Keys to Success:
A Policy Roadmap for the Fourth Industrial Revolution

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ABSTRACT

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Keys to Success: A Policy Roadmap for the Fourth Industrial Revolution seeks to provide a policy guide for lawmakers at the advent of a new industrial era. Just as the Third Industrial Revolution replaced physical labor with the advent of automated mass production technology, the Fourth Industrial Revolution will constitute technological advances that replace mental labor. Some of these technologies, such as varying degrees of artificial intelligence and automated decision-making, are already being used today in social media and natural language processing. Both allies and adversaries of the United States are investing heavily to get ahead in this era. For the prior two industrial revolutions, America was at the forefront, producing technological breakthroughs that drastically improved the standard of living for millions around the world. America's leadership role can be owed in a significant part to its technological superiority, especially in military and advanced technology applications.

At the start of the next industrial age, this thesis attempts to look back and analyze the policy environment leading up to and through the Third Industrial Revolution (also known as the "Digital Revolution" or "Internet Revolution"), isolate key policy levers material to the creation of innovative output during this period, and provide a roadmap for policymakers that outlines the optimal policy environment required to maximize the United States' share of economic output in the advanced industries of the Fourth Industrial Revolution.

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Chapter I: Introduction

Since the dawn of humanity, technology has continuously changed the nature of our interactions with each other and the world around us. In many ways, technology is a feature of our existence: in the absence of extreme external pressures, humans have a natural inclination towards discovery, finding new resources or methods of production, exploring new frontiers of possibility, and pushing the boundaries of performance. Technology can be described as the ability to produce a more desirable output by the practical application of new inputs or systems, such as knowledge, skills, or resources.[1] Until now, it has been characterized as unmoral; that is, technology constitutes the ability to accomplish an end using a new set of inputs or medium rather than a normative prescription regarding the end to be sought and how to do so.

Generally, each time a new technology has been introduced, it has advanced the productive capacity of humans. Chariots allowed the ancient Sumerians to move faster on the battlefield, Shushruta applied Ayurvedic techniques to conduct the world's first plastic surgeries in ancient India, and Bell Labs' invention of the transistor opened the door for a new era of innovation in electronics.[2] A cursory glance at history indicates that technology, over the long run, promotes the development of peoples, societies, and civilizations. For the societies in particular, technology has often conferred a critical advantage on that group's interactions with the rest of the world, be it in trade, war, or other means. The Europeans' use of guns during their conquests of North America in the 1500s and 1600s famously helped them to gain an upper hand

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[1] "Technology Definition & Meaning." *Merriam-Webster*, Merriam-Webster, https://www.merriam-webster.com/dictionary/technology.
[2] Patric Kiger. "9 Ancient Sumerian Inventions That Changed the World." *History.com*, 1 Aug. 2019, https://www.history.com/news/sumerians-inventions-mesopotamia.
; "History of Plastic Surgery." *NHS*. https://www.royalfree.nhs.uk/services/services-a-z/plastic-surgery/facial-reconstruction-and-face-transplants/history-of-plastic-surgery/.;
"What Is a Transistor?" *ROHM Semiconductor*, https://www.rohm.com/electronics-basics/transistors/history-of-transistors.

over Native American resistance.[3] In the latter half of the 20th century, the manufacturing advantage in electronics and consumer products gained by the "Asian Tiger" economies of South Korea, Taiwan, Singapore, and Hong Kong supported a prolific pace of growth, raising their countries from dire poverty to reasonable wealth.[4] Most recently, America's leadership in the Digital Revolution—the proliferation of electronic networking devices—and the Internet Revolution—the proliferation of the Internet and its constituent technologies—has generated one of the greatest concentrations of wealth the world has ever known. It should come as no surprise, then, to see an association between technological superiority and societal prosperity, whether measured by standards of living, literacy rates, or military or territorial hegemony, among other factors.

From the 17th century onward, technological progress has accelerated at an exponential rate,[5] progressing in great bounds—we call them "industrial revolutions." These periods of time denote step changes in the inputs, systems, processes, and/or skills used to generate outputs, and they are often correlated with significant increases in productivity. Often, industrial revolutions are predicated upon the discovery of a new set of foundational technologies which promulgate concurrent technologies and various applications.[6] As productivity increased through each industrial revolution, societies' productive capacities increased; in layman's terms, societies were able to make more out of less. The Modern Era has featured three industrial revolutions: the First Industrial Revolution (late-1700s), which originated in Britain and spread to North America and Europe; the Second Industrial Revolution (mid-1800s to early-1900s), which originated in the

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[3] "Guns Germs & Steel: Variables. Smallpox." *PBS*, https://www.pbs.org/gunsgermssteel/variables/smallpox.html
[4] "Four Asian Tigers." *Investopedia*, https://www.investopedia.com/terms/f/four-asian-tigers.asp.
[5] Ray Kurzweil. *The Law of Accelerating Returns « Kurzweil*. https://www.kurzweilai.net/the-law-of-accelerating-returns.
[6] Thomas Philbeck and Nicholas Davis. "THE FOURTH INDUSTRIAL REVOLUTION: SHAPING A NEW ERA." *Journal of International Affairs*, vol. 72, no. 1, 2018, pp. 17–22, https://www.jstor.org/stable/26588339.

United States; and the Third Industrial Revolution (mid-to-late 1900s), which originated in the United States. Each industrial revolution was marked by a set of "hallmark technologies" which characterized the nature of its era.

Technological Revolutions and Global Leadership

The First Industrial Revolution is also the most popularly understood iteration of the three industrial revolutions. It had its origins in India, the world's dominant economic power until the 16th century.[7] Until 1750, India was the center of world trade and manufacturing, producing the finest quality cotton textiles available for export.[8] As trade markets opened between India and Britain in the 18th century, India's superior and labor-intensive cotton textiles came in high demand by British consumers. High labor costs prevented the British from producing the same textiles at scale, prompting the development of mechanization technologies, such as the spinning frame, which eventually led to cotton mills.[9] These technologies cumulated in the first Industrial Revolution, kicking off an era of mass mechanization where productive output was no longer 1:1 with labor hours. Textile factories spread throughout Britain and eventually came to America in the early 1800s. Standardization and the organization of factory labor were key systems and cultural innovations that facilitated the rise of the new mass-production economy.

The Second Industrial Revolution leveraged the productive environment built by the First Industrial Revolution and applied new inputs, such as electricity and steel, to start producing

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[7] In 1500, India accounted for approximately 25% of the world's GDP (Angus Maddison. *The World Economy: A Millennial Perspective*. Development Centre of the Organisation for Economic Co-operation and Development, 2001. Table b-18.).

[8] World History Project. "Imperialism and De-Industrialization in India." https://www.khanacademy.org/_render.

[9] Stephen Broadberry and Bishnupriya Gupta. *Cotton COTTON TEXTILES AND THE GREAT DIVERGENCE: LANCASHIRE, INDIA AND SHIFTING COMPETITIVE ADVANTAGE, 1600-1850*. 2005. http://www.iisg.nl/hpw/papers/broadberry-gupta.pdf.

goods at scale. These goods included both capital goods and consumer goods, the former of which dramatically increased productive capacity.[10] New developments in transportation infrastructure, such as railroads and canals, connected the ends of a newly expanded republic that stretched from the burgeoning cities of San Francisco and the Midwest trading capital of Chicago to the East Coast, allowing for interconnected and rapid commerce. However, the foundational aid to invention was the widespread electrification of urban areas. Greater access to electricity spurred inventions in communication (e.g., the telegraph, phonograph, and motion pictures), production methods (e.g., standardization, the "24-hour factory," and vertical construction methods for skyscrapers), and consumer goods (e.g., the washing machine and refrigerator).[11] This extreme period of rapid technological growth culminated in the Gilded Age followed by the Great Depression at the end of the 1920s.

The Second Industrial Revolution established the United States as a dominant technological power with one of the highest productivity rates and standards of living in the world. By 1913, the United States was responsible for one-third of the world's industrial output, by far the greatest share. This period resulted in a massive urban shift, marking the first time in American history that more citizens lived in cities than in rural areas. In order to achieve this superior nation-state status, the federal government assisted industry by using tariffs to protect them from foreign competition, aggressively annexed western lands to gain greater resource access, and promoted industrial development. Additionally, industrial policies such as long working hours, child labor, and dangerous working conditions were not deemed illegal, allowing companies considerable labor flexibility.

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[10] Eric Niiler. "How the Second Industrial Revolution Changed Americans' Lives." *HISTORY*, https://www.history.com/news/second-industrial-revolution-advances.
[11] Ryan Engelman. "The Second Industrial Revolution, 1870-1914 - US History Scene." https://ushistoryscene.com/article/second-industrial-revolution/.

The Third Industrial Revolution, also known as the "Digital Revolution," was characterized by a "step change in information theory and the power of data."[12] Beginning around the late 1960s with the development of the ARPANET (the precursor to the Internet),[13] the Digital Revolution would eventually result in the most rapid and significant breakthrough innovations in world history. Prominent inventions include but are not limited to advanced electronics (e.g., transistors, semiconductors, and integrated circuits), communication (e.g., radar, telecommunications, Internet, and social media), computing (e.g., personal computer, data transfer and storage, and cloud computing), robotics (e.g., automated industrial robots and 3D printing), and production methods (e.g., mechanized mass production). This paper will define the Third Industrial Revolution as including, but not limited to, all **technologies that effectuated the replacement of physical labor.**

The Third Industrial Revolution changed the world forever. For the first time in history, direct human labor was no longer needed to produce goods at scale. With physical labor automated, the United States shifted to the next level of economic production—mental labor. Thousands of new service roles were created in technology, finance, consulting, healthcare, and education.[14] Between 1980 and 2019, employment shares of the two highest-skilled functional employment groups, non-administrative healthcare/education/communication and office workers rose from 10% to 21% and 34% to 45% shares, respectively.[15] In contrast, the two lowest-skilled functional employment groups, agriculture and manual labor, saw declines from 6% to 1% and 30% to 16% shares, respectively.

[12] Thomas Philbeck and Nicholas Davis.
[13] Kimberley Ward. "Timeline of Revolutions." *MDS Events*, 18 Feb. 2019, https://manufacturingdata.io/newsroom/timeline-of-revolutions/.
[14] Staffan Canbäck. "Transaction cost theory and management consulting." *Why do management* (1998).
[15] Stephen Rose. *Do Not Blame Trade for the Decline in Manufacturing Jobs*. https://www.csis.org/analysis/do-not-blame-trade-decline-manufacturing-jobs.

