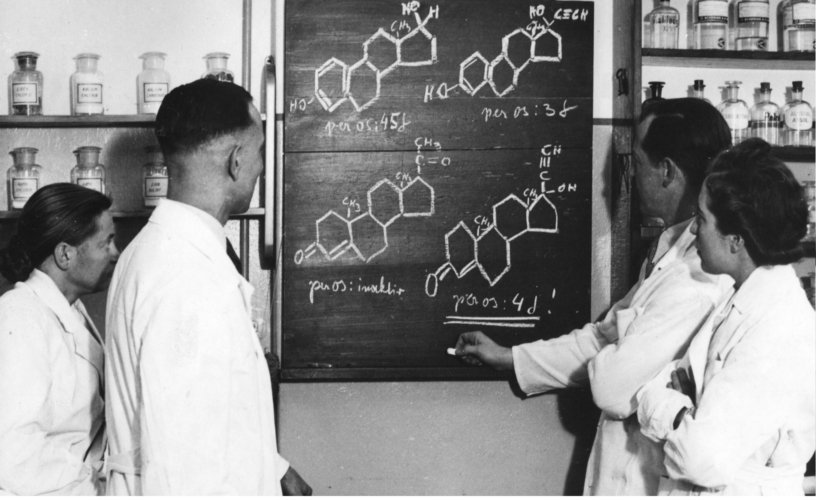
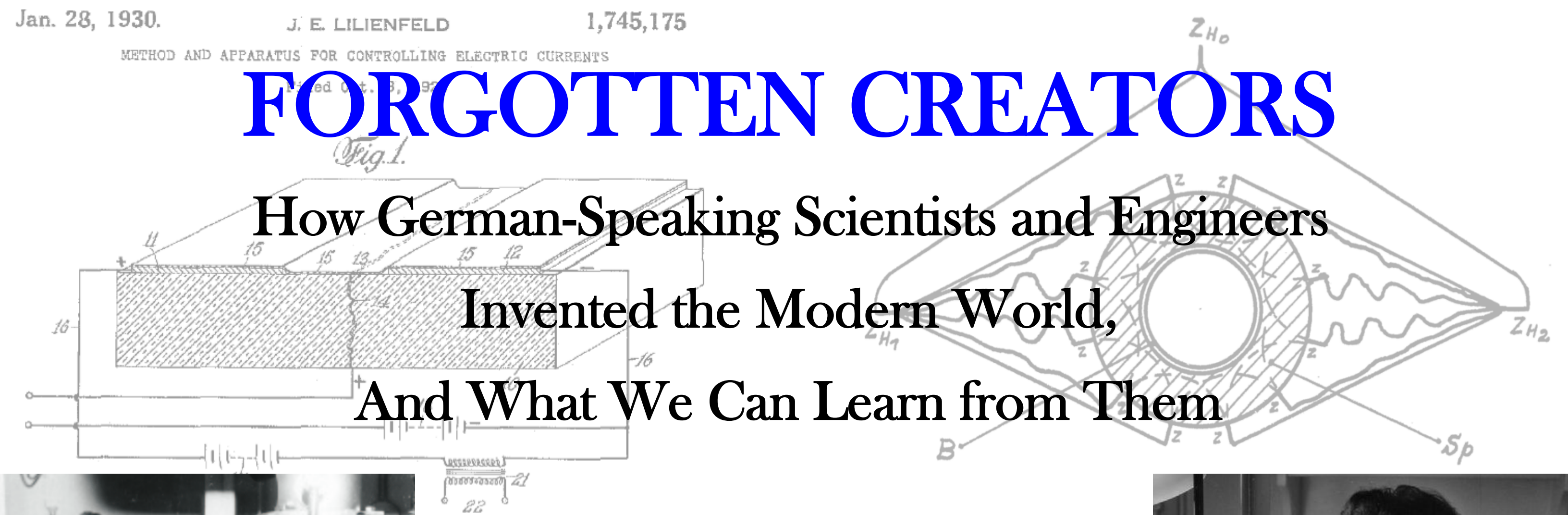
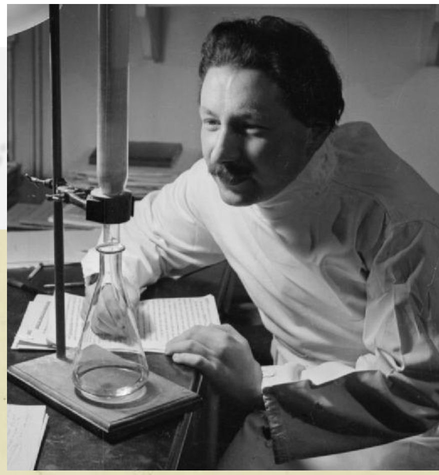


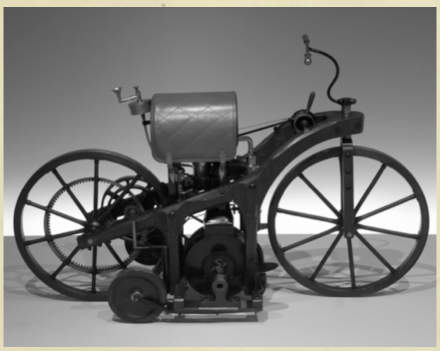


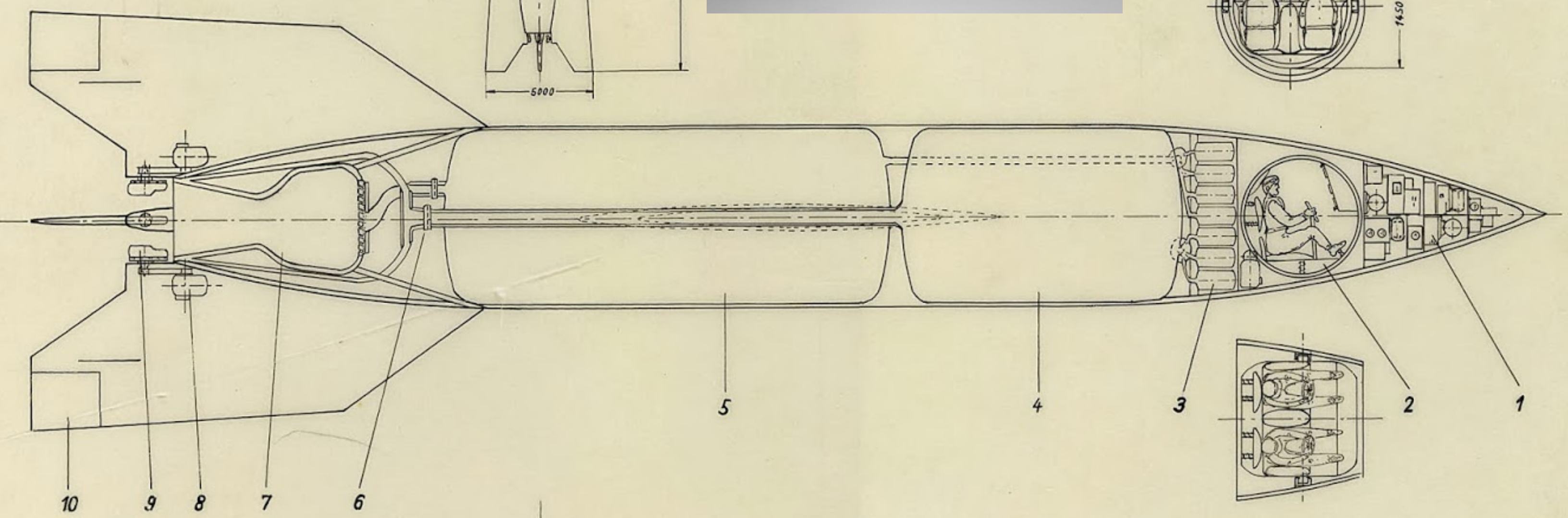
FORGOTTEN CREATORS

How German-Speaking Scientists and Engineers Invented the Modern World, And What We Can Learn from Them

Todd H. Rider







Lebe mit deinem Jahrhundert, aber sei nicht sein Geschöpf; leiste deinen Zeitgenossen, aber was sie bedürfen, nicht was sie loben.

Live with your century, but do not be its creature; create for your contemporaries, not what they praise, but rather what they need.

Friedrich Schiller, *On the Aesthetic Education of Man*, Letter 9 (1794)

FORGOTTEN CREATORS

How German-Speaking Scientists and Engineers Invented the Modern World, And What We Can Learn from Them

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First online edition: 1 February 2020
This edition: 2 June 2024

Comments from Reviewers

"Todd H. Rider's *Forgotten Creators* is a monumental treatise about and an exciting intellectual journey through the contributions of scientists and technologists in Germany and other Central European countries and German-speaking areas to universal progress. It is thoroughly researched, meticulously documented, and presented in an easy-to-perceive way. The pre-war and pre-Nazi German system of science support has lessons that would be difficult to emulate but worthy to ponder about even today. The long-range tragic consequences in science caused by National Socialism are well demonstrated as are the benefits in the West and in the East from the exodus of Jewish scientists before and the importation of others from Germany following World War II. The book is a virtually bottomless well for mining reliable information in the history of science and technology. The 'forgotten creators' are no longer forgotten. Todd is to be congratulated for his accomplishment and thanked for sharing it so generously with the international community."

István Hargittai, Professor Emeritus of Chemistry, Budapest University of Technology and Economics, author of *Buried Glory*, *Candid Science*, *Drive and Curiosity*, *Great Minds*, *Judging Edward Teller*, *Martians of Science*, and *The Road to Stockholm*

"It was really with a great feeling of appreciation that I discovered the various chapters (physics, mathematics, biology, medicine, etc.) of this monumental work (over 5,000 pages!) by Todd H. Rider, which is dedicated to the German contributions to the advancement of scientific knowledge in the modern world. Thousands of valuable pieces of information all collected in a unique source make this book a precious tool both for reading and for research."

Umberto Bartocci, Professor Emeritus of Mathematics and Mathematical History, University of Perugia

"Todd H. Rider's *Forgotten Creators* is an encyclopedic consideration of Germany's central place in the advancement of science and technology between 1800 and 1945. Drawing upon a wide range of sources, Rider has summarized that effort in a survey that will impress the reader just as much for the breadth of German intellectual achievement as for the influence that achievement has had upon the modern world."

George W. Cully, retired Director, Office of History at Air University, Maxwell Air Force Base, Alabama

"The scope and ambition of *Forgotten Creators* is really incredible. It is a work of great scholarship, an effective narrative with many historical quotes by scientists and their contemporaries that make it a very engaging read. It is richly illustrated with so many photos of researchers, where they worked, maps, patents, etc. I think this book will be of great value to historians of science and public policy institutions. I also think that as the center of economic and scientific innovation seems to be shifting from West to East, many forward-thinking people in Asia will be reading this book closely as they consider their own path ahead."

Brian Dempsey, President, Massachusetts Association of Biology Teachers

"The current fragmentation of scientific disciplines up to the point of marginalization raises the question whether examples from history do exist to overcome this situation. Todd Rider attempts an answer, posing the counter question: 'Which lessons can be learned from the most productive German-speaking inventors of the nineteenth and early twentieth century?' His intention is not only to start a discussion on the chances to successfully transfer former educational conditions to the present scientific system but also to remember the inventors. *Forgotten Creators*, published online, is an impressive compilation of German achievements, covering the natural sciences, mathematics, and engineering until WWII."

Gernot Eilers, German Federal Ministry for the Environment, Nature Conservation, and Nuclear Safety

"Todd H. Rider reminds us with *Forgotten Creators* that many key technologies like jet flight, helicopters, rocket propelled gliders, guided missiles, night vision, special alloys and welding methods, or simply synthetic rubber or polymer products that are common today were actually developed in the first half of the twentieth century in Central Europe under the control of Germany. These technologies belonged among the most valuable treasures the Allies won in the Second World War and triggered a strategic arms race among the newly emerging superpowers in the subsequent decades of the Cold War (which some say had started already in 1945 in St. Georgen/Gusen, Austria). An indispensable new reference book for all who are interested in the history of technology and the twentieth century."

Rudolf A. Haunschmied, Gusen Memorial Committee, author of *St. Georgen—Gusen—Mauthausen*

"Todd Rider's fundamental work, *Forgotten Creators*, is a formidable counter against the oblivion or even 'cancel science' regarding pre-Nazi and Nazi Germany. This era's technical and scientific achievements, although mostly along the sad Heraclid dictum '*bellum omnium pater*,' have their impacts even today. Apparently lots of documents of this period are still classified. I am convinced that the tenacious author will bring those to light and underpin his *magnum opus* further."

Manfred Höfert, former Head of Radioprotection at CERN, Geneva, Switzerland

"Todd Rider's *Forgotten Creators* is a really amazing overview of German technical history. Even contemporary historians will discover a lot of new references."

Rainer Karlsch, Institute for Contemporary History, Berlin, author of *Leuna: 100 Jahre Chemie*, *Sowjetische Demontagen in Deutschland 1944–1949*, *Playing the Game: The History of Adidas*, *Uranbergbau im Kalten Krieg*, *Uran für Moskau*, *Hitlers Bombe*, and *Für und Wider "Hitlers Bombe"*

"The book *Forgotten Creators* is a really impressive book, as Todd H. Rider tries to mention all relevant German-speaking scientists and engineers and their scientific fields up to 1945 in this mammoth project. In this form, nobody has dared to do this before. The author deserves my full respect for this. I am pleased that we were able to support him in his research."

Thomas Köhler, Peenemünde Historical-Technical Museum historian and head of the archive, author of *Vernichtender Fortschritt: Serienfertigung und Kriegseinsatz der Peenemünder "Vergeltungswaffen"*

"*Forgotten Creators* is an examination of mid-twentieth-century German science and technology, studying the question of how this era came to be so productive. Using extensive reproduction of original materials and source accounts, the author is not only able to provide an overview of what is known about wartime activities, but is also able to indicate avenues for future historical research. The careful and comprehensive referencing permits the materials presented to be used in academic studies. A notable feature of this work is the fluid format provided by online publication, allowing revisions and new materials to be added. An especially important emphasis of the book is what can be learned from both the German-speaking scientists and the World War II era in general that could improve scientific productivity and creativity now."

Thomas Kunkle, Los Alamos National Laboratory, retired

"*Forgotten Creators* shows us some aspects of the German culture in form and content: it reflects the spirit of the German soul in the best of the senses, focused on the recent history of science mainly in Germany and the U.S. The style reminds me of some of the biggest creations of German culture: ambitious, brave, sublime, erudite, extensive, rigorous in the analyses and exhorting in the discourses. Great! It grasps the sociological problems of science nowadays, and it offers lucid pessimistic views and wise observations of the facts. There are two different leitmotivs: 1) the modern decline of our scientific and technical advances; 2) the highest importance of German science in the most important contributions of the twentieth century scientific and technological advances. Hence, the author posits interesting hypotheses that relate the decline of science and the recent history of Germany and its influence in the world. Risk-taking interpretations that are worth reading and thinking about."

Martín López-Corredoira, Instituto de Astrofísica de Canarias,
author of *The Twilight of the Scientific Age*

"In the book *Forgotten Creators*, Todd H. Rider presents interesting perspectives that contribute to rethinking the story of the German nuclear project, as well as the role that heavy water had in it. The book also confirms the importance of the military actions carried out against heavy water production at Vemork."

Gunhild Lurås, Heavy Water Exhibition Curator,
Norwegian Industrial Workers Museum, Vemork

“Todd Rider has done a heroic job of bringing ‘secret Nazi research’ out of tinfoil-hat territory and into the realm of rigorous scholarship by compiling the vast primary-source material on a subject that has generally daunted mainstream historical research. And that shadowy field is only a sliver of the vast sweep of German science and technology covered in this monumental work. *Forgotten Creators* is a triumph of exactingly documented fact-finding and analysis, but it also rewards both the casual reader and the serious researcher with dynamic cross-referencing, side-by-side translations, and splendid illustrations. Rider has achieved a difficult balancing act—opening up new areas of inquiry while staying within the ever-accumulating evidence.”

Diane McWhorter, biographer of Wernher von Braun and 2002 Pulitzer Prize winner

“Encyclopedia. This was the very first word coming to my mind when reading Todd H. Rider’s book. In one publication the reader is given the opportunity to review official documents as well as getting familiar with stories told by people who were involved in the development of modern technology. The book serves as a compendium of knowledge for all who are passionate about any kind of research and inventions, not only about the ones which saw the light during the Second World War and the German national socialism era. There is no doubt that many of German speaking scientists presented in the book have strongly contributed to the colossal technological progress and the development of new disciplines of science. However, when you read the book, I would encourage you not to focus on these magnificent discoveries only. Names like Wernher von Braun, Hubertus Strughold, and Otto Ambros trigger a negative connotation to many as their activities during the period of Nazi Germany are still not completely transparent. Read, think about it, and draw your own conclusions.”

