university knowledge. For example, there was a lawsuit between the University of California, San Francisco, and Genentech over the development of the human growth hormone. In the view of Link, Danziger, and Scott (2018), the BDA has "pushed patenting too far upstream." They believe that innovation policies that provide incentives for universities to make their commercializable discoveries freely available and to disseminate them widely would be more effective, and better serve the public interest.[499]

Government-Sponsored Consortia

Another policy tool is for the government to act as a creator or convener of an organization representing all Triple-Helix entities active in a particular industry. For example, concerns about the decline of the U.S. semiconductor industry in the 1980s led to the creation of SEMATECH,[lviii] a consortium of agencies (led by the U.S. DOD), 31 universities, and private companies such as T&T, IBM, Intel, Hewlett-Packard, NCR Corporation, Rockwell International, and Texas Instruments. SEMATECH was founded very much on the Japanese MITI model. SEMATECH was created to be a "technology catalyst," it contributed a lot to revitalizing the semiconductor industry in the United States, and U.S. leadership in semiconductor manufacturing, by the mid-1990s (Kleiner, 1995).[500]

Other organizations that resemble the SEMATECH model are The Joint Center for Energy Storage Research (JCESR) to develop battery technologies, the Institute for Applied Cancer Science (IACS) to explore revolutionary new cures, and the National Network for Manufacturing Innovation (NNMI) to revive U.S. production capacity. An important dynamic is integrating the work of discovery-driven researchers, applied scientists, and engineers in the private sector (Satell 2015).[501] These relationships help to overcome the different incentives which are publications for academic researchers; rapid, large-value exits for venture capitalists; and near-term revenue and profits for corporations. Product developers can steer discovery-driven researchers

lviii Acronym created from SEmiconductor MAnufacturing TECHnology.

into directions that are likely to be more fruitful commercially. This makes it more likely that invention will lead to commercial innovation, and it greatly reduces waste by saving everyone's time and money.

Market Failures

The available scope and solution space for problems that a government is willing to address with its innovation policy will vary greatly depending on the economic philosophy that it subscribes to. However, any simplistic "capitalism vs. socialism" framing of this issue is a stale strawman, and typically only resorted to by those who take an extreme free-market stance and have a low opinion of the ability of government to deliver on its mission. During the Cold War, socialism may have been on one end of the spectrum. But there were many acceptable versions (shades of gray) of capitalism between socialism and the extreme free market on the opposite end of the spectrum; for example, the social democracies of continental Europe versus the free markets of the Anglosphere.

If you are an ardent supporter of free markets, with a laissez-faire government philosophy of minimal government involvement in the economy, you will probably favor an innovation policy that is narrowly focused on addressing market failures and government financing for pure public goods only. This still requires definitions of what market failures are addressable by government, and how broadly or narrowly public goods should be defined.

For example, is clean air a public good? Is climate stability a public good? If knowledge is a public good, to what extent should the government fund its acquisition through research grants? But is it also important for private-sector actors to be able to access and apply the knowledge so created? If so, that would argue for expanding the government's funding of knowledge to include applied research. The aim is not to resolve all these questions here, but to illustrate that even when there is agreement that government should only step in to provide public goods and address market failures, there still is a lot of leeway for determining the scope of involvement, and much room for political judgment. That is what the U.S. government has done in practice, as Bill Janeway (2018) states:

> Despite the theoretical demonstration of market failure in the funding of invention and innovation, now empirically buttressed, arguments for state intervention to address such market failures have proved only marginally compelling. Rather, it has been mission-oriented state investments that have, time after time and across national boundaries, proved effective in driving the individual sectors of the Innovation Economy. (Janeway 2018, 261–262)[502]

Several leading authors on innovation policy, from Bonvillian to Mazzucato, have exposed the misconception that the private sector is the main originator of innovation, and it is, therefore, best that the public sector largely stays out of the way of the private sector. In fact, the post-World-War-II role of the U.S. federal government in leading technological innovation is well documented. Keller and Block (2015) argue that free-market explanations for the success of U.S. innovation are misleading and obscure important sources of U.S. economic dynamism since the 1980s. They point to four primary policy innovations that historically shifted the direction of the U.S. innovation systems:[503]

1. *The DARPA model and its diffusion to other agencies such as DARPA-E*. Launched in the wake of Sputnik, DARPA was instrumental to advancing many important enabling technologies, including lasers, robotics, semiconductor chip fabrication, and the internet.
2. *The National Research Laboratories*. Initially designed to develop nuclear weapons, these laboratories broadened their scope and were given strong incentives. The Stevenson-Wydler Act of 1980 encouraged technology transfer activities as well as direct collaboration with universities, state and local governments and private firms. Thousands of public–private collaborative projects have been pursued using cooperative research and development and “work-for-others” agreements, enabling private firms to take advantage of both the substantial expertise and specialized equipment of these facilities.
3. *Public–Private Partnerships* to boost competitiveness and economic growth led to the encouragement of these arrangements since the Nixon Administration in the 1970s. The Bayh-Dole Act, that allowed universities to patent inventions made with federal funding, is a major element, but also the *University–Industry Cooperative Research Centers* program launched by the National Science Foundation in 1978 to bring together experts from private industry and academia to find solutions to shared problems. Similarly, the Engineering Research Centers were created in 1984 to foster public–private collaboration to overcome technological barriers. The SBIR, ARP (now TIP) programs, to provide matching federal grants for private firms to commercialize new technologies, and the MEP, to help manufacturers use advanced technologies, were all founded in the 1980s.
4. *Demand-Side Measures* in the form of the federal government’s procurement activities stimulate technology development, particularly by the DOD. Tax credits for renewable technologies, such as solar and wind power, are other examples.

And as a result, the United States has been the originator of most major new technologies in the post-World War II such as microelectronics, the internet, and biotechnology. These breakthrough technologies have given rise to whole new industries in which well-known private-sector companies are thriving. Linda Weiss (2014) points out that this symbiotic relationship between the state and the private sector has come about by design, not by accident. What Weiss calls the “national security state” pursues national technology leadership in order to sustain U.S. military-political primacy, not to achieve commercial advantage.[504]

Missions and Moonshots

While the ultimate goal of the state is national security, it has to rely on the private sector to advance its technology goals. And to get the private sector to participate, the state must ensure that there is also commercial demand for the technologies that it seeks to develop. That is because government demand for such technologies (i.e., the federal market), while still large, does not in many cases provide sufficient incentive for the private sector to invest. For example, the commercial market for computers is now much larger than the federal market, a reversal compared to the 1950s. In the United States, this duality has been enshrined into policy. If a firm will be working with an agency to develop a technology, it will be encouraged from the outset to create a commercial product that makes use of this technology. This is attractive for private firms as the government in practice becomes the first customer of the new technology, often sponsoring a significant part of the R&D, while the commercial market awaits the technology once it is proven. In turn, the state has to include *commercial viability* alongside national security and technological supremacy in its goals.

There is competition within the government as agencies and programs constantly jostle for limited funding, and both the executive branch and Congress exert strong influence over budgetary allocations and program evaluation criteria. This is a distributed form of innovation portfolio management. The Office of Management and Budget (OMB) and the Government Accountability Office (GAO) evaluate the effectiveness of programs for the Administration and Congress, respectively (Keller and Block 2015).[505]

A coordinating role is played by the *White House Office of Science and Technology Policy* (OSTP), created by Congress and headed by a senate-confirmed director. "The OSTP advises the President and others within the Executive Office of the President on the scientific, engineering, and technological aspects of the economy, national security, homeland security, health, foreign relations, and the environment." The OSTP also assists the OMB with an annual review of federal R&D budgets (OSTP 2022).[506]

> In the wake of the 2008–2009 financial crisis, there has been a renewed impetus for rethinking the economic foundations of our industrialized society. The *Institute for New Economic Thinking*[507] is a global network of economists and scholars "who challenge conventional wisdom and advance ideas to better serve society." Its website features research papers, articles, podcasts, and videos on key economic issues.

In his book, *How Rich Countries Got Rich– and Why Poor Countries Stay Poor*, the heterodox economist Erik Reinert (2008) stresses the importance of understanding economic philosophies that govern industrial and innovation policy in their historical context. His observation of the major fault line in the U.S. philosophy pertaining to state involvement in the economy is particularly salient:

> There is an important pattern here: since its founding fathers, the United States has always been torn between two traditions, the activist policies of Alexander Hamilton (1755–1804) and Thomas Jefferson's (1743–1826) maxim that 'the government that governs least, governs best'. Alexander Hamilton was a key figure behind the establishment of the first central bank of the United States in 1791, while Thomas Jefferson fought it and contributed to its closing down in 1811. With time and usual American pragmatism, this rivalry has been resolved by putting the Jeffersonians in charge of the rhetoric and the Hamiltonians in charge of policy. (Reinert 2008, 23)[508]

Fred Block (2008) has written about the rise of a "hidden developmental state" in the United States. In contrast with Europe, where both the EU and national governments openly declare and debate their development agendas, this conversation happens in the shadows in the United States because of the dominance of what Block calls "market fundamentalist ideas" over the last several decades.[509] Linda Weiss examines the mechanisms by which the U.S. National Security State fostered new technologies, breakthrough innovations, and the rise of new private-sector firms and industries in her book, *America Inc.?: Innovation and Enterprise in the National Security State* (2014).[510]

In the previous chapter, some of the major technological and commercial successes that came from post-World War II investments by the U.S. government were highlighted. Many of these technologies came about through mission-oriented spending, not merely through sponsorship of basic R&D as would be prescribed by the neoclassical school. If anything, the federal government is not getting enough credit for the later commercial successes that private corporations achieve with technologies created with federal funds, nor for the early government financing of private ventures, which became wildly successful later.

The Apollo program to land the first men on the moon was the original "moonshot program." The term moonshot has now become a metaphor for a massive mission-oriented government investment in science, technology, and innovation to meet a bold goal of great importance to the nation. For perspective, the United States spent $28 billion on the Apollo program to land men on the moon in the 13 years between 1960 and 1973 – about ten times that in present dollars adjusted for inflation. During this period, 60 percent of all funds for space explorations were channeled into the Apollo program. Subsequently, NASA's budget fell from a peak of $60 billion in 1965 to little over $20 billion in 1973 at the end of the Apollo program (The Planetary Society 2022).[511] Apollo consumed 4 per cent of the U.S. government budget and involved over 400,000 workers in the National Aeronautics and Space Administration (NASA), universities, and contractors (Mazzucato 2021, 3–4).[512]

Matthew Keller and Fred Block (2015) also criticize the orthodox view that U.S. innovative dynamism is due to its embrace of what is called "the liberal market economy," with markets serving as the central mechanism of economic coordination. Under this philosophy, the innovative dynamism is maximized by a hands-off approach by government, and industrial policy is minimal or nonexistent. These ideas are integral to the doctrine that has become known as *neoliberalism* or the *Washington Consensus*.[513]

The *Washington Consensus is* a term coined in 1989 by the economist John Williamson for a set of ten free-market-promoting (aka neoliberal) policies commonly prescribed to developing countries by Washington, D.C.- based institutions such the IMF, the World Bank, and the U.S. Department of the Treasury. At the time, these policies were being recommend to Latin American countries by these Washington institutions. The policies were:

1. Fiscal discipline, also known as austerity
2. A redirection of public-expenditure priorities toward fields offering both high economic returns and the potential to improve income distribution, such as primary healthcare, primary education, and infrastructure
3. Tax reform (to lower marginal rates and broaden the tax base)
4. Interest rate liberalization
5. A competitive exchange rate
6. Trade liberalization
7. Liberalization of inflows of foreign direct investment
8. Privatization
9. Deregulation (to abolish barriers to entry and exit)
10. Secure property rights

(Center for International Development 2003)[514]

The IMF more recently acknowledged that some of its neoliberal policies may not have been successful when a trio of IMF economists wrote an article titled, "Neoliberalism Oversold?" While they still praise most of the policies, they admit doubts about two specific policies: removing restrictions on capital flows and fiscal austerity to reduce deficits and debt levels (Ostry, Loungani, and Furceri 2016).[515]

The way that the public sector makes innovation policy needs to change for 21st century missions, according to Rainer Kattel and Mariana Mazzucato (2018). Current market-failure-oriented policy is made by identifying the market failure, fixing it with a policy instrument, and measuring the impact. For mission-oriented policy, the process required is to "create and shape markets with a variety of policy instruments with open-ended impact horizons, and learn through wider social engagement and coordination." Grand challenges require dynamic public–private partnerships, and for the state to have leadership and engagement capabilities to guide the creation of new technologies and new markets. Given the significance of sociopolitical considerations alongside technological capabilities, the state needs the ability to experiment, instead of only relying on market selection. That requires in-house government capabilities in human-centric design, user research, and social experiments.[516]

Critiques of the Status Quo

Over the last decade, there has been increasing calls for the government to pursue a more activist innovation policy, and abandon any last vestiges of the neoclassical restraint that government should limit its role to market failures. Some of the strongest and best-articulated appeals come from prominent academics and policy experts such as Mariana Mazzucato, William Lazonick, and John Van Reenen. Their arguments vary but often have common themes and similar critiques of the status quo.

First, there is a recognition that the current economic system in general, but particularly the current innovation paradigm has major flaws which manifest themselves in a number of undesirable outcomes, such as inequitable growth, environmental degradation, increased market concentration, and the loss of the U.S. manufacturing base.

The latter problem attracted fresh attention due to a critical shortage of personal protective equipment (PPE) for medical personnel during the first months of the COVID-19 pandemic in 2020, and some countries prohibited PPE exports. America was short on both the materials and machinery to be self-sufficient in N95 masks (Gerety 2020).[517] Not only had production of medical goods been offshored, but those of many advanced manufactured goods such as semiconductors, and computer servers. In a contemporaneous article blaming pandemic medical shortages on offshoring and advocating for a reshoring of supply chains, David Adler and Dan Breznitz (2020) point out that the United States lost 3.4 million manufacturing jobs (20 percent of its total) between 2000 and 2007, and a further 1.5 million manufacturing jobs between 2007 and 2016, a rapid loss not seen before in Western history.[518]

The loss of manufacturing capacity also means a loss in innovation capability, since so much of actual innovation occurs in the production stage, as William Bonvillian (2013) explains:

> Moving from prototype to product can take years. It requires solving engineering design problems, overcoming production and component cost problems, building production processes, creating an efficient production system, developing and applying new production and product business models, educating a workforce, building a supply chain, financing scale up, actually scaling up production to fit evolving market conditions, and reducing all these steps to a routine. The initial innovation is often thoroughly reworked. These are highly creative elements needed at the outset of production at scale, requiring much science and engineering at nearly every point. The research-to-prototype stages begin the innovation process, but the pre- and outset-of-production stages are also vital. These stages are critical for incremental technology advance, as well as for breakthrough and radical technology innovation.
>
> (Bonvillian 2013, 1173)[519]

This problem has been well-understood for some time and has received attention at the highest levels. A 2011 Obama White House report (President's Council of Advisors on Science and Technology 2011)[520] on promoting advanced manufacturing[lix] in the United States led to the creation of the *Advanced Manufacturing Partnership* (AMP) as the major instrument of a new manufacturing innovation strategy. AMP brought together industry CEOs with presidents from prominent university and senior government officials from several agencies in a public–private partnership representing all elements of the Triple Helix. AMP's first report advocated for 15 advanced manufacturing institutes; the second report added more strategic policy elements. Congress subsequently passed enabling legislation (Bonvillian 2017).[521]

Second, these undesirable outcomes are attributed to systemic problems such as the financialization of U.S. industry, and with it the breakdown of the connection between risk and reward for private actors, as well as a government that is overly timid both in its innovation policies and in its innovation spending. For example, Adler and Breznitz (2020) attribute offshoring directly to financial market and management incentives putting shareholder value above everything else, thereby encouraging the short-term pursuit of profits, stock option maximization, and stock buybacks.[522] Reducing capital equipment improves a company's return on assets (ROA), while lean manufacturing entails holding very low inventories which cannot absorb even small supply-chain disruptions. It has been frequently pointed out that with offshore manufacturing of, for example, iPhones, more prosperity is created by Silicon Valley abroad, where thousands of workers are employed making the phones, than at home, where only a few well-paid engineers and designers benefit.

Third, there is a recognition that government should get more credit for technological advancement and innovation than it usually does, and that many of the advances of the last number of decades appropriated by the private sector as their own, owe a lot more to government investment than often acknowledged. Once successful, private-sector titans such as Tesla find it easy to forget that they received government assistance at a crucial early part of their innovation process. For example, it was reported that Tesla Motors received $465 million in loan assistance in 2009 from the U.S. Department of Energy as part of a program to help auto manufacturers survive in the aftermath of the 2008 financial crisis. This was at a time when Tesla was not profitable yet and was ramping up production of its all-electric Roadster sports car and about to launch the Model S sedan (Schonfeld 2009).[523]

Last, the proposed solutions include a number of policy changes that would level the playing field and see a more activist role for government in advancing innovations aligned with certain desirable missions. There is a general desire to see more widespread prosperity from innovation success along with more inclusive economic growth to lower inequality and extend growth benefits to historically disadvantaged

lix Defined as the manufacture of conventional or novel products through processes that depend on the coordination of information, automation, computation, software, sensing, and networking, and/or make use of cutting-edge materials and emerging scientific capabilities.

parts of the population, as well as to redirect growth in an environmentally sustainable direction.

Much has been written in the past decade on growing inequality and divergent growth paths for different people. Notable publications are:

- Thomas Piketty's book, *Capital in the Twenty-First Century* (2014) was a seminal contribution that quantified and described inequality trends. Piketty and other prominent inequality researchers such as Emmanuel Saez and Gabriel Zucman have set up the *World Inequality Database*,[524] which publishes annual *World Inequality Reports* and offers an open-access database to researchers.
- In his book, *The Vanishing Middle Class: Prejudice and Power in a Dual Economy*, Peter Temin (2017) writes about how the middle class is vanishing while a dual economy with 20 percent of people at the top, and the remaining 80 percent at the bottom, is taking shape. A dual economy exists when two separate economic sectors divided by different levels of development, technology, and patterns of demand coexist within one country. Today's dual economy is comprised of the finance, technology and electronics sectors employing the richest 20 percent of the population, who mostly have college degrees. The remaining 80 percent (which is absorbing the former middle class) are workers who have lower levels of education and whose wages have been flat in real terms since the 1970s. Education is the key differentiator between these groups.[525]
- In another pessimistic book, *The Rise and Fall of American Growth: the U.S. Standard of Living Since the Civil War*, Robert Gordon (2016) argues that the tremendous American growth between 1870 and 1970 was due to innovations such as electric lighting, indoor plumbing, home appliances, motor vehicles, air travel, air conditioning, television, and medical advances that lifted the American standard of living. But Gordon contends that this growth has petered out, and that the first generation who do not exceed their parents' standard of living may be at hand unless we find new solutions.[526]

Voices for Change

The current debate between those who prefer a more activist innovation and industrial policy and those who favor the traditional laissez-faire approach of limited government intervention was likely started by a white paper, *Industrial Policy for the Twenty-First Century* (2004), written for the United Nations Industrial Development Organization (UNIDO)[lx] by Harvard professor Dani Rodrik.[527] Acknowledging the past failures of industrial policy (the so-called "picking of winners"), Rodrik (2004) goes on to provide an economic analysis to justify a new third way, between overbearing state planning on the one hand and a completely hands-off approach on the other:

lx UNIDO is an agency of the United Nations that promotes industrial development or poverty reduction, inclusive globalization and environmental sustainability.

> Few people seriously believe any more that state planning and public investment can act as the driving force of economic development. Even economists of the left share a healthy respect for the power of market forces and private initiative. At the same time, it is increasingly recognized that developing societies need to embed private initiative in a framework of public action that encourages restructuring, diversification, and technological dynamism beyond what market forces on their own would generate . . . Market forces and private entrepreneurship would be in the driving seat of this agenda, but governments would also perform a strategic and coordinating role in the productive sphere beyond simply ensuring property rights, contract enforcement, and macroeconomic stability. (Rodrik 2004, 1–2)[528]

Rodrik's initial focus was on helping entrepreneurs in emerging economies. But in the developed world, the debate about the state's proper role in promoting innovation is taking place as part of a larger reexamination of the economic system, as the twin forces of globalization and automation are seen to be diminishing high-quality manufacturing jobs, which are being replaced with inferior service-sector jobs. Öner Tulum and William Lazonick (2018) argue that the lack of productivity by U.S. pharmaceutical companies is due to the financialization of the industry with its emphasis on shareholder value, stock-based executive compensation, and resulting stock buybacks coming at the expense of drug innovation.[529] In an earlier article, Lazonick (2017) diagnosed this as a *supply-side problem of corporate resource allocation*, which undermines productivity growth in the economy in general and also results in unstable employment and inequitable growth.[530]

Mariana Mazzucato, a professor at University College London, is a prominent and prolific advocate for a more robust role for the state in the economy, and for a bold, mission-oriented innovation policy. In her best-selling book, *The Entrepreneurial State: Debunking Public Vs. Private Sector Myths* (2015), she argues that the widely accepted notion of a slow, bureaucratic public sector versus a dynamic private sector is a myth which has led to the U.S. government withdrawing from innovation when it should be investing in innovation.[531] Mazzucato's popular book, *Mission Economy: A Moonshot Guide to Changing Capitalism* (2021), advances her argument that governments can and should take on ambitious missions, also called *grand challenges* (such as the original moonshot, NASA's Apollo program), and that government has the capacity to succeed at such missions again.[532]

Mazzucato, Kattel, and Ryan-Collins (2019) argue that policymakers can determine the direction of economic growth through strategic investments in important sectors and by nurturing industry ecosystems, which the private sector can then use as platforms to develop further. This mission-oriented approach to growth is presented not as top-down planning, but as giving direction and catalyzing growth, along with lifting business expectations about where the future growth areas will be in order to spur business activity that may otherwise not happen.[533]

An important theme in Mazzucato's work is the notion of *purpose*, both the purpose of a private corporations and the purpose of public policy:

> This means restoring public purpose in policies so that they are aimed at creating tangible benefits for citizens and setting goals that matter to people – driven by public-interest considerations rather than profit. It also means placing purpose at the core of corporate governance and considering the needs of all stakeholders, including workers and community institutions, as opposed to just shareholders (owners of stock in a company). (Mazzucato 2021, 5)[534]

MIT professor John Van Reenen (2021) proposes a renewed investment by the federal government to counter slow U.S. productivity growth and even slower median-wage growth, both trends that have set in since the late 1970s. He calls it the *Grand Innovation Challenge Fund*, a proposed new federal fund for R&D to drive technological innovation and raise productivity growth. A major policy objective is to achieve more equitable income growth in the economy.[535] Van Reenen (2020) has developed the policy proposal as part of the *Hamilton Project*[536] at the Brookings Institution, a project that seeks to promote broad-based growth. The main elements of the proposed policy for governing the Fund are as follows:

- *Spending will be allocated to different, evidence-based innovation policies.* Out of the fund, 30 percent will go to direct R&D grants, 25 percent to tax credits, 20 percent to increase the STEM workforce, and 25 percent to policies that would promote innovation among underrepresented groups.
- *Decisions on Fund dispersion will be made by independent experts.* Congress can set priorities such as climate change, but the responsibility for allocating funds will be made by a body of independent experts.
- *The funds will be used for breakthrough science.* A portion of the Fund should be focused on well-identified national missions – such as healthcare and climate change. The agency must be prepared to take risks and tolerate failures to find the next moonshot.
- *A variety of incentives and rewards can be used.* Direct grants, tax incentives, and training subsidies could all be part of the policy mix. Prizes and advance market commitments may also be appropriate in some circumstances, especially for mission-oriented R&D.
- *There will be an explicit set of criteria, along with some competitive bidding, to make sure the resources are allocated geographically in a way that is both cost effective and productive.* Around 30 new innovation hubs could be created in 10 years. Regional coalitions can come together to collaborate.
- *Spending will increase funding for innovation by half a percent of GDP – or about $100 billion a year.* (Van Reenen proposes roughly doubling the federal government's spending on R&D.) Funding would scale up gradually to reach the proposed increase sustainably.

(Adapted from Van Reenen 2020, 2)[537]

In a similar vein, Matteo Deleidi and Mariana Mazzucato (2019) have argued for an end to austerity, at least as far as innovation policy is concerned. They argue that major increases in public expenditures directed toward strategic sectors and focused on the promotion and mission-oriented policies will directly stimulate private investment in R&D, which they call the "supermultiplier," thereby effecting a large increase in economic output. In addition, such a government policy would facilitate the diffusion of technical progress throughout the economic system, with additional stimulation of components of aggregate demand.[538]

Distribution-Sensitive and Inclusive Innovation

The term *distribution-sensitive innovation policy* (DSIP) was coined by Amos Zehavia and Dan Breznitz in an eponymous 2017 paper.[539] Recognizing that innovation is essential to economic growth, but also recognizing, that innovation policies may generate economic inequities, they argue for innovation policies that would both increase growth and take into account economic distribution. Zehavia and Breznitz (2017) have outlined four archetypes of DSIPs:

1. Innovation in traditional industries
2. Geographical-economic peripheries
3. Disadvantaged ascriptive groups
4. The advancement of disadvantaged consumers of technology[540]

University of Toronto professor Dan Breznitz's recent book on innovation policy, *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World* (2021), mainly explores the geographical DSIP archetype. The book is an exposition of innovation policies that avoid copying the Silicon Valley model in favor of cities and communities recognizing and building on their own advantages, which allow them to specialize in areas of innovation and production where they have distinct advantages.[541]

Inclusive innovation, defined by Gerard George, Anita M. McGahan, and Jaideep Prabhu (2012) as innovation that benefits the disenfranchised, is focused on the inequalities that may arise in the development and commercialization of innovations. It acknowledges that value creation and capture may also create inequalities. Inclusive innovation is a derivative of *inclusive growth*, which has long been established as a policy object in developing countries. An expanded definition of inclusive growth is proposed:

> *We define inclusive innovation as the development and implementation of new ideas which aspire to create opportunities that enhance social and economic wellbeing for disenfranchised members of society.*
>
> First, we consider *innovation as the development and implementation of new ideas*. The definition embraces all forms of innovation, whether these new ideas relate to products, services, processes, institutions, business models, or supply chains, with only the requirement that they are novel recombinations or new to the context.
>
> Second, we *focus on opportunities for social and economic wellbeing* on the understanding that certain sections of society have been barred structurally from achieving wellbeing. Therefore, actions that improve inclusiveness may arise from the removal of economic, geographic, social, and other structural barriers that previously blocked access to opportunity. These barriers may arise at many levels, including for employees, owners, or customers of business organizations.
>
> Finally, we *distinguish the process of inclusive innovation from its outcomes* and acknowledge that aspiring to inclusivity is valuable even when opportunity is not ultimately realized. An implication of this definition is that the study of inclusive innovation includes the evaluation of activities that may ultimately fail to deliver opportunity despite the aspiration. In other words, the process as well as the outcome is important. Practices such as fair trade, distance

learning, hospices, urban farming, waste reduction, and restorative justice are therefore all examples of inclusive innovation.