The term “Fourth Industrial Revolution” was popularized by World Economic Forum Founder and Executive Chairman Klaus Schwab in his 2016 book by the same name.[16] In his book, Schwab defines the Fourth Industrial Revolution as a revolution “characterized by a much more ubiquitous and mobile internet, by smaller and more powerful sensors that have become cheaper, and by artificial intelligence and machine learning.”[17] According to Schwab, three critical distinctions separate the Fourth Industrial Revolution from its predecessor: 1) velocity, 2) breadth and depth, and 3) systems impact. He identifies 23 major technological shifts that will characterize this revolution, ranging from the Internet of Things (IoT) to cryptocurrency to artificial intelligence. Fundamentally, the Fourth Industrial Revolution is one that assumes a digital world from the start and cumulates in the merging of the digital, physical, and biological realms. In the interim, the result is a world where intelligence is no longer a solely human resource. Competing forms of intelligence from the digital world would result in a sort of intelligence-sharing or augmentation arrangement with humanity. Towards the end of this revolution, digital intelligence is expected to reach some form of parity with human intelligence. Thus, this paper will define the Fourth Industrial Revolution as including, but not limited to, all **technologies that effectuate the replacement of mental labor.**

Chapter 1.1: Methods

This paper employs two primary research methods in throughout each state of analysis: 1) synthesis and 2) case study. Synthesis of existing resources, such as prior academic studies and secondary data on policy outcomes, is used throughout the paper principally to contribute to the paper’s own analysis of the facts. The secondary objective of employing a synthesis approach is

[16] Thomas Philbeck and Nicholas Davis.
[17] Klaus Schwab. *The Fourth Industrial Revolution*. Portfolio Penguin, 2017, pp. 7.

the ability to access a broader range of information in a shorter amount of time to meet the paper's broad scope. This allows the paper to aggregate research and data from multiple datasets, reference past conclusions, if applicable, and inform the intermediate conclusions on policy action efficacy.

Case studies are used to trace the development of specific policy actions in the lifecycle of companies and organizations understood to be integral to the development of foundational Third Industrial Revolution technologies. These individual cases (e.g., Varian Associates, Intel, and Stanford University) allow the paper to place abstract policy actions into the appropriate context, verify if they appeared to have the effect independently concluded by other academic researchers, and identify previously unknown policy action channels.

This thesis adds to the existing literature on innovation and industrial eras by providing, to the author's best knowledge, the only comprehensive evaluation of the broad prevailing policy environment at the advent of the Third Industrial Revolution. The paper does so through the development of an original, multi-step, quantitative policy evaluation framework which is used to rank the policy levers under consideration by order of influence to innovation in the Third Industrial Revolution. Additionally, to the author's best knowledge, this paper is unique in using the Third Industrial Revolution as a guide for optimizing innovative output of Fourth Industrial Revolution technologies and providing a policy roadmap for doing so.

Chapter II: Isolating Policy Levers

Chapter 2.1: The Universe of Policy Categories

The range of policy levers in the United States can be interpreted as the full range of direct government interaction with society. In other words, government exerts influence on society through certain levers, which can be divided either functionally or thematically. Functional divisions split up policy actions according to their intended outcomes. While there is no agreed-upon science to policy classification, past scholars have structured functional divisions according to medium through which policy is administered, the strength of the policy, or other criteria. For example, American political scientist Ted Lowi's model contains four primary functional types of policy: distributive, constituent, regulative, and redistributive.[18] Each policy type sits within a matrix along the "applicability of coercion" (individual vs environmental conduct) and the "likelihood of coercion" (remote vs immediate). Thus, case-specific policies like product standards fall under the regulative category, while macro-level adjustments like subsidies fall under distributive policies.

Thematic divisions, in contrast, are the traditional policy categories that come to mind when conjuring examples of government action: fiscal, monetary, immigration, foreign, education, etc. These categories overlap; in many cases, outcomes of one category are at least partially dependent on the circumstances in another. However, thinking thematically simplifies the vast universe of possible policy actions. Once a policy lateral is identified, it becomes easier to move through the vertical value chain, per se, and subdivide by level of authority and function. This paper will proceed along a thematic basis and explore functional verticals after narrowing its scope.

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[18] Theodore J Lowi. "Four Systems of Policy, Politics, and Choice." Public Administration Review, vol. 32, no. 4, [American Society for Public Administration, Wiley], 1972, pp. 298–310, https://doi.org/10.2307/974990.

To identify the universe of relevant policy levers, this paper will start by analogizing from established United States federal executive agencies. If necessary, this list will then be modified according to academic literature, state executive agencies, and past legislation. Each lever is meant to encompass a broad classification of potential policy actions, and a particular policy can span multiple levers (e.g., a spending bill to invest in chip manufacturing plants might span both Fiscal and Science & Technology policy). Policy categories and their corresponding federal agencies, boards, commissions, committees, and quasi-official agencies which are highly unlikely to affect innovation development (e.g., the Department of the Interior) are excluded. Additionally, the White House and Congress, as governmental bodies, are presumed to be primary agents of federal laws and regulations and thus are excluded from the discussion of each lever. Finally, only federal (not state or local) policy will be considered within each lever. Federal policy is the prime, even if not the only, lever that impacts economic policy targeted by this paper, though a brief description of the impact of California state law prohibiting non-compete enforcement is included, due to its important influence on Silicon Valley growth during the Third Industrial Revolution.

Chapter 2.2: Relevant Policy Levers for the Fourth Industrial Revolution

In assessing policy levers that are most relevant for this paper, major policy areas were categorized as either low, medium, or high in their direct relevance. Only the ones categorized as having high direct relevance are included beyond this section of the paper, either explicitly or in combination with another lever of high direct relevance.

- **Agriculture Policy**

- Key Governmental Bodies: United States Department of Agriculture (USDA), Environmental Protection Agency (EPA), state and local agricultural commissions
- Function and Scope: According to the USDA, agriculture policy follows a "5-year legislative cycle that produces a wide-ranging "Farm Bill" (United States Department of Agriculture). Agricultural policy spans farm production and conservation; food, nutrition, and consumer services; food safety; marketing and regulatory programs; natural resources and the environment; research, education, and economics; rural development; and trade and foreign agricultural affairs.
- Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: While key to ancient technological revolutions, agricultural policy deals with a core societal need rather than a boundary innovation. While agriculture is poised to heavily benefit from FIR innovations in ag-tech (e.g., smart irrigation and crop maintenance technologies), this policy lever is expected to have **low direct FIR relevance**.

- **Commerce Policy**
  - Key Governmental Bodies: Federal Trade Commission (FTC), Small Business Administration (SBA), United States Department of Commerce (DOC), state legislatures, city councils
  - Function and Scope: Commerce policy is varied, wide-ranging, and houses many different mandates. Some key domain areas include:
    - Intellectual property (Patent and Trademark Office)
    - International trade (sanctions, tariffs, trade enforcement, import/export, global markets and supply chains)
    - Industrial development (capital expenditure, commercial/manufacturing space)

        - Market development (mergers and acquisitions, small business growth)
    - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Commerce policy sits at the center of all economic activity in the United States, forming the policy environment in which companies and organizations start, operate, and grow. This policy lever is expected to have **high direct FIR relevance**.

- **Education Policy**
    - Key Governmental Bodies: United States Department of Education (DOEd), National Science Foundation (NSF), state boards of education
    - Function and Scope: Education policy is constitutionally delegated to the states; therefore, educational initiatives will vary across the country. At the federal level, educational policy consists of elementary and secondary school programs, postsecondary support, and grants, loans, and subsidies for postsecondary students. At the state level, state boards and commissioners of education set curricular standards, allocate funding, and oversee local school boards.
    - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Education has proven to be a central determinant in individual economic outcomes. Thus, its effectiveness, duration, and timeliness will also be consequential in training professionals with the capacity to innovate, though initiatives implemented today may take decades to bear fruit. This policy lever is expected to have **moderate direct FIR relevance**.

- **Energy Policy**

- Key Governmental Bodies: United States Department of Energy (DOEn), Environmental Protection Agency (EPA), Nuclear Regulatory Commission (NRC), state energy commissions
- Function and Scope: At the federal level, energy policy has varied in scope and purpose dramatically over the last few decades but is generally concerned with the internal production (including sources and costs), distribution, and reliability of energy. Given the security implications, energy policy also monitors international developments in energy production, distribution, and pricing.
- Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: In many countries, the ability to cheaply and efficiently access energy directly impacts research and development efforts. However, the United States does not face similar energy supply constraints. While anticipated FIR innovations, such as smart grids, autonomous vehicles, and cryptocurrency rig operations will require corresponding innovations in energy infrastructure, the dependence of those innovations on energy policy is not analogous. This policy lever is expected to have **moderate direct FIR relevance**.

- **Environmental Policy**
  - Key Governmental Bodies: Environmental Protection Agency (EPA), state and regional environmental commissions
  - Function and Scope: Environmental policy defines individuals', private organizations', and government's interaction with the environment. Typically, policy is enacted to reduce or modify the nature of human impact on natural resources, such as air, water, and land.

    - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: As climate change awareness grows, limits on carbon emissions will create incentives for lower-emissions technology, such as electric vehicles and smart grids to increase fuel efficiency. Alternative energy sources, such as natural gas and nuclear power, would be expected to take a greater share of the national energy mix, potentially increasing the cost and reducing the reliability of energy access. However, it is unclear how this would affect automation. This policy lever is expected to have **low direct FIR relevance**.

- **Financial Policy**
    - Key Governmental Bodies: Commodity Futures Trading Commission (CFTC), United States Department of Treasury (Treasury), Securities and Exchange Commission (SEC)
    - Function and Scope: According to the OECD, financial policy concerns the "regulation, supervision, and oversight of the financial and payment systems, including markets and institutions" ("OECD Glossary"). Tools, such as disclosure, capital requirements, governance standards, and investment restrictions, allow financial policy to shape how capital providers and borrowers interact with each other.
    - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Accessing capital, from public or private providers, is central to the growth of new technologies, particularly for riskier projects. Restrictions on capital access are likely to be harmful to innovative potential. This policy lever is expected to have **high direct FIR relevance**.

- **Fiscal Policy**

- Key Governmental Bodies: United States Department of Treasury (Treasury)
- Function and Scope: Fiscal policy is primarily determined by Congress, which uses a combination of taxes and government spending to seek certain economic outcomes. Fiscal policy is broad and can contain more specific allocations for certain priority items, such as healthcare, national security, research and development, etc.
- Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Due to the broad nature of this lever, it is undoubtedly true that R&D grants and subsidies, for example, which are likely precursors to innovation, will be affected by fiscal policy. In the mid-20th century, federal R&D investments during and after WWII were responsible for innovations in healthcare, aerospace, and technology. This policy lever is expected to have **high direct FIR relevance**.