Marek Michalski, author of *Labor Camp Treblinka I*,
researcher for the Treblinka Museum and Gross-Rosen Museum

“With his work, based on very comprehensive, thoroughly researched sources, Todd Rider has presented an astonishing study of the history of German science, especially in the first half of the twentieth century, which also reveals many connections that have been unjustly forgotten or little noticed. This also applies to numerous persons whose achievements are hardly known.”

Günter Nagel, author of *Wissenschaft für den Krieg*, *Himmlers Waffenforscher*,
Atomversuche in Deutschland, and *Das geheime deutsche Uranprojekt 1939–1945*

“A very valuable part of the book is devoted to the development of nuclear weapons in Germany during WWII, 1939–1945. While the histories of both the US/British Manhattan Project and the Soviet atomic project have been to a large extent declassified, little is actually known about the German work. Rider has done historians a favor by marshalling all of the evidence he could find in US, German, and Russian archives regarding the German atomic project. The inescapable conclusion is that the Germans were much farther advanced in nuclear weapons development than is generally thought.”

Lee Pondrom, Professor Emeritus of Physics, University of Wisconsin-Madison,
author of *The Soviet Atomic Project: How the Soviet Union Obtained the Atomic Bomb*

“Todd Rider’s book *Forgotten Creators*, the creation of which I was able to observe and support for more than two years, is extraordinary in every respect. The sheer size of the book shows how important the role of German-speaking scientists was in the development of new technological advances. But it also shows the author’s will to present as complete an account of this history as possible. He has succeeded in doing so. The work therefore serves both as an introductory book and as a reference book. It is highly recommended.”

Georg Ribienski, Documentation Center Manager, Jonastalverein historical society, Thuringia

“Todd Rider has created an incredible document that details the technical contributions of Central Europeans in the nineteenth and twentieth centuries. The scope and scholarship are breathtaking. This document contains useful insights into how innovation and progress actually occur, as well as useful lessons that should be implemented by leaders in corporations, government agencies, and other organizations. It is past time to eliminate or minimize bureaucratic practices that obstruct innovation.”

William C. Schneck, Jr., Colonel (ret.), U.S. Army Corps of Engineers (USAR)

"*Forgotten Creators* by Todd Rider is an extraordinary work of detailed research and new insights into the technological advances contributed by German-speaking scientists. His lengthy and in-depth study of history often overlooked or not even seen in more cursory reviews is a refreshing read. His attempt to create the fullest account possible has resulted in a fine reference book that also serves to introduce new research for the reader. Rider's contention, right up front in the Executive Summary—that inventions and discoveries had their highest concentration of revolutionary innovations from scientists and engineers from the German-speaking central European research world in the nineteenth and early twentieth centuries—demands the reader's attention. He then fills an enormous amount of over 5,000 pages with supporting details. Amazing subject matter and new revolutionary insights dug up through meticulous research make *Forgotten Creators* a 'must read' for serious historians and curious researchers alike."

D. Ray Smith, Oak Ridge Historian, retired Y-12 Historian, author, and newspaper columnist

"Todd Rider's extensively researched and amazingly detailed book opens a new world for everybody interested in the history of science. Never before has anyone dug as deeply into the sources as Todd has, such that he even discovered interesting details about our father, then a young officer, and revealed some new aspects about him to us, his children. We are very grateful for Todd's interest, dedication, and thorough research."

Andrea (Stoelzel) Edwards and Bernhard Stoelzel,
children of former Peenemünde staff member Heinz Stoelzel

"This is a truly fascinating work! Dr. Rider has produced an insightful and comprehensive survey of a highly scientifically productive domain in spacetime. It is well worth understanding why that was, and what aspects of that culture should be preserved or revived."

David Strozzi, Lawrence Livermore National Laboratory

"This truly voluminous study provides an in-depth overview of techno-scientific achievements and innovations which originated from the German-speaking world. It is a rich and fascinating history of the transnational circulation of knowledge over a period of no less than two centuries."

Helmuth Trischler, Head of Research, Deutsches Museum, Munich, author of *Luft- und Raumfahrtforschung in Deutschland 1900–1970* and *Building Europe on Expertise: Innovators, Organizers, Networkers*

"A most important and deserving book. Todd Rider's research on the German rocket and nuclear programs in World War II is especially impressive because of the number and depth of the sources cited and the meticulousness of their evaluation. Really pioneering work has been done here!"

Matthias Uhl, Deutsches Historisches Institut, Moscow, author of
Stalins V-2: Der Technologietransfer der deutschen Fernlenkwaffentechnik and
Die Organisation des Terrors: Der Dienstkalender Heinrich Himmlers 1943–1945

"Todd Rider's compendium traces the phenomenal and explosive contribution of the Central European scientific culture of the first half of the twentieth century to the modern world. The multinational renaissance was ended by the Second World War, but the participants became scientific refugees in the victorious states, driving technology around the world during the Cold War. A unique and valuable resource!"

Mark Wade, author of *Encyclopedia Astronautica*, http://www.astronautix.com

"Todd Rider has produced a meticulously researched and cogently argued *tour de force* on the men and the circumstances that drove the modern German Renaissance in science and technology. Brought out of the long shadow of the Third Reich, the story of this Golden Age of human enquiry is convincingly shown to have as much relevance to our present times as it did then. A remarkable achievement."

Stephen Walton, Senior Curator, U.K. Imperial War Museum

Executive Summary

Wo ich schaffe, bin ich wahr.	Where I create, I am true.

Rainer Maria Rilke. 8 August 1903. Letter to Lou Andreas-Salomé.

Chapter 1: Why We Should Remember What Was Forgotten. As shown in this chapter, the world does not appear to be producing truly revolutionary scientific innovations at the same rate it once did (certainly if measured in terms of revolutionary innovations per researcher or per amount of funding). Instead the academic research sector seems increasingly fixated on maximizing its rate of publishing papers regardless of their quality, redundancy, or relevance; the corporate research sector appears more and more focused on very low-risk, immediately marketable products; and the government research sector seems increasingly incapacitated by bureaucracy and budget cuts. Rather than trying to create solutions for these modern systemic problems from scratch, one may study what conditions facilitated the successes of innovators in other times and places.

Many people like to believe that their own country has been the most innovative, and indeed, inventions and discoveries have been made around the world and throughout history. Yet as illustrated by the examples in this book, the highest concentration (or at the very least, one of the highest concentrations) of revolutionary innovations appears to have come from scientists and engineers who were trained in the predominantly German-speaking central European research world in the nineteenth and early twentieth centuries. Unfortunately, the history of those innovations has been significantly obscured by World Wars I and II, the Cold War, language barriers, and cultural stereotypes, leaving the modern world less aware of the details and less able to fully reproduce the research conditions that led to so many revolutionary achievements. Therefore the objectives of this book are to:

- Elucidate the major creators and creations produced by that German-speaking world in various fields of science and engineering (Chapters 2–9 and Appendices A–E).
- Determine the systemic factors that promoted so much revolutionary innovation in that particular place and time (Chapter 10).
- Evaluate the previous successes and failures of transferring that scientific knowledge and those systemic methods to other research systems (Chapter 11).
- Propose methods by which modern governments, organizations, and/or individuals could better emulate the success of the earlier German-speaking research world (Chapter 12).

A variety of study scopes and methods would be possible and enlightening, but this book focuses on revolutionary innovators who were educated in that earlier German-speaking world[1] between approximately 1800 and 1945, as well as their subsequent careers (in some cases to the dawn of the twenty-first century). As explained in detail in this chapter, this study does not argue that the modern research system has produced no revolutionary innovations, but rather that it can and should be improved. This study is not intended to support nationalist or ethnic bragging rights, the Third Reich, or any notion that research conditions in the German-speaking world were ever perfect. At best this book can only give a concise overview of a vast field encompassing the actions of thousands of scientists and engineers across many countries over a period of two centuries, as well as investigations into that time period by countless subsequent scholars.

[1] Defined herein as German, Austrian, and Swiss researchers; eastern European and other researchers who trained in the German-speaking world; and scientists and engineers in the closely coupled Dutch research system.

The German-speaking world produced remarkable numbers of revolutionary innovators and innovations in a wide range of fields, as enumerated in eight chapters:

Chapter 2: Creators and Creations in Biology and Medicine
Advances from genetics to antibiotics

Chapter 3: Creators and Creations in Chemistry and Materials Science
Breakthroughs from color film to synthetic rubber

Chapter 4: Creators and Creations in Earth and Space Science
Discoveries about the universe from continental drift to stellar distances

Chapter 5: Creators and Creations in Physics and Mathematics
Revolutionary ideas from relativity to quantum mechanics

Chapter 6: Creators and Creations in Electrical and Electromagnetic Engineering
Inventions from semiconductors to computers

Chapter 7: Creators and Creations in Mechanical Engineering
Systems from automobiles to submarines

Chapter 8: Creators and Creations in Nuclear Science and Engineering
Reactions and applications from fission to fusion

Chapter 9: Creators and Creations in Aerospace Engineering
Vehicles from jet planes to moon rockets

Chapter 10: Creating the Creators. Based on evidence presented in this chapter, a number of specific factors within the German-speaking world promoted revolutionary innovation:

1. Science was socially glorified, from children's activities and amateur science clubs to prestigious jobs and government-lauded scientific heroes.

2. A century-long steady exponential increase in funding gave scientists, employers, and sponsors much more freedom to pursue higher-risk and/or longer-term research.

3. Many Ph.D. students were encouraged to propose their own research topics and to pursue them independently.

4. Scientists received their final degrees nearly a decade earlier in life, and independent research funding up to two decades earlier, than modern scientists do.

5. Scientists who made major contributions to multiple disciplines, and fraternization among scientists from different disciplines, were much more common than in the modern world.

6. Instead of peer review, an autocratic yet farsighted scientific management culture of "enlightened despots" granted stable jobs and funding to the most promising creators and creations.

7. Both scientists and sponsors used a systems analysis approach to focus on the most important problems and the most effective innovations to address those problems.

8. The lack of natural resources spurred the creation of a wide range of innovative alternatives.

9. International rivalry (both economic and military) was a powerful driving force for innovation.

10. German-speaking companies were less afraid of losing their own innovations to each other than of being outstripped by foreign countries, giving them a strong motivation to innovate.

Chapter 11: Immortalizing the Creations and Forgetting the Creators. As documented in this chapter, the modern world eagerly adopted the creations of the earlier German-speaking world, yet ultimately largely forgot both the creators and the systemic approaches that had made such creations possible. Over the course of waves that occurred before, during, and after the Third Reich, all of the creations, most of the creators, and some of the systemic approaches were transferred from the German-speaking world to the United States and other countries in a German scientific diaspora. Those countries spent many decades fully perfecting and mass-producing the innovations that had been created by the earlier German-speaking world, resulting in our modern world of jet aircraft, electronics, and pharmaceuticals. Most of the creators who had already died or who remained in German-speaking areas were largely forgotten by the non-German-speaking world, which often mistakenly attributed their creations to whichever non-German-speaking individuals or organizations had acquired their technical information. Most of the creators who emigrated out of German-speaking areas led well-funded but quiet lives perfecting their creations and were also ultimately forgotten. Especially during the 1940s–1960s, the United States and other countries practiced some of the general approaches that had made the earlier German-speaking world successful, thereby cultivating new innovators and innovations of their own.

By the 1970s, most of the German-speaking creators had retired or died, their creations had been refined to the point of diminishing incremental returns, and global research systems had abandoned most of the German-like practices they had adopted, significantly reducing their efficiency at producing entirely new innovators and innovations. The Cold War as a strong motivating force for innovation had also relaxed around 1970, and any truly revolutionary new innovators (or innovations) that were produced by the global research system found it increasingly difficult to obtain proper support as time went by. From the 1990s onward, with the Cold War over and officials both public and private haggling over every research dollar while spending heavily or even wastefully in other areas, the academic, corporate, and government research sectors each became increasingly dysfunctional in their own ways.

Chapter 12: Learning from the Creators. Based on the successes of the earlier German-speaking world, this final chapter offers lessons that could be applied at any scale from the national level down to an individual's career. At a nationwide or statewide level, the following policies could improve the ability of the modern scientific system to produce revolutionary innovators and innovations:

1. The social and financial status of science research should be elevated greatly. Better quality and greater variety of educational science experiment kits for children should be produced and more widely advertised and used. Student science competitions (especially ones like science fairs that emulate real scientific research) should be given much greater emphasis, and the winners of those competitions should be very publicly praised and rewarded. The salaries and working conditions of science and other teachers should be improved in order to attract very talented people to those positions and to recognize and reward the most effective teachers. Important scientific discoveries and inventions, as well as the people responsible for them, should be given much more coverage in television news programs, movies, newspapers, magazines, and popular internet sites.

2. If the amount of funding and permanent job positions better matched the number of graduating students and career researchers (by increasing funding wherever possible, or otherwise by limiting the number of students going into research), scientists would be able to spend much more of their time and energy doing productive research, and much less of their time and energy pursuing elusive funding and positions. It would also be much more acceptable to sponsors, institutions, and the scientists themselves for researchers to pursue longer-term work without an immediately demonstrable payoff, as well as more innovative higher-risk work that would be less guaranteed to yield results than very incremental, low-risk work.

3. Science students should be trained from an early age to be very creative and very self-reliant researchers. Students should be strongly encouraged to select their own research topics and methods. Research advisors should provide as much advice and assistance as is necessary (but only what is necessary) to ensure that their students are pursuing productive research topics using suitable methods. Research advisors should not use students as unpaid or low-wage labor to benefit the advisors' own research grants or lists of publications.

4. The average age at which scientists receive their final degree and obtain independent research funding should be reduced back toward their early to mid-twenties. That would greatly increase the number of productive working years during which those scientists have the greatest creativity, the most energy, and the fewest non-research obligations.

5. The system should train and reward at least some percentage of multidisciplinary scientists who can make major contributions in multiple fields, apply knowledge and methods from one field to another, and use their broader view to guide fields away from less productive areas and toward more productive ones. All scientists should be strongly encouraged to make their research comprehensible to people outside their field, and to interact with scientists in other fields in a variety of environments, in order to cross-pollinate ideas among different fields.

6. While there is certainly a place for methodical peer review, entrusting virtually all funding and hiring decisions to peer review risks overlooking those creative new scientists and ideas that are so revolutionary that they cannot easily and immediately get broad consensus from the scientific status quo. The modern research system should set aside some percentage of research funding to be allocated by "enlightened despots" who are good at identifying potentially revolutionary innovators and innovations. Such enlightened despots should have the clear authority to grant financial and political support to any people or projects they deem worthy, and to grant that support for many years without having to demonstrate that there is an immediate payoff, or even that all funded research will eventually pay off. Wherever possible, any remaining peer review should be done by reviewers unaware of the researchers' names and affiliations, so that they can more fairly evaluate the actual research in question.

7. By using systems analysis, key decision makers in government, industry, and academia could help focus more resources on the most important problems and potential solutions. If individual scientists were taught to practice systems analysis, they could use that method to guide their careers and their research projects in more promising directions, and to ensure that no potentially useful regions of the conceptual "phase space" had been overlooked.

8. In the face of dwindling natural resources and the rising long-term costs of climate change, pollution, and waste, government-funded programs and government regulations for industrial programs should prioritize the development of very innovative methods of reducing the consumption of natural resources and minimizing the creation of waste products.

9. Peaceful economic rivalry and regional pride could constructively motivate nations or states to accelerate their research programs. Regional high-tech centers could promote interactions among programs they contain, and rival high-tech centers could compete for the best scientists, projects, research funding, and economic income from resulting inventions and products.

10. Companies should view very innovative, longer-term research and development (R&D) as a worthwhile investment in staying ahead of competitors, not a financial liability whose resulting products could be copied by competitors that did not fund their own R&D. Improved tax, patent, regulatory, or other government incentives could make it much more lucrative for the first company that develops any given major innovation, and/or less lucrative for copycats.

In addition to the above lessons for national or state research systems, Chapter 12 also offers additional lessons for individual companies, organizations, and laboratories; for individual scientists and engineers; and for scholars who study past, present, and potential future innovation systems.