(Gerard, McGahan, and Prabhu 2012, 661) (Emphasis added)[542]

In July 2022 (as this book went to press), bipartisan majorities in both houses of the U.S. Congress passed a mammoth five-year $280 billion innovation bill, the *CHIPS and Science Act of 2002*.[543] The House passed the Senate version, formerly known as *the United States Innovation and Competition Act*, of two similar packages, each comprising multiple bills intended to increase U.S. competitiveness versus China in terms of technology, science, and innovation.[544]

The "chips" name reflects the priority given to the U.S. semiconductor industry with over $52 billion of direct subsidies for manufacturing, research subsidies, and workforce development; and another $24 billion in other tax provisions and incentives. The policy goal is to increase the U.S. manufacturing share of this crucial technology after years of global semiconductor shortages impacting multiple industries. The Act also contains nearly $170 billion for technology R&D across several federal agencies: The NSF will oversee a new $20 billion Directorate of Technology and Innovation to accelerate the development of key technologies to strengthen U.S. technology leadership, and receive $61 billion more for its core funding activities of research at universities and other institutions. The DOE gets $50 billion more for clean energy, nuclear physics, and high-intensity laser research. The Act sets out several new policies such as instructing NASA to prioritize research to take astronauts to Mars. A major distribution-sensitive policy aspect of the Act is that it directs the Commerce Department to create 20 regional technology hubs to create and spread more tech jobs across the country.

Chapter Summary

- The main innovation policy tools are direct R&D grants, R&D tax credits, STEM human capital increases, skilled immigration, trade and competition policy, public procurement and mission-oriented policies, and intellectual property policy.
- The Valley of Death describes the perilous transition between original scientific research and the commercialization of associated technologies. Promising technologies may not be developed far enough during early research for the private sector to pick them up and commercialize them.
- The Bayh-Dole Act was intended to bridge the Valley of Death through promoting the commercialization of research by universities by letting them own the patents for government-funded basic research.
- Despite professing an adherence to the free-market philosophy, the U.S. government has been strongly involved in technological innovation, particularly with exceptions for mission-oriented spending related to defense.
- The Washington Consensus comprises ten policies that are core to the so-called neoliberal free-market philosophy, such as austerity and trade liberalization,

which has often been prescribed to developing countries by institutions such as the IMF and World Bank.
- The federal government is being pushed to adopt a more activist innovation and industrial policy based on undesirable outcomes and systemic problems within the current system, and a newfound appreciation for the benefits of past government contributions.
- Calls are also being made to consider the distributive effect of innovation policies on industries, geographies, and disadvantaged groups. Inclusive innovation has the goal of benefiting sections of society that have been left behind by the single-minded focus on value creation and capture.

Suggested Exercises and Assignments

- Conduct a class debate on the extent to which the Washington Consensus has held back the industrial development of developing nations versus helping them to put their economies on a sound footing. Refer to the extent that the Washington Consensus helps or hinders the implementation of innovation policies intended to grow and diversify the economy.
- Write an essay on the political and economic conditions needed for innovation to thrive in a particular nation; that is, what contributes to making a country excel at innovation? Comment on how innovation policy can be designed to be more inclusive and distribution-sensitive.
- Select two countries with similar natural resources but substantially different GDP/capita. Compare and contrast their economic complexity to explain the difference in income. Make recommendations on what innovation and industrial policy the poorer country should follow to catch up.

Recommended for Further Reading

Breznitz, Dan. 2021. *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World*. New York, NY: Oxford University Press.

Edler, Jakob, Paul Cunningham, Abdullah Gök, and Philip Shapira, eds. 2016. *Handbook of Innovation* Policy Impact. Cheltenham, UK: Edward Elgar Publishing.

George, Gerard, Ted Baker, Paul Tracey and Havovi Joshi, eds. 2019. *Handbook of Inclusive Innovation*. Northampton, MA: Edward Elgar Publishing.

Mazzucato, Mariana. 2021. *Mission Economy: A Moonshot Guide to Changing Capitalism*. New York: Harper Business, an imprint of Harper Collins Publishers.

OECD. 2010. *The OECD Innovation Strategy: Getting a Head Start on Tomorrow*. Paris: OECD Publishing.

Taylor, Mark Zachary. 2016. *The Politics of Innovation: Why Some Countries Are Better Than Others at Science and Technology*. New York: Oxford University Press.

Weinberger, Sharon. 2017. *The Imagineers of War: The Untold History of DARPA, the Pentagon Agency That Changed the World*. First edition. New York: Alfred A. Knopf.
Weiss, Linda. 2014. *America Inc.? Innovation and Enterprise in the National Security State*. Ithaca, NY: Cornell University Press.
Wittmann, Florian, et al. 2021. "Governing Varieties of Mission-Oriented Innovation Policies: A New Typology." Science & Public Policy 48, no. 5: 727–38. https://doi.org/10.1093/scipol/scab044.

Recommended Data Sources

Economic complexity rankings for countries and a comprehensive country-database of exports and imports are accessible at the following two sources:
Atlas of Economic Complexity, Harvard Growth Lab, https://atlas.cid.harvard.edu/
Observatory of Economic Complexity (OEC), Datawheel (an MIT spinoff), https://oec.world/en
The OECD maintains a *Regional Innovation* database[545] that includes data on patent and co-patent by technology; R&D expenses and R&D employees; labor force and student enrolment.
The World Economic Forum (WEF) publishes an annual report intended to support innovation policymakers, titled the *Global Competitiveness Report* (WEF 2020), also with a year-specific thematic subtitle. The report contains information and data compiled from various international sources as well as results from surveys of executives.[546]

Endnotes

1 Web of Science Core Collection with search query TS = (innovation), 296,111 publications selected with publication years 1970–2022, Clarivate™ Web of Science™, Mar. 28, 2022.
2 Web of Science Core Collection with search query TS = (innovation), 291,037 publications selected with publication years 1970–2021, Clarivate™ Web of Science™.
3 https://www.merriam-webster.com/dictionary/innovation
4 https://dictionary.cambridge.org/dictionary/english/innovation
5 Harari, Oren. 2007. "Welcome to Commodity Hell: The Perils of the Copycat Economy," in *Break from the Pack: How to Compete in a Copycat Economy*, informIT, Dec. 14, 2007. Available at https://www.informit.com/articles/article.aspx?p=777370
6 Vale. 2022. "Iron Ore and Pellets," http://www.vale.com/EN/business/mining/iron-ore-pellets/Pages/default.aspx
7 Schumpeter, Joseph A. 1943 (2013). *Capitalism, Socialism and Democracy*. London: Routledge.
8 Drucker, Peter F. 1983. *Innovation and Entrepreneurship*. New York: HarperCollins.
9 Drucker, Peter F. 1983. *Innovation and Entrepreneurship*. New York: HarperCollins.
10 Drucker, Peter F. 1983. *Innovation and Entrepreneurship*. New York: HarperCollins.
11 Drucker, Peter F. 1983. *Innovation and Entrepreneurship*. New York: HarperCollins.
12 Kelley, Tom. 2001. *The Art of Innovation – Lessons in Creativity from IDEO, America's Leading Design Firm*. New York: Currency.
13 Schumpeter, Joseph A. 1943 (2013). *Capitalism, Socialism and Democracy*. London: Routledge.
14 Coley, Steve. 2009. "Enduring Ideas: The Three Horizons of Growth." *McKinsey Quarterly*, Dec. 2009.
15 Henderson, Rebecca M., and Kim B. Clark. 1990. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative Science Quarterly*: 9–30.
16 Bower, Joseph L., and Clayton M. Christensen. 1995. "Disruptive Technologies: Catching the Wave," *Harvard Business Review*, Jan-Feb 1995. Available at https://hbr.org/1995/01/disruptive-technologies-catching-the-wave
17 Christensen, Clayton M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.
18 Christensen, Clayton M., Efosa Ojomo, and Karen Dillon. 2019. *The Prosperity Paradox: How Innovation Can Lift Nations Out of Poverty*. New York: Harper Business, an imprint of Harper Collins Publishers.
19 Government Accountability Office (GAO). 2022. "Managing for Results in Government." https://www.gao.gov/key_issues/managing_for_results_in_government/issue_summary. Accessed Mar. 29, 2022.
20 Cole, Martin I., and Gregory. Parston. 2006. *Unlocking Public Value: A New Model for Achieving High Performance in Public Service Organizations*. Hoboken, NJ: John Wiley.
21 American Marketing Association. 2017. "Definition of Marketing," https://www.ama.org/the-definition-of-marketing-what-is-marketing. Accessed Mar. 29, 2022.
22 Chesbrough, Henry William. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.
23 Drucker, Peter F. *Innovation and Entrepreneurship*, New York: HarperCollins.
24 Abbate, Janet. 2001. "Government, Business, and the Making of the Internet." *Business History Review* 75, no. 1: 147–176. https://doi.org/10.2307/3116559
25 Trafton, Anne. 2021. "A Comprehensive Map of the SARS-CoV-2 Genome." *MIT News*, May 11, 2021, https://news.mit.edu/2021/map-sars-cov-2-genome-0511
26 Nowotny, Helga. 2016. *The Cunning of Uncertainty*. Cambridge, UK: Polity Press.

https://doi.org/10.1515/9783110711066-013

27 Godin, Benoît. 2008. "In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation." *Minerva* 46, no. 3: 343–360. https://doi.org/10.1007/s11024-008-9100-4
28 Godin, Benoît. 2008. "In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation." *Minerva* 46, no. 3: 343–360. https://doi.org/10.1007/s11024-008-9100-4
29 Godin, Benoît. 2008. "In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation." *Minerva* 46, no. 3: 343–360. https://doi.org/10.1007/s11024-008-9100-4
30 Godin, Benoît. 2008. "In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation." *Minerva* 46, no. 3: 343–360. https://doi.org/10.1007/s11024-008-9100-4
31 Hall, Bronwyn H. 2004. "Innovation and Diffusion." *Working Paper no. 10212. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/system/files/working_papers/w10212/w10212.pdf
32 Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.
33 Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.
34 Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.
35 Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.
36 Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.
37 Hargadon, Andrew B., and Yellowlees Douglas. 2001. "When Innovations Meet Institutions: Edison and the Design of the Electric Light." *Administrative Science Quarterly* 46, no. 3: 476–501.
38 Gartner. 2022. "The Gartner Hype Cycle." https://www.gartner.com/en/research/methodologies/gartner-hype-cycle. Accessed Feb. 28, 2022.
39 Christensen, Clayton M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.
40 Hicks, John. 1948. *The Theory of Wages*. New York: P. Smith.
41 Ruttan, Vernon W., and Yujiro Hayami. 1984. "Toward a Theory of Induced Institutional Innovation," *The Journal of Development Studies* 20, no. 4: 203–223.
42 Ruttan, Vernon W., Yūjirō Hayami, Keijiro. Otsuka, and C. Ford Runge. 2011. *Can Economic Growth Be Sustained? The Collected Papers of Vernon W. Ruttan and Yūjirō Hayam*. New York: Oxford University Press.
43 Carlaw, Kenneth I, and Richard G Lipsey. 2002. "Externalities, Technological Complementarities and Sustained Economic Growth." *Research Policy* 31, no. 8: 1305–1315. https://doi.org/10.1016/S0048-7333(02)00065-3
44 Bresnahan, Timothy F., and Manuel Trajtenberg. 1995. "General Purpose Technologies 'Engines of Growth'?" *Journal of Econometrics* 65, no. 1: 83–108.
45 Bekar, Clifford, Kenneth Carlaw, and Richard Lipsey. 2018. "General Purpose Technologies in Theory, Application and Controversy: A Review," *Journal of Evolutionary Economics* 28, no. 5: 1005–1033.
46 Ruttan, Vernon W. 2006. *Is War Necessary for Economic Growth?: Military Procurement and Technology Development*. New York: Oxford University Press.
47 Brynjolfsson, Erik, Seth Benzell, and Daniel Rock. 2020. "Understanding and Addressing the Modern Productivity Paradox." *MIT Work of the Future*. Available at https://workofthefuture.mit.edu/wp-content/uploads/2020/11/2020-Research-Brief-Brynjolfsson-Benzell-Rock.pdf
48 Andrews, Dan, Chiara Criscuolo, and Peter N. Gal. 2016. "The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy." *OECD Productivity Working Papers, no. 5,* Paris: OECD Publishing. https://doi.org/10.1787/63629cc9-en
49 David, Paul A. 1990. "The Dynamo and The Computer: An Historical Perspective on the Modern Productivity Paradox." *The American Economic Review* 80, no. 2: 355–361.
50 Comin, Diego, and Martí Mestieri. 2018. "If Technology Has Arrived Everywhere, Why Has Income Diverged?" *American Economic Journal*. Macroeconomics 10, no. 3, 2018: 137–178. https://doi.org/10.1257/mac.20150175

51 Comin, Diego, and Martí Mestieri. 2018. "If Technology Has Arrived Everywhere, Why Has Income Diverged?" *American Economic Journal of Macroeconomics* 10, no. 3: 137–178. https://doi.org/10.1257/mac.20150175
52 Lund, Susan, James Manyika, Liz Hilton Segel, et al. 2019. *The Future of Work in America: People and Places, Today and Tomorrow*. McKinsey Global Institute. Available at https://www.mckinsey.com/featured-insights/future-of-work/the-future-of-work-in-america-people-and-places-today-and-tomorrow
53 OECD. 2018. *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities. Paris/Eurostat: OECD Publishing. https://doi.org/10.1787/9789264304604-en
54 Hall, Bronwyn H. 2011. "Innovation and Productivity," *NBER Working Paper no. 17178. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. https://www.nber.org/papers/w17178
55 Mohnen, Pierre, and Bronwyn H Hall. 2014. "Innovation and Productivity: An Update." *Eurasian Business Review* 3, no. 1: 47–65. https://doi.org/10.14208/BF03353817
56 Singh, Anuraag, Giorgio Triulzi, and Christopher L Magee. 2021. "Technological Improvement Rate Predictions for All Technologies: Use of Patent Data and an Extended Domain Description." *Research Policy* 50, no. 9: 104294 https://doi.org/10.1016/j.respol.2021.104294
57 Kondratieff, Nikolai D. 1979. "The Long Waves in Economic Life." *Review Fernand Braudel Center:* 519–562.
58 Grable, John E. 2019. "An Introduction to Kondratieff Waves." *Journal of Financial Service Professionals* 73 (3): 19–22.
59 Solomou, S. 2017. "Kondratieff Cycles." In Vernengo, Matias, Esteban Perez Caldentey, Barkley J. Rosser Jr., eds., *The New Palgrave Dictionary of Economics*. London: Palgrave Macmillan UK: 3470–3475.
60 Grinin, Leonid. E., Anton. L. Grinen, and Andrey Korotayev. 2017. "Forthcoming Kondratieff Wave, Cybernetic Revolution, and Global Ageing." *Technological Forecasting & Social Change* 115: 52–68. https://doi.org/10.1016/j.techfore.2016.09.017
61 Maddison, Angus. 2007. "Fluctuations in the Momentum of Growth within the Capitalist Epoch." *Cliometrica 1*, no. 2 07: 145–175.
62 Korotayev, Andrey, Julia Zinkina, and Justislav Bogevolnov. 2011. "Kondratieff Waves in Global Invention Activity (1900–2008)." *Technological Forecasting & Social Change* 78, no. 7: 1280–8124. https://doi.org/10.1016/j.techfore.2011.02.011
63 Ayres, Robert U. 1989. "Technological Transformations and Long Waves." International Institute for Applied Systems Analysis. Available at http://pure.iiasa.ac.at/id/eprint/3225/1/RR-89-001.pdf. Accessed Mar. 29, 2022.
64 Freeman, Christopher, and Francisco. Louçã. 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press.
65 Köhler, Jonathan. 2012. "A Comparison of the Neo-Schumpeterian Theory of Kondratiev Waves and the Multi-Level Perspective on Transitions." *Environmental Innovation and Societal Transitions* 3: 1–15.
66 Perez, Carlota. 2010. "Technological Revolutions and Techno-Economic Paradigms." *Cambridge Journal of Economics* 34, no. 1: 185–202. https://doi.org/10.1093/cje/bep051
67 Kelly, Bryan, Dimitris Papanikolaou, Amit Seru, and Matt Taddy. 2021. "Measuring Technological Innovation over the Long Run." *The American Economic Review*. Insights 3, no. 3: 303–320. https://doi.org/10.1257/aeri.20190499
68 Kelly, Bryan, Dimitris Papanikolaou, Amit Seru, and Matt Taddy. 2021. "Measuring Technological Innovation over the Long Run." *The American Economic Review*. Insights 3, no. 3: 303–320. https://doi.org/10.1257/aeri.20190499

69 Schwab, Klaus. 2017. *The Fourth Industrial Revolution*. New York: Crown Business.
70 Schwab, Klaus. 2015. "The Fourth Industrial Revolution: What It Means and How to Respond." *Foreign Affairs*, Dec. 12, 2015. Available at https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution
71 Schwab, Klaus. 2015. "The Fourth Industrial Revolution: What It Means and How to Respond." *Foreign Affairs*, Dec. 12, 2015. Available at https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution
72 Schwab, Klaus. 2015. "The Fourth Industrial Revolution: What It Means and How to Respond." *Foreign Affairs*, Dec. 12, 2015. Available at https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution
73 Government of Japan. 2016. *The 5th Science and Technology Basic Plan*, Provisional Translation, Jan. 22, 2016.
74 Government of Japan. 2022. *Science and Technology Basic Plan*, 2022. Available at https://www.mext.go.jp/en/policy/science_technology/lawandplan/title01/detail01/1375311.htm
75 Government of Japan. 2021. *Science, Technology, and Innovation Basic Plan, Tentative Translation,* Mar. 26, 2021. Available at https://www8.cao.go.jp/cstp/english/sti_basic_plan.pdf
76 Fukuda, Kayano. 2020. "Science, Technology and Innovation Ecosystem Transformation Toward Society 5.0." *International Journal of Production Economics* 220: 107460–. https://doi.org/10.1016/j.ijpe.2019.07.033.
77 Fukuyama, Mayumi. 2018. "Society 5.0: Aiming for a New Human-Centered Society." *Japan Spotlight* 27: 47–50.
78 Fukuyama, Mayumi. 2018. "Society 5.0: Aiming for a New Human-Centered Society." *Japan Spotlight* 27: 47–50.
79 Government of Japan. 2016. *Outline of the Fifth Science and Technology Basic Plan*, Provisional Translation. Available at http://www.dst.tokyo/docs/5th-STBP.pdf
80 Fukuyama, Mayumi. 2018. "Society 5.0: Aiming for a new human-centered society." *Japan Spotlight* 27: 47–50.
81 Shiroishi, Yoshihiro, Kunio Uchiyama, and Norihiro Suzuki. 2018. "Society 5.0: For Human Security and Well-Being." *Computer* 51, no. 7: 91–95.
82 Gladden, Matthew E. 2019. "Who Will Be the Members of Society 5.0? Towards an Anthropology of Technologically Posthumanized Future Societies." *Social Sciences* 8, no. 5: 148.
83 Fukuyama, Mayumi. 2018. "Society 5.0: Aiming for a New Human-centered Society." *Japan Spotlight* 27: 47–50.
84 Acting Secretary of Commerce. 1934. *A Report on National Income, 1929–1932*. Bureau of Foreign and Domestic Commerce, Seventy-Third Congress, 1933–1935. Washington: U.S. Government Printing Office, 1934. Available at https://fraser.stlouisfed.org/title/971. Accessed Sept. 30, 2020.
85 United Nations Statistical Commission (UNSC). 2008. *System of National Accounts 2008–2008 SNA*. Available at https://unstats.un.org/unsd/nationalaccount/sna2008.asp
86 Bureau of Labor Statistics. 2022. *Labor Productivity and Costs*. United States Department of Labor, https://www.bls.gov/lpc/. Accessed Mar. 29, 2022.
87 Bureau of Labor Statistics. 2022b. *Multifactor Productivity*. United States Department of Labor, https://www.bls.gov/lpc/https://www.bls.gov/mfp/. Accessed Mar. 29, 2022.
88 Thomas Robert Malthus. 1798. "An Essay on the Principle of Population." *The Works of Thomas Robert Malthus*. London, Pickering & Chatto Publishers, 1986: 1–139.
89 Hansen, Gary D, and Edward C Prescott. 2002. "Malthus to Solow." *The American Economic Review* 92, no. 4: 1205–1217. https://doi.org/10.1257/00028280260344731
90 Hansen, Gary D, and Edward C Prescott. 2002. "Malthus to Solow." *The American Economic Review* 92, no. 4: 1205–1217. https://doi.org/10.1257/00028280260344731

91 Ferguson, Roger W. Jr., and William L. Wascher. 2004. "Distinguished Lecture on Economics in Government: Lessons from Past Productivity Booms." *The Journal of Economic Perspectives* 18, no. 2 (Spring): 3–28.
92 OECD. 2022. "GDP Per Capita and Productivity Growth," *OECD Productivity Statistics* (database). https://doi.org/10.1787/data-00685-en
93 Maddison, Angus. 2003. *The World Economy: Historical Statistics*. Development Centre Studies. Paris: OECD Publishing.
94 Maddison, Angus. 2021. *Maddison Historical Statistics*. Faculty of Economics and Business, University of Groningen. https://www.rug.nl/ggdc/historicaldevelopment/maddison/
95 Maddison, Angus. 2006. *The World Economy: Volume 1: A Millennial Perspective and Volume 2: Historical Statistics*. Development Centre Studies. Paris: OECD Publishing. https://doi.org/10.1787/9789264022621-en
96 Feenstra, Robert, Robert Inklaar, Marcel Timmer. 2015. "The Next Generation of the Penn World Table." *The American Economic Review* 105, no. 10: 3150–3182.
97 Groningen Growth and Development Centre. 2022. *Penn World Table Version 10.0*. Available at https://www.rug.nl/ggdc/productivity/pwt/
98 Van Zanden, Jan Luiten, Joerg Baten, Marco Mira d'Ercole, Auke Rijpma and Marcel P. Timmer, eds. 2014. *How Was Life? Global Well-Being Since 1820*. Paris: OECD Publishing.
99 Landes, David S. 2003. *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*. Cambridge UK: Cambridge University Press.
100 St. Louis Fed. 2022. "Fred Economic Data." Federal Reserve Bank of St. Louis. Available at https://fred.stlouisfed.org/
101 Romer, Paul M. 1989. "Increasing Returns and New Developments in the Theory of Growth." *Working Paper no. 3098*. *NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w3098
102 Solow, Robert M. 1956. "A Contribution to the Theory of Economic Growth," *The Quarterly Journal of Economics* 70, no. 1: 65–94.
103 Grossman, Gene M., and Elhanan Helpman. 1994. "Endogenous Innovation in the Theory of Growth." *The Journal of Economic Perspectives* 8, no. 1: 23–44.
104 Solow, Robert M. 1957. "Technical Change and the Aggregate Production Function." *The Review of Economics and Statistics* 39, no. 3: 312–320.
105 The Nobel Prize. 1987. "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1987." Royal Swedish Academy of Sciences. https://www.nobelprize.org/prizes/economic-sciences/1987/summary/
106 Aghion, Philippe, and Agnès Festré. 2017. "Schumpeterian Growth Theory, Schumpeter, and Growth Policy Design." *Journal of Evolutionary Economics* 27, no. 1: 25–42.
107 Grossman, Gene M., and Elhanan Helpman. 1994. "Endogenous Innovation in the Theory of Growth." *The Journal of Economic Perspectives* 8, no. 1: 23–44.
108 Long, John B. and Charles I. Plosser. 1983. "Real Business Cycles," *The Journal of Political Economy 91*, no. 1, 1983: 39–69.
109 Summers, Lawrence H. 1986. "Some Skeptical Observations on Real Business Cycle Theory." *Federal Reserve Bank of Minneapolis Quarterly Review* 10, no. 4, Fall 1986: 23–27.
110 The Nobel Prize. 2018. "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2018." Royal Swedish Academy of Sciences. https://www.nobelprize.org/prizes/economic-sciences/2018/romer/facts/
111 Romer, Paul M. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98, no. 5: S71–S102.
112 Romer, Paul M. 1990. "Endogenous Technological Change." Journal of Political Economy 98, no. 5: S71–S102.