- **Foreign Policy**
    - Key Governmental Bodies: United States Department of State (DOS)
    - Function and Scope: Foreign policy is typically set by the White House with Congress intervening in larger matters. Foreign policy determines America's relationships with other states and can include treaties, alliances, trade relationships, bilateral/multilateral relationships, and partnerships on specific priorities.
    - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Relationships with highly innovative countries, such as Israel and Germany, are crucial to the flow of information and sensitive technology. Foreign policy's efficacy on innovation potential would be susceptible to one-off events, such as an agreement or accord between two countries. This policy lever is expected to have **low direct FIR relevance**.

- **<u>Healthcare Policy</u>**
    - <u>Key Governmental Bodies:</u> United States Department of Health and Human Services (HHS), state and local health commissions
    - <u>Function and Scope:</u> Healthcare policy encompasses both statutory (laws passed by Congress) and regulatory (standards issued and monitored by government agencies) aspects of healthcare. HHS houses numerous sub-agencies, most notably including the Centers for Disease Control and Prevention (CDC), Food and Drug Administration (FDA), and the National Institutes of Health (NIH). These bodies award research funding, grants, and development contracts both domestically and around the world.
    - <u>Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance:</u> Setting aside regulatory aspects, public funding for biomedical research remains crucial, especially for long-term, “step-up” therapies. This policy lever is expected to have **high direct FIR relevance**.
- **<u>Housing Policy</u>**
    - <u>Key Governmental Bodies:</u> United States Department of Housing and Urban Development (HUD)
    - <u>Function and Scope:</u> Housing policy at a federal level is responsible for addressing housing needs across the country, including affordability, access, and standards. HUD is particularly focused on middle- and low-income communities, issuing grants, loans, and housing allocations through the Community Block Development Program and Section 8 housing (“Q And a about HUD”). At the state and local level, various

housing programs (new development, rent control, etc.) are implemented to expand housing availability.

- Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: While it appears unlikely that housing assistance programs would affect new innovation, conversations around housing affordability in today's Silicon Valley reflect different facts on the ground. After the rise of remote work during the COVID-19 pandemic, many technology workers left Silicon Valley, one of the most expensive regions in the world, for cheaper destinations. This lever is expected to have **low direct FIR relevance**.

- **Immigration Policy**
  - Key Governmental Bodies: Department of Homeland Security (DHS)
  - Function and Scope: While DHS and state and local law enforcement are responsible for enforcing immigration laws, Congress officially controls the volume and source of immigration (though the president also has certain jurisdiction over immigration during times of crisis). Immigration policy has changed throughout American history to favor groups of different backgrounds, national origins, races, skills, and ideologies.
  - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Numerous studies have discussed the relationship between immigration, particularly highly skilled and educated immigration, and entrepreneurship/innovation. A 2007 Duke University study found that 25% of all technology and engineering businesses founded in the U.S. between 1995 and 2005 contained a foreign-born founder.[19] In recent years, the landscape of high-skilled talent mobility has distinctly benefitted four English-speaking OECD countries—the U.S., U.K., Canada, and Australia—

[19] Rachel Konrad. "Immigrants Behind 25% of Start-Ups." *Associated Press.* p. 2.

who have capitalized on the migration of high-skill talent.[20] This lever is expected to have **high direct FIR relevance**.

- **<u>Labor Policy</u>**
    - <u>Key Governmental Bodies:</u> United States Department of Labor (DOL), Equal Employment Opportunity Commission (EEOC), Federal Labor Relations Authority (FLRA), National Labor Relations Board (NLRB)
    - <u>Function and Scope:</u> Labor policy relates to the activities in and around the workplace and applies to employers, employees/contractors, job seekers, and retirees. Key domain topics include hiring and firing, compensation and benefits, and safety. Labor policy often overlaps with immigration, commerce, and environmental policy.
    - <u>Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance:</u> Obvious points of intersection exist with innovation, including employment versus contracting, foreign workers, and hazardous materials/conditions. However, it is unclear whether traditional centers of innovation, such as startups or laboratories, have seen innovation promoted or curtailed by labor policies. While labor law was more prominent in the United States during the era of organized factory labor and still achieves scrutiny in developing countries, workplace laws in the present-day United States are generally settled and accounted for by organizations. This lever is expected to have **low direct FIR relevance**.
- **<u>National Security Policy</u>**
    - <u>Key Governmental Bodies:</u> Central Intelligence Agency (CIA), United States Department of Defense (DOD)

[20] Sari Pekkala Kerr, et al. "Global talent flows." *Journal of Economic Perspectives* 30.4 (2016): 83-106.

- Function and Scope: National security policy reflects the implementation of the United States' national framework its security and is coordinated almost entirely at the federal level. In addition to maintaining the United States' defense apparatus, national security policy directs forward strategy, such as partnerships, new initiatives, and investment and modernization plans.
- Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: National security policy has a long, shared history with innovation in the United States: many breakthroughs in healthcare, digital technology, transportation, and more originated as DOD projects. As new defense needs arise in physical warfare, cybersecurity, and space, this trend is unlikely to abate. This lever is expected to have **high direct FIR relevance**.

- **Science and Technology Policy**
  - Key Governmental Bodies: Congress, Federal Communications Commission (FCC), Federal Laboratory Consortium for Technology Transfer (FLCTT), National Aeronautics and Space Administration (NASA), Nuclear Regulatory Commission, (NRC), National Science Foundation (NSF)
  - Function and Scope: Science and technology policy spans the government's involvement with scientific and technological aspects of research, the economy, national security, education, and more. At the federal level, appropriated funds are typically distributed through an executive agency to their intended recipient.
  - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Science and technology are central to innovative potential. Thus, policy incentives and

disincentives focused on science and technology will have a targeted impact on related activities. This lever is expected to have **high direct FIR relevance**.

- **Transportation Policy**
  - Key Governmental Bodies: United States Department of Transportation (USDOT), National Transportation Safety Board (NTSB), state departments of transportation
  - Function and Scope: Transportation policy is concerned with the mobility of people and physical assets in, from, and to the United States. In the past, transportation policy was closely linked to national security policy (i.e. interstate system). Roads, bridges, ports, airports, railroads, and maritime lanes are all applications of transportation policy. Maintaining standards and enforcing regulations (e.g., safety, new vehicles, operating guidelines) are also under its purview.
  - Preliminary Assessment of Fourth Industrial Revolution (FIR) Relevance: Like agriculture, transportation infrastructure in the United States is expected to be a significant beneficiary of the FIR. However, whether transportation policy impacts FIR innovations would appear to depend on specific legislation that encourages or mandates the integration of FIR-related technology into transportation systems. This lever is expected to have **moderate direct FIR relevance**.

Additionally, the impact of regulation on innovation cannot be discounted. After laws are enacted, policies are then interpreted and enforced by executive agencies, commissions, and boards. The process by which a particular policy is interpreted and enacted has the potential to materially affect the intended outcome of the policy. In some cases, governmental bodies have representatives who must be approved by Congress but retain substantial decision-making authority once seated (e.g., Federal Reserve Chairman Jerome Powell). While outside of the scope of this paper, when relevant, material distortions by or interferences from agencies, commissions, and boards of policy that occurred during the Third Industrial Revolution will be noted and discussed.

Chapter 2.3: Functional Designations of Policy Actions

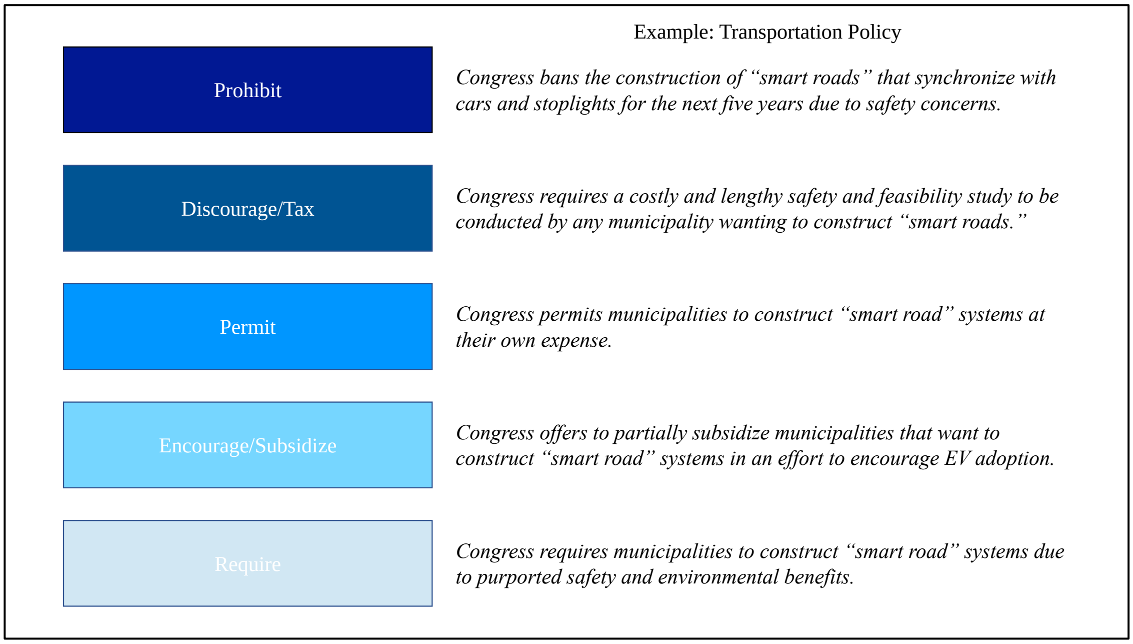

Figure 1: Innovation Contribution Framework

To gain a better understanding of the nature of policy actions taken within each vertical, a framework describing the general characteristic of the policy must be created. Such a framework should assist in describing the nature of particular policy actions; without it, it would be impossible to glean insights simply from volume or impact-based data of a policy lever.

The following framework attempts to classify policy actions based on their *actual* (not intended) effect on a particular policy theme. In action, it will serve as a "scoring criteria" for enacted policy to provide context on the general policy trends over a period of time. Given policy's variable impact, this framework would likely need to be used in combination with an "efficacy scale" similar to Lowi's model. Together and in aggregate across many policy actions, these scoring systems would be able to produce scores for each policy lever and rank them in comparison. An overall policy lever ranking would thus allow this study to make broad intermediate conclusions on the prevailing policy environment in an era.

Chapter III: The Third Industrial Revolution in the United States

Chapter 3.1: Structure and Development

The Third Industrial Revolution in the United States can be divided into two periods of time: the Silicon Valley Revolution and the Internet Revolution. The Silicon Valley Revolution spans the hypergrowth period of digital networking companies in and around San Jose, California from the late 1960s to the late 1980s. The Internet Revolution spans the development of digital technology at scale for consumer and commercial use, running through the proliferation of the Internet, the dot-com bubble, and the rise of the Internet of Things (IoT) in the late 2010s.