The appendices focus on some potentially quite advanced creations of the German-speaking world during World War II that are currently much less well understood by modern historians, and whose complexities necessitate a considerably longer treatment than could be given in Chapters 2–9:

> **Appendix A** presents archival documents that suggest that Germany had the largest and most advanced biotechnology programs in the world at that time, was developing neural interfaces to control prosthetic limbs and weapons systems, possessed a significant offensive program in biological warfare, and discovered advanced V-series nerve agents during the war.
>
> **Appendix B** gives an overview of evidence that transistors and other microelectronics innovations may have originated in the German-speaking world, and that information on those technologies may have been transferred to and exploited by Allied countries after the war.
>
> **Appendix C** presents documents that appear to show that the German-speaking world developed and tested a variety of directed-energy technologies, including particle beams, electromagnetic pulse weapons, major steps toward lasers, focused sound waves for applications ranging from ultrasound imaging to acoustic weapons, and electromagnetic railguns.
>
> **Appendix D** provides considerable evidence that Germany may have developed and even successfully tested fission bombs during the war (which would have made it the first country in world history to possess nuclear weapons), and that it may have even had a megaton-level hydrogen bomb in an advanced stage of development when the war ended.
>
> **Appendix E** presents archival documents that appear to show that wartime Germany made considerable progress toward developing the aerospace technologies that have formed the "nuclear triad" for most of the postwar decades: intercontinental jet bombers, intercontinental ballistic missiles, and submarine-launched missiles.

Although the evidence in the appendices does not constitute conclusive proof, it should prompt further archival research to clarify the true extent of those wartime programs.

The **Bibliography** of over 400 pages covers relevant books, articles, government reports, and archival documents.

To maximize the audience, longevity, and impact of this book, it is available for free on the internet. Hopefully it will spur discussion, learning, and further work in the important areas that it covers. Suggestions for improvements are very welcome.

For creators

everywhere,

past, present,

and future.

Contents

Acknowledgments

Es ist ein merkwürdiges Gefühl, schlechthin in allem auf die Hilfe der anderen angewiesen zu sein. Aber jedenfalls lernt man in solchen Zeiten dankbar werden und wird das hoffentlich nicht wieder vergessen. Im normalen Leben wird einem oft gar nicht bewußt, daß der Mensch überhaupt unendlich mehr viel mehr empfängt, als er gibt, und daß Dankbarkeit das Leben erst reich macht. Man überschätzt wohl leicht das eigene Wirken und Tun in seiner Wichtigkeit gegenüber dem, was man nur durch andere geworden ist.

It is a strange feeling to be so completely dependent on the help of other people. However, at least it teaches one to be grateful, and I hope I shall never forget that. In ordinary life we hardly realize that we receive a great deal more than we give, and that it is only with gratitude that life becomes rich. It is very easy to overestimate the importance of our own achievements in comparison with what we owe to others.

Dietrich Bonhoeffer. 13 September 1943 letter to his parents.
Eberhard Bethge, ed. 2016. *Widerstand und Ergebung: Briefe und Aufzeichnungen aus der Haft* [*Resistance and Resignation: Letters and Papers from Prison*]. Gütersloh: Gütersloher Verlag.

As a child, I read about scientists and engineers (including some of those in this book) who tackled the most important problems that were within their power, and as a result produced revolutionary discoveries and inventions that changed the world. Inspired by those examples, I have spent most of my life endeavoring to pursue innovative scientific research projects of my own (p. 5846). Over the years, unfortunately, I have personally witnessed how the modern U.S. research system is dysfunctional in many different ways, and how that dysfunction can discourage the initiation of potentially revolutionary research projects and also prematurely terminate innovative projects that have been initiated.

Eventually it dawned on me that perhaps the most important research problem is the research system itself—even modest improvements in the research system could have large effects on countless individual innovators, and amplified through them, an enormous impact on the whole world. Rather than relying on the very limited data set of my own personal experiences or even those of my colleagues, I decided to examine a far larger data set, the history of science, in hopes of better understanding the problems with and potential solutions for the modern research system.

This book is the result of that effort. It is very much a work in progress, imperfect and incomplete, yet I offer it in hopes that it will inspire ideas, discussion, and further work in the areas that it covers. **If readers have any suggestions for corrections, improvements, or additions, please send me an email (ToddHRider@gmail.com or thor@riderinstitute.org), and I will try to incorporate those suggestions into a future improved edition.**

Just as the modern world is entirely dependent upon the creations of numerous earlier inventors and scientists, this book would not have been possible without all of the earlier research and publications of large numbers of scholars and investigators (such as those listed in the Bibliography), as well as the documents, information, suggestions, and assistance that many of those people have provided directly to me. I would especially like to thank:

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Chapter 1

Why We Should Remember What Was Forgotten

Heiße Magister, heiße Doktor gar	I'm called a Master, even Doctor too
Und ziehe schon an die zehen Jahr	And now I've nearly ten years through
Herauf, herab und quer und krumm	Pulled my students by their noses to and fro
Meine Schüler an der Nase herum—	And up and down, across, about
Und sehe, daß wir nichts wissen können!	And see there's nothing we can know!
Das will mir schier das Herz verbrennen.	That all but burns my heart right out.
Zwar bin ich gescheiter als all die Laffen,	True, I am more clever than all the vain creatures,
Doktoren, Magister, Schreiber und Pfaffen;	The doctors and masters, writers and preachers;
Mich plagen keine Skrupel noch Zweifel,	No doubts plague me, nor scruples as well.
Fürchte mich weder vor Hölle noch Teufel—	I'm not afraid of devil or hell.
Dafür ist mir auch alle Freud entrissen,	To offset that, all joy is rent from me.
Bilde mir nicht ein, was Rechts zu wissen,	I do not imagine I know aught that's right;
Bilde mir nicht ein, ich könnte was lehren,	I do not imagine I could teach what might
Die Menschen zu bessern und zu bekehren.	Convert and improve humanity.

Johann von Goethe. 1808. *Faust Part One.* Nacht, Faust.
English verse translation adapted from George Madison Priest.

Science and engineering have changed the world in countless ways. While some scientific discoveries and engineering inventions may be harmful or dangerous if misused, on the whole they appear to have improved our lives. Very few people who are alive now would voluntarily choose to give up indoor plumbing, electric lights, rapid transportation, and modern medicine. Based on such historical precedents, we have good reason to hope that science and engineering could make our lives even better in the future. Thus it is in the best interests of everyone, even those who are not scientists and engineers, for the scientific research and development system to function as well as possible.

The ultimate goal of this book is to help improve our understanding of the past, the present, and the potential future of scientific research and development, and through that improved understanding, to enhance the effectiveness of the research and development system in bringing new discoveries and inventions to our lives and those of our children and grandchildren.

1.1. This chapter begins by evaluating the state of scientific innovation in the modern world:

1.1.1. Problems with the modern innovation system from everyday experience.

1.1.2. Problems with the modern innovation system from published analyses.

1.1.3. Problems with modern academic research.

1.1.4. Problems with modern corporate research.

1.1.5. Problems with modern government research.

1.2. Then this chapter turns to consider scientific innovation in the earlier German-speaking world:

1.2.1. Studying the earlier German-speaking world can help to improve the modern innovation system.

1.2.2. The scope and framework of this book are explained.

1.2.3. A number of disclaimers are presented for clarity and precision.

1.1 Scientific Innovation in the Modern World

Upon superficial inspection, the modern scientific research and development system seems to be operating very successfully [AAAS2 2018; NSF 2018; Nelson 1993; OECD 2018]:

- Each year, over 750,000 bachelor's degrees in science and engineering fields are awarded in the United States, and over 4 million worldwide, as shown in Fig. 1.1(a).
- Likewise, each year over 40,000 science and engineering doctoral degrees are awarded in the United States, and over 200,000 worldwide, as illustrated in Fig. 1.1(b).
- Some of those degree recipients go into other work, but many join the pool of people who are currently doing scientific research, which is over 1.3 million researchers in the United States and growing, and over 7 million researchers worldwide and growing, as graphed in Fig. 1.2(a).
- Each year, those researchers receive an estimated total (both public and private funding) of $500 billion in the United States and over $1.7 trillion worldwide for research and development (R&D), as shown in Fig. 1.2(b).
- With that funding, each year they produce over 2 million new journal articles worldwide, as illustrated in Fig. 1.3(a).
- Also with that funding, each year they produce over 3.3 million new patent applications worldwide, as graphed in Fig. 1.3(b).
- Along the way, modern researchers have produced recent popular products such as smartphones, a wide variety of internet sites for social networking and sales, computer-generated visual effects, new computer games, 3D printers, and pharmaceuticals ranging from Viagra to opioids.

Yet upon closer examination, the modern research system appears to have serious problems, as suggested by several different lines of evidence that are considered in the following sections.

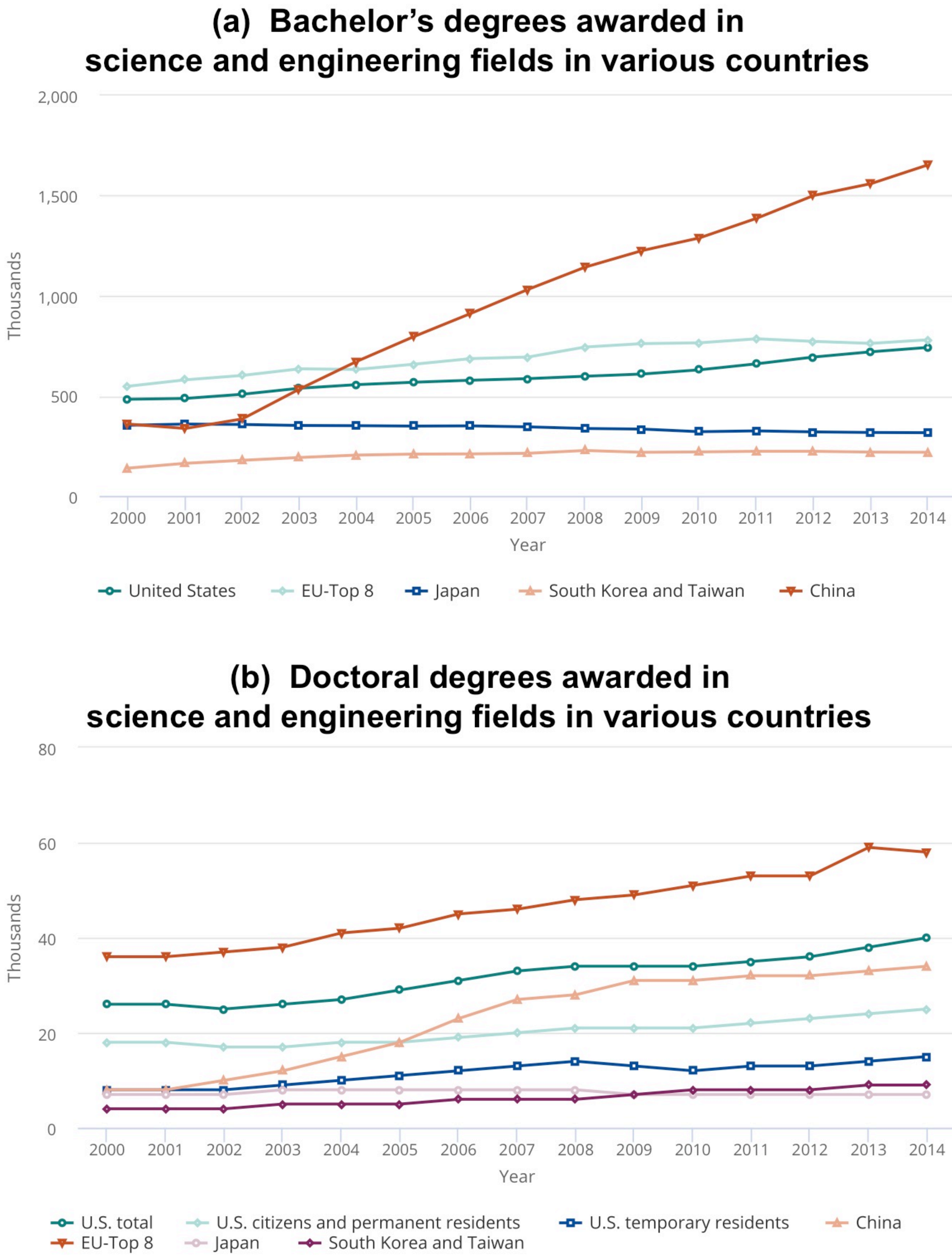

Figure 1.1: Number of (a) bachelor's degrees and (b) doctoral degrees awarded in science and engineering fields in various countries each year; note that many countries (such as India) are not included in the graphs [https://www.nsf.gov/statistics/2018/nsb20181/figures].

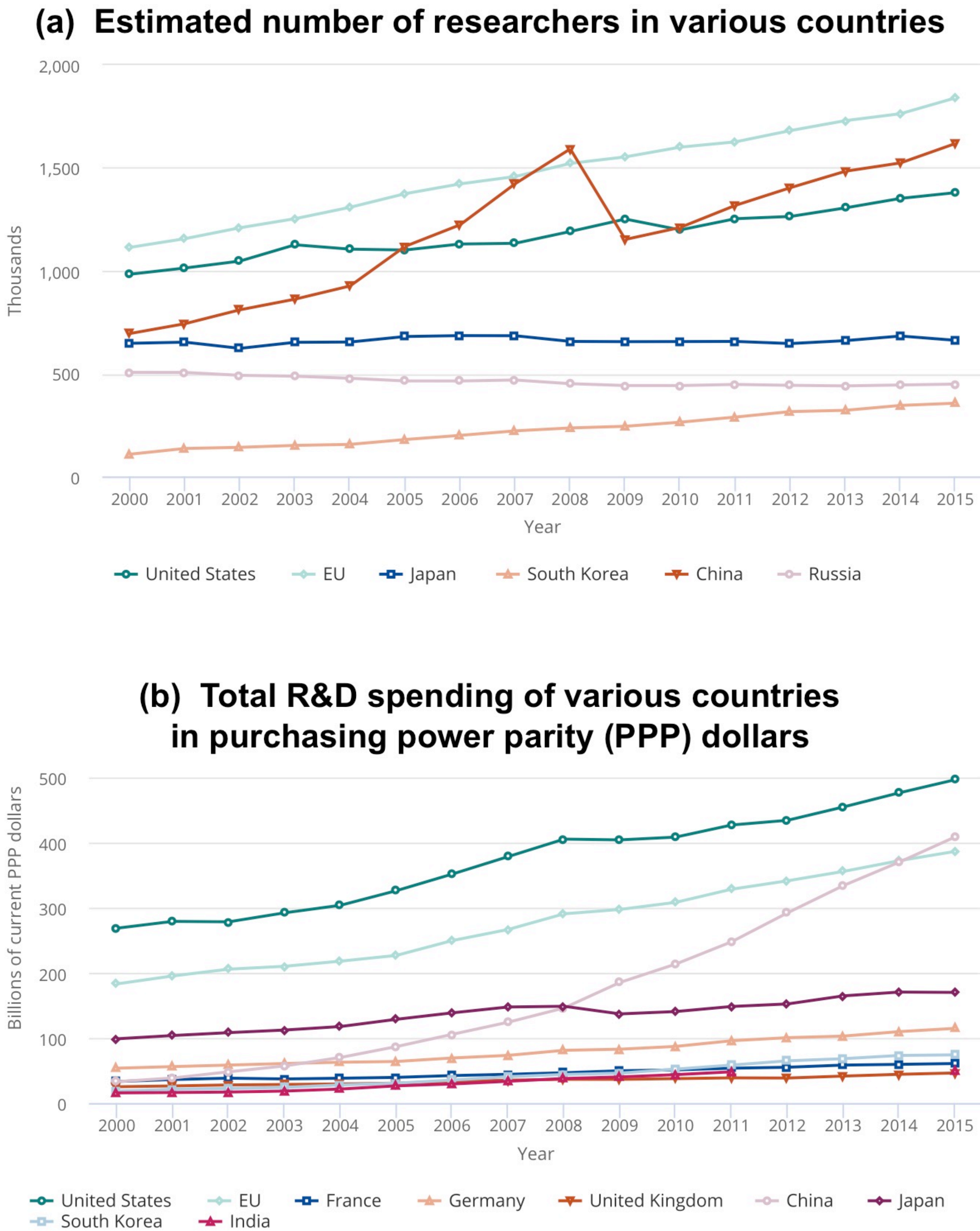

Figure 1.2: Research system sizes as measured by (a) estimated number of researchers in various countries, and (b) total R&D spending of various countries in purchasing power parity (PPP) dollars [https://www.nsf.gov/statistics/2018/nsb20181/figures]. (In the upper graph, the apparent 2008–2009 drop in researchers in China is just an artifact of a change in how Chinese researchers were counted before vs. after that time; by either method of counting, the number of Chinese researchers steadily increased throughout the time period of the graph.)