113 Romer, Paul M. 1990. "Endogenous Technological Change." Journal of Political Economy 98, no. 5: S71–S102.
114 Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60, nos. 2–3: 323–351.
115 Solow, Robert M. 1994. "Perspectives on Growth Theory." *Journal of Economic Perspectives* 8, no. 1: 45–54.
116 Alcouffe, Alain, and Thomas Kuhn. 2004. "Schumpeterian Endogenous Growth Theory and Evolutionary Economics." *Journal of Evolutionary Economics* 14, no. 2: 223–236.
117 Romer, Paul M., and Zvi Griliches. 1993. "Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards; Comments and Discussion." *Brookings Papers on Economic Activity* no. 2: 345.
118 Verspagen, Bart. 2005. "Innovation and Economic Growth." In Fagerberg, Jan, David C. Mowery, and Richard R. Nelson, eds., *The Oxford Handbook of Innovation*. Oxford, UK: Oxford University Press: 487–513.
119 Alcouffe, Alain, and Thomas Kuhn. 2004. "Schumpeterian Endogenous Growth Theory and Evolutionary Economics." *Journal of Evolutionary Economics* 14, no. 2: 223–236.
120 Nelson, Richard R. and Winter, Sidney G. 1982. *An Evolutionary Theory of Economic Change*. Cambridge, MA: Harvard University Press.
121 Perez, Carlota. 2010. "Technological Revolutions and Techno-Economic Paradigms." *Cambridge Journal of Economics* 34, no. 1: 185–202. https://doi.org/10.1093/cje/bep051
122 Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60, nos. 2–3: 323–351.
123 Keynes, John Maynard. 1936. *The General Theory of Employment, Interest and Money*. London: MacMillan Press.
124 Keynes, John Maynard. 1936. *The General Theory of Employment, Interest and Money*. London: MacMillan Press.
125 Aghion, Philippe, and Agnès Festré. 2017. "Schumpeterian Growth Theory, Schumpeter, and Growth Policy Design." *Journal of Evolutionary Economics* 27, no. 1: 25–42.
126 Cortright, Joseph. 2001. "New Growth Theory, New Growth Theory, Technology and Learning: A Practitioner's Guide A Practitioner's Guide." *Reviews of Economic Development Literature and Practice: no. 4*, U.S. Economic Development Administration. Available at https://www.researchgate.net/publication/254336193_New_Growth_Theory_New_Growth_Theory_Technology_and_Learning_Technology_and_Learning_A_Practitioner's_Guide_A_Practitioner's_Guide. Accessed Apr. 14, 2021.
127 Stiglitz, Joseph E. 1994. "Endogenous Growth and Cycles." *Innovation in Technology, Industries, and Institutions. Working Paper no. 4286. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research: 121–156. Available at https://www.nber.org/papers/w4286
128 Feenstra, Robert, Robert Inklaar, Marcel Timmer. 2015. "The Next Generation of the Penn World Table." *The American Economic Review* 105, no. 10: 3150–3182.
129 Waytz, Adam, and Malia Mason. 2012. "Your Brain at Work." *Harvard Business Review*, Jul. – Aug. 2013: 103–111.
130 Mueller, Jennifer S., Shimul Melwani, and Jack A. Goncalo. 2012. "The Bias Against Creativity: Why People Desire but Reject Creative Ideas." *Psychological Science* 23, no. 1: 13–17. https://doi.org/10.1177/0956797611421018
131 Fink, Andreas, and Benedek, Mathias. 2019. "The Neuroscience of Creativity." *Neuroforum* 25, no. 4: 233. https://doi.org/10.1515/nf-2019-0006
132 Kendra Cherry. 2020. "How Many Neurons Are in the Brain?" *Very Well Mind*, Apr. 2020. Available at https://www.verywellmind.com/how-many-neurons-are-in-the-brain-2794889#citation-1
133 Nikhil Swaminathan 2008. "Why Does the Brain Need So Much Power?" *Scientific American*, Apr. 29, 2008. https://www.scientificamerican.com/article/why-does-the-brain-need-s/

134 Seth, Anil. 2021. "How Your Brain Constructs Reality." *TED Talks*. Available at https://www.ted.com/playlists/384/how_your_brain_constructs_real
135 Mueller, Jennifer S., Shimul Melwani, and Jack A. Goncalo. 2012. "The Bias Against Creativity: Why People Desire but Reject Creative Ideas." *Psychological Science* 23, no. 1: 13–17. https://doi.org/10.1177/0956797611421018
136 Buchholz, Christian, and Benno Aerssen, eds. 2020. *The Innovator's Dictionary: 555 Methods and Instruments for More Creativity and Innovation in Your Company*. Berlin/Boston: Walter de Gruyter GmbH.
137 Kim, W. Chan, and Renée Mauborgne. 2005. *Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevan*t. Boston, MA: Harvard Business School Press.
138 Pollack, John. 2014. "Four Ways to Innovate Through Analogies." *The Wall Street Journal*, Nov. 7, 2014. Available at https://www.wsj.com/articles/four-ways-to-innovate-through-analogies-1415376079
139 Ulwick, Anthony W. 2005. *What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services*. New York: McGraw-Hill.
140 Kano, Noriaki. 1984. "Attractive Quality and Must-Be Quality." *Hinshitsu* (*Quality, The Journal of Japanese Society for Quality Control)* 14: 39–48.
141 Matzler, Kurt, and Hans H Hinterhuber. 1998. "How to Make Product Development Projects More Successful by Integrating Kano's Model of Customer Satisfaction into Quality Function Deployment." *Technovation* 18, no. 1: 25–38. https://doi.org/10.1016/S0166-4972(97)00072-2
142 Wu, Chang-Tzuoh, Ming-Tang Wang, Nien-Te Liu, and Tien-Szu Pan. 2015. "Developing a Kano-Based Evaluation Model for Innovation Design." *Mathematical Problems in Engineering*: 1–8. https://doi.org/10.1155/2015/153694
143 Griffin, Abbie, and John R. Hauser. 1993. "The Voice of the Customer." *Marketing Science* (Providence, RI) 12, no. 1: 1–27. https://doi.org/10.1287/mksc.12.1.1
144 Boyd, Drew, and Jacob Goldenberg. 2013. *Inside the Box: A Proven System of Creativity for Breakthrough Results*. New York: Simon & Schuster.
145 Ronald A. Finke, Thomas B. Ward, and Steven M. Smith. 1992. *Creative Cognition: Theory, Research, and Applications*. Cambridge, MA: The MIT Press.
146 Auernhammer, Jan, and Bernard Roth. 2011. "The Origin and Evolution of Stanford University's Design Thinking: From Product Design to Design Thinking in Innovation Management." *The Journal of Product Innovation Management* 38, no. 6: 623–644. https://doi.org/10.1111/jpim.12594
147 D.school. 2022. "Design Thinking Bootleg." Hasso Plattner, Institute of Design at Stanford, Stanford University https://dschool.stanford.edu/resources/design-thinking-bootleg. Accessed Mar. 9, 2022.
148 Johansson, Frans. 2004. *The Medici Effect: Breakthrough Insights at the Intersection of Ideas, Concepts, and Cultures*. Boston, MA: Harvard Business School Press.
149 Hewlett, Sylvia Ann, Melinda Marshall, and Laura Sherbin. 2013. "How Diversity Can Drive Innovation." *Harvard Business Review,* Dec. 2013: 30.
150 Isaacson, Walter. 2018. *Leonardo da Vinci*. New York: Simon & Schuster.
151 McKinsey & Company. 2022. "Organizational Health Index." OrgSolutions. Available at https://www.mckinsey.com/solutions/orgsolutions/overview/organizational-health-index. Accessed Mar. 29, 2022.
152 Kanigel, Robert. 2005. *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency*. New York: Penguin Books.
153 Whyte, William H. 1956. *The Organization Man*. New York: Simon and Schuster.
154 Krafcik, John F. 1988. "Triumph of The Lean Production System." *MIT Sloan Management Review* 30, no. 1: 41.

155 Hammer, Michael, and Champy, James. 1994. *Reengineering the Corporation – A Manifesto for Business Revolution*. London: Nicholas Brealey Publishing.
156 Maslow, Abraham H. 1943. "Conflict, Frustration, and the Theory of Threat." *The Journal of Abnormal and Social Psychology* 38, no. 1: 81.
157 Maslow, Abraham H. 1954. *Motivation and Personality*. New York: Harper and Bros.
158 Herzberg, Frederick, Bernard Mausner, and Barbara Snyderman. 1959. *The Motivation to Work*. New York: Wiley.
159 McGregor, Douglas. 1960. *The Human Side of Enterprise*. New York: McGraw-Hill.
160 McClelland, David C., and Eric W Johnson. 1984. *Learning to Achieve*. Glenview, Illinois: Scotti. Foresman & Co.
161 Vroom, Victor H. 1964. *Work and Motivation*. New York: John Wiley and Sons.
162 Tushman, Michael., and Charles A. O'Reilly. 1997. *Winning through Innovation: A Practical Guide to Leading Organizational Change and Renewal*. Boston, MA: Harvard Business School Press.
163 Rosing, Kathrin, Michael Frese, and Andreas Bausch. 2011. "Explaining the Heterogeneity of the Leadership-Innovation Relationship: Ambidextrous Leadership." *The Leadership Quarterly* 22, no. 5: 956–974. https://doi.org/10.1016/j.leaqua.2011.07.014
164 Rosing, Kathrin, Michael Frese, and Andreas Bausch. 2011. "Explaining the Heterogeneity of the Leadership-Innovation Relationship: Ambidextrous Leadership." *The Leadership Quarterly* 22, no. 5: 956–974. https://doi.org/10.1016/j.leaqua.2011.07.014
165 Rosing, Kathrin, Michael Frese, and Andreas Bausch. 2011. "Explaining the Heterogeneity of the Leadership-Innovation Relationship: Ambidextrous Leadership." *The Leadership Quarterly* 22, no. 5: 956–974. https://doi.org/10.1016/j.leaqua.2011.07.014
166 Zacher, Hannes, and Kathrin Rosing. 2015. "Ambidextrous Leadership and Team Innovation." *Leadership & Organization Development Journal* 36, no. 1: 54–68. https://doi.org/10.1108/LODJ-11-2012-0141
167 Chen, Yan. 2017. "Dynamic Ambidexterity: How Innovators Manage Exploration and Exploitation." *Business Horizons* 60, no. 3: 385–394. https://doi.org/10.1016/j.bushor.2017.01.001
168 Chen, Yan. 2017. "Dynamic Ambidexterity: How Innovators Manage Exploration and Exploitation." *Business Horizons* 60, no. 3: 385–394. https://doi.org/10.1016/j.bushor.2017.01.001
169 Chen, Yan. 2017. "Dynamic Ambidexterity: How Innovators Manage Exploration and Exploitation." *Business Horizons* 60, no. 3: 385–394. https://doi.org/10.1016/j.bushor.2017.01.001
170 Lockheed Martin. 2022 *Missions Impossible: The Skunk Works® Story*. Available at https://www.lockheedmartin.com/en-us/news/features/history/skunk-works.html. Accessed on Mar. 9, 2022.
171 McGann, Michael, Emma Blomkamp, and Jenny M. Lewis. 2018. "The Rise of Public Sector Innovation Labs: Experiments in Design Thinking for Policy." *Policy Sciences* 51, nos. 3–9: 249–267.
172 IDEO. 2022. "About the Ten Faces." https://www.ideo.com/post/the-ten-faces-of-innovation. Accessed Mar. 9, 2022.
173 The Economist. 2021. "How to Prevent Conflict on the Way to Mars," *The Economist*, Dec. 18, 2021. Available at https://www.economist.com/christmas-specials/2021/12/18/how-to-prevent-conflict-on-the-way-to-mars
174 Amabile, Teresa M. 1988. "A Model of Creativity and Innovation in Organizations." *Research in Organizational Behavior* 10, no. 1: 123–167.
175 Michaelis, Timothy L, Roberly Aladin, and Jeffrey M Pollack. 2018. "Innovation Culture and the Performance of New Product Launches: A Global Study." *Journal of Business Venturing Insights* 9: 116–127. https://doi.org/10.1016/j.jbvi.2018.04.001
176 Chesbrough, Henry. 2006. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.
177 Chesbrough, Henry. 2006. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

178 Chesbrough, Henry. 2006. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.
179 Christensen, Clayton M. 1997. *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business Review Press.
180 Chesbrough, Henry. 2006. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.
181 Chesbrough, Henry. 2006. "Open Innovation: A New Paradigm for Understanding Industrial Innovation." In Chesbrough, Henry, Vahaverbeke, Wim, and West, Joel, eds., *Open Innovation: Researching a New Paradigm*. Oxford University Press.
182 Chesbrough, Henry. 2017. "The Future of Open Innovation," *Research Technology Management* 60, no. 1: 35.
183 Chesbrough, Henry. 2017. "The Future of Open Innovation," *Research Technology Management* 60, no. 1: 35–38.
184 Chesbrough, Henry. 2006. "Open Innovation: A New Paradigm for Understanding Industrial Innovation." In Chesbrough, Henry, Vahaverbeke, Wim, and West, Joel, eds., *Open Innovation: Researching a New Paradigm*. Oxford University Press.
185 Von Hippel, Eric. 2006. *Democratizing Innovation*. Cambridge, MA: MIT Press.
186 Surowiecki, James. 2005. *The Wisdom of Crowds*. New York: Anchor.
187 Hadhazy, Adam. 2016. "Crowdsourcing the Universe: How Citizen Scientists are Driving Discovery." *Space.com*, Jan. 14, 2016. https://www.space.com/31626-crowdsourced-astronomy-finding-faint-galaxies-in-deep-space.html. Accessed Mar. 10, 2022.
188 Prahalad, Coimbatore K., and Venkat Ramaswamy. 2004. "Co-Creating Unique Value with Customers." *Strategy & Leadership*, 32, no. 3: 4–9. https://doi.org/10.1108/10878570410699249
189 Prahalad, Coimbatore K., and Venkat Ramaswamy. 2004. "Co-Creating Unique Value with Customers." *Strategy & Leadership*, 32, no. 3: 4–9. https://doi.org/10.1108/10878570410699249
190 Innovation Leader. 2019. "Understanding Co-Creation and Innovation Ecosystems Is No Longer Optional . . . " *Best Practices: Co-creation and Ecosystem Development*, Innovation Leader, Q1 2019.
191 Walsh, John P, You-Na Lee, and Sadao Nagaoka. 2016. "Openness and Innovation in the US: Collaboration Form, Idea Generation and Implementation." *Research Policy* 45, no. 8: 1660–1671. https://doi.org/10.1016/j.respol.2016.04.013
192 Henz, Tobias, Miao Wang, and Tawanda Sibanda. 2020. "Flipping the Odds on Corporate-Startup Collaboration." *Alumni Webcast*, McKinsey & Company, Oct. 15, 2020.
193 Terwiesch, Christian, and Yi Xu. 2008. "Innovation Contests, Open Innovation, and Multiagent Problem Solving." *Management Science* 54, no. 9: 1529–1543.
194 Howells, Jeremy. 2006. "Intermediation and the Role of Intermediaries in Innovation." *Research Policy 35*, no. 5: 715–728.
195 European Commission's Directorate-General for Research & Innovation (RTD). 2016. *Open Innovation, Open Science, Open to the World - a Vision for Europe*. European Commission. Available at https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe
196 Von Hippel, Eric. 2006. *Democratizing Innovation*. Cambridge, MA: MIT Press.
197 European Commission's Directorate-General for Research & Innovation (RTD). 2016. *Open Innovation, Open Science, Open to the World - a Vision for Europe*. European Commission. Available at https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe
198 Gassmann, Oliver, and Ellen Enkel. 2004. "Towards a Theory of Open Innovation: Three Core Process Archetypes." Institute of Technology Management, University of St. Gallen, Switzerland. Available at https://www.alexandria.unisg.ch/274/1/Gassmann_Enkel.pdf

199 Baldwin, Carliss, and Eric von Hippel. 2011. "Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation." *Organization Science* 22, no. 6: 1399–1417.
200 Baldwin, Carliss, and Eric von Hippel. 2011. "Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation." *Organization Science* 22, no. 6: 1399–1417.
201 Baldwin, Carliss, and Eric von Hippel. 2011. "Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation." *Organization Science* 22, no. 6: 1399–1417.
202 Baldwin, Carliss, and Eric von Hippel. 2011. "Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation." *Organization Science* 22, no. 6: 1399–1417.
203 General Mills. 2022. "Criteria and FAQ," General Mills Worldwide Innovation Network (G-WIN), https://gwin.secure.force.com/FAQs. Accessed Mar. 10, 2022
204 Saebi, Tina, and Nicolai J. Foss. 2015. "Business Models for Open Innovation: Matching Heterogeneous Open Innovation Strategies with Business Model Dimensions." *The European Management Journal* 33, no. 3: 201–213.
205 Pedersen, Keld. 2018. *The Purpose of Public Sector Open Innovation*. Reading: Academic Conferences International Limited.
206 Mergel, Ines. 2018. "Open Innovation in the Public Sector: Drivers and Barriers for the Adoption of Challenge.gov." *Public Management Review* 20, no. 5: 726–745.
207 Hartley, Jean, Eva Sørensen, and Jacob Torfing. 2013. "Collaborative Innovation: A Viable Alternative to Market Competition and Organizational Entrepreneurship." *Public Administration Review* 73, no. 6: 821–830. doi:10.1111/puar.12136
208 Government Accountability Office (GAO). 2017. *OPEN INNOVATION Executive Branch Developed Resources to Support Implementation, but Guidance Could Better Reflect Leading Practices*. GAO-17-507 Report to Congressional Committees.
209 Government Accountability Office (GAO). 2017. *OPEN INNOVATION Executive Branch Developed Resources to Support Implementation, but Guidance Could Better Reflect Leading Practices*. GAO-17-507 Report to Congressional Committees.
210 Gascó, Mila. 2017. "Living Labs: Implementing Open Innovation in the Public Sector." *Government Information Quarterly* 34, no. 1: 90–98.
211 Dias, Albertina, and Bror Salmelin. 2018. "Living Labs and Open Innovation in European Context." In Dias, Albertina, Bror Salmelin, David Pereira, and Miguel Sales Dias, eds., *Modeling Innovation Sustainability and Technologies*. Cham, Switzerland: Springer.
212 Fulgencio, Harry, Hans Le Fever, and Bernhard Katzy. 2012. "Living Lab: Innovation through Pastiche." In *Proceedings of the eChallenges e-2012 Conference*. Lisbon: IMC: 1–8.
213 Janssen, Marijn, David Konopnicki, Jane L. Snowdon, and Adegboyega Ojo. 2017. "Driving Public Sector Innovation using Big and Open Linked Data (BOLD)." *Information Systems Frontiers* 19, no. 2: 189–195.
214 Open Knowledge Foundation. 2022. "What Is Open?" Available at https://okfn.org/opendata/
215 Open Knowledge Foundation. 2022. "What is Open Data?" *The Open Data Handbook*. 2022. Available at https://opendatahandbook.org/guide/en/what-is-open-data/
216 Jetzek, Thorhildur, Michel Avital, and Niels Bjorn-Andersen. 2014. "Data-Driven Innovation through Open Government Data." *Journal of Theoretical and Applied Electronic Commerce Research* 9, no. 2: 100–120.
217 Open Knowledge Foundation. 2022. "Global Open Data Index." Available at https://index.okfn.org/
218 Lämmerhirt, D., M. Rubinstein, and O. Montiel. 2017. *The State of Open Government Data in 2017: Creating Meaningful Open Data Through Multi-Stakeholder Dialogue*. Open Knowledge International.
219 The White House, President Barack Obama. 2009. *Open Government Directive*, issued Dec. 8, 2009. In Obama Whitehouse Archives, https://obamawhitehouse.archives.gov/open/documents/open-government-directive. Accessed Mar. 11, 2022.

220 Massa, Lorenzo, Christopher L. Tucci, and Allan Afuah. 2017. "A Critical Assessment of Business Model Research." *Academy of Management Annals* 11, no. 1: 73–104.
221 Teece, David J. 2010. "Business Models, Business Strategy and Innovation." *Long Range Planning* 43, no. 2: 172–194. https://doi.org/10.1016/j.lrp.2009.07.003
222 Zott, Christoph, Raphael Amit, and Lorenzo Massa. 2011. "The Business Model: Recent Developments and Future Research." *Journal of Management* 37, no. 4: 1019–1042.
223 Amit, Raphael, and Christoph Zott. 2012. "Creating Value Through Business Model Innovation." *MIT Sloan Management Review* 53, no. 3: 41.
224 Wirtz, Bernd W, Adriano Pistoia, Sebastian Ullrich, and Vincent Göttel. 2016. "Business Models: Origin, Development and Future Research Perspectives." *Long Range Planning* 49, no. 1: 36–54. https://doi.org/10.1016/j.lrp.2015.04.001
225 Foss, Nicolai J., and Tina Saebi. 2017. "Fifteen Years of Research on Business Model Innovation: How Far Have We Come, and Where Should We Go?" *Journal of Management* 43, no. 1: 200–227.
226 Christensen, Clayton Magleby, Thomas Bartman, and Derek Van Bever. 2017. "The Hard Truth About Business Model Innovation." *MIT Sloan Management Review* 58, no. 1: 31–40.
227 Massa, Lorenzo, and Christopher L. Tucci. 2013. "Business Model Innovation." In Dodgson, Mark, David Gann, and Nelson Phillips, eds., *The Oxford Handbook of Innovation Management* 20, no. 18: 420–441. New York: Oxford.
228 Christensen, Clayton Magleby, Thomas Bartman, and Derek Van Bever. 2017. "The Hard Truth About Business Model Innovation." *MIT Sloan Management Review* 58, no. 1: 31–40.
229 Markides, Constantinos C. 2013. "Business Model Innovation: What Can the Ambidexterity Literature Teach Us?" *Academy of Management Perspectives* 27, no. 4: 313–323.
230 Linder, Jane, and Susan Cantrell. 2000. "Changing business models: Surveying the landscape," Accenture Institute for Strategic Change, Cambridge, May 24, 2000. Available at http://www.businessmodels.eu/images/banners/Articles/Linder_Cantrell.pdf. Accessed Mar. 14, 2022.
231 Salesforce. 2021. "The History of Salesforce." Available at https://www.salesforce.com/news/stories/the-history-of-salesforce/. Accessed on Mar. 11, 2022.
232 Sanchez, Pablo, and Joan E. Ricart. 2010. "Business Model Innovation and Sources of Value Creation in Low-Income Markets." *European Management Review* 7, no. 3: 138–154.
233 Chesbrough, Henry, and Richard S Rosenbloom. 2002. "The Role of the Business Model in Capturing Value from Innovation: Evidence from Xerox Corporation's Technology Spin-off Companies." *Industrial and Corporate Change* 11, no. 3: 529–555. https://doi.org/10.1093/icc/11.3.529
234 Chesbrough, Henry. 2010. "Business Model Innovation: Opportunities and Barriers." *Long Range Planning* 43, no. 2: 354–363. https://doi.org/10.1016/j.lrp.2009.07.010
235 Richardson, James. 2008. "The Business Model: An Integrative Framework for Strategy Execution." *Strategic Change* 17, nos. 5–6: 133–144. https://doi.org/10.1002/jsc.821
236 Pieroni, Marina P.P, Tim C McAloone, and Daniela C.A Pigosso. 2019. "Business Model Innovation for Circular Economy and Sustainability: A Review of Approaches." *Journal of Cleaner Production* 215: 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036
237 Parker, Geoffrey G., Marshall Van Alstyne, and Sangeet Paul Choudary. 2016. *Platform Revolution: How Networked Markets Are Transforming the Economy and How to Make Them Work for You*. W. W. Norton & Company. Kindle Edition.
238 Janeway, William H. 2018. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, UK: Cambridge University Press.
239 Bhatia, Tushar, Mohsin Imtiaz, Eric Kutcher, and Dilip Wagle. 2017. "How Tech Giants Deliver Outsized Returns—and What It Means for the Rest of Us." McKinsey & Company. Available at https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights

/how-tech-giants-deliver-outsized-returns-and-what-it-means-for-the-rest-of-us. Accessed Mar. 15, 2021.
240 Boons, Frank, and Nancy Bocken. 2018. "Towards a Sharing Economy – Innovating Ecologies of Business Models." *Technological Forecasting & Social Change* 137: 40–52. https://doi.org/10.1016/j.techfore.2018.06.031
241 Frank, Alejandro G., Glauco HS Mendes, Néstor F. Ayala, and Antonio Ghezzi. 2019. "Servitization and Industry 4.0 Convergence in the Digital Transformation of Product Firms: A Business Model Innovation Perspective." *Technological Forecasting and Social Change* 141: 341–351.
242 Ibarra, Dorleta, Jaione Ganzarain, and Juan Ignacio Igartua. 2018. "Business Model Innovation Through Industry 4.0: A Review." *Procedia Manufacturing* 22: 4–10.
243 Yang, Heyoung, Su Youn Kim, and Seongmin Yim. 2019. "A Case Study of the Korean Government's Preparation for the Fourth Industrial Revolution: Public Program to Support Business Model Innovation." *Journal of Open Innovation* 5, no. 2: 35. https://doi.org/10.3390/joitmc5020035
244 Osterwalder, Alexander, and Yves Pigneur. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, NJ: Wiley.
245 Osterwalder, Alexander, and Yves Pigneur. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, NJ: Wiley.
246 Osterwalder, Alexander, Yves Pigneur, Gregory Bernarda, and Alan Smith. 2014. *Value Proposition Design: How to Create Products and Services Customers Want*. Hoboken, NJ: John Wiley & Sons, Inc.
247 National Inventors Hall of Fame. 2022. "King Camp Gillette." https://www.invent.org/inductees/king-camp-gillette. Accessed Mar. 14, 2022.
248 Euchner, Jim, and Abhijit Ganguly. 2014."Business Model Innovation in Practice: A Systematic Approach to Business Model Innovation Can Help Capture Value and Reduce Risks." *Research Technology Management* 57, no. 6: 33–39. https://doi.org/10.5437/08956308X5706013
249 Blank, Steve, and Alexander Osterwalder. 2016. "The Mission Model Canvas – An Adapted Business Model Canvas for Mission-Driven Organizations." *SteveBlank.com*, posted Feb 23., 2016. Available at https://steveblank.com/2016/02/23/the-mission-model-canvas-an-adapted-business-model-canvas-for-mission-driven-organizations/. Accessed Mar. 15, 2022.
250 Blank, Steve, and Alexander Osterwalder. 2016. "The Mission Model Canvas – An Adapted Business Model Canvas for Mission-Driven Organizations," *SteveBlank.com*, posted Feb. 23, 2016. Available at https://steveblank.com/2016/02/23/the-mission-model-canvas-an-adapted-business-model-canvas-for-mission-driven-organizations/. Accessed Mar. 15, 2022.
251 Ries, Eric. 2011. *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*. London: Portfolio Penguin.
252 Blank, Steven G. 2005. *The Four Steps to the Epiphany: Successful Strategies for Products That Win*. 3rd ed., 4th rev. printing. California: S.G. Blank.
253 Blank, Steven, and Bob Dorf. 2005. "The Path to Epiphany: The Customer Development Model." In *The Four Steps to the Epiphany*. California: S.G. Blank: 17–28.
254 Blank, Steve. 2013. "Why the Lean Start-Up Changes Everything." *Harvard Business Review* 91, no. 5: 63–72.
255 Blank, Steve, and Jim Euchner. 2018. "The Genesis and Future of Lean Startup: An Interview with Steve Blank." *Research Technology Management* 61, no. 5: 15–21. https://doi.org/10.1080/08956308.2018.1495963
256 Blank, Steve, and Jim Euchner. 2018. "The Genesis and Future of Lean Startup: An Interview with Steve Blank." *Research Technology Management* 61, no. 5: 15–21. https://doi.org/10.1080/08956308.2018.1495963
257 Ries, Eric. 2011. *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*. London: Portfolio Penguin.