Defining the Policy Environment

A holistic understanding of the policy environment leading up to and during the Third Industrial Revolution requires segmenting policy actions into the relevant levers discussed in Chapter II. To do so, a generally comprehensive list of policy actions enacted under each policy lever will be categorized according to the scoring framework and sorted in chronological order. The timespan under consideration is the length of the Third Industrial Revolution (1960-2000) and up to 20 years prior, with exceptions for especially relevant policy actions. In arriving at an overall policy climate assessment for each lever, levers will be assessed in two steps. First, the lever will be assessed relative to its historical position before the assessment period (e.g., "strong positive movement"). Second, the lever will be assessed according to likely impact on innovation during the Third Industrial Revolution.

Accounting for policy levers with medium to high Fourth Industrial Revolution relevance leaves us with the following list:

- Commerce
- Education
- Energy
- Financial
- Fiscal
- Healthcare
- Immigration
- National Security
- Science and Technology
- Transportation

Given the scope of this paper, it is necessary to narrow down the breadth of policy levers so that appropriate attention may be given to each one's considerable history. Additionally, in the list above, several categories overlap. For example, early Silicon Valley firms benefited from Department of Defense grants for telecommunications, circuit, and missile technology[21]; these grants could be construed as parts of both fiscal and national security levers. Technology export controls on items of national security relevance are regulated by the Department of Commerce's Bureau of Industry and Security (BIS) and the Department of State's International Traffic in Arms Regulations (ITAR), though in close coordination with the Department of Defense.

To arrive at a list of levers for final consideration, policy overlaps and degree of relevance to technological innovation at the time of the Third Industrial Revolution were assessed to produce a final list of five policy levers:

- Commerce

[21] "Silicon Valley Rooted in Backing from US Military." *Financial Times*, 9 June 2013, https://www.ft.com/content/8c0152d2-d0f2-11e2-be7b-00144feab7de.

- Education
- Fiscal/Financial
- Immigration
- Science and Technology

Chapter 3.2: Commerce Policy

As outlined in its policy lever description, commerce policy is a wide-ranging lever with several component parts, including intellectual property, antitrust, trade, manufacturing/commercial space, and industrial development. Throughout World War II, commerce policy entailed rapidly increasing the nation's manufacturing base and enforcing trade embargoes against other nations. After the war's conclusion, the focus of commerce policy largely turned towards the creation of a regime to manage economic growth, spurred by a rapidly expanded industrial base.

- Intellectual Property

  Intellectual property, specifically patent law, has had a central relationship with innovation throughout the history of the United States. Periods of economic growth or recession have influenced attitudes towards patents by citizens and legislatures. For example, during the Great Depression, patents faced negative perceptions as symbols of abusive, monopolistic behavior by big corporations.[22] The patent system became more favorable with the economic impact of World War II but returned to scrutiny with the economic depression of the 1970s, a period of heightened anti-trust activity. Rising

[22] "A Brief History of the Patent Law of the United States." *Ladas & Perry*, 07 May 2014, https://ladas.com/education-center/a-brief-history-of-the-patent-law-of-the-united-states-2/.

incomes and general prosperity during the “Reagan Boom” of the mid-1980s predictably restored patents to symbols of American ingenuity. Around the same time, as globalization began to take hold, intellectual property policy efforts turned towards establishing a stable set of standards to encourage American inventors and protect the commercialization of their technology abroad.

The development of intellectual property policy in the early-to-mid 20th century—preceding and during the early stages of the Third Industrial Revolution—revealed two key themes: 1) establishing private industry as the innovation leader and 2) strengthening the American intellectual property regime.

Private industry as the innovation leader. During World War II, the United States government renewed its 1917 legislation from World War I targeting sensitive patents and ordering that they be kept secret for the duration of the war.[23] Research by Duke economist Daniel Gross found that this policy had a chilling effect on follow-on innovation. Given that the United States Patent and Trade Office (USPTO) mostly targeted the most significant and sensitive inventions, other inventors did not benefit from the knowledge of a public patent. Additionally, the Federal Procurement Regulation dictated that inventions supported by federal funding were required to list the federal government as an assignee on the patent.[24] The result was an intellectual property engine that was heavily reliant upon the government to function.

[23] Belsie Laurent. “WWII Policy Kept Patents Secret, Slowed Innovation.” *National Burueau of Economic Research*, no. No. 7, July 2019, https://www.nber.org/digest/jul19/wwii-policy-kept-patents-secret-slowed-innovation.
[24] “Background materials on government patent policies: the ownership of inventions resulting from federally funded research and development.” *Subcommittee on Domestic and International Scientific Planning and Analysis of the Committee on Science and Technology U.S. House of Representatives*, Aug. 1976. pp. 29–49. https://archive.org/details/bownetri00unit/mode/2up?view=theater.

Policymakers recognized that the private sector, not the government, needed the tools to take the lead on innovation. Their answer was the Bayh-Dole Act of 1980, a landmark piece of legislation that allowed individuals, corporations, universities, and non-profits to retain ownership of inventions supported by federal funding.[25] Nearly overnight, most research universities installed technology transfer offices to assist with the licensing and commercialization of patents. This act also allowed the government to enter into exclusive licenses to commercialize its own patents, which it had successfully done for just 5% of its 28,000 patents in 1980. As the first domestic intellectual property overhaul in 30 years, Bayh-Dole marked a high point for pro-private innovation policy post-World War II. a. Since Bayh-Dole's enactment, the legislation has led to the creation of over $1.3tn in economic growth, 4.2 million jobs, and assisted the success of over 11,000 university-originated startups.[26]

At the same time, the Stevenson-Wydler Act of 1980 encouraged the federal government to take an active role in technology transfer of intellectual property developed by collaborative work between federal laboratories and industry where no direct federal funding is involved by establishing a designated technology transfer office in labs with greater than 200 scientists. [27] The act was amended by the Federal Technology Transfer Act of 1986, which established cooperative research and development agreements (CRADAs) which allowed laboratory directors and agencies

[25] Kenji Kushida. A Strategic Overview of the Silicon Valley Ecosystem: Towards Effectively "Harnessing" Silicon Valley. 2015-6. *Stanford Working Paper*.
[26] Gabrielle Athanasia. "The Legacy of Bayh-Dole's Success on U.S. Global Competitiveness Today." *Perspectives on Innovation*, https://www.csis.org/blogs/perspectives-innovation/legacy-bayh-doles-success-us-global-competitiveness-today.
[27] Wendy Schacht. "Patent Ownership and Federal Research and Development (R&D): A Discussion on the BayhDole Act and the Stevenson-Wydler Act." *Congressional Research Service*.

greater flexibility to dispense patents as they see fit and negotiate ownership.[28] The government under the act retained a “nonexclusive, nontransferable, irrevocable, paid-up license to practice the invention or have the invention practiced throughout the world by or on behalf of the Government for research or other Government purposes.”[29] The underlying principle of both Stevenson-Wydler and Bayh-Dole was that “companies that do not control the inventions arising from their investments (in money or effort) tend to be less likely to engage in related R&D necessary to bring an idea to marketplace.”

Additionally, key judicial decisions broadened the range of patentable intellectual property under the Patent Act of 1952. In their 1981 decision in *Diamond v. Diehr*, the Supreme Court ruled that software used for industrial purposes could be patentable if it “transformed the process into an inventive application of the [mathematical] formula” (i.e., applied abstract code to improve an industry process).[30] The standard—and others like it—provided greater patentability for software related inventions.

Strengthening the intellectual property regime. After World War II, to address the pent-up demand for patents and a vastly expanded military-industrial base, Congress felt that a complete overhaul of the United States’ intellectual property system was needed. In an environment where patent skepticism had pervaded the public psyche and a “revise and codify” movement was in vogue, lawmakers’ first step was to strengthen the standards required to obtain a patent. The Patent Act of 1952 addressed these concerns by

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[28] *Federal Technology Transfer Act and Related Legislation*. United States Environmental Protection Agency. 29, Oct. 2021. https://www.epa.gov/ftta/federal-technology-transfer-act-and-related-legislation#:~:text=The%20Federal%20Technology%20Transfer%20Act,laboratories%20by%20non%2Dfederal%20organizations.

[29] Schacht.

[30] Michael Webb, et al. *Some facts of high-tech patenting*. No. w24793. National Bureau of Economic Research, 2018.; McDonnell Boehnen Hulbert & Berghoff LLP. “Supreme Court Issues Decision in Alice Corp. v. CLS Bank.” *JD Supra*, https://www.jdsupra.com/legalnews/supreme-court-issues-decision-in-alice-c-62486/.

codifying "non-obvious" as a condition of patentability, requiring the inclusion of a definition of infringement in the patent application, and introducing the penalty of *contributory infringement* which held liable those who actively induced the infringement of patents.[31] This act was intended to restore confidence in the patent process, both to prove that high standards existed to obtain a patent as well as consummate protections existed to protect them. Policymakers also sought to increase the scope of protection for American patents abroad, recognizing that it was in America's best interest to push for tougher intellectual privacy standards in the international community. They succeeded in 1978 with the enactment of the Patent Cooperation Treaty, which streamlined the patent application process for the same invention by creating a standardized application system across 35 countries. The act also encouraged smaller businesses and individuals to become more aggressive in seeking patent protection in other countries. Both of these pieces of legislation illustrated a broader movement to create a stable, robust, and scalable intellectual property regime for the next technological wave.

Today, depending on one's point of view, these efforts largely succeeded. James Bessen and Robert Hunt (2007) show that, in the present day, traditionally dominant firms in patenting, such as IBM, General Electric, Mitsubishi, and Sony, still remain overall leaders in patent grants.[32] However, Fourth Industrial Revolution-relevant patent areas, such as machine learning and drones, show that newer firms lead incumbents in patent grants. This shift is geographic as well; traditional incumbents (and current leaders) are primarily American and Japanese, while Chinese and American firms lead in Fourth Industrial Revolution-relevant spaces. In other words, it would appear that the policy

[31] "Patent Act of 1952." *IT Law Wiki*, https://itlaw.fandom.com/wiki/Patent_Act_of_1952.
[32] Michael Webb, et al. *Some facts of high-tech patenting*.

actions of the last half-century have not displaced big players with flush balance sheets while simultaneously engendering a new generation of innovative firms.

In comparing the charts of patent grants in software compared to total patent grants, one finds a marked correlation, indicating that software patents have constituted a significant share of patent grants from 1975 onward, though it is slowly beginning to change. Additionally, Bessen and Hunt found that, on a per-inventor basis, new technological fields are characterized by "rapid bursts of innovation from a relatively small group of inventors," which is then succeeded by a decrease in "per-inventor productivity as more inventors pursue these opportunities." While the relative value of early versus late patents cannot be assessed through data, the implicit lesson behind "burst patenting" rewards countries that are first to innovate.