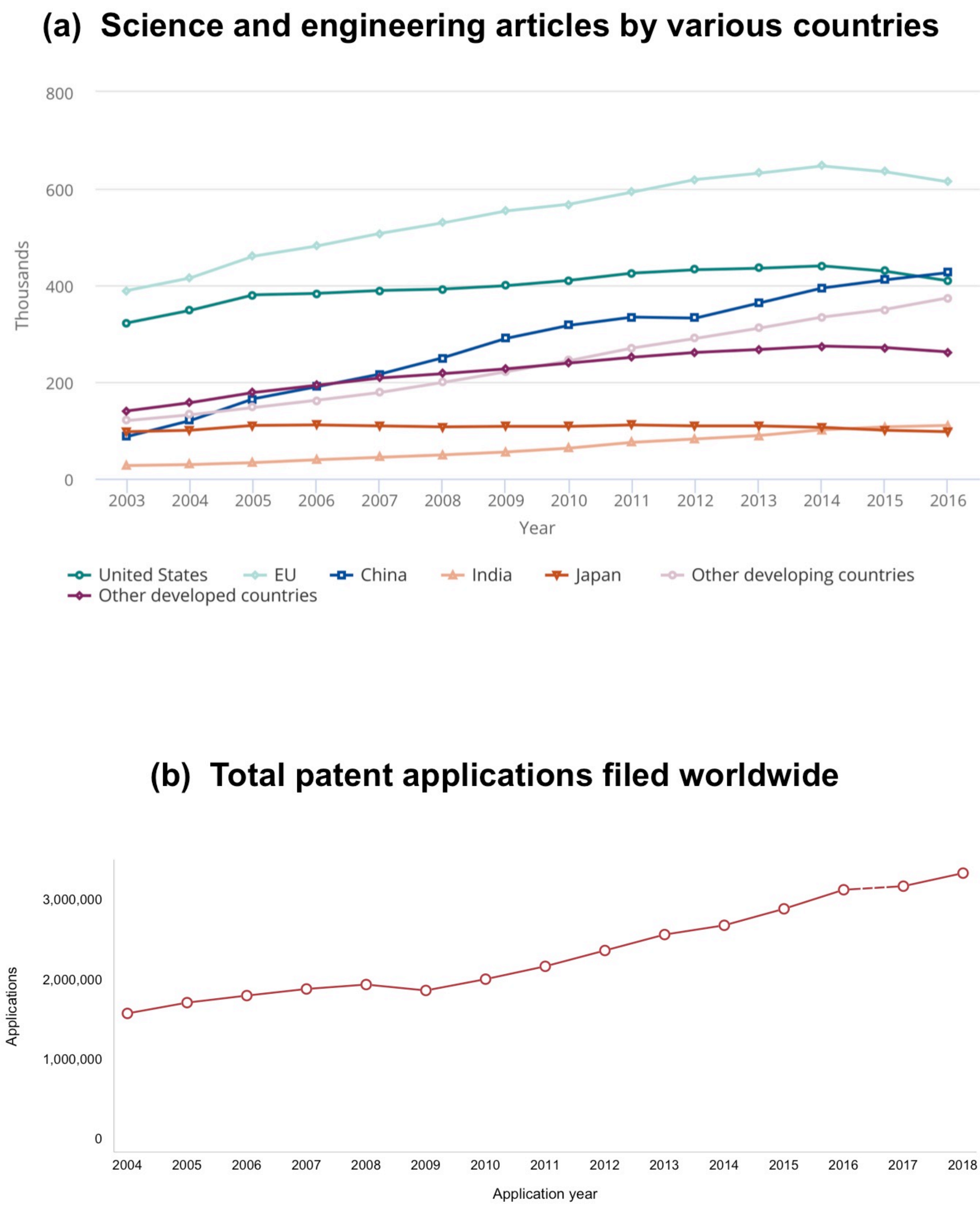

Figure 1.3: Annual production of (a) science and engineering articles by various countries, and (b) total patent applications filed worldwide [https://www.nsf.gov/statistics/2018/nsb20181/figures; https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2019.pdf].

1.1.1 Problems from Everyday Experience

At least in the developed world, most of the technologies encountered in people's daily lives have not changed much over the last half century. We still travel around in very similar automobiles and jet planes, spend too much time in front of color video screens (even if they are nicer now and come in more sizes), and struggle to cure cancer. Only a few visible technologies have changed significantly over the last 50 years: virtually everyone has a phone in their pocket instead of on their desk, and anyone can use a computer instead of just workers in large offices. In contrast, there were large numbers of completely transformative technological changes over any 50-year span during the nineteenth century and for most of the twentieth century: electric lighting and appliances, indoor plumbing and air-conditioning, trains and automobiles, vaccines and antibiotics, jets and helicopters, transistors and lasers, nuclear power and weapons, submarines on the ocean floor and astronauts on the moon. By the standards of everyday experience, in absolute terms the rate of modern scientific innovation seems much lower now than it had been decades ago, despite the record-breaking amounts of funding, people, and papers involved in the modern system. Certainly the rate of revolutionary innovation per dollar or per person working in the system appears to be far lower now than in the past.

The longtime science journalist Michael Hanlon summed up this apparent decline [Hanlon 2014]:

> Yet there once was an age when speculation matched reality. It spluttered to a halt more than 40 years ago. Most of what has happened since has been merely incremental improvements upon what came before. That true age of innovation—I'll call it the Golden Quarter—ran from approximately 1945 to 1971. Just about everything that defines the modern world either came about, or had its seeds sown, during this time. The Pill. Electronics. Computers and the birth of the internet. Nuclear power. Television. Antibiotics. Space travel... The Green Revolution in agriculture... Mass aviation... Cheap, reliable and safe automobiles. High-speed trains. We put a man on the Moon, sent a probe to Mars, beat smallpox and discovered the double-spiral key of life. The Golden Quarter was a unique period of less than a single human generation, a time when innovation appeared to be running on a mix of dragster fuel and dilithium crystals.
>
> Today, progress is defined almost entirely by consumer-driven, often banal improvements in information technology. The US economist Tyler Cowen, in his essay *The Great Stagnation* (2011), argues that, in the US at least, a technological plateau has been reached. Sure, our phones are great, but that's not the same as being able to fly across the Atlantic in eight hours or eliminating smallpox. As the US technologist Peter Thiel once put it: "We wanted flying cars, we got 140 characters."
>
> But it could have been so much better. If the pace of change had continued, we could be living in a world where Alzheimer's was treatable, where clean nuclear power had ended the threat of climate change, where the brilliance of genetics was used to bring the benefits of cheap and healthy food to the bottom billion, and where cancer really was on the back foot. Forget colonies on the Moon; if the Golden Quarter had become the Golden Century, the battery in your magic smartphone might even last more than a day.

As illustrated by additional data in the next section, Hanlon's diagnosis of an innovation decline appears to be correct. However, like most people in the modern world, he incorrectly perceived most modern innovations as having come from the United States during the first few decades after World War II. As this book shows, the specific innovations that he cited, and the highly creative scientists and engineers who produced them, can actually be traced to a different time and place.

1.1.2 Problems from Published Analyses

Using more quantitative and detailed methods of analysis, various researchers have studied the rate of production of major scientific and technological innovations and published their conclusions that the rate has indeed been declining over the last several decades. A few examples are shown in Figs. 1.4–1.5.

Stanford researchers Nicholas Bloom, Charles I. Jones, John Van Reenen, and Michael Webb conducted a detailed study [Bloom et al. 2020]. They found that between 1930 and 2000, the number of researchers in the United States increased by a factor of 23, whereas the U.S. economic growth rate due to research innovation fell by a factor of approximately 1.78, so the productive innovation rate per researcher fell by a factor of 41. (See Fig. 1.4 top.) In other words, according to this study, the average researcher in 1930 produced 41 times more innovation than the average researcher in 2000. The same study found similar declines in innovation productivity as measured in specific fields such as medicine, electronics, and agriculture:

> [W]e proceed to measure research productivity in many different contexts. Our robust finding is that research productivity is falling sharply everywhere we look. Taking the US aggregate number as representative, research productivity falls in half every 13 years: ideas are getting harder and harder to find. Put differently, just to sustain constant growth in GDP per person, the United States must double the amount of research effort every 13 years to offset the increased difficulty of finding new ideas. [...] A first-order fact of growth empirics is that research productivity is falling sharply. [...]
>
> Akcigit and Kerr (2018) suggests that "follow on" innovations may be smaller than original innovations and provide evidence that research productivity declines with firm size. Incumbent firms may shift to "defensive" R&D to protect their market position, and this could cause research productivity to decline; Dinopoulos and Syropoulos (2007) provides a model along these lines. Or perhaps declines in basic research spending, potentially related to the US decline in publicly-funded research as a share of GDP, have negatively impacted overall research productivity. Clearly this would have important policy implications.

U.S. Navy physicist Jonathan Huebner published an earlier analysis of the number of revolutionary innovations per person per year. (See Fig. 1.4 middle.) Although his data sources and methods of analysis were significantly different than those of Bloom et al., Huebner also found a steep decline in the number of innovations per person per year over the last several decades [Huebner 2005]:

> There is a general consensus that technology is advancing exponentially, and that this advance will continue into the distant future. The basic assumption behind this view is that either there is no limit to technological advance, or if there is a limit, then we are far from reaching it. The history of technological innovation from the end of the Dark Ages to the present time is examined, and evidence is provided that we are closer to a technological limit than many people realize.

> There are two different technological limits. The first limit is a physical one, due to the laws of physics, such as the impossibility of building a perpetual motion machine. The second limit is economic; it is physically possible to dig a canal from the Pacific Ocean to the Atlantic Ocean across the continental United States, but it is not economically feasible. This paper addresses the economic limit, as we will reach this limit before the physical limit. [...]
>
> In conclusion, the evidence presented indicates that the rate of innovation reached a peak over a hundred years ago and is now in decline. This decline is most likely due to an economic limit of technology or a limit of the human brain that we are approaching. We are now approximately 85% of the way to this limit, and the pace of technological development will diminish with each passing year.

Molecular geneticist Jan Vijg analyzed the historical innovation rate too [Vijg 2011]. (See Fig. 1.4 bottom.) Whereas Bloom et al. and Huebner presented their results as declines in the number of innovations per person per year, Vijg simply plotted the total number of innovations per year (not also per person). According to Vijg, that total innovation rate has fallen markedly for several decades, even though the population has greatly increased during that time. Thus Vijg's statement about innovation decline is even stronger than those by Bloom et al. and Huebner. Vijg explained [Vijg 2011, p. 31]:

> Of the more than 300 macro-inventions listed in the table, fewer than 50 were made before 500 BC, with over 100 only from the last 100 years. What this tells us is that inventions accumulated faster in more recent times, which confirms the expectations of most futurologists and is undoubtedly something most of us would intuitively expect. Sometimes intuition is right and when plotting the number of new inventions since 500 BC, we do indeed see an exponential increase[....] The same is true when plotting not the accumulated number of inventions, but the number of new inventions per year, i.e. a measure for inventiveness [Fig. 1.4 bottom]. However, from this graph we can also see the beginning of a decline around 1970 with no sign of a restoration yet[....]

In the most extensive study yet, management professors Michael Park, Erin Leahey, and Russell Funk statistically analyzed millions of journal articles and patents. (See Fig. 1.5.) They demonstrated a pronounced decline over recent decades in the average amount of innovation (the CD_5 or Coefficient of Disruption 5 years after publication) per paper or per patent [Park et al. 2023]:

> Recent decades have witnessed exponential growth in the volume of new scientific and technological knowledge, thereby creating conditions that should be ripe for major advances. Yet contrary to this view, studies suggest that progress is slowing in several major fields. Here, we analyse these claims at scale across six decades, using data on 45 million papers and 3.9 million patents from six large-scale datasets, together with a new quantitative metric—the CD index—that characterizes how papers and patents change networks of citations in science and technology. We find that papers and patents are increasingly less likely to break with the past in ways that push science and technology in new directions. This pattern holds universally across fields and is robust across multiple different citation- and text-based metrics.

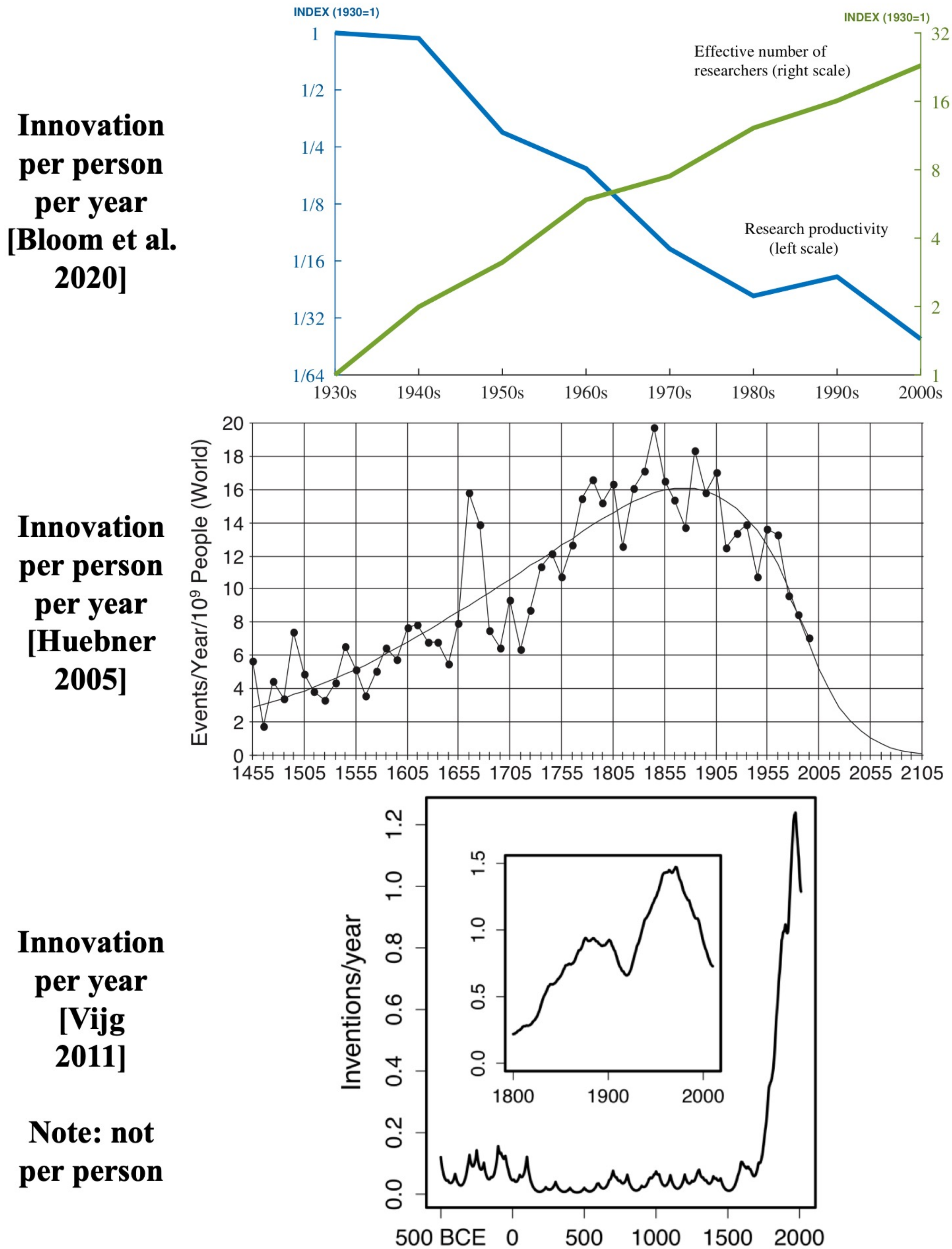

Figure 1.4: Examples of independent analyses indicating a modern decline in number of new scientific innovations per person per year [Bloom et al. 2020; Huebner 2005; Vijg 2011].