258 Agile Alliance. 2022. "Manifesto for Agile Software Development." Agile Essentials. https://www.agilealliance.org/agile101/the-agile-manifesto/
259 Ries, Eric. 2011. *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*. London: Portfolio Penguin.
260 The Economist. 2022. "SpaceX's monstrous, dirt-cheap Starship may transform space travel." *The Economist*, Feb. 19, 2022. Available at https://www.economist.com/science-and-technology/2022/02/19/spacexs-monstrous-dirt-cheap-starship-may-transform-space-travel. Accessed Mar. 21, 2022.
261 Project Management Institute (PMI). 2021. *The Standard for Project Management and a Guide to the Project Management Body of Knowledge* (PMBOK Guide). Seventh Edition. Newtown Square, PA: Project Management Institute, Inc.
262 Kerzner, Harold. 2017. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, Twelfth Edition. Chichester, West Sussex, UK: Wiley.
263 Knight, Frank H. 1921. *Risk, Uncertainty, and Profit*. Pantianos Classics.
264 Zeckhauser, Richard. 2006. "Investing in the Unknown and Unknowable." *Capitalism and Society* 1, no. 2: 5. https://doi.org/10.2202/1932-0213.1009
265 Kaplan, Robert S., and David P Norton. 2004. "The Strategy Map: Guide to Aligning Intangible Assets." *Strategy & Leadership* 32, no. 5: 10–17. https://doi.org/10.1108/10878570410699825
266 Kaplan, Robert S., and David P. Norton. 1996. *The Balanced Scorecard: Translating Strategy into Action*. Boston: Harvard Business Review Press.
267 Kaplan, Robert S., and David P Norton. 2004. "The Strategy Map: Guide to Aligning Intangible Assets." *Strategy & Leadership* 32, no. 5: 10–17. https://doi.org/10.1108/10878570410699825
268 Kaplan, Robert S., and David P Norton. 2004. "The Strategy Map: Guide to Aligning Intangible Assets." *Strategy & Leadership* 32, no. 5: 10–17. https://doi.org/10.1108/10878570410699825
269 Kaplan, Robert S., and David P Norton. 2004. "The Strategy Map: Guide to Aligning Intangible Assets." *Strategy & Leadership* 32, no. 5: 10–17. https://doi.org/10.1108/10878570410699825
270 Rupietta, Christian, and Uschi Backes-Gellner. 2019. "Combining Knowledge Stock and Knowledge Flow to Generate Superior Incremental Innovation Performance — Evidence from Swiss Manufacturing." Journal of Business Research 94: 209–222. https://doi.org/10.1016/j.jbusres.2017.04.003
271 O'Dell, Carla, and C. Jackson Grayson. 1998. "If Only We Knew What We Know: Identification and Transfer of Internal Best Practices." *California Management Review* 40, no. 3: 154–174. https://doi.org/10.2307/41165948
272 Adams, Richard, John Bessant, and Robert Phelps. 2006. "Innovation Management Measurement: A Review." *International Journal of Management Reviews: IJMR 8*, no. 1: 21–47. https://doi.org/10.1111/j.1468-2370.2006.00119.x
273 OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*. Paris*:* OECD Publishing https://doi.org/10.1787/9789264239012-en
274 International Organization for Standardization (ISO). 2019. *ISO 56002, Innovation Management — Innovation Management System — Guidance* (2019). Available at https://www.iso.org/standard/68221.html
275 International Organization for Standardization (ISO). 2019. *ISO 56002, Innovation Management — Innovation Management System — Guidance* (2019). Available at https://www.iso.org/standard/68221.html
276 Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.
277 Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.

278 Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.
279 Budanovic, Nicola. 2016. "Heinz Guderian, The Father of The Blitzkrieg," War History Online, https://www.warhistoryonline.com/world-war-ii/heinz-guderian-the-father-of-the-blitzkrieg.html
280 Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.
281 Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.
282 Borins, Sandford. 2000. "Loose Cannons and Rule Breakers, Or Enterprising Leaders? Some Evidence about Innovative Public Managers." *Public Administration Review* 60, no. 6: 498–507.
283 Muller E., Héraud JA., Zenker A. 2017. "Are Innovation Systems Complex Systems?" In Bourgine P., Collet P., Parrend P., eds., *First Complex Systems Digital Campus World E-Conference 2015. Springer Proceedings in Complexity*. Springer, Cham. https://doi.org/10.1007/978-3-319-45901-1_17
284 Cooper, Robert G., Scott J. Edgett, and Elko J. Kleinschmidt. 1999. "New Product Portfolio Management: Practices and Performance." *Journal of Product Innovation Management: An International Publication of The Product Development & Management Association* 16, no. 4: 333–351.
285 Cooper, Robert G., Scott J. Edgett, and Elko J. Kleinschmidt. 1999. "New Product Portfolio Management: Practices and Performance." *Journal of Product Innovation Management: An International Publication of The Product Development & Management Association* 16, no. 4: 333–351.
286 Menke, Michael M. 2013. "Making R&D Portfolio Management More Effective." *Research-Technology Management* 56, no. 5: 34–44.
287 Spieth, P. and Lerch, M. 2014. "IPPM Performance and Management Perception and Satisfaction." *R&D Management* 44: 498–515. doi:10.1111/radm.12092
288 Urhahn, Christian, and Patrick Spieth. 2014. "Governing the Portfolio Management Process for Product Innovation—A Quantitative Analysis on the Relationship Between Portfolio Management Governance, Portfolio Innovativeness, and Firm Performance." *IEEE Transactions on Engineering Management* 61, no. 3: 522–533, doi:10.1109/TEM.2014.2327254.
289 Kock, Alexander, and Hans Georg Gemünden. 2016. "Antecedents to Decision-Making Quality and Agility in Innovation Portfolio Management." *The Journal of Product Innovation Management* 33, no. 6: 670–686. https://doi.org/10.1111/jpim.12336
290 Meifort, Anna. 2016. "Innovation Portfolio Management: A Synthesis and Research Agenda." *Creativity & Innovation Management* 25, no. 2: 251–269.
291 Meifort, Anna. 2016. "Innovation Portfolio Management: A Synthesis and Research Agenda." *Creativity & Innovation Management* 25, no. 2: 251–269.
292 Martinsuo, Miia, Tuomas Korhonen, and Teemu Laine. 2014. "Identifying, Framing and Managing Uncertainties in Project Portfolios." *International Journal of Project Management* 32, no. 5: 732–746. https://doi.org/10.1016/j.ijproman.2014.01.014
293 Loewe, Pierre, Peter Williamson, and Robert Chapman Wood. 2001. "Five Styles of Strategy Innovation and How to Use Them." *The European Management Journal* 19, no. 2: 115–125. https://doi.org/10.1016/S0263-2373(00)00081-5
294 Mikkola, Juliana Hsuan. 2001. "Portfolio Management of R&D Projects: Implications for Innovation Management." *Technovation* 21, no. 7: 423–435. https://doi.org/10.1016/S0166-4972(00)00062-6
295 Nagji, Bansi, and George Tuff. 2012. "Managing Your Innovation Portfolio." *Harvard Business Review* 90, no. 5: 66–74.
296 Markowitz, Harry. 1952. "Portfolio Selection." *The Journal of Finance* 7: 77–91.
297 Chan, Vanessa, Marc de Jong, and Vidyadhar Ranada. 2014. "Finding the Sweet Spot for Allocating Innovation Resources." *McKinsey Quarterly*, May 2014, https://www.mckinsey.com/busi

ness-functions/strategy-and-corporate-finance/our-insights/finding-the-sweet-spot-for-allocating-innovation-resources
298 Kahneman, Daniel, and Amos Tversky. 1979. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* 47, no. 2: 263–291.
299 VisualCapitalist. 2017. "Cognitive Bias Codex." https://www.visualcapitalist.com/wp-content/uploads/2017/09/cognitive-bias-infographic.html
300 Kahneman, Daniel. 2011. *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux.
301 Mun, Johnathan. 2020. "Risk-Based ROI, Capital Budgeting, and Portfolio Optimization in the Department of Defense." *Defense Acquisition Research Journal* 27, no. 91: 60–107. https://doi.org/10.22594/dau.19-829.27.01
302 Girotra, Karan, Christian Terwiesch, and Karl T. Ulrich. 2007. "Valuing R&D Projects in a Portfolio: Evidence from the Pharmaceutical Industry." *Management Science* 53, no. 9: 1452–1466.
303 Cooper, Robert Gravlin, Scott J. Edgett, and Elko J. Kleinschmidt. 2001. "Portfolio Management for New Products." Retrieved from https://www.academia.edu/download/3468542/wp_11.pdf
304 Cooper, Robert G., and Scott J. Edgett. 2006. "Ten Ways to Make Better Portfolio and Project Selection Decisions." *PDMA Visions Magazine* 30, no. 3: 11–15.
305 Project Management Institute (PMI). https://www.pmi.org/
306 Project Management Institute. 2021. *The Standard for Project Management and a Guide to the Project Management Body of Knowledge (PMBOK Guide)*. Seventh Edition. Newtown Square, PA: Project Management Institute, Inc. See https://www.pmi.org/pmbok-guide-standards/foundational/pmbok
307 Product Development and Management Association (PDMA). 2020. *PDMA Body of Knowledge, 2nd Edition*. Kindle. See https://www.pdma.org/page/npdp-bok-second-edition
308 White, J. Chris,8 and Sholtes, Robert M. 2011. "Going beyond CPM." Paper presented at *PMI® Global Congress 2011—North America, Dallas, TX*. Newtown Square, PA: Project Management Institute. Available at https://www.pmi.org/learning/library/going-beyond-critical-path-method-6297
309 Stage-Gate Inc., Trademark Notice. Available at https://www.stage-gate.com/trademarks-notice/
310 Cooper, Robert G. 1990. "Stage-Gate Systems: A New Tool for Managing New Products." *Business Horizons* 33, no. 3: 44–54. https://doi.org/10.1016/0007-6813(90)90040-I
311 Sethi, Rajesh, and Zafar Iqbal. 2008. "Stage-Gate Controls, Learning Failure, and Adverse Effect on Novel New Products." *Journal of Marketing* 72, no. 1: 118–134. https://doi.org/10.1509/jmkg.72.1.118
312 Van Oorschot, Kim, Kishore Sengupta, Henk Akkermans, and Luk Van Wassenhove. 2010. "Get Fat Fast: Surviving Stage-Gate® in NPD." *The Journal of Product Innovation Management* 27, no. 6: 828–839. https://doi.org/10.1111/j.1540-5885.2010.00754.x
313 Cooper, Robert G., and Anita Friis Sommer. 2018. "Agile-Stage-Gate for Manufacturers: Changing the Way New Products Are Developed Integrating Agile Project Management Methods into a Stage-Gate System Offers Both Opportunities and Challenges." *Research Technology Management* 61, no. 2: 17–26. https://doi.org/10.1080/08956308.2018.1421380
314 Cooper, Robert G. 2017. "Idea-to-Launch Gating Systems: Better, Faster, and More Agile: Leading Firms Are Rethinking and Reinventing Their Idea-to-Launch Ggating Systems, Adding Elements of Agile to Traditional Stage-Gate Structures to Add Flexibility and Speed While Retaining Structure." *Research Technology Management* 60, no. 1: 48–52.
315 Gronlund, Johan, David Ronnberg Sjodin, and Johan Frishammar. 2010. "Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development." *California Management Review* 52, no. 3: 106–131. https://doi.org/10.1525/cmr.2010.52.3.106

316 U.S. Department of Defense. 1985. *Military Standard – Technical Reviews and Audits for Systems, Equipments, and Computer Software*, MIL-STD-1521B, June 4, 1985. Available at https://product-lifecycle-management.com/download/MIL-STD-1521B.pdf
317 IEEE Standards Association. 2015. *IEEE 15288.2-2014 – IEEE Standard for Technical Reviews and Audits on Defense Programs*. Available at https://standards.ieee.org/standard/15288_2-2014.html
318 International Organization for Standardization (ISO). 2015. ISO/IEC/IEEE 15288:2015 – *Systems and software engineering — System life cycle processes*. Available at https://www.iso.org/standard/63711.html
319 MITRE. 2022. *Systems Engineering Guide (SEG)*. Available at https://www.mitre.org/publications/systems-engineering-guide/systems-engineering-guide
320 Department of Defense. 2020. *DOD Instruction 5000.85. Major Capability Acquisition*. Available at https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093
321 Schumpeter, Joseph A. 1939. *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.
322 Schumpeter, Joseph A. 1939. *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.
323 Knight, Frank H. 1921. *Risk, Uncertainty, and Profit*. Pantianos Classics.
324 Zeckhauser, Richard. 2006. "Investing in the Unknown and Unknowable." *Capitalism and Society 1*, no. 2: 5. https://doi.org/10.2202/1932-0213.1009
325 Rumsfeld, Donald H. 2002. "DOD News Briefing – Secretary Rumsfeld and Gen. Myers." CNN transcript, Feb. 12, 2002. http://www.cnn.com/TRANSCRIPTS/0202/12/se.04.html. Also see Rumsfeld, Donald. YouTube video, from DOD News Briefing on Feb. 12, 2002, posted by "Ali" Aug. 7, 2009, https://youtu.be/GiPe1OiKQuk
326 Zeckhauser, Richard. 2006. "Investing in the Unknown and Unknowable." *Capitalism and Society* 1, no. 2: 5. https://doi.org/10.2202/1932-0213.1009
327 Keynes, John Maynard. 1936. *The General Theory of Employment, Interest, and Money*, London: MacMillan Press.
328 Keynes, John Maynard. 1937. "The General Theory of Employment." *Quarterly Journal of Economics* 51, no. 2, 209–223.
329 Barrero, Jose Maria, Nicholas Bloom, and Ian Wright. 2017. "Short and Long Run Uncertainty". *Working Paper no. w23676*. *NBER Working Paper Series*. Cambridge, MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w23676
330 Janeway, William H. 2018. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, UK: Cambridge University Press.
331 Hall, Robert E., and Susan E. Woodward. 2010. "The Burden of the Nondiversifiable Risk of Entrepreneurship." *The American Economic Review 100*, no. 3: 1163–1194. https://doi.org/10.1257/aer.100.3.1163
332 Fowler, Ben. 2022. "Stages of Venture Capital." Silicon Valley Bank. Available at https://www.svb.com/startup-insights/vc-relations/stages-of-venture-capital. Accessed Mar. 24, 2022.
333 PitchBook. 2022. *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor
334 Pitchbook 2022b. Data downloaded from PitchBook, *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc., 2022. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor
335 PitchBook. 2022. *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor

336 Pitchbook. 2022b. Data downloaded from PitchBook, *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor
337 CBInsights. 2022a. *State of Venture 2021 Report*: 8, 26. Available at https://www.cbinsights.com/research/report/venture-trends-2021/. Accessed Feb. 2, 2022.
338 CBInsights. 2022b, *State Of CVC*: *Global 2021*. Available at https://www.cbinsights.com/research/report/corporate-venture-capital-trends-2021/. Accessed Mar. 24, 2022
339 PitchBook. 2022c. *US PE Breakdown 2021 Annual, 2022*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/2021-annual-us-pe-breakdown
340 Reads, Edith M. 2022. "Assets managed by top 10 sovereign wealth funds hit $7.4 trillion." *FinancePR.com*, Jan. 24, 2022. Available at https://financepr.com/assets-managed-by-top-10-sovereign-wealth-funds-hit-7-4-trillion/
341 PitchBook. 2022. *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor
342 CBInsights. 2022c. *State of Venture 2021 Report*, data file. Available at https://www.cbinsights.com/research/report/venture-trends-2021/. Accessed Feb. 2, 2022.
343 Kenney, Martin, and John Zysman. 2019. "Unicorns, Cheshire cats, and the new dilemmas of entrepreneurial finance." *Venture Capital* 21, no. 1: 35–50.
344 Kenney, Martin, and John Zysman. 2019. "Unicorns, Cheshire cats, and the new dilemmas of entrepreneurial finance." *Venture Capital* 21, no. 1: 35–50.
345 Ewens, Michael, Ramana Nanda, and Matthew Rhodes-Kropf. 2018. "Cost of Experimentation and the Evolution of Venture Capital." *Journal of Financial Economics* 128, no. 3: 422–442. https://doi.org/10.1016/j.jfineco.2018.03.001
346 Ewens, Michael, Ramana Nanda, and Christopher T. Stanton. 2020. "The Evolution of CEO Compensation in Venture Capital Backed Startups." *Working Paper no. 27296. NBER Working Paper Series*. Cambridge, MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w27296
347 Lerner, Josh, and Ramana Nanda. 2020. "Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn." *The Journal of Economic Perspectives* 34, no. 3: 237–261.
348 Lerner, Josh, and Ramana Nanda. 2020. "Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn." *The Journal of Economic Perspectives* 34, no. 3: 237–261.
349 Bessemer Venture Partners. 2022. "The Anti-Portfolio. Honoring the Companies We Missed." Available at https://www.bvp.com/anti-portfolio. Accessed Mar. 29, 2022.
350 Scott, Erin L, Pian Shu, and Roman M Lubynsky. 2020. "Entrepreneurial Uncertainty and Expert Evaluation: An Empirical Analysis." *Management Science* 66, no. 3: 1278–99. https://doi.org/10.1287/mnsc.2018.3244
351 Arrow, Kenneth. 1962."Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors; a Conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Council*. Princeton: Princeton University Press.
352 The Economist. 2022. "Big Tech's Private Passions." *The Economist*, Jan. 22, 2022. Available at https://www.economist.com/briefing/2022/01/22/what-americas-largest-technology-firms-are-investing-in Accessed Feb. 16, 2022.
353 Arrow, Kenneth. 1962. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors; a Conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Council*. Princeton: Princeton University Press.

354 National Venture Capital Association (NVCA). 2022. https://nvca.org/
355 Pitchbook. 2022. https://pitchbook.com/
356 CBInsights. 2022. "The Complete List of Unicorn Companies." https://www.cbinsights.com/research-unicorn-companies
357 CBIsights. 2021. *State of Venture 2021 Report*. https://www.cbinsights.com/research/report/venture-trends-2021/
358 Godin, Benoît. 2006. "The Linear Model of Innovation: The Historical Construction of an Analytical Framework." *Science, Technology, & Human Values*, 31, no. 6: 639–667.
359 Bush, Vannevar. 1945. *Science, the Endless Frontier*. Princeton University Press. Kindle Edition.
360 Kevles, Daniel J. 1977. "The National Science Foundation and the Debate over Postwar Research Policy, 1942-1945: A Political Interpretation of Science––The Endless Frontier." *Isis* 68, no. 1: 5–26.
361 OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*. Paris: OECD Publishing. https://doi.org/10.1787/9789264239012-en
362 OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*. Paris: OECD Publishing. https://doi.org/10.1787/9789264239012-en
363 OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*. Paris: OECD Publishing. https://doi.org/10.1787/9789264239012-en
364 Office of Management and Budget (OMB). 2021. *Circular no. A–11 – Preparation, Submission, and Execution of the Budget*, Executive Office of the President: 3–84.
365 U.S. Department of Defense. 2017. *DOD Financial Management Regulation*, Chapter 5: *Research, Development, Test and Evaluation Appropriations*. Available at https://comptroller.defense.gov/Portals/45/documents/fmr/Volume_02b.pdf. Accessed Mar. 24, 2022
366 U.S. Department of Defense. 2017. *DOD Financial Management Regulation*, Chapter 5: *Research, Development, Test and Evaluation Appropriations*. Available at https://comptroller.defense.gov/Portals/45/documents/fmr/Volume_02b.pdf. Accessed Mar. 24, 2022.
367 Parker, Miles. 2016. "The Rothschild Report (1971) and the Purpose of Government-Funded R&D—A Personal Account." *Palgrave Communications* 2, no. 1. https://doi.org/10.1057/palcomms.2016.53
368 Nelson, Richard R. 2006. "Reflections on 'The Simple Economics of Basic Scientific Research': Looking Back and Looking Forward." *Industrial and Corporate Change* 15, no. 6: 903–917. https://doi.org/10.1093/icc/dtl022
369 Nelson, Richard R. "Reflections on 'The Simple Economics of Basic Scientific Research': Looking Back and Looking Forward." *Industrial and Corporate Change* 15, no. 6: 903–917. https://doi.org/10.1093/icc/dtl022
370 Stokes, Donald E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington DC: Brookings Institution Press.
371 Rosenberg, Nathan. 1996. "Uncertainty and Technical Change." In Landau, Ralph, Timothy Taylor and Gavin Wright eds., *The Mosaic of Economic Growth*. Stanford, CA: Stanford University Press.
372 Stokes, Donald E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington DC: Brookings Institution Press.
373 Godin, Benoît. 2006. "The Linear Model of Innovation: The Historical Construction of an Analytical Framework." *Science, Technology, & Human Values*, 31, no. 6: 639–667.

374 OECD. 2018. *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*, 4th Edition, The Measurement of Scientific, Technological and Innovation Activities. Paris/Eurostat: OECD Publishing. https://doi.org/10.1787/9789264304604-en
375 Arrow, Kenneth. 1962. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors; a Conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Council*. Princeton: Princeton University Press.
376 Nelson, Richard R. 1959. "The Economics of Invention: A Survey of the Literature." *The Journal of Business* 32, no. 2: 101–127. https://doi.org/10.1086/294247
377 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
378 Bonvillian, William B. 2014. "The New Model Innovation Agencies: An Overview." *Science and Public Policy* 41, no. 4: 425–437.
379 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
380 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
381 SBA. 2021. *Fiscal Year 2019 SBIR/STTR Annual Report*. Available at https://www.sbir.gov/annual-reports-files
382 SBA. 2021. *Fiscal Year 2019 SBIR/STTR Annual Report*. Available at https://www.sbir.gov/annual-reports-files
383 Phase III contracts are procurement contracts that agencies may enter into any time with companies who previously received Phase 1 or II funding. There is no limit on the number, duration, type, or dollar value of Phase III contracts.
384 Orazem, Geoff, and Peet van Biljon. 2021. "What Makes Public Sector Innovation Different?" *Contract Management*, National Contract Management Association (NCMA), March 2021: 56–61.
385 Orazem, Geoff, and Peet van Biljon. 2021. "What Makes Public Sector Innovation Different?" *Contract Management*, National Contract Management Association (NCMA), March 2021: 56–61.
386 Orazem, Geoff, and Peet van Biljon. 2021. "What Makes Public Sector Innovation Different?" *Contract Management*, National Contract Management Association (NCMA), March 2021: 56–61.
387 William R. Kerr, Ramana Nanda, and Matthew Rhodes-Kropf. 2014. "Entrepreneurship as Experimentation." *The Journal of Economic Perspectives* 28, no. 3: 25–48. https://doi.org/10.1257/jep.28.3.25
388 William R. Kerr, Ramana Nanda, and Matthew Rhodes-Kropf. 2014. "Entrepreneurship as Experimentation." *The Journal of Economic Perspectives* 28, no. 3: 25–48. https://doi.org/10.1257/jep.28.3.25
389 Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. "A Toolkit of Policies to Promote Innovation." *The Journal of Economic Perspectives* 33, no. 3: 163–184. https://doi.org/10.1257/jep.33.3.163
390 Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. "A Toolkit of Policies to Promote Innovation." *The Journal of Economic Perspectives* 33, no. 3: 163–184. https://doi.org/10.1257/jep.33.3.163
391 Lucking, Brian, Nicholas Bloom, and John Van Reenen. 2018. "Have R&D spillovers changed?" *Working Paper no. 24622. NBER Working Paper Series*. Cambridge, MA: National Bureau of Economic Research. Available at https://www.nber.org/system/files/working_papers/w24622/w24622.pdf
392 Fleming, L, H Greene, G Li, M Marx, and D Yao. 2019. "Government-Funded Research Increasingly Fuels Innovation." *Science (American Association for the Advancement of Science)* 364, no. 6446: 1139–1141. https://doi.org/10.1126/science.aaw2373