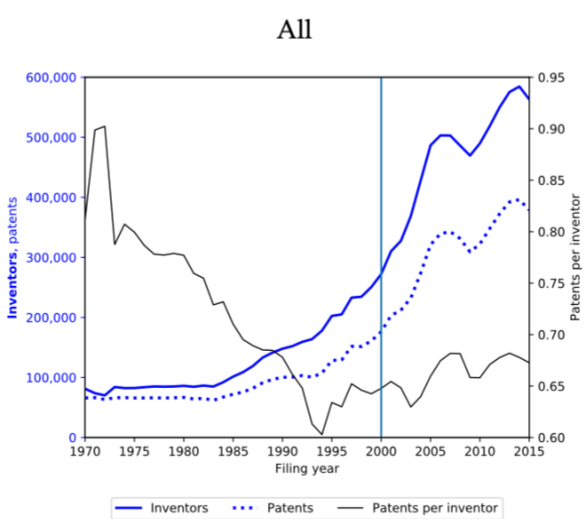

Figure 2: All Patents, Inventors, Patents per Inventor (Bessen)

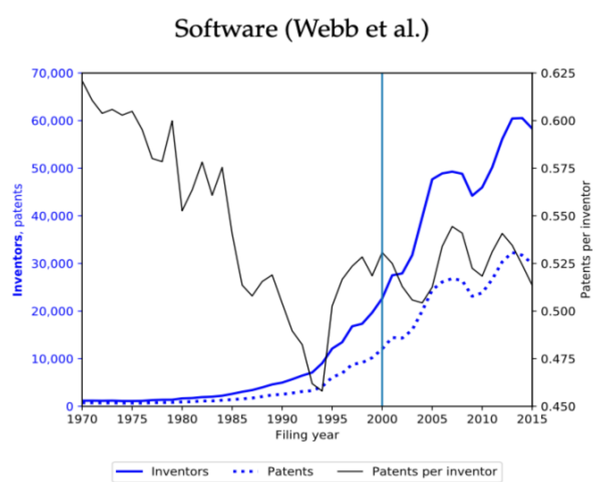

Figure 3: Software Patents, Inventors, Patents per Inventor (Bessen)

- <u>Antitrust</u>

The ability of firms to continue to keep their human capital and IP portfolio intact as they scale has potentially material consequences for their ability to innovate. Breakups of resource-rich companies—including segments of patent portfolios, labs/equipment, and human capital—have the potential to create valuable spinoffs. On the flipside, antitrust climates might have a chilling effect on incumbent innovation while incentivizing new firm innovation. Ever since the establishment of the Sherman Antitrust Act of 1890 and its companions, the Clayton Antitrust Act of 1914 and the Federal Trade Commission Act of 1914, the United States has gone through cycles of aggressive antitrust enforcement followed by reduced scrutiny.

Antitrust policy is unique among sub-levers in that the statutes that support it have not changed meaningfully from the original three founding statutes. Rather, it is the interpretation of these statutes by the courts in light of changing scholarship, data, case studies, and national sentiment that has changed over the last century. In a Harvard Business Review study by law professors Maurice Stucke and Ariel Ezrachi, these changes have spanned four general periods.

The first period, at the outset of the century, spanned the years 1900 to 1920, and was characterized by strong antitrust sentiment, evidenced by the passages of the triumvirate of antitrust statutes.[33] This period saw the infamous *Standard Oil Co. of New Jersey v. United States* case, which resulted in the creation of Exxon, Amoco, Mobil, Chevron, Conoco, and 29 other successor companies. Similar actions were taken and won

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[33] Maurice E. Stucke, and Ariel Ezrachi. "The Rise, Fall, and Rebirth of the U.S. Antitrust Movement." *Harvard Business Review*, 15 Dec. 2017. *hbr.org*, https://hbr.org/2017/12/the-rise-fall-and-rebirth-of-the-u-s-antitrust-movement.

against the American Tobacco Company and Northern Securities Co. (a railway monopoly). The second period, from 1920 to 1940, revealed a swing back to the middle. Antitrust enforcement died down with success stories like the Ford Motor Co., with administrations preferring “industry-government cooperation” as the New Deal came into effect. During this period, the Robinson-Patman Act of 1936 was passed to prohibit predatory pricing by larger “megachains” against smaller, local retailers as well as supplier coercion.[34]

The third cycle, from 1940 to 1970 (preceding the Third Industrial Revolution), is considered to be the “golden era of antitrust action.” As the world devolved into a race between state-sponsored conglomerate communism and free-market competition capitalism, antitrust action took on both an economic and political significance. The use of *per se* illegality came into being and vastly expanded the range of punishable actions, including tying, group boycotts, and vertical constraints up or down the value chain.[35] The Celler-Kefauver Act of 1950 banned “asset or stock consolidations which fell short of creating dominance,” acting as a deterrent to vertical integrations and conglomerate formation. The fourth cycle, from the 1970s to the end of the century, saw a marked decline in antitrust enforcement as a result of the rise of Chicago School economic thought, which pushed back on the uniform illegality imputed by *per se* interpretations and promoted a belief in self-correcting markets.[36] Antitrust’s prior focus on preventing market concentration was gradually replaced by a focus on “consumer welfare.” [37]

[34] Daniel S Campagna. "Robinson-Patman Act". Encyclopedia Britannica, 17 Apr. 2018, https://www.britannica.com/topic/Robinson-Patman-Act.
[35] William E. Kovacic, and Carl Shapiro. "Antitrust policy: A century of economic and legal thinking." *Journal of Economic perspectives* 14.1 (2000): 43-60.
[36] Maurice E. Stucke, and Ariel Ezrachi. “The Rise, Fall, and Rebirth of the U.S. Antitrust Movement.”
[37] Maurice E. Stucke. "Reconsidering antitrust's goals." *BCL Rev.*53 (2012): 551.

Several studies have concluded that, since the 1970s, market power (and concentration) of companies has increased due to increased profitability, which is in turn a result of higher operating margins.[38] These margins have not resulted from increased operational efficiency but rather higher prices.[39] Additionally, firms in industries with the greatest increases in market concentration have, on average, greater profit margins, stock returns, and M&A deals, signaling the greater importance of market power as a value source. The data provides support for these studies on market power: young firms accounted for about half of all firms and one-fifth of total employment in 1982, but only accounted for one-third of all firms and one-tenth of total employment in 2013.[40]

Both the data and much of the scholarship reviewed with regard to this fourth cycle temporally correlate with the rise of Silicon Valley behemoths, like IBM, in the early innings of the Third Industrial Revolution. Future giants such as Microsoft and Apple would also survive intense antitrust scrutiny later in the revolution. The free-market faith of the fourth cycle might therefore have contributed to the rise of these technology giants, providing an incubation period of sorts to allow disruptive technologies to scale and diffuse. Today, however, it appears that hegemony may be established, and a critical concentration of market power is slowing new enterprise formation. The question for the Fourth Industrial Revolution is whether i) the current antitrust sentiment will continue (recent policy discussions do not support continuation)

[38] Jan De Loecker, Jan Eeckhout, and Gabriel Unger. "The rise of market power and the macroeconomic implications." *The Quarterly Journal of Economics* 135.2 (2020): 561-644.
[39] Gustavo Grullon, Yelena Larkin, and Roni Michaely. "Are US industries becoming more concentrated?" *Review of Finance* 23.4 (2019): 697-743.
[40] Jason Furman. "Beyond Antitrust: The Role of Competition Policy in Promoting Inclusive Growth." *Obama White House Archives*, 16 Sept. 2016, https://obamawhitehouse.archives.gov/sites/default/files/page/files/20160916_searle_conference_competition_furman_cea.pdf.

and ii) whether hegemonic scale is now an advantage in a world of global competition and higher barriers to entry for technology firms.

- International Trade

World War II, which occurred a couple of decades before the start of the Third Industrial Revolution, forever changed the structure of United States trade policy. In. 1971, a study by William Branson and Helen Junz made notable conclusions regarding the nature of this structural shift. [41] Before World War II, the United States was a net importer of consumer goods by a small margin, and this small deficit in consumer goods held steady from 1925 to 1938. In the same era, the United States maintained large surpluses capital goods; while exports of capital goods were much more volatile (varying between $400–600mm), they remained far higher than imports which remained flat (between $10–40mm).

After World War II, these patterns became entirely disrupted. In consumer goods, the temporary surplus during the war and immediately afterwards disappeared, with imports overtaking exports in 1959. By 1970, the consumer goods deficit reached $4.8bn. Deficits also arose across industrial inputs, fuels/lubricants, and raw materials. In capital goods, pre-war surpluses ballooned due to the United States' position as the only industrial economy left undamaged. By 1970, surpluses in capital goods reached $10bn.

[41] William H. Branson, et al. "Trends in U.S. Trade and Comparative Advantage." *Brookings Papers on Economic Activity*, vol. 1971, no. 2, 1971, p. 285. *DOI.org (Crossref)*, https://doi.org/10.2307/2534225.

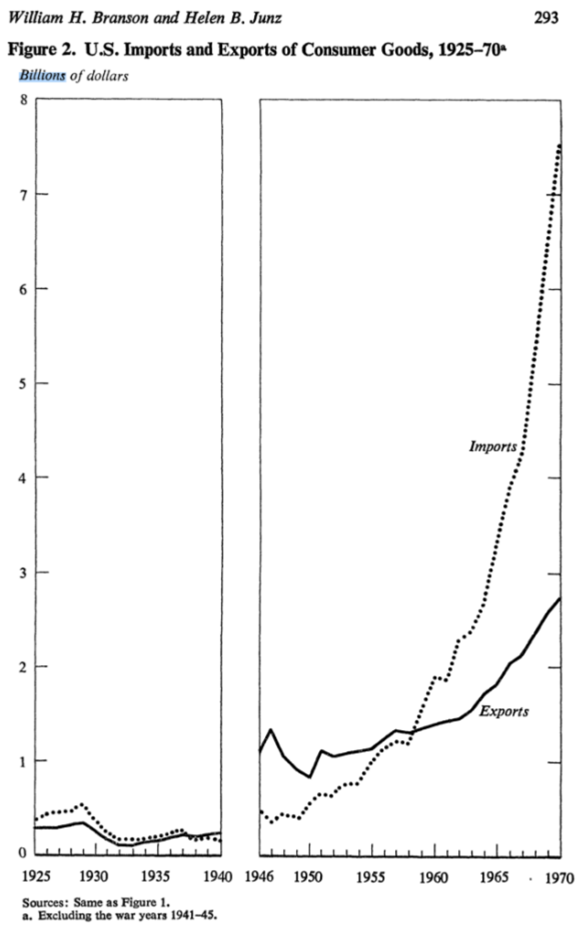

Figure 4: U.S. Imports and Exports of Consumer Goods, 1925-70 (Branson)