Innovation per journal article [Park et al. 2023]

Innovation per patent [Park et al. 2023]

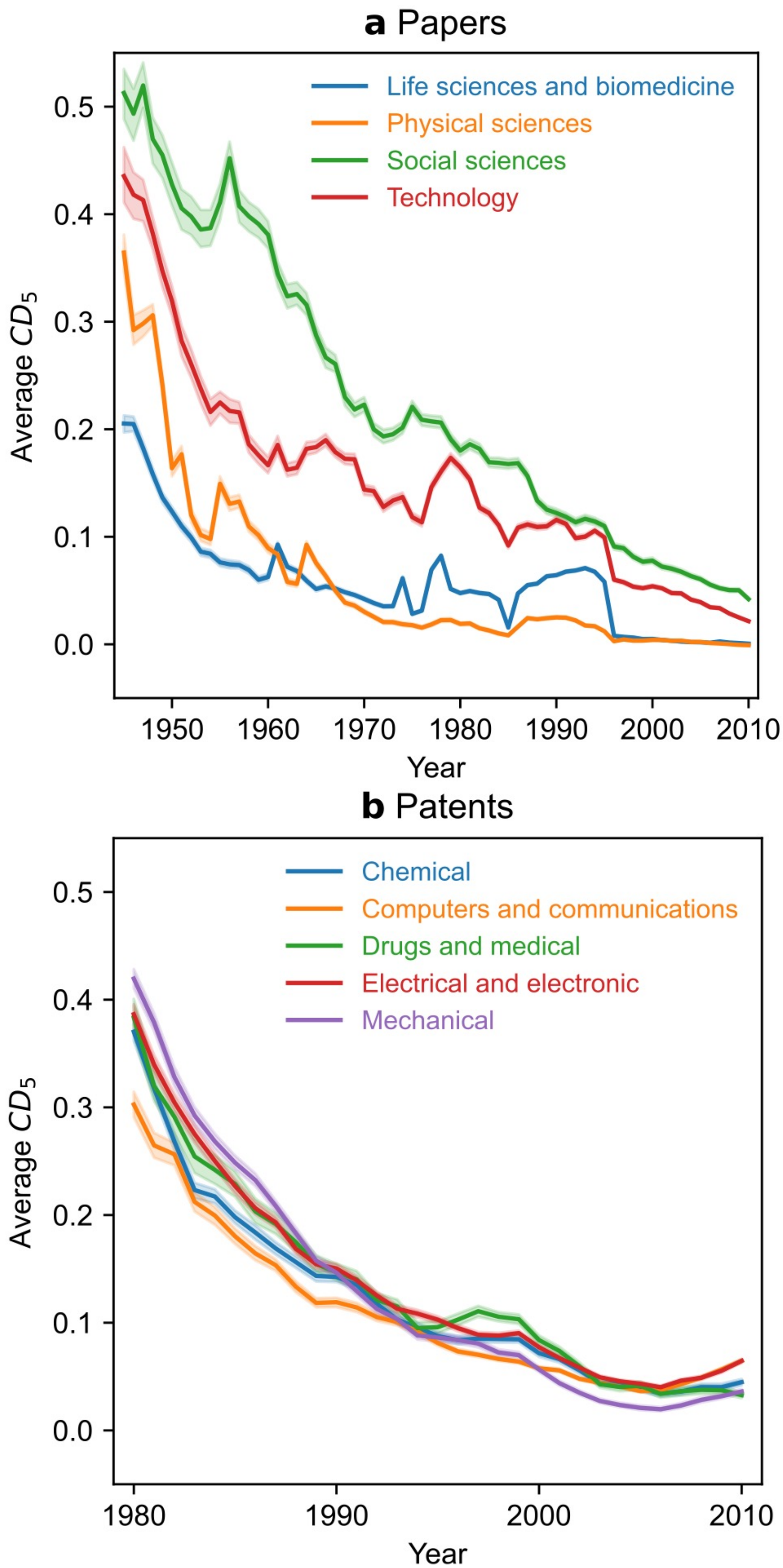

Figure 1.5: Further examples of independent analyses indicating a modern decline in the amount of innovation (the CD_5 or Coefficient of Disruption 5 years after publication) per journal article or per patent [Park et al. 2023].

These four analyses showing a significant decline in the number of revolutionary innovations per person per year, or even the total number of revolutionary innovations per year, are not isolated studies or outlier results. Some other analysts warning of the recent innovation decline include:

- Marc Andreessen, a venture capitalist [Andreessen 2020]
- Ashish Arora, Sharon Belenzon, and Andrea Patacconi, economists [Arora et al. 2015, 2019]
- Robert Atkinson, an economist [Atkinson 2014a, 2014b; Foote and Atkinson 2019]
- Professor Jeremy Baumberg, a nanotechnology researcher at Cambridge University [Baumberg 2018]
- Professors Jay Bhattacharya and Mikko Packalen [Bhattacharya and Packalen 2020]
- Professors Kevin J. Boudreau, Eva C. Guinan, Karim R. Lakhani, and Christoph Riedl [Boudreau et al. 2016]
- Donald Braben, a retired British Petroleum research manager [Braben 1994, 2004, 2008, 2014]
- Bill Buxton, a *Bloomberg Businessweek* writer [Buxton 2008]
- Nicholas Carr, a *Wall Street Journal* writer and book author [Carr 2012, 2015]
- ETH Zürich professors Peter Cauwels and Didier Sornette [Cauwels and Sornette 2020]
- Professors Johan S. G. Chu and James A. Evans [Chu and Evans 2021]
- Patrick Collison and Michael Nielsen, Silicon Valley venture capitalists [Collison and Nielsen 2018; Collison and Cowen 2019; Noah Smith 2020]
- Tyler Cowen, an economist [Collison and Cowen 2019; Cowen 2011; Cowen and Southwood 2019]
- Steve Denning, a *Forbes* writer [Denning 2013]
- Ross Douthat, a *New York Times* columnist [Douthat 2020]
- Elizabeth Dzeng, a scholar at Cambridge University [Dzeng 2014]
- Judy Estrin, a veteran Silicon Valley entrepreneur [Estrin 2008; NYT 2008-09-01, p. C4]
- Justin Fox, a former *Harvard Business Review* editorial director [Fox 2012]

- Robert Gordon, an economist [Gordon 2000, 2012, 2016]
- Lynn Gref, a retired NASA and Defense Department manager [Gref 2010]
- Jonathan Gruber and Simon Johnson, MIT economists [Gruber and Johnson 2019]
- John Horgan, a science journalist [Horgan 2015]
- Greg Ip, chief economics commentator for the *Wall Street Journal* [Ip 2016]
- Walter Isaacson, historian of science [Isaacson 2019]
- Leslie Kwoh, a *Wall Street Journal* writer [Kwoh 2012]
- Martín López-Corredoira, an astrophysicist [López-Corredoira 2013]
- Michael Mandel, a *Bloomberg Businessweek* writer [Mandel 2009]
- Chris Matthews, a *Fortune* magazine writer [Matthews 2015]
- Derek de Solla Price, an historian of science [Price 1986]
- Simon Ramo, a retired TRW cofounder [Ramo 1980a, 1983, 1988]
- Richard Rosenbloom, a Harvard Business School professor [Rosenbloom and Spencer 1996]
- Daniel Sarewitz, an Arizona State University science policy professor [Sarewitz 2016]
- William Spencer, a former Sematech CEO [Rosenbloom and Spencer 1996]
- Neal Stephenson, a science fiction author [Stephenson 2011]
- Peter Thiel, a technology investor [Thiel 2011, 2016, 2023]
- Derek Thompson, a journalist at *The Atlantic* [Derek Thompson 2021]
- Dietrich Vollrath, a University of Houston professor [Vollrath 2020]
- A high-ranking panel from the American Academy of Arts & Sciences [AAAS1 2014]
- A high-ranking panel from MIT [MIT 2015]
- A high-ranking panel from the U.S. National Academy of Sciences [NAS 2007, 2010]

1.1.3 Problems with Modern Academic Research

While universities have produced innovators, discoveries, and inventions for centuries, many observers have reported widespread problems with the modern academic system.[1] Examples include:

(a) Professors at many universities are generally evaluated primarily or exclusively for research, so they tend to neglect teaching. Professors who are deemed to invest too much effort in teaching may even be denied tenure or otherwise punished, while other professors often delegate teaching to poorly paid adjunct professors or graduate students.

(b) The modern academic system seems to be extremely focused on publishing as many papers as possible, even if they are highly repetitive of previous papers by the same researchers, do little to actually advance their field, and often are of dubious quality (or even plagiarized or faked entirely).[2] Researchers openly talk about maximizing the number of "minimum publishable units." Academics are so judged by their continuous high production rate of papers that they cannot really afford to get negative results. For that reason, they tend to pursue experiments (1) with a readily predictable and immediate payoff, (2) with insufficient optimization for repeatability, (3) with very little risk or innovation, and (4) preferably without focusing on truly practical applications that would take much longer to perfect. Likewise, academics usually cannot afford the time to publish any negative results if they do happen to get them (which would be very helpful to warn others of dead ends or misconceptions). The result appears to be an exponentially increasing deluge of repetitious, minimally innovative, or even spurious papers.

(c) Although it is considered to be by far the most important product of the system, this output of papers seems to end up largely unread and unutilized because (1) the number of papers is so incomprehensibly vast, (2) the papers are inaccessible to most of the world due to exorbitant online journal paywalls or the cost or obscurity of the printed volumes in which they appear, and (3) most academic researchers are too busy frantically writing their own papers to spend much time reading, trying to replicate, or applying other researchers' papers.

(d) Instead of multidisciplinary cross-pollination or even proper perspective within a given field, modern academia seems to demand extreme microspecialization. To compound the problem, researchers in each subfield appear to continually develop more and more unnecessarily specialized vocabulary, and this "tower of Babel" effect makes it much more difficult for (1) students to learn a given field, (2) researchers in different fields to communicate or spread ideas, (3) the public to understand and appreciate the work, and (4) the work to have any impact in the real world beyond the virtually inaccessible specialized literature.

[1] E.g., Aitkenhead 2013; Alberts et al. 2014; Armstrong 1997; Baumberg 2018; Begley 2009; Belluz et al. 2016a, 2016b; Bhattacharya and Packalen 2020; Blumenstyk 2014; Brenner 2014; Brezis 2007; Carey 2015; Carr 2009; Childress 2019; Chu and Evans 2021; Dzeng 2014; *Economist* 2010; Farrow 2019; Feighery 2013; Frey 2003; Garner 2006; Gee 2017; Gillies 2008; Godlee et al. 1998; Horrobin 1990; Ietto-Gillies 2008; Junod 2013; Kendzior 2015; Kennefick 2009; Lin 2014; López-Corredoira 2013; Maddox 1995; Mahoney 1997; Merton 1968; O'Shaughnessy 2012; Peters and Ceci 1982; Racker 1989; Ritchie 2020; Rothwell and Martyn 2000; Sandal 2011a, 2011b, 2016; Scott 2012; Taschner 2007; Tarver 2007; Warner 2020; Ziman 1995.

[2] E.g., Begley and Ellis 2012; Buranyi 2017; Errington et al. 2021a, 2021b; Francis 2020; Schneider 2016, 2017, 2020.

(e) Universities now seem to be bottomless pits for tuition, research grants, donations, university-hosted conference fees, and other funding, with tuition rising far faster than inflation for many decades, university faculty and staff endlessly pursuing wealthy donors and sponsor grants full-time, untapped university endowments mounting ever higher, and an explosion of administrators, extravagant campus architectural projects, ever more expensive athletic programs and facilities, and other costs with at best a tenuous connection to actual research and education.

(f) For decades there has been an exponential multiplication of professors and postdocs who want to be professors. Although this process began as a way to build up an academic system from minimal roots, in the modern environment in which the number of positions for professors has been relatively constant for years, it now functions for all practical purposes as a pyramid or Ponzi scheme that primarily benefits those who got in earlier. Those entering the system more recently tend to work very long hours to make the whole system function, are paid quite poorly, and have very dim career prospects.

Many observers (such as those cited) have reported these problems, but the most colorful summation was provided by Mark Tarver, a former professor at the University of Leeds [Tarver 2007]:

> Teaching was not the only criterion of assessment. Research was another and, from the point of view of getting promotion, more important. Teaching being increasingly dreadful, research was both an escape ladder away from the coal face and a means of securing a raise. The mandarins in charge of education decreed that research was to be assessed, and that meant counting things. Quite what things and how wasn't too clear, but the general answer was that the more you wrote, the better you were. So lecturers began scribbling with the frenetic intensity of battery hens on overtime, producing paper after paper, challenging increasingly harassed librarians to find the space for them. New journals and conferences blossomed and conference hopping became a means to self-promotion. Little matter if your effort was read only by you and your mates. It was there and it counted.
>
> Today this ideology is totally dominant all over the world, including North America. You can routinely find lecturers with more than a hundred published papers and you marvel at these paradigms of human creativity. These are people, you think, who are fit to challenge Mozart who wrote a hundred pieces or more of music. And then you get puzzled that, in this modern world, there should be so many Mozarts—almost one for every department.
>
> The more prosaic truth emerges when you scan the titles of these epics. First, the author rarely appears alone, sharing space with two or three others. Often the collaborators are Ph.D. students who are routinely doing most of the spade work on some low grant in the hope of climbing the greasy pole. Dividing the number of titles by the author's actual contribution probably reduces those hundred papers to twenty-five. Then looking at the titles themselves, you'll see that many of the titles bear a striking resemblance to each other. "Adaptive Mesh Analysis" reads one and "An Adaptive Algorithm for Mesh Analysis" reads another. Dividing the total remaining by the average number of repetitions halves the list again. Mozart disappears before your very eyes.

> But the last criterion is often the hardest. Is the paper important? Is it something people will look back on and say "That was a landmark." Applying this last test requires historical hindsight—not an easy thing. But when it is applied, very often the list of one hundred papers disappears altogether. Placed under the heat of forensic investigation the list finally evaporates and what you are left with is the empty set.
>
> And this, really, is not a great surprise, because landmark papers in any discipline are few and far between. Mozarts are rare and to be valued, but the counterfeit academic Mozarts are common and a contributory cause to global warming and deforestation.

[For the history of these trends, see for example: Buranyi 2017; Francis 2020.]

Because of all of the above problems, and because it is now more efficient and far cheaper for students to do much of their academic coursework online, utilizing the best recorded lectures and curriculum materials, it is currently unclear how universities should or will change in the coming decades.

1.1.4 Problems with Modern Corporate Research

Decades ago, corporate research programs made sizeable investments in very innovative, longer-term research and development projects, ultimately leading to products ranging from revolutionary microelectronics to whole new classes of pharmaceuticals. Unfortunately, corporate research (even including start-up companies and venture capitalists) now appears to be hobbled by several widespread problems, such as:[3]

(a) With top management and investors seemingly focused only on tomorrow's stock prices and next year's products, companies are generally only interested in developing very near-term, very low-risk (non-innovative) products.

(b) There appears to be a strong financial incentive for companies to take whatever amount of innovation does exist in their R&D pipeline and spread that innovation out for as many years as possible over a long succession of slightly improved products, in order to ensure planned obsolescence of each product and profitable sales of the next version of the product. There seems to be a strong disincentive to release as much innovation as possible as quickly as possible, which would spur the need for much more extensive and accelerated innovative research programs to refill the pipeline with future products.

(c) Research and development for any period of time is apparently viewed as an immediate financial loss for the company, not an investment in the company's future, and scaled back or entirely replaced with the hope of finding some other company's research that can be bought out or simply imitated. It is presumably much more lucrative to wait for someone else to

[3] E.g., Arora 2015; Buxton 2008; Denning 2013, 2014; Hsueh 2015; Kwoh 2012; Lyons 2016, 2018; Matthews 2015; Mittra 2009; O'Neill 2012; Pearlstein 2018; Ramo 1980a, 1983, 1988; Rosenbloom and Spencer 1996; Slywotzky 2009; Terkel 2011; NYT 2011-05-02, 2015-05-20, 2016-06-30.

invest in developing an innovative product, then just copy that product and try to capture as much of the market share as possible.

(d) Companies tend to be very unstable, with an endless series of mergers, acquisitions, or internal reorganizations that can completely redirect any research and development priorities on an almost annual basis.

(e) Profits for top management and investors seem to grow ever larger while rewards and working conditions for the actual research and development employees have stagnated at low levels or even worsened in recent years. Upper management tends to view the workers as disposable, interchangeable cogs in the machine that can be frequently and easily replaced, not skilled experts whose abilities should be cultivated, allowed to reach their maximum potential, and rewarded with and for longtime service.