393 Fleming, L, H Greene, G Li, M Marx, and D Yao. 2019. "Government-Funded Research Increasingly Fuels Innovation." *Science (American Association for the Advancement of Science)* 364, no. 6446: 1139–1141. https://doi.org/10.1126/science.aaw2373
394 Hall, Bronwyn H, and Josh Lerner. 2010. "The Financing of R&D and Innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation* Vol. 1, no. 1 C: 609–39. https://doi.org/10.1016/S0169-7218(10)01014-2
395 Moretti, Enrico, Claudia Steinwender, and John Van Reenen. 2019. "The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers." *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3498716
396 Nelson, Richard R, and Gavin Wright. 1992. "The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective." *Journal of Economic Literature* 30, no. 4: 1931–1964.
397 Nelson, Richard R, and Gavin Wright. 1992. "The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective." *Journal of Economic Literature* 30, no. 4: 1931–1964.
398 OECD. 2022. "Main Science and Technology Indicators, Volume 2022 Issue 2,." OECD Directorate for Science, Technology and Innovation. Data updated as of Apr. 6, 2022,. https://doi.org/10.1787/a4cf3cb8-en. Accessed on Jul. 18, 2022.
399 Office of Technology Policy. 1997. *The Global Context for U.S. Technology Policy*, Department of Commerce.
400 National Science Foundation. 2021. "National Patterns of R&D Resources: 2018–19 Data Update." NSF 21-325, Table 6, April 9, 2021, https://ncses.nsf.gov/pubs/nsf21325. Note: 2019 data are preliminary and may be revised.
401 National Science Foundation. 2021. "National Patterns of R&D Resources: 2018–19 Data Update." NSF 21-325, Table 1, April 9, 2021, https://ncses.nsf.gov/pubs/nsf21325. Note: 2019 data are preliminary and may be revised.
402 National Science Foundation. 2021. "National Patterns of R&D Resources: 2018–19 Data Update." NSF 21-325, Table 8, April 9, 2021, https://ncses.nsf.gov/pubs/nsf21325. Note: 2019 data are preliminary and may be revised.
403 National Science Foundation. 2021. "National Patterns of R&D Resources: 2018–19 Data Update." NSF 21-325, Tables 6-9, April 9, 2021, https://ncses.nsf.gov/pubs/nsf21325. Note: 2019 data are preliminary and may be revised.
404 National Center for Science and Engineering Statistics. 2021. "Survey of Federal Funds for Research and Development." FYs 2019–20, NSF 21-329 Table 6. https://ncses.nsf.gov/pubs/nsf21329. Note: Preliminary data for 2020.
405 Satia, Priya. 2020. *Empire of Guns: The Violent Making of the Industrial Revolution*. Stanford, CA: Stanford University Press. https://doi.org/10.1515/9781503610828
406 Mowery, David C. 2010. "Military R&D and Innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation* 1, no. 1 C: 609–639. https://doi.org/10.1016/S0169-7218(10)02013-7
407 Industrial Base Policy Office. 2022. "Congressional Interests and Reports." Department of Defense. https://www.businessdefense.gov/resources.html
408 Bruce, Joshua R., and John M. de Figueiredo. 2020. "Innovation in the U.S. Government." *Working Paper no. 27181. NBER Working Paper Series*. Cambridge, MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w27181
409 Bruce, Joshua R., and John M. de Figueiredo. 2020. "Innovation in the U.S. Government". *Working Paper no. 27181*. NBER Working Paper Series. Cambridge, MA: National Bureau of Economic Research. https://www.nber.org/papers/w27181

410 OECD. 2022. "Gross domestic spending on R&D". https://doi.org/10.1787/d8b068b4-en Accessed on Feb. 24, 2022.
411 WIPO. 2021. "Global Innovation Index (GII)." Available at https://www.globalinnovationindex.org/Home
412 Edler, Jakob, and Jan Fagerberg. 2017. "Innovation Policy: What, Why, and How." *Oxford Review of Economic Policy* 33, no. 1: 2–23. https://doi.org/10.1093/oxrep/grx001
413 Edler, Jakob, and Jan Fagerberg. 2017. "Innovation Policy: What, Why, and How." *Oxford Review of Economic Policy* 33, no. 1: 2–23. https://doi.org/10.1093/oxrep/grx001
414 Schot, Johan, and W. Edward Steinmueller. 2018. "Three Frames for Innovation Policy: R&D, Systems of Innovation and Transformative Change." *Research Policy* 47, no. 9: 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011
415 Martin, Ben R. 2012. "The Evolution of Science Policy and Innovation Studies." *Research Policy* 41, no. 7: 1219–1239. https://doi.org/10.1016/j.respol.2012.03.012
416 Elsevier. 2022. *Research Policy*. https://journals.elsevier.com/research-policy
417 Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. "Systems of innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation*, Vol. 2: 1159–1180. North-Holland. https://doi.org/10.1016/S0169-7218(10)02011-3
418 Freeman, Christopher. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.
419 Freeman, Christopher. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.
420 Freeman, Chris. 1995. "The 'National System of Innovation' in historical perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24.
421 Nelson, Richard R. 1993. *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.
422 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
423 Freeman, Christopher. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.
424 Johnson, Chalmers. 1982. *MITI and the Japanese Miracle: The Growth of Industrial Policy*, 1925–1975. Stanford University Press.
425 Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. "Systems of Innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds. *Handbook of the Economics of Innovation* Vol. 2: 1159–1180. North-Holland.
426 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
427 Lundvall, Bengt-Åke. 2016. "National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning." In *The Learning Economy and the Economics of Hope*, 98. Anthem Press.
428 Atkinson, Robert D. 2014. "Understanding the U.S. National Innovation System." The Information Technology & Innovation Foundation (ITIF), June 2014, Available at SSRN: https://ssrn.com/abstract=3079822 or http://dx.doi.org/10.2139/ssrn.3079822
429 Hamilton, Alexander. 1791. *Report on the Subject of Manufactures*. Founders Online, National Archives. Available at https://founders.archives.gov/documents/Hamilton/01-10-02-0001-0007. Accessed Feb. 16, 2022.
430 List, Friedrich. 1841. *Das Nationale System der Politischen Ökonomie*: Basel: Kyklos. *The National System of Political Economy*. London: Longmans, Green and Co.
431 List, Friedrich. 1841. *Das Nationale System der Politischen Ökonomie*: Basel: Kyklos. *The National System of Political Economy*. London: Longmans, Green and Co.

432 Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. "Systems of innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation* Vol. 2: 1159–1180. North-Holland.
433 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
434 Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309
435 Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. "Systems of Innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation*, Vol.2: 1159–1180. North-Holland.
436 Lundvall, Bengt-Åke. 2016. "National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning." In *The Learning Economy and the Economics of Hope,* 85–106. Anthem Press.
437 Atkinson, Robert D. 2014. "Understanding the U.S. National Innovation System." The Information Technology & Innovation Foundation (ITIF), June 2014, Available at SSRN: https://ssrn.com/abstract=3079822 or http://dx.doi.org/10.2139/ssrn.3079822
438 Conti, Annamaria, and Jorge Guzman. "What Is the US Comparative Advantage in Entrepreneurship? Evidence from Israeli Migrations to the US." *Academy of Management Proceedings* 2019, no. 1: 11931. https://doi.org/10.5465/AMBPP.2019.295
439 Teece, David J. 1986. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *Research Policy* 15, no. 6: 285–305. https://doi.org/10.1016/0048-7333(86)90027-2.
440 Porter, Michael E. 1990. *The Competitive Advantage of Nations*. New York: Free Press.
441 Furman, Jeffrey L, Michael E Porter, and Scott Stern. 2002. "The Determinants of National Innovative Capacity." *Research Policy* 31, no. 6: 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4
442 Furman, Jeffrey L, Michael E Porter, and Scott Stern. 2002. "The Determinants of National Innovative Capacity." *Research Policy* 31, no. 6: 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4
443 Moser, Petra. 2013. "Patents and Innovation: Evidence from Economic History." *The Journal of Economic Perspectives 27,* no. 1: 23–44. https://doi.org/10.1257/jep.27.1.23
444 Fagerberg, Jan, and Martin Srholec. 2008. "National Innovation Systems, Capabilities and Economic Development." *Research Policy* 37, no. 9: 1417–1435. https://doi.org/10.1016/j.respol.2008.06.003
445 Cirera, Xavier, and William F. Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank. doi:10.1596/978-1-4648-1160-9. License: Creative Commons Attribution CC BY 3.0 IGO.
446 Hidalgo, César A., and Ricardo Hausmann. 2009. "The Building Blocks of Economic Complexity." *Proceedings of the National Academy of Sciences*, 106, no. 26: 10570–10575. Available at https://www.pnas.org/content/pnas/106/26/10570.full.pdf
447 Hidalgo, César A., and Ricardo Hausmann. 2009. "The Building Blocks of Economic Complexity." *Proceedings of the National Academy of Sciences*, 106, no. 26: 10570–10575. Available at https://www.pnas.org/content/pnas/106/26/10570.full.pdf
448 Cirera, Xavier, and William F. Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank. doi:10.1596/978-1-4648-1160-9. License: Creative Commons Attribution CC BY 3.0 IGO.
449 Hartmann, Dominik, Miguel R Guevara, Cristian Jara-Figueroa, et al. 2017. "Linking Economic Complexity, Institutions, and Income Inequality." *World Development* 93: 75–93. https://doi.org/10.1016/j.worlddev.2016.12.020

450 Balland, Pierre-Alexandre, Tom Broekel, Dario Diodato, et al. 2022. "The New Paradigm of Economic Complexity." *Research Policy* 51, no. 3: 104450. https://doi.org/10.1016/j.respol.2021.104450
451 Balland, Pierre-Alexandre, Tom Broekel, Dario Diodato, et al. 2022. "The New Paradigm of Economic Complexity." *Research Policy* 51, no. 3: 104450. https://doi.org/10.1016/j.respol.2021.104450
452 Growth Lab of Harvard University. 2022. "The Atlas of Economic Complexity." https://atlas.cid.harvard.edu/
453 OEC. 2022. https://oec.world/en
454 Simoes, Alex J.G., and Cesar A. Hidalgo. 2011. "The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development." *Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence*.
455 Etzkowitz, Henry, and Loet Leydesdorff. 2000. "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University–industry–government Relations." *Research Policy* 29, no. 2: 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4
456 Etzkowitz, Henry, and Loet Leydesdorff. 2000. "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University–industry–government Relations." *Research Policy* 29, no. 2: 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4
457 Etzkowitz, Henry, and Loet Leydesdorff. 1995. "The Triple Helix–University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development." *EASST Review* 14, no. 1: 14–19.
458 Leydesdorff, Loet and Henry Etzkowitz. 1998. "Triple Helix of Innovation: Introduction." *Science and Public Policy* 25, no. 6: 358–364.
459 Etzkowitz, Henry, and Loet Leydesdorff. 2000. "The Dynamics of Innovation: From National Systems and 'Mode 2' to a Triple Helix of University–industry–government Relations." *Research Policy* 29, no. 2: 109–423. https://doi.org/10.1016/S0048-7333(99)00055-4
460 The Triple Helix Association. https://www.triplehelixassociation.org/
461 The Triple Helix Association. 2022. Homepage, https://www.triplehelixassociation.org/. Accessed on Feb. 8, 2022.
462 Etzkowitz, Henry. 2008. *The Triple Helix: University-Industry-Government Innovation in Action*. New York: Routledge: 12–18.
463 Etzkowitz, Henry. 2008. *The Triple Helix: University-Industry-Government Innovation in Action*. New York: Routledge: 12–18.
464 Gibbons, Michael, Camille Limoges, Helga Nowotny, et al. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Stockholm: Sage.
465 Nowotny, Helga, Peter Scott, and Michael Gibbons. 2003. "Introduction: 'Mode 2' Revisited: The New Production of Knowledge." *Minerva* 41, no. 3: 179–194.
466 Nowotny, Helga, Peter Scott, and Michael Gibbons. 2003. "Introduction: 'Mode 2' Revisited: The New Production of Knowledge." *Minerva* 41, no. 3: 179–194.
467 Etzkowitz, Henry, and Loet Leydesdorff. 1995. "The Triple Helix–University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development." *EASST Review* 14, no. 1: 14.
468 Carayannis, Elias G., and David F.J. Campbell. 2009. "'Mode 3' and 'Quadruple Helix': Toward a 21st Century Fractal Innovation Ecosystem." *International Journal of Technology Management* 46, nos. 3–4: 201–234.
469 Carayannis, Elias G., and David F.J. Campbell. 2009. "'Mode 3' and 'Quadruple Helix': Toward a 21st Century Fractal Innovation Ecosystem." *International Journal of Technology Management* 46, nos. 3–4: 201–234.
470 Carayannis, Elias G., and David F.J. Campbell. 2009. "'Mode 3' and 'Quadruple Helix': Toward a 21st Century Fractal Innovation Ecosystem." *International Journal of Technology Management* 46, nos. 3–4: 201–234.

471 Carayannis, Elias G., Thorsten D. Barth, and David F.J. Campbell. 2012. “The Quintuple Helix Innovation Model: Global Warming as a Challenge and Driver for Innovation.” *Journal of Innovation and Entrepreneurship* 1, no. 1: 1–12. https://doi.org/10.1186/2192-5372-1-2
472 Brundin, Ethel, Caroline Wigren, Eslyn Isaacs, Chris Friedrich, and Kobus Visser. 2008. “Triple Helix Networks in a Multicultural Context: Triggers and Barriers for Fostering Growth and Sustainability.” *Journal of Developmental Entrepreneurship* 13, nos. 1–3: 77–98.
473 Leydesdorff, Loet. 2012. “The Triple Helix, Quadruple Helix, . . ., and an N-Tuple of Helices: Explanatory Models for Analyzing the Knowledge-Based Economy?” *The Journal of the Knowledge Economy* 3, no. 1: 25–35.
474 Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. “A Toolkit of Policies to Promote Innovation.” The *Journal of Economic Perspectives* 33, no. 3: 163–184. https://doi.org/10.1257/jep.33.3.163
475 Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. “A Toolkit of Policies to Promote Innovation.” The *Journal of Economic Perspectives* 33, no. 3: 163–184. https://doi.org/10.1257/jep.33.3.163
476 Appelt, Silvia, and Fernando Galindo-Rueda. 2016. *Measuring the Link Between Public Procurement and Innovation*. Paris: OECD Publishing. http://dx.doi.org/10.1787/5jlvc7sl1w7h-en
477 Bonvillian, William B. 2018. “DARPA and Its ARPA-E and IARPA Clones: A Unique Innovation Organization Model.” *Industrial and Corporate Change* 27, no. 5: 897–914. https://doi.org/10.1093/icc/dty026
478 CMS. 2022. *Medicare & You 2022. the Official U.S. Government Medicare Handbook*. Available at https://www.medicare.gov/Pubs/pdf/10050-medicare-and-you.pdf
479 https://www.cms.gov/
480 CMS. 2021. “CMS Releases 2022 Medicare Advantage and Part D Star Ratings to Help Medicare Beneficiaries Compare Plans”. *CMS.gov*. Press release, Oct. 8, 2021. Available at https://www.cms.gov/newsroom/press-releases/cms-releases-2022-medicare-advantage-and-part-d-star-ratings-help-medicare-beneficiaries-compare
481 Edler, Jakob, and Jan Fagerberg. 2017. “Innovation Policy: What, Why, and How.” *Oxford Review of Economic Policy 33*, no. 1: 2–23. https://doi.org/10.1093/oxrep/grx001
482 Biniek, Jeannie Fuglesten et al. 2021. “Medicare Advantage in 2021: Star Ratings and Bonuses.” KFF. Jun. 21, 2021. Available at https://www.kff.org/medicare/issue-brief/medicare-advantage-in-2021-star-ratings-and-bonuses/
483 Edler, Jakob, and Jan Fagerberg. 2017. “Innovation Policy: What, Why, and How.” *Oxford Review of Economic Policy 33*, no. 1: 2–23. https://doi.org/10.1093/oxrep/grx001.
484 OECD. 2022. “EC-OECD STIP-Compass.” https://stip.oecd.org/stip/. Accessed on Mar. 30, 2022.
485 Auerswald, Philip E., and Lewis M. Branscomb. 2003. “Valleys of Death and Darwinian Seas: Financing the Invention to Innovation Transition in the United States.” *Journal of Technology Transfer* 28, nos. 3-4: 227–239.
486 Ellwood, Paul, Ceri Williams, and John Egan. 2022. “Crossing the Valley of Death: Five Underlying Innovation Processes.” *Technovation* 109: 102162. https://doi.org/10.1016/j.technovation.2020.102162
487 Mazzucato, Mariana. 2015. *The Entrepreneurial State: Debunking Public Vs. Private Sector Myths*. Revised edition. New York: PublicAffairs.
488 Satell, Greg. 2015. “Technology Progresses When Business, Government, and Academia Work Together,” *Harvard Business Review*, Jun. 16, 2015.
489 Arora, Ashish, Sharon Belenzon, Andrea Patacconi, and Jungkyu Suh. 2020. “The Changing Structure of American Innovation: Cautionary Remarks for Economic Growth.” In *Innovation Policy and the Economy*, Volume 20. Lerner and Stern.

490 Bonvillian, William. B. 2014. "The New Model Innovation Agencies: An Overview." *Science and Public Policy* 41, no. 4: 425–437.
491 More formerly known as the *Patent and Trademark Law Amendments Act,* Public Law 96-517. Dec. 12, 1980. Available at https://uscode.house.gov/statutes/pl/96/517.pdf
492 Schoettle, Anthony. 2020. "University Professors Rev Up Efforts to Commercialize Research, Launch Startups." *Indianapolis Business Journal*, Oct. 30, 2020. Available at https://www.ibj.com/articles/professors-rev-up-efforts-to-commercialize-research. Accessed on Feb. 4, 2022.
493 Gotkin, Joel. 2012. "Introduction." In *The United States Bayh-Dole Act and Its Effect on University Technology Transfer*: 15-21. Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH. http://www.jstor.org/stable/j.ctv941t20.5
494 Miller, Kristel, Rodney McAdam, and Maura McAdam. 2018. "A Systematic Literature Review of University Technology Transfer from a Quadruple Helix Perspective: Toward a Research Agenda." *R&D Management* 48, no. 1: 7–24. https://doi.org/10.1111/radm.12228
495 Leydesdorff, Loet, and Martin Meyer. 2013. "A Reply to Etzkowitz' Comments to Leydesdorff and Martin (2010): Technology Transfer and the End of the Bayh-Dole Effect." *Scientometrics* 97, no. 3: 927–934. https://doi.org/10.1007/s11192-013-0997-5
496 Hudson, John, and Hanan F. Khazragui. 2013. "Into the Valley of Death: Research to Innovation." *Drug Discovery Today* 18, nos. 13–14: 610–613. https://doi.org/10.1016/j.drudis.2013.01.012
497 Gotkin, Joel. 2012. "Perceived Successes and Shortfalls of the Bayh-Dole Act." In *The United States Bayh-Dole Act and Its Effect on University Technology Transfer*: 28–33. Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH. http://www.jstor.org/stable/j.ctv941t20.5
498 Gotkin, Joel. 2012. "Perceived Successes and Shortfalls of the Bayh-Dole Act." In *The United States Bayh-Dole Act and Its Effect on University Technology Transfer*: 28–33. Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH. http://www.jstor.org/stable/j.ctv941t20.5
499 Link, Albert N., Robert S. Danziger, and John T. Scott. 2018. "Is the Bayh-Dole Act Stifling Biomedical Innovation?" *Issues in Science and Technology 34*, no. 2: 33–35.
500 Kleiner, Diana J. 2022. "Sematech." *Handbook of Texas Online*. Accessed February 19, 2022, https://www.tshaonline.org/handbook/entries/sematech. Published by the Texas State Historical Association.
501 Satell, Greg. 2015. "Technology Progresses When Business, Government, and Academia Work Together." *Harvard Business Review*, June 16, 2015.
502 Janeway, William H. 2018. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, UK: Cambridge University Press.
503 Keller, Matthew R., and Fred Block. 2015. "Do as I Say, or as I Do? US Innovation and Industrial Policy Since the 1980s." In Felipe, Jesus, ed., *Development and Modern Industrial Policy in Practice*. Cheltenham UK: Edward Elgar Publishing.
504 Weiss, Linda. 2014. *America Inc.?: Innovation and Enterprise in the National Security State*. Ithaca, NY: Cornell University Press.
505 Keller, Matthew R., and Fred Block. 2015. "Do as I Say, or as I Do? US Innovation and Industrial Policy Since the 1980s." In Felipe, Jesus ed., *Development and Modern Industrial Policy in Practice*. Cheltenham UK: Edward Elgar Publishing.
506 OSTP. 2022. Homepage. The White House. https://www.whitehouse.gov/ostp/
507 Institute for New Economic Thinking. https://www.ineteconomics.org/
508 Reinert, Erik S. 2008. *How Rich Countries Got Rich– and Why Poor Countries Stay Poor*. New York: Public Affairs; Kindle edition.
509 Block, Fred. 2008. "Swimming Against the Current: The Rise of a Hidden Developmental State in the United States." *Politics & Society* 36, no. 2: 169–206. https://doi.org/10.1177/0032329208318731

510 Weiss, Linda. 2014. *America Inc.?: Innovation and Enterprise in the National Security State*. Ithaca, NY: Cornell University Press.
511 "How Much Did the Apollo Program Cost?" The Planetary Society, https://www.planetary.org/space-policy/cost-of-apollo. Accessed on Feb. 22, 2022.
512 Mazzucato, Mariana. 2021. *Mission Economy: A Moonshot Guide to Changing Capitalism*. First U.S. edition. New York: Harper Business, an imprint of HarperCollins Publishers.
513 Keller, Matthew R., and Fred Block. 2015. "Do as I Say, or as I Do? US Innovation and Industrial Policy Since the 1980s." In Felipe, Jesus ed., *Development and Modern Industrial Policy in Practice*. Cheltenham UK: Edward Elgar Publishing.
514 Center for International Development at Harvard University. 2003. "Washington Consensus Global Trade Negotiations." https://web.archive.org/web/20170715151421/http://www.cid.harvard.edu/cidtrade/issues/washington.html
515 Ostry, Jonathan D., Prakash Loungani, and Davide Furceri. 2016. "Neoliberalism: Oversold? Instead of Delivering Growth, Some Neoliberal Policies Have Increased Inequality, in Turn Jeopardizing Durable Expansion." *Finance & Development* 53, no. 2: 38–41.
516 Kattel, Rainer, and Mariana Mazzucato. 2018. "Mission-Oriented Innovation Policy and Dynamic Capabilities in the Public Sector." *Industrial and Corporate Change*: 787–801.
517 Gerety, Rowan Moore. 2020. "Unmade in America." *MIT Technology Review* 123, no. 5: 68–75.
518 Adler, David, and Dan Breznitz. 2020. "Reshoring Supply Chains: A Practical Policy Agenda." *American Affairs* 4, no. 1: 6–17.
519 Bonvillian, William B. 2013. "Advanced Manufacturing Policies and Paradigms for Innovation." *Science* (American Association for the Advancement of Science) 342, no. 6163: 1173–1175. https://doi.org/10.1126/science.1242210
520 President's Council of Advisors on Science and Technology. 2011. *Report to the President on Ensuring American Leadership in Advanced Manufacturing*. Executive Office of the President. Available at https://www.energy.gov/sites/prod/files/2013/11/f4/pcast_june2011.pdf
521 Bonvillian, William B. 2017. "Advanced Manufacturing: A New Policy Challenge." *Annals of Science and Technology Policy* 1, no. 1: 1–131. http://dx.doi.org/10.1561/110.00000001
522 Adler, David, and Dan Breznitz. 2020. "Reshoring Supply Chains: A Practical Policy Agenda." *American Affairs* 4, no. 1: 6–17.
523 Schonfeld, Erick. 2009. "The Government Comes Through for Tesla With A $465 Million Loan For Its Electric Sedan," *Tech Crunch*, Jun. 23, 2009. Available at https://techcrunch.com/2009/06/23/the-government-comes-through-for-tesla-with-a-465-million-loan-for-its-electric-sedan/? Accessed on Jan. 31, 2022.
524 World Inequality Database. https://wid.world/
525 Temin, Peter. 2017. *The Vanishing Middle Class: Prejudice and Power in a Dual Economy*. Cambridge, MA: The MIT Press.
526 Gordon, Robert J. 2016. *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War*. Princeton: Princeton University Press.
527 Rodrik, Dani. 2004. *Industrial Policy for the Twenty-First Century*. SSRN 666808. Copy at https://tinyurl.com/y9yjzpdq
528 Rodrik, Dani. 2004. *Industrial Policy for the Twenty-First Century*. SSRN 666808. Copy at https://tinyurl.com/y9yjzpdq
529 Tulum, Öner, and William Lazonick. 2018. "Financialized Corporations in a National Innovation System: The U.S. Pharmaceutical Industry." *International Journal of Political Economy* 47, nos. 3–4: 281–316. https://doi.org/10.1080/08911916.2018.1549842
530 Lazonick, William. 2017. "The New Normal Is 'Maximizing Shareholder Value': Predatory Value Extraction, Slowing Productivity, and the Vanishing American Middle Class." *International Journal of Political Economy* 46, no. 4: 217–226. https://doi.org/10.1080/08911916.2017.1407736

531 Mazzucato, Mariana. 2015. *The Entrepreneurial State: Debunking Public Vs. Private Sector Myths*. Revised edition. New York: PublicAffairs.
532 Mazzucato, Mariana. 2021. *Mission Economy: A Moonshot Guide to Changing Capitalism*. First U.S. edition. New York: Harper Business, an imprint of HarperCollins Publishers.
533 Mazzucato, Mariana, Rainer Kattel, and Josh Ryan-Collins. 2019. "Challenge-Driven Innovation Policy: Towards a New Policy Toolkit." *Journal of Industry, Competition and Trade* 20, no. 2: 421–437. https://doi.org/10.1007/s10842-019-00329-w
534 Mazzucato, Mariana. 2021. *Mission Economy: A Moonshot Guide to Changing Capitalism*. First U.S. edition. New York: Harper Business, an imprint of HarperCollins Publishers.
535 Van Reenen, John. 2021. "Innovation Policy to Restore American Prosperity." *CentrePiece - The Magazine for Economic Performance* 599, Centre for Economic Performance, LSE.
536 The Hamilton Project. Brookings Institution. https://www.hamiltonproject.org/
537 Van Reenen, John. 2020. *Innovation Policies to Boost Productivity*, *Executive Summary*. The Hamilton Project, Brookings. Available at https://www.brookings.edu/research/innovation-policies-to-boost-productivity/
538 Deleidi, Matteo, and Mariana Mazzucato. 2019. "Putting Austerity to Bed: Technical Progress, Aggregate Demand and the Supermultiplier." *Review of Political Economy* 31, no. 3: 315–335. https://doi.org/10.1080/09538259.2019.1687146
539 Zehavi, Amos, and Dan Breznitz. 2017. "Distribution Sensitive Innovation Policies: Conceptualization and Empirical Examples." *Research Policy* 46, no. 1: 327–336.
540 Zehavi, Amos, and Dan Breznitz. 2017. "Distribution Sensitive Innovation Policies: Conceptualization and Empirical Examples." *Research Policy* 46, no. 1: 327–336.
541 Breznitz, Dan. 2021. *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World*. New York: Oxford University Press.
542 United States Congress. 2022. "View the CHIPS+ Legislation," U.S. Senate Committee on Commerce, Science, & Transportation, https://www.commerce.senate.gov/2022/7/view-the-chips-legislation. Accessed Aug. 1, 2022.
543 United States Congress. S.1260 - *United States Innovation and Competition Act of 2021*. https://www.congress.gov/bill/117th-congress/senate-bill/1260. Accessed Aug. 1, 2022.
544 United States Congress. *S.1260 - United States Innovation and Competition Act of 2021*. https://www.congress.gov/bill/117th-congress/senate-bill/1260
545 OECD. 2021. "Regional Innovation." OECD Regional Statistics database. Available at https://doi.org/10.1787/1c89e05a-en
546 WEF. 2020. *Global Competitiveness Report Special Edition 2020: How Countries are Performing on the Road to Recovery*. Available at https://www.weforum.org/reports/the-global-competitiveness-report-2020

Bibliography

Abbate, Janet. 2001. "Government, Business, and the Making of the Internet." *Business History Review* 75, no. 1: 147–176. https://doi.org/10.2307/3116559.