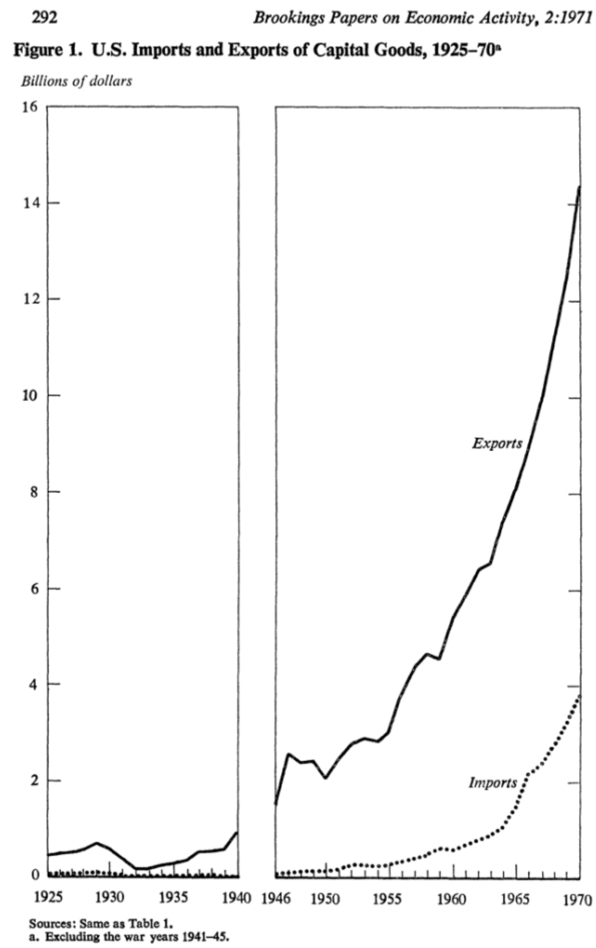

Figure 5: U.S. Imports and Exports of Capital Goods, 1925-70 (Branson)

According to Branson and Junz, the central structural shift was one that is now familiar today, from exports intensive in “physical capital” (i.e., labor) to those intensive in “human capital” (i.e., skills/expertise). Critically, in an analysis of explanatory variables, they found one of the highest correlations between the R&D expenditure ratio (the ratio of research and development expenditures to value added) and net exports of manufactured goods. This high degree of correlation persisted when controlling for human capital, preventing the circular argument that high R&D expenditures were simply correlated with companies that employ more employees to conduct research (scientists and researchers, in particular). At minimum, it revealed that the United States' comparative advantage in manufactured goods was not simply a result of exceptional human capital.

From a policy perspective, two central themes emerged in post-World War II trade policy: i) **reducing executive authority over trade policy relative to Congress**, and ii) **liberalizing the economic world order**. According to Robert Baldwin's analysis on the evolution of United States trade policy for the National Bureau of Economic Research in 1984, foreign policy leaders of the Democratic party were convinced that the lack of "an open world economy during the 1930s was a major contributory cause" of World War II, and that it was incumbent upon the United States to take a leadership role and install one.[42] The theory implicit was that in order to secure peace, according to President Roosevelt, the "economic foundations … [must be] as secure as the political foundations." At the same time, Congress was increasingly reluctant to bestow the president with increased economic powers, which it viewed had erroneously been transferred to the Executive Branch over the course of the Great Depression and the emergency powers needed to address the operational demands of World War II.

The Trade Expansion Act of 1962 was the United States' first effort at achieving the two broad objectives outlined above. This act gave the president the authority to impose tariffs on goods that threatened the nation's national security interests, directed the president to eliminate "unjustifiable" restrictions on foreign imports, and gave him the authority to suspend or withdraw concessions given to countries imposing trade

[42] Robert E. Baldwin, "The Changing Nature of U.S. Trade Policy since World War II." *The Structure and Evolution of Recent US Trade Policy*, University of Chicago Press, 1984, pp. 5–32. *National Bureau of Economic Research*, https://www.nber.org/books-and-chapters/structure-and-evolution-recent-us-trade-policy/changing-nature-us-trade-policy-world-war-ii.

burdens on American exports. This was followed by the Trade Act of 1974 ahead of the Tokyo Round of multilateral negotiations, which granted the president fast track authority to negotiate trade agreements with tariff and non-tariff barrier (NTB) components. In tandem, it also reassumed powers given to the Executive Branch over the last few decades by requiring any agreements to receive Congressional approval before effect.

Policy through the 1980s continued to cut tariffs as Japan, the United States, and the European Union sought to liberalize global trade.[43] Simultaneously, provisions were made domestically to provide relief for vulnerable industries and monitor unethical trade practices (e.g., dumping) were taken. The 1988 Omnibus Trade and Competitiveness Act established the United States' objectives for the Uruguay Round, including additional decreases of tariffs and other trade barriers.

In 1993, the United States committed to the results of the Uruguay Round and helped establish the World Trade Organization. The North American Free Trade Agreement (NAFTA) was entered into force in 1994; while this act is alleged to have contributed to the decline of manufacturing activity in the United States, the timing of its enactment as well as the absence of advanced technology industries in Canada or Mexico makes it unlikely to be a material driver of innovative output.[44]

In many ways, the United States' shift in comparative advantage closely preceded total trade deficits that continue to the present day. The United States' first year of total deficits began in 1972 and has only accelerated since then, hitting new highs shortly after

[43] *U.S. Trade Policy since 1934*. United States International Trade Commission, https://www.usitc.gov/publications/332/us_trade_policy_since1934_ir6_pub4094.pdf.
[44] David Floyd. "NAFTA's Winners and Losers." *Investopedia*, https://www.investopedia.com/articles/economics/08/north-american-free-trade-agreement.asp.

the passage of NAFTA in 1994 and the entrance of China in the WTO in 2001.[45] Brian Reinbold and Yi Wen at the St. Louis Fed, however, point to the abandonment of the gold standard in 1971 and the subsequent demand for the dollar as the world's reserve currency as the cause for persistent deficits.[46] They propose that the progression of the United States' comparative advantage from an industrial, labor-intensive economy to a "service-oriented welfare state" is not unique. The United Kingdom transitioned from a capital-intensive mass production power to a welfare state in the early-20th century while the United States took its place. After World War II, the United States began to enter a welfare state and relocated its manufacturing sector abroad to Japan and, later, the Asian Tigers. By the 1990s, the Asian Tigers moved to capital-intensive mass production and China took their place as the labor-intensive center of production. Today, as labor costs have risen in China, the country is moving to a capital-intensive mass production phase. If Reinbold and Wen's theory is correct, then China's projected economic slowdown around 2050 might signal its final transition to a service-oriented welfare state.

Chapter 3.3: Science & Technology Policy

As outlined in the policy lever description, science and technology policy directly concerns national activities around the development of scientific research and industry as well as its funding and support. This policy lever is primarily concerned with the United States' support for activities in science and technology development, which is proximately reasoned to

[45] James McBride and Andrew Chatzky. "The U.S. Trade Deficit: How Much Does It Matter?" *Council on Foreign Relations*, https://www.cfr.org/backgrounder/us-trade-deficit-how-much-does-it-matter.

[46] The specific reason is the imbalance between savings and investment rates. As global countries held more dollar reserves, the US had to issue more dollars to compensate (Brian Reinbold and Yi Wen. *Understanding the Roots of the U.S. Trade Deficit.* https://www.stlouisfed.org/publications/regional-economist/third-quarter-2018/understanding-roots-trade-deficit.)

contribute to innovation. Key components of science and technology policy include research and development expenditures, federal funding of public and private research, cooperative research programs, and spillover effects of public research. Because much of federal R&D funding was tied to defense programs, science-related defense and national security spending is also considered within this lever. On the other hand, closely related capabilities, such as the development of capable scientists and the commercialization process of scientific discoveries, are left for other levers (Education and Commerce, for the prior example).

- Federal R&D Spending

  Since the data became available in 1949, total R&D spending by the federal government has increased in absolute dollars.

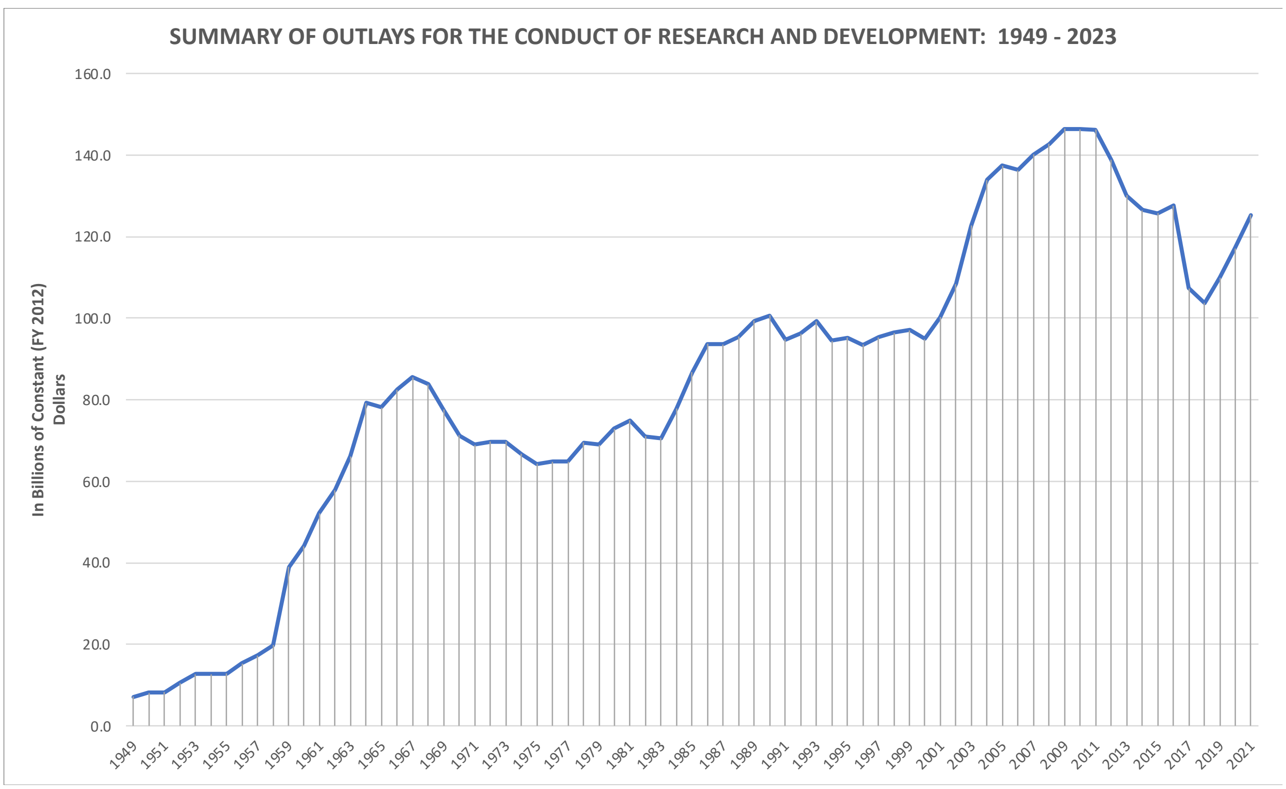

Figure 6: Summary of Outlays for the Conduct of Research and Development 1949-2023 (White House Office of Management and Budget)

The Composition of Outlays for the Conduct of Research and Development (see Figure 6) illustrates total federal spending on R&D programs over time in constant FY2012 dollars. With exceptions post-moon landing and most recently beginning in 2011, total spending has generally increased with the size of the government. In less than 10 years, from 1958 to its era-peak in 1967, R&D spending jumped a staggering 332% to $85.6bn, representing 10.1% of total federal spending. Although R&D spending continued to trend lower as a percentage of total spending, it rebounded in absolute dollars during the Reagan administration's science-and-technology offensive against the Soviet Union in the 1980s and again during the Global War on Terror in 2010s.