Simon Ramo, cofounder of TRW, saw these problems arise in the 1970s [Ramo 1980a, pp. 55–56]:

> New technology is by its nature speculative. Risk taking is part of the task of management in the private sector but in periods of diminishing rewards smaller risks will be favored. This means priority will go to sticking to existing technology and making only small changes in techniques of manufacture and in the products themselves. Managers of R&D in American corporations are now reporting a heavy shift in emphasis to short-term programs either to produce safe, non-speculative, incremental improvements or else to learn how to comply with new government environmental and safety regulations. Basic research has been disappearing from private U.S. industry. Another factor is that principal executives, while not disinterested in long-term investments that may enhance the company's position after they have retired, have a natural desire to see results while they are still in the driver's seat. They are increasingly less motivated to make risky, long-term investments as their concern grows about U.S. economic-political stability over the lengthening period required to see a speculative investment through to successful completion. [...]
>
> After World War II there was a burgeoning in the United States of new technological industries: computers, agricultural technology, instant copiers, telecommunications, jet transport, semiconductors, nuclear reactors, spacecraft, fast foods, new chemicals and pharmaceuticals, and many more. Some of these product areas are now approaching maturity. We need new ideas and enterprises as well as continued enhancement and expansion of the fields in which we have a strong position.

The problems succinctly diagnosed by Ramo in 1980 have only worsened in the several decades since then, as shown by the references about corporate research cited above.

As with Michael Hanlon (see p. 42), most or all of the innovations that Ramo attributed to the United States during the first few decades after World War II can actually be traced to a different time and place, as this book shows.

1.1.5 Problems with Modern Government Research

Although government-run or government-funded laboratories played major roles in developing revolutionary innovations (nuclear technology, radar, space flight, guidance systems, etc.) many decades ago, they now seem to be mired in a number of problems.[4] In general the problems include:

(a) Each lab appears to be strongly focused on some core technology that was very innovative roughly three-quarters of a century ago when the lab was founded, but that is now very mature and for which government funding is steadily declining.

(b) Because of their previously reliable government funding and potentially dangerous core technologies, government labs tended to develop very risk-averse management cultures in which it is generally much safer politically to do nothing than to support any progress or change.

(c) Any new work at government labs seems to be highly constrained by a wide variety of internal and external regulations that have greatly increased in number and severity over the last 75 or so years.

(d) As funding for government labs has declined in recent years, not only have their research staff sizes decreased, but the surviving staff members have had to devote larger and larger fractions of their time to pursuing outside resources instead of actually conducting research. In many cases, the staff members spend much of their time writing proposals to try to obtain funding from outside sponsors. In other cases, the surviving staff are no longer allowed to conduct their own research, but rather must spend their time selecting and managing outside contractors to do the research.

(e) In cases where government labs have attempted to reform their structures and their areas of research, those reforms often mimic some of the worst practices of modern industry, for example either by focusing on very short-term, non-innovative, low-risk work or else by investing in a rapid succession of poorly thought-out "get rich quick" schemes.

(f) For all of the preceding reasons, government labs often have great difficulty attracting and retaining talented scientific professionals, and may instead accumulate mediocre personnel to fill out available positions, with some of those mediocre personnel ultimately rising to management positions at all levels as managerial openings become available over time.

[4] E.g., Alvarez 2014; GAO 2016; Gref 2010; Harris and Benincasa 2014; King 2011; Kramer 2016; Lucibella and Levine 2010; Mann 2011; McCurdy 1993; Nesbit 2016; Odenwald 1995; Sisk 2015; Steinbock 2015; Trento and Trento 1987; Trigaux 2015; Young 2015a, 2015b; NYT 2011-01-23, 2011-09-11.

Howard McCurdy, professor of public affairs at American University, summarized these problems in his detailed analysis of NASA's management history [McCurdy 1993, pp. 1–2]:

> The people who ran the National Aeronautics and Space Administration (NASA) when the agency was young developed methods of doing business that allowed them to carry out extraordinarily difficult tasks. NASA civil servants discovered ways to circumvent bureaucratic restrictions and avoid failure when it threatened to occur. They adopted an organizational philosophy suited to the scientific and technological missions they were asked to perform. NASA acquired a reputation as a high-performance government organization.
>
> As NASA grew older, it changed. Beliefs about how the agency should be run persisted, but no longer did those beliefs elicit the behavior that characterized the early years. NASA grew more bureaucratic. It became more concerned with maintaining its survival. In the eyes of some people, its performance declined. The onset of maturity changed NASA. The agency that embarked upon the 1990s was a different one than the NASA that sent astronauts to the Moon. The NASA story helps reveal forces that work to mollify the capabilities of high-performance organizations in the public sector. Unlike business firms, whose fundamental outlooks tend to persist over long periods of time, NASA's organizational culture blossomed and lost strength within just thirty years. The NASA experience suggests that high-performance cultures within the public sector are inherently unstable, given the conditions with which they must deal.

Thus government-run or government-funded laboratories fell into increasing dysfunction over the course of several decades, just as the academic and corporate research sectors did.

1.2 Scientific Innovation in the Earlier German-Speaking World

Trying to imagine completely new methods of improving the innovation system would be rather challenging (though not impossible), and any new methods might have inadequacies or even major adverse consequences that would not be discovered until they were tested in practice. As a more tractable alternative, studying the conditions that facilitated the major successes of earlier scientists and engineers in history can offer road-tested insights into how to maximize the productivity of modern researchers. Although inventions and discoveries have been made throughout the world and throughout history, high concentrations of major innovations within a given place and time should indicate especially conducive conditions for cultivating innovators and innovations.

1.2.1 Motivation for Studying the Earlier German-Speaking World

One of the highest concentrations (and arguably the highest concentration) of revolutionary discoveries and inventions came from scientists and engineers who were trained in the predominantly German-speaking central European research world in the nineteenth and early twentieth centuries. For the purposes of this study, that world is defined as containing German, Austrian, and Swiss researchers, eastern European and other researchers who were educated and/or worked in the German-speaking world, and scientists and engineers in the closely coupled Dutch research system. (Some historians of science have previously classified the Dutch system as part of the greater German-speaking scientific world [e.g., Laurie Brown et al. 1995, p. 17].) Figure 1.6 presents a map of Europe in 1914 to help visualize the relevant geographical areas.

This book focuses on scientists and engineers who received some or all of their training in that world between approximately 1800, when the German-speaking scientific world first began to take recognizable form, and 1945, when that world was essentially destroyed and then subsequently slowly rebuilt. For completeness, this book also includes all the accomplishments of those who were educated before 1945 but continued to make significant contributions after 1945.

As shown in Table 1.1, of the 99 people who received Nobel Prizes in Physics, Chemistry, and Physiology or Medicine through 1932, or prior to the Third Reich and all the problems it caused, half (49) were trained in the German-speaking research world. The other Nobel laureates were divided among a number of other research systems, including the United Kingdom, the United States, France, Sweden, Italy, etc., so the German-speaking world had by far the largest share.

Predominantly German-speaking scientific world of the nineteenth and early twentieth centuries

Germany	**Hungary, esp. Budapest**
Poland	**Czechia (Bohemia/Moravia)**
Switzerland	**Netherlands—closely coupled**
Austria	**Outsiders who came for education and/or work**

Figure 1.6: As shown on this 1914 map, the predominantly German-speaking scientific world of the nineteenth and early twentieth centuries included modern Germany, Poland, Switzerland, Austria, Hungary (especially Budapest), Czechia (Bohemia/Moravia), the Netherlands (closely coupled to the German world), and people who came from elsewhere for scientific education and/or work.

Year	Physics Nobel	Chemistry Nobel	Physiology/Med. Nobel
1901	**Wilhelm Röntgen**	**Jacobus van 't Hoff**	**Emil von Behring**
1902	**Hendrik Lorentz** **Pieter Zeeman**	**Emil Fischer**	Ronald Ross
1903	Henri Becquerel Pierre Curie Marie Curie	Svante Arrhenius	Niels Finsen
1904	Lord Rayleigh	William Ramsay	Ivan Pavlov
1905	**Philipp Lenard**	**Adolf von Baeyer**	**Robert Koch**
1906	J. J. Thomson	Henri Moissan	Camillo Golgi Ramón y Cajal
1907	**Albert Michelson**	**Eduard Buchner**	Alphonse Laveran
1908	Gabriel Lippmann	Ernest Rutherford	**Élie Metchnikoff** **Paul Ehrlich**
1909	Guglielmo Marconi **Karl Braun**	**Wilhelm Ostwald**	**Theodor Kocher**
1910	**Johannes van der Waals**	**Otto Wallach**	**Albrecht Kossel**
1911	**Wilhelm Wien**	Marie Curie	Allvar Gullstrand
1912	Gustaf Dalén	Victor Grignard Paul Sabatier	Alexis Carrel
1913	**Heike Kamerlingh Onnes**	**Alfred Werner**	Charles Richet
1914	**Max von Laue**	Theodore Richards	**Róbert Bárány**
1915	William Henry Bragg William Lawrence Bragg	**Richard Willstätter**	—
1916	—	—	—
1917	Charles Barkla	—	—
1918	**Max Planck**	**Fritz Haber**	—
1919	**Johannes Stark**	—	Jules Bordet
1920	Charles Guillaume	**Walther Nernst**	August Krogh
1921	**Albert Einstein**	Frederick Soddy	—
1922	Niels Bohr	Francis Aston	A. V. Hill **Otto Meyerhof**
1923	Robert Millikan	**Fritz Pregl**	Frederick Banting John Macleod
1924	Manne Siegbahn	—	**Willem Einthoven**
1925	**James Franck** **Gustav Hertz**	**Richard Zsigmondy**	—
1926	Jean Perrin	Theodor Svedberg	**Johannes Fibiger**
1927	Arthur Compton Charles Wilson	**Heinrich Wieland**	**Julius Wagner-Jauregg**
1928	Owen Richardson	**Adolf Windaus**	Charles Nicolle
1929	Louis de Broglie	Arthur Harden **Hans von Euler-Chelpin**	**Christiaan Eijkman** Frederick Hopkins
1930	C. V. Raman	**Hans Fischer**	**Karl Landsteiner**
1931	—	**Carl Bosch** **Friedrich Bergius**	**Otto Warburg**
1932	**Werner Heisenberg**	**Irving Langmuir**	Charles Sherrington Edgar Douglas Adrian

Table 1.1: Prior to the Third Reich (1901–1932), 99 scientists won Nobel Prizes in Physics, Chemistry, and Physiology or Medicine. Of those scientists, 49 were trained in the German-speaking world. That figure includes **38 native German speakers (German, Austro-Hungarian, or Swiss), 7 Dutch scientists, and 4 others who were educated in the German world.** Marie Curie won two Nobel Prizes in the table, and prizes were not awarded in years with dashes.

Highly innovative scientists and engineers who were educated in that German-speaking world prior to 1945 (**creators**, as they are called throughout this book) produced a huge number of revolutionary discoveries and inventions (**creations**) that have shaped the modern world:

- Biomedical advances from genetics to antibiotics
- Chemical breakthroughs from color film to synthetic rubber
- Discoveries about the universe from continental drift to stellar distances
- Revolutionary physics from relativity to quantum mechanics
- Electrical inventions from semiconductors to computers
- Mechanical systems from automobiles to submarines
- Nuclear reactions and applications from fission to fusion
- Aerospace vehicles from jet planes to moon rockets

Almost all of the inventions cited by Hanlon (p. 42) and Ramo (p. 52) as examples of post-1945 U.S. innovation actually originated from pre-1945 German-speaking creators.

A wide range of scientific experts from outside the early German-speaking research world and after its downfall have testified about its scientific success. For example, Sir Brian Pippard from the Cavendish Laboratory of the University of Cambridge wrote [Laurie Brown et al. 1995, p. 7]:

> It cannot be doubted that in physics, as in nearly every branch of scholarship, Germany at this time [early twentieth century[5]] led the world. The universities and their researchers were highly esteemed by their own people, their learned journals were eagerly followed everywhere, and there was an abundance of local societies to meet the needs of amateurs.

[5] Wherever I insert my own editorial comments into quoted text, I put my comments in square brackets and in blue to make them clearly distinguishable.

John Cornwell, another British scholar from the University of Cambridge, similarly observed [Cornwell 2003, p. 7]:

> By the end of the first decade of the twentieth century, Germany had become the international Mecca of science. Researchers, basic and applied, flocked to German universities from all over the world; learned German to read the leading science journals and to participate in conferences and seminars.

As an example of an American perspective, David Hounshell, a Carnegie Mellon University professor and historian of science, wrote [Rosenbloom and Spencer 1996, pp. 19–20]:

> During the last third of the nineteenth century and the first decade and a half of the twentieth century, a preponderance of U.S. physicists and chemists earned graduate degrees in Germany. These scientists not only observed a different system of graduate education in German universities but also witnessed the evolution of a nationwide system of scientific research and industrial-academic relations that had begun after German unification in 1871. By the beginning of World War I, Germany possessed the world's most complex and advanced research system, comprised of university research programs, government- and industry-sponsored research institutes, and industrial R&D programs. These components were linked by research scientists committed to advancing science and, as necessary to this goal, technology and industry.

Despite the deleterious impact of two World Wars and the intervening economic Depression on the German-speaking world, U.S. Army Air Forces General Curtis LeMay was so impressed by the scientific innovations the United States found in German-speaking areas in 1945 that he wrote [LeMay 1946, p. 17]:

> At Wright Field, O[hio]., German scientists are now assisting American scientists in translating great masses of captured German scientific documents. These documents reveal, as the materiel at Freeman Field indicates, the extent to which German science had out-distanced American science in basic and applied scientific research and in aircraft development. It has been estimated that the Germans were 10 to 15 years ahead of us in fundamental research.

L. B. Kilgore from the U.S. Technical Industrial Intelligence Division (TIID) confirmed the very high level of the German-language scientific achievements found by the United States after the wars; in fact, he admitted that their quantity and quality were almost beyond description [L. B. Kilgore, Proposal for a Compendium of German War Time Technology, Draft No. 2, 10 January 1947, NARA RG 40, Entry UD-75, Box 3, Folder Inter-Office Memoranda: To and From Robert Reiss]:

> The accumulation of the technical industrial information, which has resulted from the detailed investigations of the German industry for the past two years by this office, has reached such enormous proportions that it has become difficult to inform the public of the possible benefits available to it. This accumulation of information not only represents the greatest transfer of mass intelligence ever made from one country to another, but it also represents one of the most valuable acquisitions ever made by this country.

A 1946 U.S. Senate report on the establishment of the National Science Foundation noted that even the major scientific accomplishments of the United States during World War II were directly derived from earlier German-speaking creators [NSF 1946, p. 6]:

> It should be somewhat humiliating to us to realize that the revolutionary sulfa drugs had their beginning in German research laboratories; that atom splitting was discovered in Berlin; that the basic pioneer work that has led to radio and radar and the enormous American electronic industries was that of a German professor. Penicillin came from England [where it was purified by Ernst Chain, a German refugee]; DDT from Germany and Switzerland.

Although the Soviet Union was much less vocal with its praise of the German-speaking scientific world, its actions spoke volumes. Beginning in 1945, the Soviet Union removed thousands of scientists and many hundreds of whole laboratories and factories from German-speaking territory, and historians have shown that the subsequent Soviet nuclear, aircraft, rocket, electronics, and other development programs owed a huge debt to the German-speaking scientists and scientific information.[6]

Unfortunately, the history of the German-speaking creators and their transformative creations has been greatly obscured by a combination of factors including:

- World War I and its aftermath
- World War II and its aftermath
- The Cold War and its secrecy requirements
- Language barriers
- Pervasive and long-standing cultural stereotypes of German-speaking scientists in the rest of the world (villainous as in James Bond and Indiana Jones stories, insane as in Frankenstein films and other mad scientist stories, and/or foolish and ridiculous as in *Hogan's Heroes* and *Dr. Strangelove*)

The creators who invented so much of the modern world have been largely forgotten (especially by non-German speakers), leaving the modern world less aware of key details in its history and less able to fully reproduce the research conditions that led to so many revolutionary achievements.