Acting Secretary of Commerce. 1934. *A Report on National Income, 1929–1932*. Bureau of Foreign and Domestic Commerce, Seventy-Third Congress, 1933–1935. Washington: U.S. Government Printing Office, 1934. Available at https://fraser.stlouisfed.org/title/971. Accessed Sept. 30, 2020.

Adams, Richard, John Bessant, and Robert Phelps. 2006. "Innovation Management Measurement: A Review." *International Journal of Management Reviews*: IJMR 8, no. 1: 21–47. https://doi.org/10.1111/j.1468-2370.2006.00119.x

Adler, David, and Dan Breznitz. 2020. "Reshoring Supply Chains: A Practical Policy Agenda." *American Affairs* 4, no. 1: 6–17.

Aghion, Philippe, and Agnès Festré. 2017. "Schumpeterian Growth Theory, Schumpeter, and Growth Policy Design." *Journal of Evolutionary Economics* 27, no. 1: 25–42.

Aghion, Philippe, and Peter Howitt. 1992. "A Model of Growth Through Creative Destruction." *Econometrica* 60, nos. 2–3:323–351.

Agile Alliance. 2022. "Manifesto for Agile Software Development." Agile Essentials. https://www.agilealliance.org/agile101/the-agile-manifesto/

Alcouffe, Alain, and Thomas Kuhn. 2004. "Schumpeterian Endogenous Growth Theory and Evolutionary Economics." *Journal of Evolutionary Economics* 14, no. 2: 223–236.

Amabile, Teresa M. 1988. "A Model of Creativity and Innovation in Organizations." *Research in Organizational Behavior* 10, no. 1: 123–167.

American Marketing Association. 2017. "Definition of Marketing," https://www.ama.org/the-definition-of-marketing-what-is-marketing Accessed Mar. 29, 2022.

Amit, Raphael, and Christoph Zott. 2012. "Creating Value Through Business Model Innovation." *MIT Sloan Management Review* 53, no. 3: 41.

Andrews, Dan, Chiara Criscuolo, and Peter N. Gal. 2016. "The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy." *OECD Productivity Working Papers*, no. 5, Paris: OECD Publishing. https://doi.org/10.1787/63629cc9-en

Appelt, Silvia, and Fernando Galindo-Rueda. 2016. *Measuring the Link Between Public Procurement and Innovation*. Paris: OECD Publishing. http://dx.doi.org/10.1787/5jlvc7sl1w7h-en

Arora, Ashish, Sharon Belenzon, Andrea Patacconi, and Jungkyu Suh. 2020. "The Changing Structure of American Innovation: Cautionary Remarks for Economic Growth." *Innovation Policy and the Economy*, Volume 20. Lerner and Stern.

Arrow, Kenneth. 1962. "Economic Welfare and the Allocation of Resources for Invention." In *The Rate and Direction of Inventive Activity: Economic and Social Factors; a Conference of the Universities-National Bureau Committee for Economic Research and the Committee on Economic Growth of the Social Science Research Council*. Princeton: Princeton University Press.

Atkinson, Robert D. 2014. "Understanding the U.S. National Innovation System." The Information Technology & Innovation Foundation (ITIF), June 2014, Available at SSRN: https://ssrn.com/abstract=3079822 or http://dx.doi.org/10.2139/ssrn.3079822

Auernhammer, Jan, and Bernard Roth. 2011. "The Origin and Evolution of Stanford University's Design Thinking: From Product Design to Design Thinking in Innovation Management." *The Journal of Product Innovation Management* 38, no. 6: 623–644. https://doi.org/10.1111/jpim.12594

https://doi.org/10.1515/9783110711066-014

Auerswald, Philip E., and Lewis M. Branscomb. 2003. “Valleys of Death and Darwinian Seas: Financing the Invention to Innovation Transition in the United States.” *Journal of Technology Transfer* 28, nos. 3–4: 227–239.

Ayres, Robert U. 1989. “Technological Transformations and Long Waves.” International Institute for Applied Systems Analysis. Available at http://pure.iiasa.ac.at/id/eprint/3225/1/RR-89-001.pdf Accessed Mar. 29, 2022.

Baldwin, Carliss, and Eric von Hippel. 2011. “Modeling a Paradigm Shift: From Producer Innovation to User and Open Collaborative Innovation.” *Organization Science* 22, no. 6: 1399–1417.

Balland, Pierre-Alexandre, Tom Broekel, Dario Diodato, et al. 2022. “The New Paradigm of Economic Complexity.” *Research Policy* 51, no. 3: 104450. https://doi.org/10.1016/j.respol.2021.104450

Barrero, Jose Maria, Nicholas Bloom, and Ian Wright. 2017. “Short and Long Run Uncertainty.” *Working Paper no. w23676. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w23676

Bekar, Clifford, Kenneth Carlaw, and Richard Lipsey. 2018. “General Purpose Technologies in Theory, Application and Controversy: A Review,” *Journal of Evolutionary Economics* 28, no. 5: 1005–1033.

Bessemer Venture Partners. 2022. “The Anti-Portfolio. Honoring the Companies We Missed.” Available at https://www.bvp.com/anti-portfolio Accessed Mar. 29, 2022.

Bhatia, Tushar, Mohsin Imtiaz, Eric Kutcher, and Dilip Wagle. 2017. “How Tech Giants Deliver Outsized Returns – and What It Means for the Rest of Us.” McKinsey & Company. Available at https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/how-tech-giants-deliver-outsized-returns-and-what-it-means-for-the-rest-of-us Accessed Mar. 15, 2021.

Biniek, Jeannie Fuglesten et al. 2021. “Medicare Advantage in 2021: Star Ratings and Bonuses.” *KFF*, Jun. 21, 2021. Available at https://www.kff.org/medicare/issue-brief/medicare-advantage-in-2021-star-ratings-and-bonuses/

Blank, Steve, and Alexander Osterwalder. 2016. “The Mission Model Canvas – An Adapted Business Model Canvas for Mission-Driven Organizations.” *SteveBlank.com*, posted Feb. 23, 2016. Available at https://steveblank.com/2016/02/23/the-mission-model-canvas-an-adapted-business-model-canvas-for-mission-driven-organizations/ Accessed Mar. 15, 2022.

Blank, Steve, and Jim Euchner. 2018. “The Genesis and Future of Lean Startup: An Interview with Steve Blank.” *Research Technology Management* 61, no. 5: 15–21. https://doi.org/10.1080/08956308.2018.1495963

Blank, Steve. 2013. “Why the Lean Start-Up Changes Everything.” *Harvard Business Review* 91, no. 5: 63–72.

Blank, Steven G. 2005. *The Four Steps to the Epiphany: Successful Strategies for Products That Win*. 3rd ed., 4th rev. printing. California: S.G. Blank.

Blank, Steven, and Bob Dorf. 2005. “The Path to Epiphany: The Customer Development Model.” In *The Four Steps to the Epiphany*. California: S.G. Blank: 17–28.

Block, Fred. 2008. “Swimming Against the Current: The Rise of a Hidden Developmental State in the United States.” *Politics & Society* 36, no. 2: 169–206. https://doi.org/10.1177/0032329208318731

Bloom, Nicholas, John Van Reenen, and Heidi Williams. 2019. “A Toolkit of Policies to Promote Innovation.” *The Journal of Economic Perspectives* 33, no. 3: 163–184. https://doi.org/10.1257/jep.33.3.163

Bonvillian, William B. 2013. “Advanced Manufacturing Policies and Paradigms for Innovation.” *Science (American Association for the Advancement of Science)* 342, no. 6163: 1173–1175. https://doi.org/10.1126/science.1242210

Bonvillian, William B. 2014. “The New Model Innovation Agencies: An Overview.” *Science and Public Policy* 41, no. 4: 425–437.

Bonvillian, William B. 2017. “Advanced Manufacturing: A New Policy Challenge.” *Annals of Science and Technology Policy* 1, no. 1: 1–131. http://dx.doi.org/10.1561/110.00000001

Bonvillian, William B. 2018. “DARPA and Its ARPA-E and IARPA Clones: A Unique Innovation Organization Model.” *Industrial and Corporate Change* 27, no. 5: 897–914. https://doi.org/10.1093/icc/dty026

Boons, Frank, and Nancy Bocken. 2018. “Towards a Sharing Economy – Innovating Ecologies of Business Models.” *Technological Forecasting & Social Change* 137: 40–52. https://doi.org/10.1016/j.techfore.2018.06.031

Borins, Sandford. 2000. “Loose Cannons and Rule Breakers, Or Enterprising Leaders? Some Evidence about Innovative Public Managers.” *Public Administration Review* 60, no. 6: 498–507.

Bower, Joseph L., and Clayton M. Christensen. 1995. “Disruptive Technologies: Catching the Wave,” *Harvard Business Review*, Jan-Feb 1995. Available at https://hbr.org/1995/01/disruptive-technologies-catching-the-wave

Boyd, Drew, and Jacob Goldenberg. 2013. *Inside the Box: A Proven System of Creativity for Breakthrough Results*. New York: Simon & Schuster.

Bresnahan, Timothy F., and Manuel Trajtenberg. 1995. “General Purpose Technologies ‘Engines of Growth’?” *Journal of Econometrics* 65, no. 1: 83–108.

Breznitz, Dan. 2021. *Innovation in Real Places: Strategies for Prosperity in an Unforgiving World*. New York: Oxford University Press.

Bruce, Joshua R., and John M. de Figueiredo. 2020. “Innovation in the U.S. Government.” *Working Paper no. 27181. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. https://www.nber.org/papers/w27181

Brundin, Ethel, Caroline Wigren, Eslyn Isaacs, Chris Friedrich, and Kobus Visser. 2008. “Triple Helix Networks in a Multicultural Context: Triggers and Barriers for Fostering Growth and Sustainability.” *Journal of Developmental Entrepreneurship* 13, nos. 1–3:77–98.

Brynjolfsson, Erik, Seth Benzell, and Daniel Rock. 2020. “Understanding and Addressing the Modern Productivity Paradox.” MIT Work of the Future. Available at https://workofthefuture.mit.edu/wp-content/uploads/2020/11/2020-Research-Brief-Brynjolfsson-Benzell-Rock.pdf

Buchholz, Christian, and Benno Aerssen, eds. 2020. *The Innovator’s Dictionary: 555 Methods and Instruments for More Creativity and Innovation in Your Company*. Berlin/Boston: Walter de Gruyter GmbH.

Budanovic, Nicola. 2016. “Heinz Guderian, The Father of The Blitzkrieg,” War History Online, https://www.warhistoryonline.com/world-war-ii/heinz-guderian-the-father-of-the-blitzkrieg.html

Bureau of Labor Statistics. 2022. *Labor Productivity and Costs*. United States Department of Labor, https://www.bls.gov/lpc/ Accessed Mar. 29, 2022.

Bureau of Labor Statistics. 2022b. *Multifactor Productivity*. United States Department of Labor, https://www.bls.gov/lpc/https://www.bls.gov/mfp/ Accessed Mar. 29, 2022.

Bush, Vannevar. 1945. *Science, the Endless Frontier*. Princeton University Press. Kindle Edition.

Carayannis, Elias G., and David F.J. Campbell. 2009. “‘Mode 3’ and ‘Quadruple Helix’: Toward a 21st Century Fractal Innovation Ecosystem.” *International Journal of Technology Management* 46, nos. 3–4:201–234.

Carayannis, Elias G., Thorsten D. Barth, and David F.J. Campbell. 2012. “The Quintuple Helix Innovation Model: Global Warming as a Challenge and Driver for Innovation.” *Journal of Innovation and Entrepreneurship* 1, no. 1: 1–12. https://doi.org/10.1186/2192-5372-1-2

Carlaw, Kenneth I, and Richard G Lipsey. 2002. “Externalities, Technological Complementarities and Sustained Economic Growth.” *Research Policy* 31, no. 8: 1305–1315. https://doi.org/10.1016/S0048-7333(02)00065-3

CBIsights. 2021. State of Venture 2021 Report. https://www.cbinsights.com/research/report/venture-trends-2021/

CBInsights. 2022. “The Complete List of Unicorn Companies,” https://www.cbinsights.com/research-unicorn-companies

CBInsights. 2022a. *State of Venture 2021 Report*: 8, 26. Available at https://www.cbinsights.com/research/report/venture-trends-2021/ Accessed Feb. 2, 2022.

CBInsights. 2022b. *State Of CVC: Global 2021*. Available at https://www.cbinsights.com/research/report/corporate-venture-capital-trends-2021/ Accessed Mar. 24, 2022

CBInsights. 2022c. *State of Venture 2021 Report*, data file. Available at https://www.cbinsights.com/research/report/venture-trends-2021/ Accessed Feb. 2, 2022.

Center for International Development at Harvard University. 2003. “Washington Consensus Global Trade Negotiations.” https://web.archive.org/web/20170715151421/http://www.cid.harvard.edu/cidtrade/issues/washington.html

Chan, Vanessa, Marc de Jong, and Vidyadhar Ranada. 2014. “Finding the Sweet Spot for Allocating Innovation Resources.” *McKinsey Quarterly*, May 2014. Available at https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/finding-the-sweet-spot-for-allocating-innovation-resources

Chen, Yan. 2017. “Dynamic Ambidexterity: How Innovators Manage Exploration and Exploitation.” *Business Horizon*s 60, no. 3: 385–394. https://doi.org/10.1016/j.bushor.2017.01.001

Chesbrough, Henry William. 2003. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Chesbrough, Henry, and Richard S Rosenbloom. 2002. “The Role of the Business Model in Capturing Value from Innovation: Evidence from Xerox Corporation’s Technology Spin-off Companies*.” Industrial and Corporate Change* 11, no. 3: 529–555. https://doi.org/10.1093/icc/11.3.529

Chesbrough, Henry. 2006. “Open Innovation: A New Paradigm for Understanding Industrial Innovation.” In Chesbrough, Henry, Vahaverbeke, Wim, and West, Joel, eds., *Open Innovation: Researching a New Paradigm*. Oxford University Press.

Chesbrough, Henry. 2006. *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Chesbrough, Henry. 2010. “Business Model Innovation: Opportunities and Barriers.” *Long Range Planning* 43, no. 2: 354–363. https://doi.org/10.1016/j.lrp.2009.07.010

Chesbrough, Henry. 2017. “The Future of Open Innovation,” *Research Technology Management* 60, no. 1: 35–38.

Christensen, Clayton M. 1997. *The Innovator’s Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Christensen, Clayton M., Efosa Ojomo, and Karen Dillon. 2019. *The Prosperity Paradox: How Innovation Can Lift Nations Out of Poverty*. New York: Harper Business, an imprint of Harper Collins Publishers.

Christensen, Clayton Magleby, Thomas Bartman, and Derek Van Bever. 2017. “The Hard Truth About Business Model Innovation.” *MIT Sloan Management Review* 58, no. 1: 31–40.

Cirera, Xavier, and William F. Maloney. 2017. *The Innovation Paradox: Developing-Country Capabilities and the Unrealized Promise of Technological Catch-Up*. Washington, DC: World Bank. doi:10.1596/978-1-4648-1160-9 License: Creative Commons Attribution CC BY 3.0 IGO.

CMS. 2021. “CMS Releases 2022 Medicare Advantage and Part D Star Ratings to Help Medicare Beneficiaries Compare Plans”. CMS.gov. Press release, Oct. 8, 2021. Available at https://www.

cms.gov/newsroom/press-releases/cms-releases-2022-medicare-advantage-and-part-d-star-ratings-help-medicare-beneficiaries-compare

CMS. 2022. *Medicare & You 2022. the Official U.S. Government Medicare Handbook*. Available at https://www.medicare.gov/Pubs/pdf/10050-medicare-and-you.pdf

Cole, Martin I., and Gregory. Parston. 2006. Unlocking Public Value: A New Model for Achieving High Performance in Public Service Organizations. Hoboken, NJ: John Wiley.

Coley, Steve. 2009. "Enduring Ideas: The Three Horizons of Growth." *McKinsey Quarterly*, Dec. 2009.

Comin, Diego, and Martí Mestieri. 2018. "If Technology Has Arrived Everywhere, Why Has Income Diverged?" *American Economic Journal. Macroeconomics* 10, no. 3, 2018: 137–178. https://doi.org/10.1257/mac.20150175

Conti, Annamaria, and Jorge Guzman. "What Is the US Comparative Advantage in Entrepreneurship? Evidence from Israeli Migrations to the US." *Academy of Management Proceedings* 2019, no. 1: 11931. https://doi.org/10.5465/AMBPP.2019.295

Cooper, Robert G. 1990. "Stage-Gate Systems: A New Tool for Managing New Products." *Business Horizons* 33, no. 3: 44–54. https://doi.org/10.1016/0007-6813(90)90040-I

Cooper, Robert G. 2017. "Idea-to-Launch Gating Systems: Better, Faster, and More Agile: Leading Firms Are Rethinking and Reinventing Their Idea-to-Launch Ggating Systems, Adding Elements of Agile to Traditional Stage-Gate Structures to Add Flexibility and Speed While Retaining Structure." *Research Technology Management* 60, no. 1: 48–52.

Cooper, Robert G., and Anita Friis Sommer. 2018. "Agile-Stage-Gate for Manufacturers: Changing the Way New Products Are Developed Integrating Agile Project Management Methods into a Stage-Gate System Offers Both Opportunities and Challenges." *Research Technology Management* 61, no. 2: 17–26. https://doi.org/10.1080/08956308.2018.1421380

Cooper, Robert G., and Scott J. Edgett. 2006. "Ten Ways to Make Better Portfolio and Project Selection Decisions." *PDMA Visions Magazine* 30, no. 3: 11–15.

Cooper, Robert G., Scott J. Edgett, and Elko J. Kleinschmidt. 1999. "New Product Portfolio Management: Practices and Performance." *Journal of Product Innovation Management: An International Publication of The Product Development & Management Association* 16, no. 4: 333–351.

Cooper, Robert Gravlin, Scott J. Edgett, and Elko J. Kleinschmidt. 2001. "Portfolio Management for New Products." Retrieved from https://www.academia.edu/download/3468542/wp_11.pdf

Cortright, Joseph. 2001. "New Growth Theory, New Growth Theory, Technology and Learning: A Practitioner's Guide A Practitioner's Guide." *Reviews of Economic Development Literature and Practice*: no. 4, U.S. Economic Development Administration. Available at https://www.researchgate.net/publication/254336193_New_Growth_Theory_New_Growth_Theory_Technology_and_Learning_Technology_and_Learning_A_Practitioner's_Guide_A_Practitioner's_Guide Accessed Apr. 14, 2021.

D.school. 2022. "Design Thinking Bootleg." Hasso Plattner, Institute of Design at Stanford, Stanford University https://dschool.stanford.edu/resources/design-thinking-bootleg Accessed Mar. 9, 2022.

David, Paul A. 1990. "The Dynamo and The Computer: An Historical Perspective on the Modern Productivity Paradox." *The American Economic Review* 80, no. 2: 355–361.

Deleidi, Matteo, and Mariana Mazzucato. 2019. "Putting Austerity to Bed: Technical Progress, Aggregate Demand and the Supermultiplier." *Review of Political Economy* 31, no. 3: 315–335. https://doi.org/10.1080/09538259.2019.1687146

Department of Defense. 2020. *DOD Instruction 5000.85. Major Capability Acquisition*. Available at https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500002p.pdf?ver=2020-01-23-144114-093

Dias, Albertina, and Bror Salmelin. 2018. “Living Labs and Open Innovation in European Context.” In Albertina Dias, Bror Salmelin, David Pereira, and Miguel Sales Dias, eds., *Modeling Innovation Sustainability and Technologies*. Cham, Switzerland: Springer.

Drucker, Peter F. 1983. *Innovation and Entrepreneurship*. New York: HarperCollins.

Edler, Jakob, and Jan Fagerberg. 2017. “Innovation Policy: What, Why, and How.” *Oxford Review of Economic Policy* 33, no. 1: 2–23. https://doi.org/10.1093/oxrep/grx001

Ellwood, Paul, Ceri Williams, and John Egan. 2022. “Crossing the Valley of Death: Five Underlying Innovation Processes.” *Technovation* 109: 102162. https://doi.org/10.1016/j.technovation.2020.102162

Elsevier. 2022. *Research Policy*. https://journals.elsevier.com/research-policy

Etzkowitz, Henry, and Loet Leydesdorff. 1995. “The Triple Helix–University-Industry-Government Relations: A Laboratory for Knowledge Based Economic Development.” *EASST Review* 14, no. 1: 14–19.

Etzkowitz, Henry, and Loet Leydesdorff. 2000. “The Dynamics of Innovation: From National Systems and ‘Mode 2’ to a Triple Helix of University–industry–government Relations.” *Research Policy* 29, no. 2: 109–123. https://doi.org/10.1016/S0048-7333(99)00055-4

Etzkowitz, Henry. 2008. *The Triple Helix: University-Industry-Government Innovation in Action*. New York: Routledge.

Euchner, Jim, and Abhijit Ganguly. 2014. ”Business Model Innovation in Practice: A Systematic Approach to Business Model Innovation Can Help Capture Value and Reduce Risks.” *Research Technology Management* 57, no. 6: 33–39. https://doi.org/10.5437/08956308X5706013

European Commission’s Directorate-General for Research & Innovation (RTD). 2016. *Open Innovation, Open Science, Open to the World – a Vision for Europe*. European Commission. Available at https://ec.europa.eu/digital-single-market/en/news/open-innovation-open-science-open-world-vision-europe

Ewens, Michael, Ramana Nanda, and Christopher T. Stanton. 2020. “The Evolution of CEO Compensation in Venture Capital Backed Startups.” *Working Paper no. 27296. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w27296

Ewens, Michael, Ramana Nanda, and Matthew Rhodes-Kropf. 2018. “Cost of Experimentation and the Evolution of Venture Capital.” *Journal of Financial Economics* 128, no. 3: 422–442. https://doi.org/10.1016/j.jfineco.2018.03.001

Fagerberg, Jan, and Martin Srholec. 2008. “National Innovation Systems, Capabilities and Economic Development.” *Research Policy* 37, no. 9: 1417–1435. https://doi.org/10.1016/j.respol.2008.06.003

Feenstra, Robert, Robert Inklaar, Marcel Timmer. 2015. “The Next Generation of the Penn World Table.” *The American Economic Review* 105, no. 10: 3150–3182.

Ferguson, Roger W. Jr., and William L. Wascher. 2004. “Distinguished Lecture on Economics in Government: Lessons from Past Productivity Booms.” *The Journal of Economic Perspectives* 18, no. 2 (Spring): 3–28

Fink, Andreas, and Benedek, Mathias. 2019. “The Neuroscience of Creativity.” *Neuroforum* 25, no. 4: 233. https://doi.org/10.1515/nf-2019-0006.

Fleming, L, H Greene, G Li, M Marx, and D Yao. 2019. “Government-Funded Research Increasingly Fuels Innovation.” *Science (American Association for the Advancement of Science)* 364, no. 6446: 1139–1141. https://doi.org/10.1126/science.aaw2373

Foss, Nicolai J., and Tina Saebi. 2017. “Fifteen Years of Research on Business Model Innovation: How Far Have We Come, and Where Should We Go?” *Journal of Management* 43, no. 1: 200–227.

Fowler, Ben. 2022. “Stages of Venture Capital.” Silicon Valley Bank. Available at https://www.svb.com/startup-insights/vc-relations/stages-of-venture-capital Accessed Mar. 24, 2022.

Frank, Alejandro G., Glauco HS Mendes, Néstor F. Ayala, and Antonio Ghezzi. 2019. "Servitization and Industry 4.0 Convergence in the Digital Transformation of Product Firms: A Business Model Innovation Perspective." *Technological Forecasting and Social Change* 141: 341–351.

Freeman, Chris. 1995. "The 'National System of Innovation' in Historical Perspective." *Cambridge Journal of Economics* 19, no. 1: 5–24. https://doi.org/10.1093/oxfordjournals.cje.a035309

Freeman, Christopher, and Francisco. Louçã. 2001. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press.

Freeman, Christopher. 1987. *Technology Policy and Economic Performance: Lessons from Japan*. London: Pinter.

Fukuda, Kayano. 2020. "Science, Technology and Innovation Ecosystem Transformation Toward Society 5.0." *International Journal of Production Economics* 220: 107460–. https://doi.org/10.1016/j.ijpe.2019.07.033

Fukuyama, Mayumi. 2018. "Society 5.0: Aiming for a New Human-Centered Society." *Japan Spotlight* 27: 47–50.

Fulgencio, Harry, Hans Le Fever, and Bernhard Katzy. 2012. "Living Lab: Innovation through Pastiche." In *Proceedings of the eChallenges e-2012 Conference*. Lisbon: IMC: 1–8.

Furman, Jeffrey L., Michael E. Porter, and Scott Stern. 2002. "The Determinants of National Innovative Capacity." *Research Policy* 31, no. 6: 899–933. https://doi.org/10.1016/S0048-7333(01)00152-4

Gartner. 2022. "The Gartner Hype Cycle." https://www.gartner.com/en/research/methodologies/gartner-hype-cycle Accessed Feb. 28, 2022.

Gascó, Mila. 2017. "Living Labs: Implementing Open Innovation in the Public Sector." *Government Information Quarterly* 34, no. 1: 90–98.