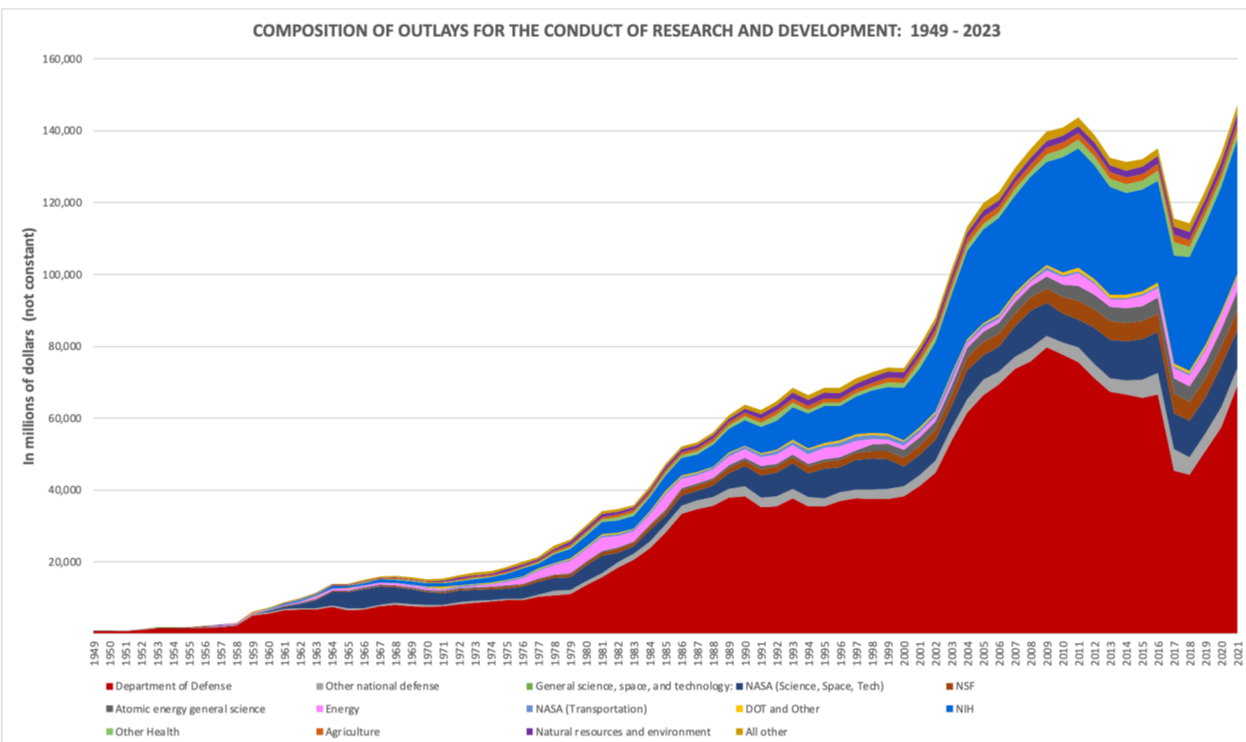

Figure 7: Composition of Outlays for the Conduct of Research and Development: 1949-2023 (White House Office of Management and Budget)

In the years leading up to the start of the Third Industrial Revolution around 1970, the Department of Defense and NASA made up the two largest contributors of federal R&D dollars (see Figure 7). Shortly after the moon landing in 1969, NASA's share began to fall, replaced by growth in allocations to the Department of Energy and the National Institutes of Health (NIH). Over the course of the Third Industrial Revolution, particularly beginning in the early 1990s, the NIH far and away received the greatest share of total research budget authority of all federal agencies, with the Department of Defense coming in second. By the end of the Third Industrial Revolution around 2010, NASA's research budget authority had fallen below the Department of Agriculture.

These datapoints confirm the first major theme in federal R&D policy at the outset of the Third Industrial Revolution: **the majority of R&D dollars were public, and the availability of these dollars increased at an exponential pace.** The sharp increases in federal R&D spending by the late 1960s were critical for the formation of a flourishing ecosystem around advanced electronics. Public R&D funding produced numerous "spillover effects" that benefited universities, trained a highly skilled workforce, allowed for the licensing of advanced technology by smaller firms, and encouraged private capital investment.[47]

Frederick Terman, Stanford's Dean of Engineering in 1946, was a central figure at the center of R&D and commercialization efforts in the post-war electronics industry. Before the war, most of the largest R&D laboratories were on the East Coast in centralized, corporate installations with limited mobility and lackluster new firm growth.

[47] Stuart W. Leslie, and Robert H. Kargon. "Selling Silicon Valley: Frederick Terman's model for regional advantage." *Business History Review* 70.4 (1996): 435-472.

However, due to the sharp rise in government sponsorship of advanced electronics technology development, much of the resulting intellectual property was held by the government and thereby available for public use.[48] Terman recognized a golden opportunity to break the control the East Coast behemoths held over the electronics industry.

Terman's plan was taking form at the same time that federal R&D dollars on the East Coast began producing the first innovations in the electronics industry. US Army sponsorship focused on the Massachusetts Institute of Technology (MIT) and the University of Pennsylvania for early research programs into computers.[49] These efforts paid off in 1946, when University of Pennsylvania researchers Mauchly and Eckert produced the ENIAC, the world's first general purpose calculator. The ENIAC was massive and unwieldy, weighing 30 tons and occupying a full gymnasium. However, by 1951, this machine had been successfully commercialized by Remington Rand into the UNIVAC-1. This success encouraged other private companies, such as IBM and Sperry Rand, to develop computers of their own, with the support of military contracts and government-sponsored research at MIT. Within ten years, IBM would come to dominate the computer mainframe market with its 7090 and 360/370 models.

Later on, in 1982, the Small Business Innovation Development Act would require all federal agencies with substantial R&D budgets to fund innovative projects of their choosing at small businesses.[50] These grants were made on a competitive basis and were

[48] In 1980, the Bayh-Dole Act permitted private firms to retain the rights to commercialize intellectual property developed using government funding.
[49] Manuel Castells. *The Rise of the Network Society*. Wiley-Blackwell, 2009. https://onlinelibrary.wiley.com/doi/book/10.1002/9781444319514.
[50] National Academy of Sciences (US) Committee on Criteria for Federal Support of Research and Development. *Box II.1, GOVERNMENT-UNIVERSITY-INDUSTRY COOPERATIVE R&D POLICIES*. National Academies Press (US), 1995, https://www.ncbi.nlm.nih.gov/books/NBK45556/.

meant to increase the coordination between the R&D activities of small technology enterprises and federal or public needs.

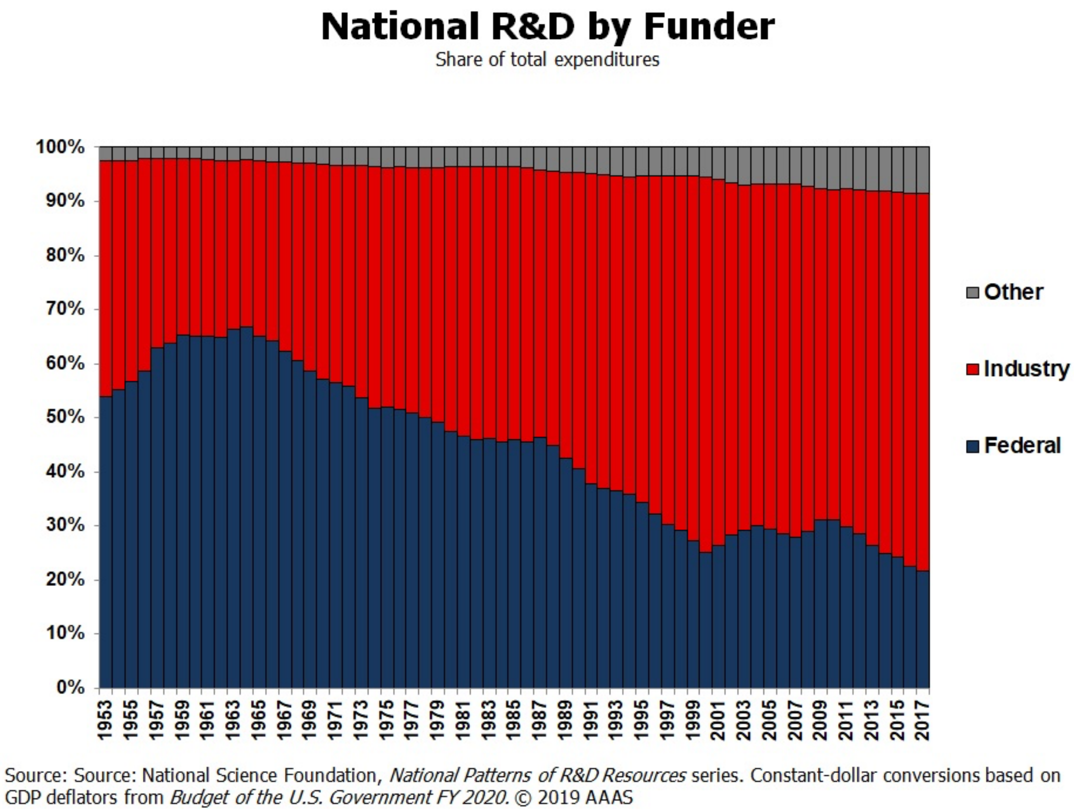

Figure 8: National R&D by Funder (American Association for the Advancement of Sciences)