[6] E.g., Albrecht et al. 1992; von Ardenne 1990, 1997; Barkleit 2008; Barwich and Barwich 1970; Fengler 2014; Fengler and Sachse 2012; Graham 1993; Heinemann-Gruder 1992; Holloway 1994; Karlsch and Laufer 2002; Kozyrev 2005; Kruglov 2002; Jürgen Michels 1997; Mick 2000; Nagel 2016; Naimark 1995; Oleynikov 2000; Pondrom 2018; Przybilski 1999, 2002a, 2002b; Riabev 2002a; Riehl and Seitz 1993; Siddiqi 2009; Sokolov 1955; Uhl 2001; Zeman and Karlsch 2008; *News Chronicle* 1945-10-15 p. 1; NYT 1945-10-15 p. 4, 1945-10-31 p. 6, 1946-01-29 p. 1, 1946-11-28 p. 16, 1946-12-06 p. 17, 1947-02-24 p. 1, 1948-05-26 p. 3, 1948-12-28 p. 10b; *Spokane Daily Chronicle* 1948-03-16 p. 6; *Sydney Morning Herald* 1946-04-20 p. 2; *Times* 1945-05-15, 1945-05-18.

1.2.2 Scope and Outline of this Book

Due to the length of this book, all of the sections and appendices are designed to be as self-contained as possible (even though that necessitates some degree of overlap and redundancy among some sections). Please use this outline or the Table of Contents to find whatever section interests you the most, and jump straight to that without any shame.

Motivated by the reasons explained earlier in this chapter, this book presents an overview and analysis of the historical German-speaking scientific world. The revolutionary creators and creations that world produced are divided into eight very broad fields over the next eight chapters:

Chapter 2: Biology and medicine

Chapter 3: Chemistry and materials science

Chapter 4: Earth and space science

Chapter 5: Physics and mathematics

Chapter 6: Electrical and electromagnetic engineering

Chapter 7: Mechanical engineering

Chapter 8: Nuclear science and engineering

Chapter 9: Aerospace engineering

Before delving into those specific fields, it would be useful to lay out the general approach of Chapters 2–9:

- The main objective of these chapters is to illustrate both the vast number and the profound modern impact of creators and creations arising from the earlier German-speaking world.
- In order to make such a broad overview accessible within a finite number of pages and a limited amount of readers' time and attention, the presentation in these chapters is primarily visual using figures, with accompanying pages of relatively brief text to put the figures in their proper context and to refer interested readers to sources of much more detailed information.
- The sections throughout Chapters 2–9 are based on information from general sources[7] as well as additional information from more specialized references on individual science and engineering fields as listed in the Bibliography.
- Within each of the eight fields covered by Chapters 2–9, creators and creations are grouped into specific topics to facilitate an overview of the details. There is considerable overlap for some of the fields, topics, creators, and creations, and it would easily be possible to categorize the same material in many other ways.

[7]Especially ACLS 2000; Albrecht et al. 1992; Ash and Söllner 1996; Bar-Zohar 1967; Bower 1987; Bunch and Hellemans 2004; Challoner 2009; Cornwell 2003; Crim 2018; EB 1911, 2010; Gillispie 1970–1990; Gimbel 1990a; Glatt 1994; Hall 2019a; István Hargittai 2006, 2011; Linda Hunt 1991; Impey et al. 2008; Jacobsen 2014; Koertge 2007; Kurowski 1982; Lasby 1971; Lusar 1956, 1971; Medawar and Pyke 2000; Mick 2000; Murray 2003; Nachmansohn 1979; NDB 1953–2020; Neufeld 2012; Nouzille and Huwart 1999; O'Reagan 2014, 2019; Porter 1994; Charles Walker 1946; Peter Watson 2010; Weitensfelder 2009.

- German-derived creations for some topics are less studied and less well understood by modern historians than those for other topics. For a handful of especially important yet historically murky topics, evidence for German-language innovations in those areas is briefly mentioned in these chapters, then presented in much more detail in Appendices A–E.

- In order to give some context for the major German-speaking creators, each section also briefly mentions some major creators in that field who were outside the German-speaking world, how relevant information was imported into the German-speaking world from other innovation systems, and how the German-speaking creators' inventions and discoveries were exported to the rest of the world. A common theme for many of the sections is that non-German-speaking (especially French and British) scientists initially dominated a given field up to the mid-nineteenth century or so, German-speaking scientists adopted that work as a starting point and entered the field sometime during the nineteenth century, and by 1945 German-speaking scientists had contributed most of the major new innovations in that field and were far ahead of their competitors (in many cases by a decade or more).

- The coverage of fields, innovators, and innovations in Chapters 2–9 is reasonably thorough but certainly not exhaustive. Hopefully those that have been included here are at least sufficient to elucidate both the impact of the German-speaking creators and the systemic principles underlying their successes.

Chapter 10 investigates why the earlier German-speaking scientific world was able to produce so many revolutionary creators and creations even though it had far fewer researchers than the modern scientific world, far less funding, and a long string of dire political challenges. Its success is even more remarkable when one considers the fact that over the course of a century or so, the German-speaking scientific world went from being far behind to being far ahead of its competitors in so many different fields. Systemic innovation-promoting factors that are examined include the social status of science and scientists, the growth rate of research funding, some characteristics of the education system, the popularity of interdisciplinary scientific work, the style of scientific management, the employment of systems analysis, incentives due to natural resource constraints, and incentives due to economic and military rivalries with other countries.

Chapter 11 considers how the global community adopted so many creations from the earlier German-speaking world while forgetting so many of their creators. In different waves that occurred before, during, and after the Third Reich, many thousands of German-speaking scientists, hundreds of thousands of tons of documents on their innovations, and complete inventions and even the factories to produce them were transferred to the United States, the Soviet Union, the United Kingdom, France, and other countries. Along with those creators and creations, some innovation-promoting systemic approaches were also transferred from the earlier German-speaking world to other countries, where they facilitated further scientific innovation during the Cold War. Chapter 11 explores which general approaches were adopted, and how they were ultimately abandoned.

Chapter 12 focuses on what the modern scientific research system can learn from the earlier German-speaking world. Based on the perspective accumulated in Chapters 1–11, Chapter 12 offers suggestions for:

- State or national innovation systems that would like to increase their production of revolutionary research

- Individual companies, organizations, or laboratories that would like to pursue more innovative research

- Individuals who are now trying to pursue careers in innovative research in the existing state of the global system

- Scholars who would like to further study the past, present, and potential future of revolutionary scientific innovators and innovations

The appendices focus on some potentially quite advanced creations of the German-speaking world during World War II that are currently much less well understood by modern historians, and whose complexities necessitate a considerably longer treatment than could be given in Chapters 2–9:

> **Appendix A** presents archival documents that suggest that Germany had the largest and most advanced biotechnology programs in the world at that time, was developing neural interfaces to control prosthetic limbs and weapons systems, possessed a significant offensive program in biological warfare, and discovered advanced V-series nerve agents during the war.
>
> **Appendix B** gives an overview of evidence that transistors and other microelectronics innovations may have originated in the German-speaking world, and that information on those technologies may have been transferred to and exploited by Allied countries after the war.
>
> **Appendix C** presents documents that appear to show that the German-speaking world developed and tested a variety of directed-energy technologies, including particle beams, electromagnetic pulse weapons, major steps toward lasers, focused sound waves for applications ranging from ultrasound imaging to acoustic weapons, and electromagnetic railguns.
>
> **Appendix D** provides considerable evidence that Germany may have developed and even successfully tested fission bombs during the war (which would have made it the first country in world history to do so), and that it may have even had a megaton-level hydrogen bomb in an advanced stage of development when the war ended.
>
> **Appendix E** presents archival documents that appear to show that wartime Germany made considerable progress toward developing the aerospace technologies that have formed the "nuclear triad" for most of the postwar decades: intercontinental jet bombers, intercontinental ballistic missiles, and submarine-launched missiles.

Although the evidence in the appendices does not constitute conclusive proof, it should prompt further archival research to clarify the true extent of those wartime programs.

The primary motivation for this study is one of practical modern self-interest, to identify factors that might improve present and future scientific productivity. However, there is also an underlying historical obligation. The names of Marco Polo, Christopher Columbus, Neil Armstrong and Buzz Aldrin, and other pioneers are remembered by the modern world. The German-speaking scientists and engineers who played such vital roles in creating our modern world deserve to be remembered as well.

1.2.3 Disclaimers

Before proceeding, it would be prudent to note several disclaimers, caveats, and assumptions, many of which are graphically illustrated in Fig. 1.7:

1. It should be emphasized that this study does not argue that the modern research system has produced no revolutionary innovations. Rather, this study proceeds based on the assumption (derived from the analyses of other scholars such as those cited in Section 1.1) that compared to earlier times, the modern system appears to have produced fewer revolutionary innovations per year, or at least fewer revolutionary innovations per year per person in the system, or fewer innovations per year per amount of money spent on the system.

    (a) One should certainly consider the possibility that the apparent decline in the innovation rate is only an artifact of how revolutionary innovation is defined. One should also bear in mind the possibility that it may appear that there has been a recent decline in innovation simply because there are large numbers of current innovations whose true impact can only be correctly viewed and judged in hindsight, many decades from now. Nonetheless, it seems unlikely that the recent innovation decline is merely an artifact of our perception. Whereas once the world changed dramatically every few years, due to discoveries that were made only a few years before their impact was felt, now the world appears to have been largely free of similarly revolutionary changes for half a century, with only a few exceptions.

    (b) Similarly, this study does not argue that non-revolutionary R&D is not important. Typically it takes far fewer people, far less time, and far less money to first come up with a revolutionary innovation than it does to then take that existing innovation and fully develop it all the way to a mature product. Therefore one would expect an optimally efficient research and development system to devote only a relatively small fraction of its people and funding to creating revolutionary new innovations, and most of its resources to perfecting previously created innovations. However, relative to previous periods that produced and perfected many revolutionary innovations, the modern system seems to be (i) devoting a smaller fraction of its resources to creating new innovations, and/or (ii) constructively advancing a smaller fraction of such innovations all the way through to later-stage development.

2. Having concluded that the modern innovation rate has declined, this study proceeds on the assumption that it is possible that the modern innovation rate **can** be increased. One cannot discount the possibility that we are simply nearing the physical limits of innovation. Perhaps most things that can be invented or discovered, within the constraints of human resources and interests, have already been invented or discovered. In that case, the innovation decline is due to the well of possibilities gradually running dry. On the other hand, on many previous occasions humanity has believed that it had reached the limits of innovation, and on each occasion it was mistaken (for example, during the Roman Empire; before each succeeding wave of the Industrial Revolution; once classical physics was mature but before quantum and relativistic physics were discovered; the state of medicine prior to the development of anesthetics, antiseptics, and antibiotics; etc.). Therefore, we should adopt the assumption that we are not now at an actual physical limit for innovation, and at least try to increase the innovation rate to see if any physical limits are encountered.

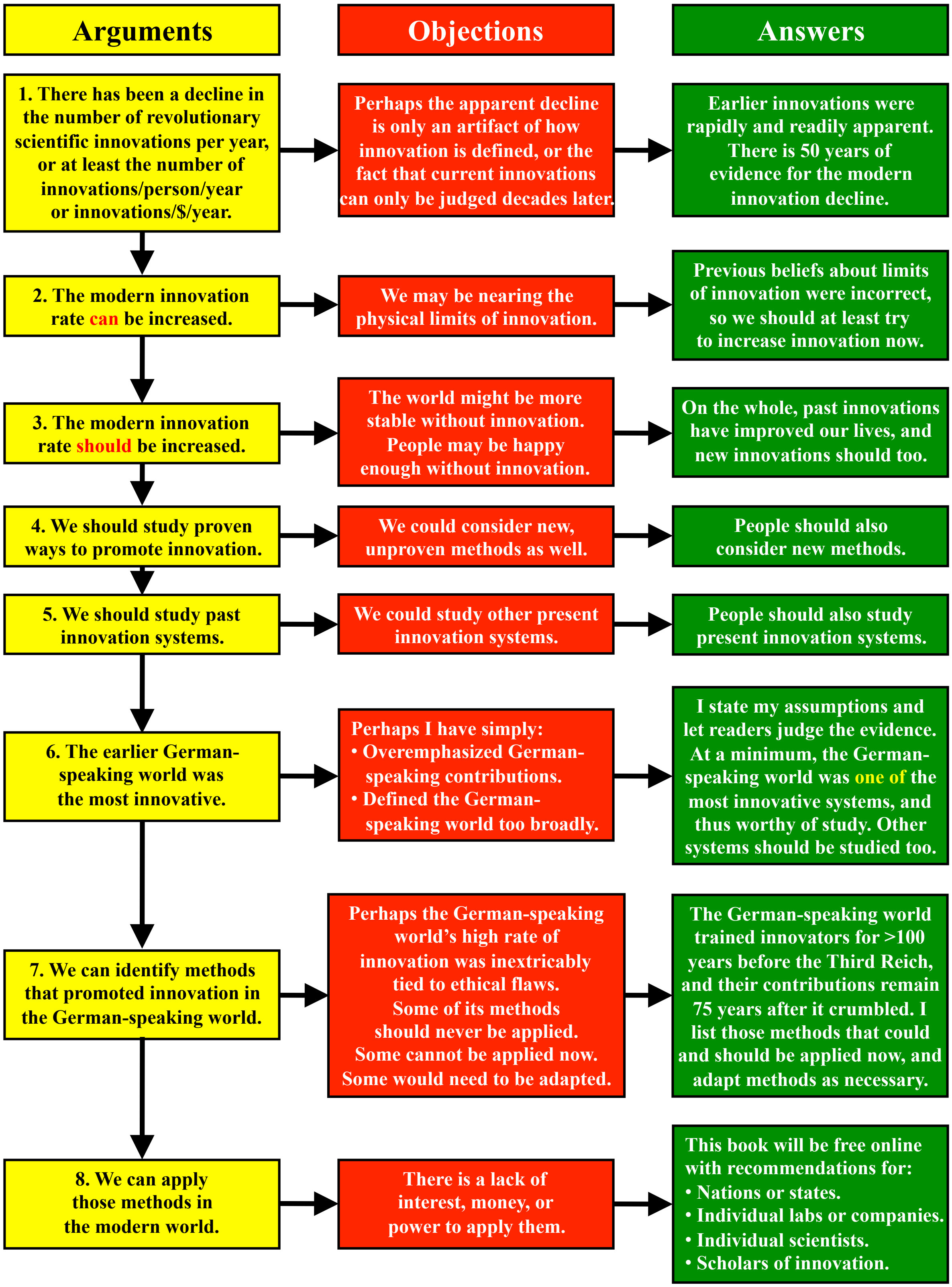

Figure 1.7: Flowchart of the key arguments underlying this book, some possible objections, and answers to those objections.

3. Moreover, this study operates on the assumption that the modern innovation rate **should** be increased. Someone may object that the world might be more stable without innovation, or that people are currently happy enough without further innovation, and those objections do have some merit. Yet on the whole, past innovations have improved our lives. How many people would prefer to forsake modern technology and medicine and live as people did in the year 1900, or 1800, or 1200? Thus this study proceeds with the belief that at least on balance, new innovations will also improve people's lives and are morally and socially desirable.

4. Rather than trying to reinvent the wheel, this study focuses on studying already proven ways to promote innovation. It does not consider new, unproven methods to promote innovation, although other scholars certainly should propose and evaluate new methods as well.

5. Among those proven ways to promote innovation, this study specifically considers past innovation systems. With mountains of historical documentation and many decades of hindsight, it is more straightforward to fully evaluate past innovation systems and their ultimate impact than to properly evaluate present innovation systems around the world. Nevertheless, other scholars should be and are evaluating various current innovation systems worldwide, and there is much to learn from those studies.

6. Out of all past innovation systems, I wanted to focus on the most productive one, whatever that was. I eventually came to the conclusion that the German-speaking world was the most innovative, based on the number and the importance of the creators and creations summarized in Chapters 2–9 and the appendices, as well as considerable reading about other historical innovation systems. Readers are entirely welcome to disagree with my conclusion, but hopefully my presentation shows that the German-speaking world was at the very least **one of** the most innovative systems, and thus imminently worthy of detailed study.

   (a) Some readers may feel that I have overemphasized the contributions of the German-speaking world relative to those of other historical innovation systems. It is not at all my intent to belittle the scientific contributions of other places or times, which have been made by innovators ranging from Archimedes to Louis Pasteur to Rosalind Franklin. Ideally it would be desirable to analyze factors that have promoted innovation in all places and times, but in order to keep the scope manageable, I had to pick one innovation system, and I chose the German-speaking world of the nineteenth and early twentieth centuries. Nevertheless, I highly recommend that readers of this book seek out or even conduct their own studies of scientific innovations from other places and times. Such other studies may even find some of the same contributing factors as this study, or they may identify additional useful systemic methods for promoting innovation.