Gassmann, Oliver, and Ellen Enkel. 2004. "Towards a Theory of Open Innovation: Three Core Process Archetypes." Institute of Technology Management, University of St. Gallen, Switzerland. Available at https://www.alexandria.unisg.ch/274/1/Gassmann_Enkel.pdf

General Mills. 2022. "Criteria and FAQ," General Mills Worldwide Innovation Network (G-WIN), https://gwin.secure.force.com/FAQs Accessed Mar. 10, 2022

George, Gerard, Anita M. McGahan, and Jaideep Prabhu. 2012. "Innovation for Inclusive Growth: Towards a Theoretical Framework and a Research Agenda." *Journal of Management Studies* 49, no. 4: 661–683.

Gerety, Rowan Moore. 2020. "Unmade in America." *MIT Technology Review* 123, no. 5: 68–75.

Gibbons, Michael, Camille Limoges, Helga Nowotny, et al. 1994. *The New Production of Knowledge: The Dynamics of Science and Research in Contemporary Societies*. Stockholm: Sage.

Girotra, Karan, Christian Terwiesch, and Karl T. Ulrich. 2007. "Valuing R&D Projects in a Portfolio: Evidence from the Pharmaceutical Industry." *Management Science* 53, no. 9: 1452–1466.

Gladden, Matthew E. 2019. "Who Will Be the Members of Society 5.0? Towards an Anthropology of Technologically Posthumanized Future Societies." *Social Sciences* 8, no. 5: 148.

Godin, Benoît. 2006. "The Linear Model of Innovation: The Historical Construction of an Analytical Framework." *Science, Technology, & Human Values*, 31, no. 6: 639–667.

Godin, Benoît. 2008. "In the Shadow of Schumpeter: W. Rupert Maclaurin and the Study of Technological Innovation." *Minerva* 46, no. 3: 343–360. https://doi.org/10.1007/s11024-008-9100-4

Gordon, Robert J. 2016. *The Rise and Fall of American Growth: The U.S. Standard of Living Since the Civil War*. Princeton: Princeton University Press.

Gotkin, Joel. 2012. "Introduction." In *The United States Bayh-Dole Act and Its Effect on University Technology Transfer*: 15–21. Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH http://www.jstor.org/stable/j.ctv941t20.5

Gotkin, Joel. 2012. “Perceived Successes and Shortfalls of the Bayh-Dole Act.” In *The United States Bayh-Dole Act and Its Effect on University Technology Transfer*: 28–33. Baden-Baden, Germany: Nomos Verlagsgesellschaft mbH. http://www.jstor.org/stable/j.ctv941t20.5

Government Accountability Office (GAO). 2017. *OPEN INNOVATION Executive Branch Developed Resources to Support Implementation, but Guidance Could Better Reflect Leading Practices. GAO-17-507 Report to Congressional Committees*.

Government Accountability Office (GAO). 2022. “Managing for Results in Government.” https://www.gao.gov/key_issues/managing_for_results_in_government/issue_summary Accessed Mar. 29, 2022.

Government of Japan. 2016. *Outline of the Fifth Science and Technology Basic Plan, Provisional Translation*. Available at http://www.dst.tokyo/docs/5th-STBP.pdf

Government of Japan. 2016. *The 5th Science and Technology Basic Plan, Provisional Translation*, Jan. 22, 2016.

Government of Japan. 2021. *Science, Technology, and Innovation Basic Plan, Tentative Translation*, Mar. 26, 2021. Available at https://www8.cao.go.jp/cstp/english/sti_basic_plan.pdf

Government of Japan. 2022. *Science and Technology Basic Plan, 2022*. Available at https://www.mext.go.jp/en/policy/science_technology/lawandplan/title01/detail01/1375311.htm

Grable, John E. 2019. “An Introduction to Kondratieff Waves.” *Journal of Financial Service Professionals* 73 (3): 19–22.

Griffin, Abbie, and John R. Hauser. 1993. “The Voice of the Customer.” *Marketing Science* (Providence, RI) 12, no. 1: 1–27. https://doi.org/10.1287/mksc.12.1.1

Grinin, Leonid. E., Anton. L. Grinen, and Andrey Korotayev. 2017. “Forthcoming Kondratieff Wave, Cybernetic Revolution, and Global Ageing.” *Technological Forecasting & Social Change* 115: 52–68. https://doi.org/10.1016/j.techfore.2016.09.017

Groningen Growth and Development Centre. 2022. *Penn World Table Version 10.0*. Available at https://www.rug.nl/ggdc/productivity/pwt/

Gronlund, Johan, David Ronnberg Sjodin, and Johan Frishammar. 2010. “Open Innovation and the Stage-Gate Process: A Revised Model for New Product Development.” *California Management Review* 52, no. 3: 106–131. https://doi.org/10.1525/cmr.2010.52.3.106

Grossman, Gene M., and Elhanan Helpman. 1994. “Endogenous Innovation in the Theory of Growth.” *The Journal of Economic Perspectives* 8, no. 1: 23–44.

Growth Lab of Harvard University. 2022. “The Atlas of Economic Complexity.” https://atlas.cid.harvard.edu/

Hadhazy, Adam. 2016. “Crowdsourcing the Universe: How Citizen Scientists are Driving Discovery.” *Space.com*, Jan. 14, 2016. https://www.space.com/31626-crowdsourced-astronomy-finding-faint-galaxies-in-deep-space.html Accessed Mar. 10, 2022.

Hall, Bronwyn H, and Josh Lerner. 2010. “The Financing of R&D and Innovation.” In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation Vol. 1*, no. 1 C: 609–39. https://doi.org/10.1016/S0169-7218(10)01014-2

Hall, Bronwyn H. 2004 “Innovation and diffusion.” *Working Paper no. 10212. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/system/files/working_papers/w10212/w10212.pdf

Hall, Bronwyn H. 2011. “Innovation and Productivity.” *Working Paper no. 17178. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. https://www.nber.org/papers/w17178

Hall, Robert E., and Susan E. Woodward. 2010. “The Burden of the Nondiversifiable Risk of Entrepreneurship.” *The American Economic Review* 100, no. 3: 1163–1194. https://doi.org/10.1257/aer.100.3.1163

Hamilton, Alexander. 1791. *Report on the Subject of Manufactures*. Founders Online, National Archives. Available at https://founders.archives.gov/documents/Hamilton/01-10-02-0001-0007 Accessed Feb. 16, 2022.

Hammer, Michael, and Champy, James. 1994. *Reengineering the Corporation – A Manifesto for Business Revolution*. London: Nicholas Brealey Publishing.

Hansen, Gary D, and Edward C Prescott. 2002. "Malthus to Solow." *The American Economic Review* 92, no. 4: 1205–1217. https://doi.org/10.1257/00028280260344731

Hargadon, Andrew B., and Yellowlees Douglas. 2001. "When Innovations Meet Institutions: Edison and the Design of the Electric Light." *Administrative Science Quarterly* 46, no. 3: 476–501.

Hartley, Jean, Eva Sørensen, and Jacob Torfing. 2013. "Collaborative Innovation: A Viable Alternative to Market Competition and Organizational Entrepreneurship." *Public Administration Review* 73, no. 6: 821–830. doi:10.1111/puar.12136.

Hartmann, Dominik, Miguel R Guevara, Cristian Jara-Figueroa, et al. 2017. "Linking Economic Complexity, Institutions, and Income Inequality." *World Development* 93: 75–93. https://doi.org/10.1016/j.worlddev.2016.12.020

Henderson, Rebecca M., and Kim B. Clark. 1990. "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms." *Administrative Science Quarterly*: 9–30.

Henz, Tobias, Miao Wang, and Tawanda Sibanda. 2020. "Flipping the Odds on Corporate-Startup Collaboration." Alumni Webcast, McKinsey & Company, Oct. 15, 2020.

Herzberg, Frederick, Bernard Mausner, and Barbara Snyderman. 1959. *The Motivation to Work*. New York: Wiley.

Hewlett, Sylvia Ann, Melinda Marshall, and Laura Sherbin. 2013. "How Diversity Can Drive Innovation." *Harvard Business Review*, Dec. 2013: 30.

Hicks, John. 1948. *The Theory of Wages*. New York: P. Smith.

Hidalgo, César A., and Ricardo Hausmann. 2009. "The Building Blocks of Economic Complexity." Proceedings of the National Academy of Sciences, 106, no. 26: 10570–10575. Available at https://www.pnas.org/content/pnas/106/26/10570.full.pdf

Howells, Jeremy. 2006. "Intermediation and the Role of Intermediaries in Innovation." *Research Policy* 35, no. 5: 715–728.

Hudson, John, and Hanan F. Khazragui. 2013. "Into the Valley of Death: Research to Innovation." *Drug Discovery Today* 18, nos. 13–14: 610–613. https://doi.org/10.1016/j.drudis.2013.01.012

Ibarra, Dorleta, Jaione Ganzarain, and Juan Ignacio Igartua. 2018. "Business Model Innovation Through Industry 4.0: A Review." *Procedia Manufacturing* 22: 4–10.

IDEO. 2022. "About the Ten Faces." https://www.ideo.com/post/the-ten-faces-of-innovation Accessed Mar. 9, 2022.

IEEE Standards Association. 2015. *IEEE 15288.2-2014 – IEEE Standard for Technical Reviews and Audits on Defense Programs*. Available at https://standards.ieee.org/standard/15288_2-2014.html

Industrial Base Policy Office. 2022. "Congressional Interests and Reports." Department of Defense. https://www.businessdefense.gov/resources.html

Innovation Leader. 2019. "Understanding Co-Creation and Innovation Ecosystems Is No Longer Optional . . . ." *Best Practices: Co-creation and Ecosystem Development*, Innovation Leader, Q1 2019.

Institute for New Economic Thinking. https://www.ineteconomics.org/

International Organization for Standardization (ISO). 2015. *ISO/IEC/IEEE 15288:2015 – Systems and software engineering – System life cycle processes*. Available at https://www.iso.org/standard/63711.html

International Organization for Standardization (ISO). 2019. ISO 56002, Innovation Management – Innovation Management System – Guidance. Available at https://www.iso.org/standard/68221.html

Isaacson, Walter. 2018. *Leonardo da Vinci*. New York: Simon & Schuster.

Janeway, William H. 2018. *Doing Capitalism in the Innovation Economy: Reconfiguring the Three-Player Game Between Markets, Speculators and the State*. Second Edition. Cambridge, UK: Cambridge University Press.

Janssen, Marijn, David Konopnicki, Jane L. Snowdon, and Adegboyega Ojo. 2017. "Driving Public Sector Innovation using Big and Open Linked Data (BOLD)." *Information Systems Frontiers* 19, no. 2: 189–195.

Jetzek, Thorhildur, Michel Avital, and Niels Bjorn-Andersen. 2014. "Data-Driven Innovation through Open Government Data." *Journal of Theoretical and Applied Electronic Commerce Research* 9, no. 2: 100–120.

Johansson, Frans. 2004. *The Medici Effect: Breakthrough Insights at the Intersection of Ideas, Concepts, and Cultures*. Boston, MA: Harvard Business School Press.

Johnson, Chalmers. 1982. *MITI and the Japanese Miracle: The Growth of Industrial Policy, 1925–1975*. Stanford University Press.

Kahneman, Daniel, and Amos Tversky. 1979. "Prospect Theory: An Analysis of Decision under Risk." *Econometrica* 47, no. 2: 263–291.

Kahneman, Daniel. 2011. *Thinking, Fast and Slow*. New York: Farrar, Straus and Giroux.

Kanigel, Robert. 2005. *The One Best Way: Frederick Winslow Taylor and the Enigma of Efficiency*. New York: Penguin Books.

Kano, Noriaki. 1984. "Attractive Quality and Must-Be Quality." *Hinshitsu* (Quality, The Journal of Japanese Society for Quality Control) 14: 39–48.

Kaplan, Robert S., and David P Norton. 2004. "The Strategy Map: Guide to Aligning Intangible Assets." *Strategy & Leadership* 32, no. 5: 10–17. https://doi.org/10.1108/10878570410699825

Kaplan, Robert S., and David P. Norton. 1996. *The Balanced Scorecard: Translating Strategy into Action*. Boston: Harvard Business Review Press.

Kattel, Rainer, and Mariana Mazzucato. 2018. "Mission-Oriented Innovation Policy and Dynamic Capabilities in the Public Sector." *Industrial and Corporate Change*: 787–801.

Keller, Matthew R., and Fred Block. 2015. "Do as I Say, or as I Do? US Innovation and Industrial Policy Since the 1980s." In Felipe, Jesus, ed., *Development and Modern Industrial Policy in Practice*. Cheltenham UK: Edward Elgar Publishing.

Kelley, Tom. 2001. *The Art of Innovation – Lessons in Creativity from IDEO, America's Leading Design Firm*. New York: Currency.

Kelly, Bryan, Dimitris Papanikolaou, Amit Seru, and Matt Taddy. 2021. "Measuring Technological Innovation over the Long Run." *The American Economic Review*. Insights 3, no. 3: 303–320. https://doi.org/10.1257/aeri.20190499

Kendra Cherry. 2020. "How Many Neurons Are in the Brain?" *Very Well Mind*, Apr. 2020. Available at https://www.verywellmind.com/how-many-neurons-are-in-the-brain-2794889#citation-1

Kenney, Martin, and John Zysman. 2019. "Unicorns, Cheshire cats, and the new dilemmas of entrepreneurial finance." *Venture Capital* 21, no. 1: 35–50.

Kerzner, Harold. 2017. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling, Twelfth Edition*. Chichester, West Sussex, UK: Wiley.

Kevles, Daniel J. 1977. "The National Science Foundation and the Debate over Postwar Research Policy, 1942–1945: A Political Interpretation of Science – The Endless Frontier." *Isis* 68, no. 1: 5–26.

Keynes, John Maynard. 1936. *The General Theory of Employment, Interest, and Money*. London: MacMillan Press.

Keynes, John Maynard. 1937. "The General Theory of Employment." *Quarterly Journal of Economics* 51, no. 2, 209–223.
Kim, W. Chan, and Renée Mauborgne. 2005. *Blue Ocean Strategy: How to Create Uncontested Market Space and Make the Competition Irrelevant*. Boston, MA: Harvard Business School Press.
Kleiner, Diana J. 2022. "Sematech." *Handbook of Texas Online*. Accessed February 19, 2022, https://www.tshaonline.org/handbook/entries/sematech Published by the Texas State Historical Association.
Knight, Frank H. 1921. *Risk, Uncertainty, and Profit*. Pantianos Classics.
Kock, Alexander, and Hans Georg Gemünden. 2016. "Antecedents to Decision-Making Quality and Agility in Innovation Portfolio Management." *The Journal of Product Innovation Management* 33, no. 6: 670–686. https://doi.org/10.1111/jpim.12336
Köhler, Jonathan. 2012. "A Comparison of the Neo-Schumpeterian Theory of Kondratiev Waves and the Multi-Level Perspective on Transitions." *Environmental Innovation and Societal Transitions* 3: 1–15.
Kondratieff, Nikolai D. 1979. "The Long Waves in Economic Life." *Review Fernand Braudel Center*: 519–562.
Korotayev, Andrey, Julia Zinkina, and Justislav Bogevolnov. 2011. "Kondratieff Waves in Global Invention Activity (1900–2008)." *Technological Forecasting & Social Change* 78, no. 7: 1280–8124. https://doi.org/10.1016/j.techfore.2011.02.011
Krafcik, John F. 1988. "Triumph of The Lean Production System." *MIT Sloan Management Review* 30, no. 1: 41.
Lämmerhirt, D., M. Rubinstein, and O. Montiel. 2017. *The State of Open Government Data in 2017: Creating Meaningful Open Data Through Multi-Stakeholder Dialogue*. Open Knowledge International.
Landes, David S. 2003. *The Unbound Prometheus: Technological Change and Industrial Development in Western Europe from 1750 to the Present*. Cambridge UK: Cambridge University Press.
Lazonick, William. 2017. "The New Normal Is 'Maximizing Shareholder Value': Predatory Value Extraction, Slowing Productivity, and the Vanishing American Middle Class." *International Journal of Political Economy* 46, no. 4: 217–226. https://doi.org/10.1080/08911916.2017.1407736
Lerner, Josh, and Ramana Nanda. 2020. "Venture Capital's Role in Financing Innovation: What We Know and How Much We Still Need to Learn." *The Journal of Economic Perspectives* 34, no. 3: 237–261.
Leydesdorff, Loet and Henry Etzkowitz. 1998. "Triple Helix of Innovation: Introduction." *Science and Public Policy* 25, no. 6: 358–364.
Leydesdorff, Loet, and Martin Meyer. 2013. "A Reply to Etzkowitz' Comments to Leydesdorff and Martin (2010): Technology Transfer and the End of the Bayh-Dole Effect." *Scientometrics* 97, no. 3: 927–934. https://doi.org/10.1007/s11192-013-0997-5
Leydesdorff, Loet. 2012. "The Triple Helix, Quadruple Helix, . . ., and an N-Tuple of Helices: Explanatory Models for Analyzing the Knowledge-Based Economy?" *The Journal of the Knowledge Economy* 3, no. 1: 25–35.
Linder, Jane, and Susan Cantrell. 2000. "Changing business models: Surveying the landscape," Accenture Institute for Strategic Change, Cambridge, May 24, 2000. Available at http://www.businessmodels.eu/images/banners/Articles/Linder_Cantrell.pdf Accessed Mar. 14, 2022.
Link, Albert N., Robert S. Danziger, and John T. Scott. 2018. "Is the Bayh-Dole Act Stifling Biomedical Innovation?" *Issues in Science and Technology* 34, no. 2: 33–35.

List, Friedrich. 1841. *Das Nationale System der Politischen Ökonomie*. Basel: Kyklos. *The National System of Political Economy*. London: Longmans, Green and Co.

Lockheed Martin. 2022. *Missions Impossible: The Skunk Works® Story*. Available at https://www.lockheedmartin.com/en-us/news/features/history/skunk-works.html Accessed on Mar. 9, 2022.

Loewe, Pierre, Peter Williamson, and Robert Chapman Wood. 2001. "Five Styles of Strategy Innovation and How to Use Them." *The European Management Journal* 19, no. 2: 115–125. https://doi.org/10.1016/S0263-2373(00)00081-5

Long, John B. and Charles I. Plosser. 1983. "Real Business Cycles," *The Journal of Political Economy* 91, no. 1, 1983: 39–69.

Lucking, Brian, Nicholas Bloom, and John Van Reenen. 2018. "Have R&D spillovers changed?" *Working Paper no. 24622. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/system/files/working_papers/w24622/w24622.pdf

Lund, Susan, James Manyika, Liz Hilton Segel, et al. 2019. *The Future of Work in America: People and Places, Today and Tomorrow*. McKinsey Global Institute. Available at https://www.mckinsey.com/featured-insights/future-of-work/the-future-of-work-in-america-people-and-places-today-and-tomorrow

Lundvall, Bengt-Åke. 2016. "National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning." In *The Learning Economy and the Economics of Hope*, 85–106. Anthem Press.

Maddison, Angus. 2003. *The World Economy: Historical Statistics*. Development Centre Studies. Paris: OECD Publishing.

Maddison, Angus. 2006. *The World Economy: Volume 1: A Millennial Perspective*. Development Centre Studies. Paris: OECD Publishing. https://doi.org/10.1787/9789264022621-en

Maddison, Angus. 2006. *The World Economy: Volume 2: Historical Statistics*. Development Centre Studies. Paris: OECD Publishing. https://doi.org/10.1787/9789264022621-en

Maddison, Angus. 2007. "Fluctuations in the Momentum of Growth within the Capitalist Epoch." *Cliometrica* 1, no. 2 07: 145–175.

Maddison, Angus. 2021. *Maddison Historical Statistics*. Faculty of Economics and Business, University of Groningen. https://www.rug.nl/ggdc/historicaldevelopment/maddison/

Markides, Constantinos C. 2013. "Business Model Innovation: What Can the Ambidexterity Literature Teach Us?" *Academy of Management Perspectives* 27, no. 4: 313–323.

Markowitz, Harry. 1952. "Portfolio Selection." *The Journal of Finance* 7: 77–91.

Martin, Ben R. 2012. "The Evolution of Science Policy and Innovation Studies." *Research Policy* 41, no. 7: 1219–1239. https://doi.org/10.1016/j.respol.2012.03.012

Martinsuo, Miia, Tuomas Korhonen, and Teemu Laine. 2014. "Identifying, Framing and Managing Uncertainties in Project Portfolios." *International Journal of Project Management* 32, no. 5: 732–746. https://doi.org/10.1016/j.ijproman.2014.01.014

Maslow, Abraham H. 1943. "Conflict, Frustration, and the Theory of Threat." *The Journal of Abnormal and Social Psychology* 38, no. 1: 81.

Maslow, Abraham H. 1954. *Motivation and Personality*. New York: Harper and Bros.

Massa, Lorenzo, and Christopher L. Tucci. 2013. "Business Model Innovation." In Dodgson, Mark, David Gann, and Nelson Phillips, eds., *The Oxford Handbook of Innovation Management* 20, no. 18: 420–441. New York: Oxford.

Massa, Lorenzo, Christopher L. Tucci, and Allan Afuah. 2017. "A Critical Assessment of Business Model Research." *Academy of Management Annals* 11, no. 1: 73–104.

Matzler, Kurt, and Hans H Hinterhuber. 1998. "How to Make Product Development Projects More Successful by Integrating Kano's Model of Customer Satisfaction into Quality Function Deployment." *Technovation* 18, no. 1: 25–38. https://doi.org/10.1016/S0166-4972(97)00072-2

Mazzucato, Mariana, Rainer Kattel, and Josh Ryan-Collins. 2019. “Challenge-Driven Innovation Policy: Towards a New Policy Toolkit.” Journal of Industry, *Competition and Trade* 20, no. 2: 421–437. https://doi.org/10.1007/s10842-019-00329-w

Mazzucato, Mariana. 2015. *The Entrepreneurial State: Debunking Public Vs. Private Sector Myths*. Revised edition. New York: PublicAffairs.

Mazzucato, Mariana. 2021. *Mission Economy: A Moonshot Guide to Changing Capitalism*. First U.S. edition. New York: Harper Business, an imprint of HarperCollins Publishers.

McClelland, David C., and Eric W Johnson. 1984. *Learning to Achieve*. Glenview, Illinois: Scotti. Foresman & Co.

McGann, Michael, Emma Blomkamp, and Jenny M. Lewis. 2018. “The Rise of Public Sector Innovation Labs: Experiments in Design Thinking for Policy.” *Policy Sciences* 51, nos. 3–9:249–267.

McGregor, Douglas. 1960. The Human Side of Enterprise. New York: McGraw-Hill.

McKinsey & Company. 2022. “Organizational Health Index.” OrgSolutions. Available at https://www.mckinsey.com/solutions/orgsolutions/overview/organizational-health-index. Accessed Mar. 29, 2022.

Meifort, Anna. 2016. “Innovation Portfolio Management: A Synthesis and Research Agenda.” *Creativity & Innovation Management* 25, no. 2: 251–269.

Menke, Michael M. 2013. “Making R&D Portfolio Management More Effective.” *Research-Technology Management* 56, no. 5: 34–44.

Mergel, Ines. 2018. “Open Innovation in the Public Sector: Drivers and Barriers for the Adoption of Challenge.gov.” *Public Management Review* 20, no. 5: 726–745.

Michaelis, Timothy L, Roberly Aladin, and Jeffrey M Pollack. 2018. “Innovation Culture and the Performance of New Product Launches: A Global Study.” *Journal of Business Venturing Insights* 9: 116–127. https://doi.org/10.1016/j.jbvi.2018.04.001

Mikkola, Juliana Hsuan. 2001. “Portfolio Management of R&D Projects: Implications for Innovation Management.” *Technovation* 21, no. 7: 423–435. https://doi.org/10.1016/S0166-4972(00)00062-6

Miller, Kristel, Rodney McAdam, and Maura McAdam. 2018. “A Systematic Literature Review of University Technology Transfer from a Quadruple Helix Perspective: Toward a Research Agenda.” *R&D Management* 48, no. 1: 7–24. https://doi.org/10.1111/radm.12228

MITRE. 2022. *Systems Engineering Guide* (SEG). Available at https://www.mitre.org/publications/systems-engineering-guide/systems-engineering-guide

Mohnen, Pierre, and Bronwyn H Hall. 2014. “Innovation and Productivity: An Update.” *Eurasian Business Review* 3, no. 1: 47–65. https://doi.org/10.14208/BF03353817

Moretti, Enrico, Claudia Steinwender, and John Van Reenen. 2019. “The Intellectual Spoils of War? Defense R&D, Productivity and International Spillovers.” *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3498716

Moser, Petra. 2013. “Patents and Innovation: Evidence from Economic History.” *The Journal of Economic Perspectives 27*, no. 1: 23–44. https://doi.org/10.1257/jep.27.1.23

Mowery, David C. 2010. “Military R&D and Innovation.” In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation* 1, no. 1 C: 609–639. https://doi.org/10.1016/S0169-7218(10)02013-7

Mueller, Jennifer S., Shimul Melwani, and Jack A. Goncalo. 2012. “The Bias Against Creativity: Why People Desire but Reject Creative Ideas.” *Psychological Science* 23, no. 1: 13–17. https://doi.org/10.1177/0956797611421018

Muller E., Héraud JA., Zenker A. 2017. “Are Innovation Systems Complex Systems?” In Bourgine P., Collet P., Parrend P., eds., *First Complex Systems Digital Campus World E-Conference 2015*.

Springer Proceedings in Complexity. Springer, Cham. https://doi.org/10.1007/978-3-319-45901-1_17

Mun, Johnathan. 2020. "Risk-Based ROI, Capital Budgeting, and Portfolio Optimization in the Department of Defense." *Defense Acquisition Research Journal* 27, no. 91: 60–107. https://doi.org/10.22594/dau.19-829.27.01

Nagji, Bansi, and George Tuff. 2012. "Managing Your Innovation Portfolio." *Harvard Business Review* 90, no. 5: 66–74.

National Center for Science and Engineering Statistics. 2021. "Survey of Federal Funds for Research and Development." FYs 2019–20, NSF 21-329 Table 6. https://ncses.nsf.gov/pubs/nsf21329 Note: Preliminary data for 2020.

National Inventors Hall of Fame. 2022. "King Camp Gillette." https://www.invent.org/inductees/king-camp-gillette Accessed Mar. 14, 2022.

National Science Foundation. 2021. "National Patterns of R&D Resources: 2018–19 Data Update." NSF 21-325, April 9, 2021, https://ncses.nsf.gov/pubs/nsf21325 Note: 2019 data are preliminary and may be revised.

Nelson, Richard R., and Gavin Wright. 1992. "The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective." *Journal of Economic Literature* 30, no. 4: 1931–1964.

Nelson, Richard R. "Reflections on 'The Simple Economics of Basic Scientific Research': Looking Back and Looking Forward." *Industrial and Corporate Change* 15, no. 6: 903–917. https://doi.org/10.1093/icc/dtl022

Nelson, Richard R. 1959. "The Economics of Invention: A Survey of the Literature." *The Journal of Business* 32, no. 2: 101–127. https://doi.org/10.1086/294247

Nelson, Richard R. 1993. *National Innovation Systems: A Comparative Analysis*. New York: Oxford University Press.

Nelson, Richard R. 2006. "Reflections on 'The Simple Economics of Basic Scientific Research': Looking Back and Looking Forward." *Industrial and Corporate Change* 15, no. 6: 903–917. https://doi.org/10.1093/icc/dtl022

Nelson, Richard R. and Winter, Sidney G. 1982. *An Evolutionary Theory of Economic Change*. Cambridge,

Nikhil Swaminathan 2008. "Why Does the Brain Need So Much Power?" *Scientific American*, Apr. 29, 2008. https://www.scientificamerican.com/article/why-does-the-brain-need-s/

Nowotny, Helga, Peter Scott, and Michael Gibbons. 2003. "Introduction: 'Mode 2' Revisited: The New Production of Knowledge." *Minerva* 41, no. 3: 179–194.

Nowotny, Helga. 2016. *The Cunning of Uncertainty*. Cambridge, UK: Polity Press.

O'Dell, Carla, and C. Jackson Grayson. 1998. "If Only We Knew What We Know: Identification and Transfer of Internal Best Practices." *California Management Review* 40, no. 3: 154–174. https://doi.org/10.2307/41165948

OECD. 2015. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities*. Paris: OECD Publishing https://doi.org/10.1787/9789264239012-en

OECD. 2018. *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*, *4th Edition*, *The Measurement of Scientific, Technological and Innovation Activities*. Paris/Eurostat: OECD Publishing. https://doi.org/10.1787/9789264304604-en

OECD. 2021. "Regional Innovation." OECD Regional Statistics database. Available at https://doi.org/10.1787/1c89e05a-en

OECD. 2022. "Main Science and Technology Indicators, Volume 2021, Issue 2." OECD Directorate for Science, Technology and Innovation. Data updated as of Apr. 6, 2022. https://doi.org/10.1787/2304277x Accessed on Feb. 24, 2022.

OECD. 2022. “Gross domestic spending on R&D”. https://doi.org/10.1787/d8b068b4-en Accessed on Feb. 24, 2022.

OECD. 2022. “EC-OECD STIP-Compass.” https://stip.oecd.org/stip/ Accessed on Mar. 30, 2022.

OECD. 2022. “GDP Per Capita and Productivity Growth,” OECD Productivity Statistics (database). https://doi.org/10.1787/data-00685-en

OECD. 2022. “Gross domestic spending on R&D”. https://doi.org/10.1787/d8b068b4-en Accessed on Feb. 24, 2022.

Office of Management and Budget (OMB). 2021. Circular no. A–11 – Preparation, Submission, and Execution of the Budget, *Executive Office of the President:* 3–84.

Office of Technology Policy. 1997. *The Global Context for U.S. Technology Policy, Department of Commerce*.

Open Knowledge Foundation. 2022. “Global Open Data Index.” Available at https://index.okfn.org/

Open Knowledge Foundation. 2022. “What is Open Data?” *The Open Data Handbook*. Available at https://opendatahandbook.org/guide/en/what-is-open-data/

Open Knowledge Foundation. 2022. “What Is Open?” Available at https://okfn.org/opendata/

Orazem, Geoff, and Peet van Biljon. 2021. “What Makes Public Sector Innovation Different?” *Contract Management*, National Contract Management Association (NCMA), March 2021: 56–61.

Harari, Oren. 2007. “Welcome to Commodity Hell: The Perils of the Copycat Economy,” in *Break from the Pack: How to Compete in a Copycat Economy*, informIT, Dec. 14, 2007. https://www.informit.com/articles/article.aspx?p=777370

Osterwalder, Alexander, and Yves Pigneur. 2010. *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers*. Hoboken, NJ: Wiley.

Osterwalder, Alexander, Yves Pigneur, Gregory Bernarda, and Alan Smith. 2014. *Value Proposition Design: How to Create Products and Services Customers Want*. Hoboken, NJ: John Wiley & Sons, Inc.

Ostry, Jonathan D., Prakash Loungani, and Davide Furceri. 2016. “Neoliberalism: Oversold? Instead of Delivering Growth, Some Neoliberal Policies Have Increased Inequality, in Turn Jeopardizing Durable Expansion.” *Finance & Development* 53, no. 2: 38–41.

Parker, Geoffrey G., Marshall Van Alstyne, and Sangeet Paul Choudary. 2016. *Platform Revolution: How Networked Markets Are Transforming the Economy and How to Make Them Work for You*. W. W. Norton & Company. Kindle Edition.

Parker, Miles. 2016. “The Rothschild Report (1971) and the Purpose of Government-Funded R&D – A Personal Account.” *Palgrave Communications* 2, no. 1. https://doi.org/10.1057/palcomms.2016.53

Pedersen, Keld. 2018. *The Purpose of Public Sector Open Innovation*. Reading: Academic Conferences International Limited.

Perez, Carlota. 2010. “Technological Revolutions and Techno-Economic Paradigms.” *Cambridge Journal of Economics* 34, no. 1: 185–202. https://doi.org/10.1093/cje/bep051

PitchBook. 2022. *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor

Pitchbook. 2022b. Data downloaded from PitchBook, *PitchBook-NVCA Venture Monitor Q4 2021*. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/q4-2021-pitchbook-nvca-venture-monitor

PitchBook. 2022c. US PE Breakdown 2021 Annual, 2022. PitchBook Data, Inc. Available at https://pitchbook.com/news/reports/2021-annual-us-pe-breakdown

Pollack, John. 2014. “Four Ways to Innovate Through Analogies.” *The Wall Street Journal*, Nov. 7, 2014. Available at https://www.wsj.com/articles/four-ways-to-innovate-through-analogies-1415376079

Porter, Michael E. 1990. *The Competitive Advantage of Nations*. New York: Free Press.

Prahalad, Coimbatore K., and Venkat Ramaswamy. 2004. "Co-Creating Unique Value with Customers." *Strategy & Leadership*, 32, no. 3: 4–9 https://doi.org/10.1108/10878570410699249

President's Council of Advisors on Science and Technology. 2011. *Report to the President on Ensuring American Leadership in Advanced* Manufacturing. *Executive Office of the President*. Available at https://www.energy.gov/sites/prod/files/2013/11/f4/pcast_june2011.pdf

Product Development and Management Association (PDMA). 2020. *PDMA Body of Knowledge*, *2nd Edition*. Kindle. See https://www.pdma.org/page/npdp-bok-second-edition

Project Management Institute (PMI). 2021. *The Standard for Project Management and a Guide to the Project Management Body of Knowledge (PMBOK Guide). Seventh Edition*. Newtown Square, PA: Project Management Institute, Inc. See https://www.pmi.org/pmbok-guide-standards/foundational/pmbok

Reads, Edith M. 2022. "Assets managed by top 10 sovereign wealth funds hit $7.4 trillion." *FinancePR.com*, Jan. 24, 2022. Available at https://financepr.com/assets-managed-by-top-10-sovereign-wealth-funds-hit-7-4-trillion/

Reinert, Erik S. 2008. *How Rich Countries Got Rich– and Why Poor Countries Stay Poor*. New York: Public Affairs; Kindle edition.

Richardson, James. 2008. "The Business Model: An Integrative Framework for Strategy Execution." *Strategic Change* 17, nos. 5–6: 133–144. https://doi.org/10.1002/jsc.821

Ries, Eric. 2011. *The Lean Startup: How Constant Innovation Creates Radically Successful Businesses*. London: Portfolio Penguin.

Rodrik, Dani. 2004. "Industrial Policy for the Twenty-First Century." SSRN 666808. Copy at https://tinyurl.com/y9yjzpdq

Rogers, Everett M. 1962. *Diffusion of Innovations*. 4th Edition. Free Press. Kindle Edition.

Romer, Paul M. 1989. "Increasing Returns and New Developments in the Theory of Growth." *Working Paper no. 3098. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w3098

Romer, Paul M. 1990. "Endogenous Technological Change." *Journal of Political Economy* 98, no. 5: S71–S102.

Romer, Paul M., and Zvi Griliches. 1993. "Implementing a National Technology Strategy with Self-Organizing Industry Investment Boards; Comments and Discussion." *Brookings Papers on Economic Activity no. 2*: 345.

Ronald A. Finke, Thomas B. Ward, and Steven M. Smith. 1992. *Creative Cognition: Theory, Research, and Applications*. Cambridge, MA: The MIT Press.

Rosenberg, Nathan. 1996. "Uncertainty and Technical Change." In Landau, Ralph, Timothy Taylor and Gavin Wright, eds., *The Mosaic of Economic Growth*. Stanford, CA: Stanford University Press.

Rosing, Kathrin, Michael Frese, and Andreas Bausch. 2011. "Explaining the Heterogeneity of the Leadership-Innovation Relationship: Ambidextrous Leadership." *The Leadership Quarterly* 22, no. 5: 956–974. https://doi.org/10.1016/j.leaqua.2011.07.014

Rumsfeld, Donald H. 2002. "DOD News Briefing – Secretary Rumsfeld and Gen. Myers." CNN transcript, Feb. 12, 2002. http://www.cnn.com/TRANSCRIPTS/0202/12/se.04.html Also see Rumsfeld, Donald. YouTube video, from DOD News Briefing on Feb. 12, 2002, posted by "Ali" Aug. 7, 2009, https://youtu.be/GiPe1OiKQuk

Rupietta, Christian, and Uschi Backes-Gellner. 2019. "Combining Knowledge Stock and Knowledge Flow to Generate Superior Incremental Innovation Performance – Evidence from Swiss Manufacturing." *Journal of Business Research* 94: 209–222. https://doi.org/10.1016/j.jbusres.2017.04.003

Ruttan, Vernon W. 2006. *Is War Necessary for Economic Growth?: Military Procurement and Technology Development*. New York: Oxford University Press.

Ruttan, Vernon W., and Yujiro Hayami. 1984. "Toward a Theory of Induced Institutional Innovation," *The Journal of Development Studies* 20, no. 4: 203–223.

Ruttan, Vernon W., Yūjirō Hayami, Keijiro. Otsuka, and C. Ford Runge. 2011. *Can Economic Growth Be Sustained? The Collected Papers of Vernon W. Ruttan and Yūjirō Hayam*. New York: Oxford University Press.

Saebi, Tina, and Nicolai J. Foss. 2015. "Business Models for Open Innovation: Matching Heterogeneous Open Innovation Strategies with Business Model Dimensions." *European Management Journal* 33, no. 3: 201–213.

Salesforce. 2021. "The History of Salesforce." Available at https://www.salesforce.com/news/stories/the-history-of-salesforce/ Accessed on Mar. 11, 2022.

Sanchez, Pablo, and Joan E. Ricart. 2010. "Business Model Innovation and Sources of Value Creation in Low-Income Markets." *European Management Review* 7, no. 3: 138–154.

Satell, Greg. 2015. "Technology Progresses When Business, Government, and Academia Work Together," *Harvard Business Review*, Jun. 16, 2015.

Satia, Priya. 2020. *Empire of Guns: The Violent Making of the Industrial Revolution*. Stanford, CA: Stanford University Press. https://doi.org/10.1515/9781503610828

SBA. 2021. *Fiscal Year 2019 SBIR/STTR Annual Report*. Available at https://www.sbir.gov/annual-reports-files

Schoettle, Anthony. 2020. "University Professors Rev Up Efforts to Commercialize Research, Launch Startups." *Indianapolis Business Journal*, Oct. 30, 2020. Available at https://www.ibj.com/articles/professors-rev-up-efforts-to-commercialize-research Accessed on Feb. 4, 2022.

Schonfeld, Erick. 2009. "The Government Comes Through for Tesla with A $465 Million Loan for Its Electric Sedan," *Tech Crunch*, Jun. 23, 2009. Available at https://techcrunch.com/2009/06/23/the-government-comes-through-for-tesla-with-a-465-million-loan-for-its-electric-sedan/? Accessed on Jan. 31, 2022.

Schot, Johan, and W. Edward Steinmueller. 2018. "Three Frames for Innovation Policy: R&D, Systems of Innovation and Transformative Change." *Research Policy* 47, no. 9: 1554–1567. https://doi.org/10.1016/j.respol.2018.08.011

Schumpeter, Joseph A. 1939. *Business Cycles: A Theoretical, Historical, and Statistical Analysis of the Capitalist Process*. New York: McGraw-Hill.

Schumpeter, Joseph A. 1943. *Capitalism, Socialism and Democracy*. London: Routledge.

Schwab, Klaus. 2015. "The Fourth Industrial Revolution: What It Means and How to Respond." *Foreign Affairs*, Dec. 12, 2015. Available at https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution

Schwab, Klaus. 2017. *The Fourth Industrial Revolution*. New York: Crown Business.

Scott, Erin L, Pian Shu, and Roman M Lubynsky. 2020. "Entrepreneurial Uncertainty and Expert Evaluation: An Empirical Analysis." *Management Science* 66, no. 3: 1278–99. https://doi.org/10.1287/mnsc.2018.3244

Seth, Anil. 2021. "How Your Brain Constructs Reality." *TED Talks*. Available at https://www.ted.com/playlists/384/how_your_brain_constructs_real

Sethi, Rajesh, and Zafar Iqbal. 2008. "Stage-Gate Controls, Learning Failure, and Adverse Effect on Novel New Products." *Journal of Marketing* 72, no. 1: 118–134. https://doi.org/10.1509/jmkg.72.1.118

Shiroishi, Yoshihiro, Kunio Uchiyama, and Norihiro Suzuki. 2018. "Society 5.0: For Human Security and Well-Being." *Computer* 51, no. 7: 91–95.

Simoes, Alex J.G., and Cesar A. Hidalgo. 2011. "The Economic Complexity Observatory: An Analytical Tool for Understanding the Dynamics of Economic Development." *Workshops at the Twenty-Fifth AAAI Conference on Artificial Intelligence*.

Singh, Anuraag, Giorgio Triulzi, and Christopher L Magee. 2021. "Technological Improvement Rate Predictions for All Technologies: Use of Patent Data and an Extended Domain Description." *Research Policy 50*, no. 9: 104294 https://doi.org/10.1016/j.respol.2021.104294

Soete, Luc, Bart Verspagen, and Bas Ter Weel. 2010. "Systems of innovation." In Hall, Bronwyn H., and Nathan Rosenberg, eds., *Handbook of the Economics of Innovation*, *Vol. 2*: 1159–1180. North-Holland. https://doi.org/10.1016/S0169-7218(10)02011-3

Solomou, S. 2017. "Kondratieff Cycles." In Vernengo, Matias, Esteban Perez Caldentey, Barkley J. Rosser Jr., eds., *The New Palgrave Dictionary of Economics*. London: Palgrave Macmillan UK: 3470–3475.

Solow, Robert M. 1956. "A Contribution to the Theory of Economic Growth," *The Quarterly Journal of Economics* 70, no. 1: 65–94.

Solow, Robert M. 1957. "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics* 39, no. 3: 312–320.

Solow, Robert M. 1994. "Perspectives on Growth Theory." *Journal of Economic Perspectives* 8, no. 1: 45–54.

Spieth, P. and Lerch, M. 2014. "IPPM Performance and Management Perception and Satisfaction." *R&D Management 44*: 498–515. doi:10.1111/radm.12092.

St. Louis Fed. 2022. "Fred Economic Data." Federal Reserve Bank of St. Louis. Available at https://fred.stlouisfed.org/

Stiglitz, Joseph E. 1994. "Endogenous Growth and Cycles." Innovation in Technology, Industries, and Institutions. *Working Paper no. 4286. NBER Working Paper Series*. Cambridge MA: National Bureau of Economic Research. Available at https://www.nber.org/papers/w4286

Stokes, Donald E. 1997. *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington DC: Brookings Institution Press.

Summers, Lawrence H. 1986. "Some Skeptical Observations on Real Business Cycle Theory." *Federal Reserve Bank of Minneapolis Quarterly Review* 10, no. 4, Fall 1986: 23–27.

Surowiecki, James. 2005. *The Wisdom of Crowds*. New York: Anchor.

Teece, David J. 1986. "Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy." *Research Policy* 15, no. 6: 285–305. https://doi.org/10.1016/0048-7333(86)90027-2.

Teece, David J. 2010. "Business Models, Business Strategy and Innovation." *Long Range Planning* 43, no. 2: 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Temin, Peter. 2017. *The Vanishing Middle Class: Prejudice and Power in a Dual Economy*. Cambridge, MA: The MIT Press.

Terwiesch, Christian, and Yi Xu. 2008. "Innovation Contests, Open Innovation, and Multiagent Problem Solving." *Management Science* 54, no. 9: 1529–1543.

The Economist. 2021. "How to Prevent Conflict on the Way to Mars," *The Economist*, Dec. 18, 2021. Available at https://www.economist.com/christmas-specials/2021/12/18/how-to-prevent-conflict-on-the-way-to-mars

The Economist. 2022. "Big Tech's Private Passions." *The Economist*, Jan. 22, 2022. Available at https://www.economist.com/briefing/2022/01/22/what-americas-largest-technology-firms-are-investing-in Accessed Feb. 16, 2022.

The Economist. 2022. "SpaceX's monstrous, dirt-cheap Starship may transform space travel." *The Economist*, Feb. 19, 2022. Available at https://www.economist.com/science-and-technology/2022/02/19/spacexs-monstrous-dirt-cheap-starship-may-transform-space-travel Accessed Mar. 21, 2022.

The Nobel Prize. 1987. "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 1987." Royal Swedish Academy of Sciences. https://www.nobelprize.org/prizes/economic-sciences/1987/summary/

The Nobel Prize. 2018. "The Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel 2018." Royal Swedish Academy of Sciences. https://www.nobelprize.org/prizes/economic-sciences/2018/romer/facts/

The Planetary Society. 2022. "How Much Did the Apollo Program Cost?" https://www.planetary.org/space-policy/cost-of-apollo Accessed on Feb. 22, 2022.

The White House, President Barack Obama. 2009. *Open Government Directive*, issued Dec. 8, 2009. In Obama Whitehouse Archives, https://obamawhitehouse.archives.gov/open/documents/open-government-directive Accessed Mar. 11, 2022.

Thomas Robert Malthus. 1798. "An Essay on the Principle of Population." *The Works of Thomas Robert Malthus*. London, Pickering & Chatto Publishers, 1986: 1–139.

Trafton, Anne. 2021. "A Comprehensive Map of the SARS-CoV-2 Genome." *MIT News*, May 11, 2021, https://news.mit.edu/2021/map-sars-cov-2-genome-0511

Tulum, Öner, and William Lazonick. 2018. "Financialized Corporations in a National Innovation System: The U.S. Pharmaceutical Industry." *International Journal of Political Economy* 47, nos. 3–4: 281–316. https://doi.org/10.1080/08911916.2018.1549842

Tushman, Michael., and Charles A. O'Reilly. 1997. *Winning through Innovation: A Practical Guide to Leading Organizational Change and Renewal*. Boston, MA: Harvard Business School Press.

U.S. Department of Defense. 1985. *Military Standard – Technical Reviews and Audits for Systems, Equipments, and Computer Software, MIL-STD-1521B, June 4, 1985*. Available at https://product-lifecycle-management.com/download/MIL-STD-1521B.pdf

U.S. Department of Defense. 2017. *DOD Financial Management Regulation, Chapter 5: Research, Development, Test and Evaluation Appropriations*. Available at https://comptroller.defense.gov/Portals/45/documents/fmr/Volume_02b.pdf Accessed Mar. 24, 2022,"

Ulwick, Anthony W. 2005. *What Customers Want: Using Outcome-Driven Innovation to Create Breakthrough Products and Services*. New York: McGraw-Hill.

United Nations Statistical Commission (UNSC). 2008. *System of National Accounts 2008-2008 SNA*. Available at https://unstats.un.org/unsd/nationalaccount/sna2008.asp

United States Congress. *H.R.4521 – America COMPETES Act of 2022*. https://www.congress.gov/bill/117th-congress/house-bill/4521

United States Congress. *S.1260 – United States Innovation and Competition Act of 2021*. https://www.congress.gov/bill/117th-congress/senate-bill/1260

Urhahn, Christian, and Patrick Spieth. 2014. "Governing the Portfolio Management Process for Product Innovation – A Quantitative Analysis on the Relationship Between Portfolio Management Governance, Portfolio Innovativeness, and Firm Performance." *IEEE Transactions on Engineering Management* 61, no. 3: 522–533, doi:10.1109/TEM.2014.2327254.

Vale. 2022. "Iron Ore and Pellets," http://www.vale.com/EN/business/mining/iron-ore-pellets/Pages/default.aspx

Van Oorschot, Kim, Kishore Sengupta, Henk Akkermans, and Luk Van Wassenhove. 2010. "Get Fat Fast: Surviving Stage-Gate® in NPD." *The Journal of Product Innovation Management* 27, no. 6: 828–839. https://doi.org/10.1111/j.1540-5885.2010.00754.x

Van Reenen, John. 2020. *Innovation Policies to Boost Productivity, Executive Summary*. The Hamilton Project, Brookings. Available at https://www.brookings.edu/research/innovation-policies-to-boost-productivity/

Van Reenen, John. 2021. "Innovation Policy to Restore American Prosperity." *CentrePiece – The Magazine for Economic Performance* 599, Centre for Economic Performance, LSE.

Van Zanden, Jan Luiten, Joerg Baten, Marco Mira d'Ercole, Auke Rijpma and Marcel P. Timmer, eds. 2014. *How Was Life? Global Well-Being Since 1820*. Paris: OECD Publishing. https://doi-org.proxy.library.georgetown.edu/10.1787/9789264214262-en
Verspagen, Bart. 2005. "Innovation and Economic Growth." In Fagerberg, Jan, David C. Mowery, and Richard R. Nelson, eds., *The Oxford Handbook of Innovation*. Oxford, UK: Oxford University Press: 487–513.
VisualCapitalist. 2017. "Cognitive Bias Codex." https://www.visualcapitalist.com/wp-content/uploads/2017/09/cognitive-bias-infographic.html
Von Hippel, Eric. 2006. *Democratizing Innovation*. Cambridge, MA: MIT Press.
Vroom, Victor H. 1964. *Work and Motivation*. New York: John Wiley and Sons.
Walsh, John P, You-Na Lee, and Sadao Nagaoka. 2016. "Openness and Innovation in the US: Collaboration Form, Idea Generation and Implementation." *Research Policy* 45, no. 8: 1660–1671. https://doi.org/10.1016/j.respol.2016.04.013
Waytz, Adam, and Malia Mason. 2012. "Your Brain at Work." *Harvard Business Review*, Jul. – Aug. 2013: 103–111.
WEF. 2020. *Global Competitiveness Report Special Edition 2020: How Countries are Performing on the Road to Recovery*. Available at https://www.weforum.org/reports/the-global-competitiveness-report-2020
Weiss, Linda. 2014. *America Inc.? Innovation and Enterprise in the National Security State*. Ithaca, NY: Cornell University Press.
White, J. Chris,8 and Sholtes, Robert M. 2011. "Going beyond CPM." Paper presented at *PMI® Global Congress 2011 – North America, Dallas, TX*. Newtown Square, PA: Project Management Institute. Available at https://www.pmi.org/learning/library/going-beyond-critical-path-method-6297
Whyte, William H. 1956. *The Organization Man*. New York: Simon and Schuster.
William R. Kerr, Ramana Nanda, and Matthew Rhodes-Kropf. 2014. "Entrepreneurship as Experimentation." *The Journal of Economic Perspectives* 28, no. 3: 25–48. https://doi.org/10.1257/jep.28.3.25
Wilson, James Q. 1989. *Bureaucracy: What Government Agencies Do and Why They Do It*. New York: Basic Books.
WIPO. 2021. "Global Innovation Index (GII)." Available at https://www.globalinnovationindex.org/Home
Wirtz, Bernd W, Adriano Pistoia, Sebastian Ullrich, and Vincent Göttel. 2016. "Business Models: Origin, Development and Future Research Perspectives." *Long Range Planning* 49, no. 1: 36–54. https://doi.org/10.1016/j.lrp.2015.04.001
World Inequality Database. https://wid.world/
Wu, Chang-Tzuoh, Ming-Tang Wang, Nien-Te Liu, and Tien-Szu Pan. 2015. "Developing a Kano-Based Evaluation Model for Innovation Design." *Mathematical Problems in Engineering*: 1–8. https://doi.org/10.1155/2015/153694.
Yang, Heyoung, Su Youn Kim, and Seongmin Yim. 2019. "A Case Study of the Korean Government's Preparation for the Fourth Industrial Revolution: Public Program to Support Business Model Innovation." *Journal of Open Innovation* 5, no. 2: 35. https://doi.org/10.3390/joitmc5020035
Zacher, Hannes, and Kathrin Rosing. 2015. "Ambidextrous Leadership and Team Innovation." *Leadership & Organization Development Journal* 36, no. 1: 54–68. https://doi.org/10.1108/LODJ-11-2012-0141
Zeckhauser, Richard. 2006. "Investing in the Unknown and Unknowable." *Capitalism and Society* 1, no. 2: 5. https://doi.org/10.2202/1932-0213.1009
Zehavi, Amos, and Dan Breznitz. 2017. "Distribution Sensitive Innovation Policies: Conceptualization and Empirical Examples." *Research Policy* 46, no. 1: 327–336.
Zott, Christoph, Raphael Amit, and Lorenzo Massa. 2011. "The Business Model: Recent Developments and Future Research." *Journal of Management* 37, no. 4: 1019–1042.

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