   (b) Other readers may object that I have inflated the accomplishments of the German-speaking world by defining that world too broadly. Admittedly, the topic I have chosen, revolutionary scientific innovations in the German-speaking world of the nineteenth and early twentieth centuries, has very fuzzy boundaries. One should certainly recognize that this topic could be defined in many other possible ways, with the boundaries of the topic set at other limits. I have chosen to define the boundaries very broadly in order to analyze as much data as possible. Another advantage of defining the boundaries so broadly in this study is that if some readers prefer to set different limits for the boundaries, it would be much easier for them to simply exclude some of the data I provide in order to shrink the boundaries than it would be for them to collect the large amounts of new data that would be required to expand the boundaries. The three major categories of boundaries used in defining the scope of this study are:

i. Spatial boundaries. Depending on personal preferences and definitions, the German-speaking world could be defined to include the Netherlands and parts of eastern Europe, as other scholars have done previously and I have done here, or those could be excluded. Even within that German-speaking world, there could be important differences in innovation systems in different regions, as that world was hardly homogeneous. Moreover, people, ideas, and methods flowed back and forth across national borders, and thus the German-speaking scientific world was never truly independent of the scientific communities in other regions. To deal with these difficulties, I have tried to define and analyze the system as a scientist would analyze a physical system: choosing a well-defined if somewhat arbitrary boundary around that system, studying what happens within that system, and keeping track of what flows into and out of that system across the boundary.

ii. Temporal boundaries. The German-speaking scientific world had a very long and very slow rise, with no clear beginning point. It was definitely booming by the time of German unification in 1871. In order to capture most of the rise, this book considers scientists and discoveries well before that date, back to around 1800, but other beginning dates could equally well be chosen. Likewise, the end date of the German-speaking world to be studied could easily be defined in different ways. When the Third Reich began in 1933, roughly 25% of scientists (mostly of Jewish background) left the German-speaking world, and conditions greatly changed for those who remained in it. By 1945, that world had been destroyed by a combination of the Third Reich's behavior, the Allied military campaign, and Allied removals of scientists and scientific material from the German-speaking world. The slow reconstitution of scientific systems in West and East Germany (and later in reunified Germany) and in Austria after 1945 is beyond the scope of this book, although the book does track the post-1945 worldwide contributions of scientists who had been educated primarily or entirely in the German-speaking world before 1945. Finally, of course, it must be recognized that national borders, governments, and population ethnic compositions changed repeatedly over the time period covered in this book.

iii. Intellectual boundaries. There are no clear-cut definitions for, and no obvious boundary between, truly revolutionary and more evolutionary (progress by incremental improvements) scientific work. I have tried to focus on the more revolutionary and innovative inventions and discoveries, as generally recognized in the sources listed in the Bibliography. The result cannot help but be somewhat arbitrary and definitely incomplete, yet I hope that it will serve as a representative selection to facilitate the overarching analysis in this book. In order to keep the scope manageable, I have excluded the social sciences—psychology, linguistics, philosophy, economics, and others—from this book; that is simply my personal choice, and there would undoubtedly be much to learn from other researchers who do address those areas. Also largely excluded are scientific failures and mediocrity in the areas covered by this book, simply because there is so little available literature and data on them compared to what exists for the much more visible successes. (I do not know how to readily rectify this deficiency, but I do at least want to acknowledge it.)

(c) This study is not intended to make an argument for nationalist or ethnic bragging rights. The scientific research world in question spanned several nations, and even several very different types of government within a single nation's history. The scientists had a wide variety of ancestral backgrounds. The key to their success appears to lie in their intellectual approach, not their nationality or ethnicity.

(d) This study does not mean to imply that there is anything unique or magical about the German language—speaking German does not make scientists smarter. "German-speaking" is used throughout this book as the most convenient phrase to describe a geographical region in central Europe, centered on the German-speaking countries of Germany, Austria, and Switzerland, but also spilling over to surrounding areas to which they were most closely coupled during the time period in question (especially the Netherlands and parts of Czechoslovakia, Poland, and Hungary). "German-speaking" is also employed throughout this book to describe scientists and engineers who received part or all of their training in that region, regardless of whether German was their primary language, or even the language in which most of their education and research were conducted. Thus "German-speaking" is used to denote a population of scientists who were molded by the research world in this central region of Europe, in order to facilitate the study of those scientists and of common factors in their training that may have contributed to their ultimate success.

(e) Similarly, the label "scientists" is used throughout this book as shorthand to denote people who contributed to scientific discoveries or technological inventions, even though those people included not only degreed scientists but also engineers, mathematicians, medical doctors, veterinarians, technicians, military personnel, and individuals with only incomplete or no formal scientific education who made important contributions.

(f) As a final note on definitions, "forgotten" is employed in this book's title to succinctly encapsulate the apparent overall trend regarding general worldwide awareness of these scientists. Of course I realize that some of these scientists (such as Albert Einstein, Edward Teller, and Wernher von Braun) became household names, that modern scientists will recognize many more names in some of these fields, and that huge numbers of books, articles, and encyclopedia entries have been written about various German-speaking scientists (as cited in the Bibliography). Nevertheless, I believe that most readers will find it as surprisingly enlightening as I have (i) to learn about many of the creators and creations that are included in this book, (ii) to realize that this limited portion of geography and time could produce revolutionary creators and creations with such overwhelming numbers and importance, and (iii) to consider what innovation-promoting approaches our modern world may be able to learn from that history. (One should also note that the problem of innovators not being properly recognized or remembered is not exclusive to German-speaking creators.)

(g) It is certainly not my intent to claim that all major innovations have come from German-speaking scientists, or even that all elements and steps in any given innovation have come from German-speaking scientists. Yet I believe the examples cited in this book show that the number of major innovative contributions by German-speaking scientists in the nineteenth and twentieth centuries was astoundingly large, and that those contributions have had a remarkably profound and long-lasting impact on our modern world. As already mentioned, even if the German-speaking world was only one of the top innovation systems and not the greatest one, then it warrants a detailed analysis to see what we can learn from it.

7. This study assumes that we can identify useful methods that promoted innovation in the earlier German-speaking world.

   (a) This study is at best a concise overview of a vast field encompassing the actions of thousands of scientists and engineers across many countries over a period of two centuries (including the post-1945 careers many of them had), as well as investigations of those innovators and their innovations by countless subsequent scholars. For much more information on people and projects that can only be briefly mentioned here, please consult the cited references and even their references. Due to space limits, this book cannot include all scientific fields or all creations and creators within each field. Nonetheless, hopefully the sizable numbers of fields, creations, and creators that have been included are sufficient to elucidate both the impact of the German-speaking creators and the systemic principles underlying their successes. Much more work on these topics could and should be conducted, however.

   (b) I do not mean to imply that the earlier German-speaking world was entirely different or unique; some of its innovation-promoting factors may also have been successfully implemented at other times and places, or may already be a part of the modern research system.

   (c) For those innovation-promoting factors that are different, one must recognize the larger differences that existed between the earlier German-speaking world and the modern world. A strategy that facilitated innovation in the older German-speaking world may need to be suitably adapted to operate successfully in the modern world. Other factors that promoted innovation in the earlier German-speaking world may not be possible or even desirable to implement now. Nonetheless, I hope that enough strategies can be identified and adapted to be beneficial.

   (d) Some people may only be familiar with research programs that were conducted during the Third Reich, or might wonder if perhaps the German-speaking world's high rate of innovation was inextricably tied to ethical flaws. In no way is this study an argument that the Third Reich had inherently superior scientific research approaches. This study focuses on innovators who were trained in the scientific world that existed for more than a century prior to the Third Reich, and many of them lived their entire productive careers before the Third Reich. For those creators whose productive careers extended beyond 1933, their careers and the scientific research world itself were greatly impacted or destroyed by the Third Reich.[8] The key is the earlier research world, which had a long and illustrious history prior to the Third Reich, and which produced creators and creations whose impact is still felt at least three-quarters of a century after the Third Reich crumbled.

[8]The Third Reich drove out, fired, imprisoned, and/or killed a large fraction of the creators. Most of the remaining creators were mistreated and misused, even if some of their creations did receive lavish funding. The Third Reich also caused huge numbers of its students (many of whom would have become future scientists) and some of its existing scientists to die fighting in the war, made the schools and universities highly ideological and dysfunctional, and made scientists focus their energies solely on developing military projects without also refilling the research pipeline by training the next generation of creators and making new discoveries in fundamental science. Even if the Third Reich had won the war, the German-speaking scientific world that had been so carefully cultivated by earlier generations would have been destroyed.

(e) This study does not claim that research conditions in the earlier German-speaking world were ever perfect, even before the Third Reich came along. Throughout the time period and geographical areas in question, there were plenty of examples of interpersonal conflicts, discrimination, bureaucratic obstruction, overlooked innovators, insufficient job opportunities and funding, and other problems. Nonetheless, despite these pervasive and persistent human problems, the amount of revolutionary innovation per scientist in the earlier German-speaking world seems to compare quite favorably with that in the modern world.

(f) Both to keep the scope and length manageable and also to concentrate on topics that have not been well addressed previously, this study is focused only on the factual questions of what innovations were created, what innovators created them, and what factors facilitated the development of those innovators and innovations. This study cannot even begin to address the large number of related ethical questions—whether certain innovations should have been created, how they should have been used, how innovators were treated by or behaved during the Third Reich, how Allied countries treated the German-speaking world after World Wars I and II, etc. There is a vast body of existing literature on such moral questions, and I highly recommend that all readers seek out those books and study them.[9]

8. The ultimate objective of this study is to make these methods of improving innovation available to the modern world. Yet I recognize that there may be a lack of interest, funding, or power to apply them. Accordingly, I have tried to do everything possible to ensure that this book will ultimately find a receptive audience at some time, place, and level.

(a) I have divided the concluding recommendations into those that would require support from entire nations or states, those that could be implemented by individual organizations or laboratories, those that could be useful for individual scientists, and those that should be considered by scholars of innovation systems.

(b) In order to maximize the potential audience, longevity, and impact of this study, I decided to make the document freely available on the internet instead of publishing it as a printed book, which might be expensive and difficult to obtain and might rapidly go out of print, as so many of the cited references have. An online resource also has the advantage that it can be periodically updated with corrections or additional information. In choosing this path, I am following the model of other researchers who have made large amounts of technical information freely available online, for example Carey Sublette's website (http://nuclearweaponarchive.org), Mark Wade's website (http://www.astronautix.com), and the website of the Stichting Centrum voor Duitse Verbindingen en aanverwante Technologieën (http://www.cdvandt.org).

[9] E.g., Bar-Zohar 1967; Beyerchen 1977; Black 2012a, 2012b, 2017; Borkin 1978; Bower 1987; Campbell and Harsch 2013; Cornwell 2003; Crim 2018; Deichmann 1996; Joseph Fisher 2017; Friedrich et al. 2017; Geissler 1998a, 1998b, 1999; Gellermann 1986; Georg 2012; Gimbel 1986, 1990a, 1990b, 1990c; Gröhler 1989; Guillemin 2005; Friedrich Hansen 1993; István Hargittai 2006; Harris Paxman 2002; Haunschmied et al. 2007; Hayes 2001; Heim et al. 2009; Hentschel and Hentschel 1996; Linda Hunt 1991; Jacobsen 2014; Jeffreys 2008; Karlsch and Laufer 2002; Kaszeta 2020; Kater 1989; Keynes 2019; Klee 2001; Kurowski 1982; Lasby 1971; Leff 2019; Le Maner and Sellier 2001; Julian Lewis 2002; Lichtblau 2014; Macrakis 1993; Milton Mayer 2017; Medawar and Pyke 2000; Mick 2000; Nachmansohn 1979; Nash 2013; Michael Neufeld 1995, 2002, 2003, 2007; Plumpe 1990; Posner and Ware 2000; Pringle 2006; Renneberg and Walker 1993; Sasuly 1947; Schambach 2011; Sellier 2003; Simpson 1988; Spitz 2005; Stoltzenberg 1994, 2005; Sutton 1976; Szöllösi-Janze 2001, 2015; Tucker 2006; Wachsmann 2015; Bernd Wagner 2000; Jens-Christian Wagner 2011, 2015; Wallace 2004; Whitman 2018.

(c) For the same reasons, I decided to write this document in English, which currently is arguably the most widely accessible international language. I would be happy to offer advice or assistance with translating the contents into other languages if that would be of interest.

9. Here are a few final points:

    (a) **I have deliberately left a blank space where images of some creators or creations should go.** Those are people or projects that I felt were important enough that they should definitely be shown in this book, yet I have not yet been able to locate a suitable image that I have permission to use, despite my searches in Europe and in the United States. If readers have any relevant images and could send them to me, I would be very grateful and will include them in future editions of this book. Even where a suitable photo cannot be located, I believe that leaving a blank space pays tribute both to the scientific importance of that creator or creation and to how that historical fact has been very nearly forgotten.

    (b) Similarly, some first names, nationalities, or dates of birth and death are indicated as unknown if I have not been able to find them. Relevant information from readers would be very welcome.

    (c) Throughout the book, I have made a deliberate choice to quote experts and source documents on various topics as much as possible, rather than asking readers to accept my own account of innovators, innovations, events, and their importance. While the resulting text may not flow as smoothly as a unified narration, I hope that the presentation benefits far more from the objectivity and the persuasive amount of data that are afforded by this approach.

    (d) Lengthy or tangential sets of evidence have been placed in the appendices to avoid interrupting the flow of the discussion in the main chapters of the book.

        i. In order not to obscure the book's arguments by simply referring readers to numerous documents that may be difficult to obtain, relevant excerpts from a large number of key sources are presented in the appendices.

        ii. All or parts of some key documents are presented as photographs, which I have tried to make as clear and readable as possible, subject to the constraints of the original documents and the book format.

        iii. To make the contents computer-searchable for readers and internet search engines, most documents have been retyped (with annotations as appropriate).

        iv. Where I have retyped documents, I have tried to preserve the formatting of the original documents (underlining, etc.) as much as possible.

        v. To avoid variant spellings that would not come up in a computer text search, I have silently corrected some obvious typographical errors in some of the quoted source documents. U.S. and U.K. documents that were typed during and shortly after World War II were often careless in their spellings of the German names of people and places.

vi. Neither archival documents nor cited reference works are guaranteed to be unbiased or free from error. In the text, and especially in Appendices A–E, I quote sources that I believe are worthy of serious consideration.[10] Some readers may come to different conclusions about the accuracy or interpretation of some of those sources. By making this collection of sources freely available, I hope to facilitate such discussions.

vii. In order to avoid increasing the length of this already enormous book by a factor of several fold, I have abridged portions of the documents that seemed less relevant, as denoted by [...] in the quoted text.

viii. Where I wanted to add emphasis to passages in quoted documents to draw the attention of readers, I have displayed those passages in red. Even passages not in red are relevant too, though, which is why I have taken the time to type them up and include them as well.

ix. To add my own commentary regarding quoted documents yet clearly distinguish my commentary from the text of the source documents, [my commentary appears in blue text inside square brackets].

x. Key sources not in English are presented in both their original language and a parallel English translation.

xi. Citations direct interested readers to the original sources of these documents in case readers would like to verify their authenticity and read them in full.

xii. Each source quote has been placed in the most relevant section, but it may be germane to other sections as well, as indicated by cross-references.

(e) The Bibliography is organized into a number of broad categories, instead of being one long list with everything mixed together. Hopefully any difficulties in figuring out in which category a citation may be found are greatly outweighed by the convenience to those who are interested in easily perusing all references on a given topic.

(f) Even though there is a tremendous amount of available literature in this field, many lifetimes could be spent pursuing answers to all of the important questions that remain. Those answers may lie in personal collections or official archives anywhere around the world, if new investigators are willing to take up the quest.

(g) Because the body of information on German-speaking innovators is both so large and so incomplete, this book cannot help but be incomplete and imperfect. **For readers who find that specific assumptions, definitions, information, arguments, or conclusions I have given are incorrect or incomplete, I would welcome any suggestions for improvements to future editions (ToddHRider@gmail.com or thor@riderinstitute.org).**

(h) At the very least, hopefully this book will spur discussion, learning, and further work in the important areas that it covers.

[10] In recent decades, the topic of advanced German wartime research has been plagued by some completely bogus documents and information. I have tried my best to exclude that here. Please let me know if you think I have included something that is bogus or excluded something that is real. Some references that are cited in the Bibliography but not quoted in the text are included simply for completeness, not as any endorsement of their quality.