The allocation of early federal R&D dollars signaled the second major policy theme: **public support for advanced industries with high uncertainty, significant productivity enhancement potential, and scalability.** World War II had significantly expanded the United States' industrial capacity, giving it a head start on procuring advanced parts during the Korean War in a shorter amount of time. The military's need for "microwave tubes for radar, electronic countermeasures, and communications" transformed companies with specializations in niche electronic technologies into massive enterprises nearly overnight.[51] Klystrons, a type of microwave receiver and transmitter

[51] Stuart W. Leslie and Robert H. Karagon, pp. 78.

invented in 1937 by the Varian brothers, were in extremely high demand as a component part. Prominent examples included Varian Associates, Litton Enterprises, Eimac, and Huggins Laboratories, nearly all of whom focused on the development of klystrons and microwave tubes.[52]

These small firms were the recipients of millions in Department of Defense loans, contracts, subsidies, and grants that directly funded research, representing a microcosm of the immense amount of federal money being pumped into R&D at Silicon Valley. From 1951 to 1953, California received $13bn worth of prime military contracts, overtaking New York State as the leading recipient.[53] By 1959, half of all electronics sales (about $3bn/year) went to the military, and Silicon Valley represented about a third of the nation's tube and klystron sales at the turn of the decade. As the Cold War ramped up, science and technology, particularly within aerospace and space exploration, became a national security priority for the federal government. This newfound attention attracted the talents of large East Coast firms, including General Electric and Lockheed Missiles and Space, to set up research centers in Silicon Valley. By 1964, Lockheed was the region's largest employer with 25,000 employees, and the majority of its sales went to the government.[54] All of the aforementioned companies would purchase space at Stanford Industrial Park, hire Stanford graduates, and send employees to Stanford's honors cooperative program.[55]

[52] "Stanford also played a key role in fostering the klystron, perhaps the most important electronics innovation developed on the West Coast before World War II. In 1937 the Varian brothers, working with several Stanford physicists, invented the klystron, an **original and extremely flexible microwave receiver and transmitter**. Under an unusual contract with the university, the Varians were granted access to faculty, laboratory space, and modest funding for materials in return for a half interest in any resulting patents." Ibid, 76.
[53] Ibid, 78.
[54] Kushida, 13.
[55] Stuart W. Leslie and Robert H. Karagon, pp. 82.

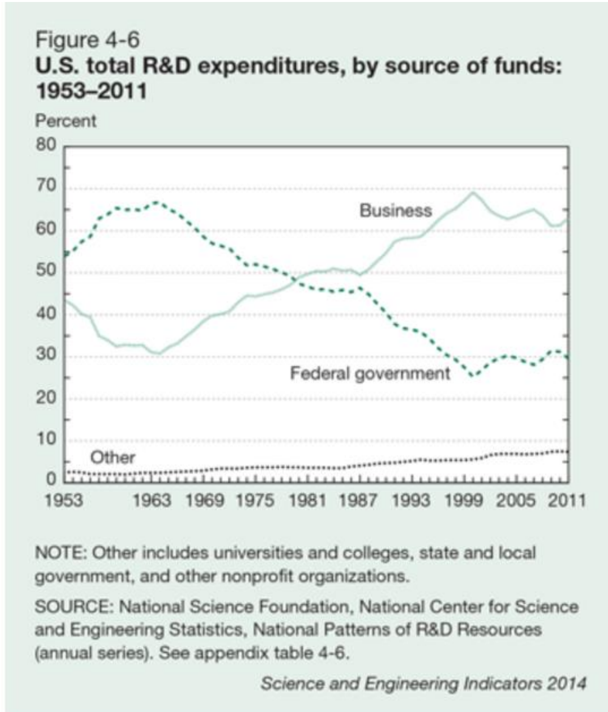

Figure 9: US total R&D expenditures, by source of funds: 1953-2011 (National Science Foundation)

Having government as the lead buyer was important for the invention of technologies without an obvious commercial purpose at the time, such as microwave tubes, radio communications technology, and computers. However, a big shift occurred in the early 1960s when the government became stricter with its issuance of contracts and procurement processes in an effort to control spending. Excess inventories were removed, "splurge" projects were cancelled, and new weapons system development was halted.[56] The worst impacts were levied on manufacturers of electronic components, such as microwave tubes, silicon transistors, and klystrons. By 1964, spending on these key components had fallen back to or below 1960 levels. This change had a significant impact on the revenues of electronics companies across Silicon Valley, who suffered steep declines in profitability. Thousands of employees were laid off, firms went

[56] Lécuyer, Christophe. *Making Silicon Valley: Innovation and the growth of high tech, 1930-1970*. MIT Press, 2006.

bankrupt or were acquired,[57] and inventories piled up. As a result, this policy shift came to be known as the "McNamara Depression," after Robert McNamara, the Secretary of Defense under John F. Kennedy. Public R&D expenditures as a percentage of national outlays would continue to decline through the rest of the 20th century to be overtaken by industry R&D expenditures in the 1980s (see Figure 9).

Silicon Valley electronic component suppliers were forced to diversify into commercial markets to wean off their dependence on military contracts. While this was initially painful, it was consequential in the development of the Third Industrial Revolution. Litton entered the microwave oven business, while Varian diversified into scientific instruments and vacuum pump systems on the back of an in-house tube invention. The engineers at Fairchild Semiconductor were the most famous. In 1959, Jean Hoerni invented the planar process, which allowed silicon components to be manufactured precisely, and Robert Noyce designed the first planar integrated circuit.[58] Integrated circuits allowed electronic components (transistors, capacitors, etc.) to be miniaturized and combined into one unit, spawning the advent of consumer electronics as we know it today. Internal troubles with management led to a wave of engineering and management departures. Noyce and Fairchild's head of R&D, Gordon Moore, recognized the commercial opportunity in memory circuits, especially for computers and their accessories, and left to found Intel in 1968. Other Fairchild spin-offs included Amelco (later Teledyne Semiconductor and then Telcom Semiconductor), Applied Materials,

[57] Ibid. Many East Coast firms who had opened research divisions in Silicon Valley, such as Philco, Sylvania, GE, RCA, and Westinghouse, downsized or exited the market. Varian Associates merged with Eitel-McCullough in 1965, allowing the combined entity to re-obtain a substantial portion of the klystron and vaccum tube markets.
[58] Piero Scaruffi. "A Timeline of Silicon Valley," 2009. https://www.scaruffi.com/svhistory/silicon.html.

National Semiconductor, Intel, and Advanced Micro Devices (AMD).[59] Fairchild alumni also helped establish the venture capital industry in Silicon Valley, including Kleiner Perkins Caufield & Byers and Sequoia Capital.

While R&D spillover effects are difficult to measure, a study by Moretti, Steinwender, and Van Reenen on defense-related R&D found that, for every 10% increase in government R&D expenditures, a commensurate 5-6% additional increase in privately funded R&D could be expected.[60] In other words, public R&D "crowds in" rather than "crowds out" private R&D spending. The study also found evidence for positive spillover effects in R&D internationally for the same industry as well as an 8.3% average increase in annual total factor productivity growth.

Today, public R&D funding appears to be exhibiting a rebound after a decade of declines under the Obama administration (Figure 7: "Composition of Outlays for the Conduct of Research and Development"). In contrast to the early years of the Third Industrial Revolution when public R&D made up a majority of total R&D outlays, today public R&D expenditures make up less than a third of total R&D spending in the United States (Figure 8: "National R&D by Funder"). Additionally, within public R&D spending, the share of science, space, and technology-related outlays has declined the most, dropping from an average of 31.9% in the years 1965-1971 to an average of 16.0% in the years 2014-2020.[61] The largest beneficiary in its place has been health-related R&D (directed overwhelmingly to the NIH), which saw its share increase from 6.0% to 26.7%

[59] "Fairchildren." *Computer History Museum.* https://computerhistory.org/fairchildren/.
[60] Enrico Moretti, Claudia Steinwender, and John Van Reenen. *The intellectual spoils of war? Defense r&d, productivity and international spillovers*. No. w26483. National Bureau of Economic Research, 2019.
[61] "Table 9.8—Composition of Outlays for the Conduct of Research and Development: 1949–2023." White House Office of Management and Budget. https://www.whitehouse.gov/omb/budget/historical-tables/.

over the same period. Defense-related R&D has remained largely the same, seeing a slight drop from a 51.5% share to a 48.7% share.

- <u>Cooperative R&D Programs</u>

In 1973, the National Science Foundation created the Industry–University Cooperative Research Centers (IUCRC) program in 1973 to provide structures for research sharing between government, industry, and academia. IUCRCs were designed to help tailor university research to meet federal science and technology objectives and, in turn, facilitate technology transfer from universities to firms. As a result, they depended mostly on industry support. In a study of the centers, Adams, et al. (2001) found that IUCRCs did indeed promote industry-university technology transfer, though in small increments.[62]

Renewed attention was shed upon industry collaboration efforts in the 1980s with the passage of the Omnibus Trade and Competitiveness Act of 1988. This act established an Advanced Technology Program (ATP) through the National Institute of Standards and Technology (NIST) that established a program of competitive awards for technology development projects, particularly in semiconductor and advanced manufacturing technologies.[63] Feldman and Kelley (2003) found that ATP awards provided a material mark of credibility for winning firms that aided them in attracting future investments.[64]

Chapter 3.4: Fiscal and Financial Policy

[62] James D. Adams, Eric P. Chiang, and Katara Starkey. "Industry-university cooperative research centers." *The Journal of Technology Transfer* 26.1 (2001): 73-86.
[63] *U.S. Trade Policy since 1934*.
[64] Maryann P. Feldman, and Maryellen R. Kelley. "Leveraging research and development: Assessing the impact of the US Advanced Technology Program." *Small Business Economics* 20.2 (2003): 153-165.

As outlined in its policy lever description, fiscal and financial policy primarily concerns the flow of capital in the economy, and more specifically, in the private sector. This lever can be broken into its two named component parts: fiscal policy and financial policy. The key distinction between the two is that fiscal policy is directly overseen by Congress and primarily concerns cash payments, such as taxes and subsidies, on individuals and corporations in the United States, while financial policy primarily concerns the oversight and regulation of the flow of capital in public (e.g., New York Stock Exchange) and private (e.g., venture capital, private equity) markets. While financial policy is also written by Congress, its interpretation and enforcement is delegated to a variety of regulatory organizations, such as the Securities and Exchange Commission and the Commodity Futures Trading Commission, and to the Departments of Treasury and Justice, to a lesser extent. In contrast, fiscal policy is primarily administered through the Internal Revenue Service, a child organization of the Department of Treasury.

- <u>Fiscal Policy</u>

  Fiscal policy can be broken into two categories: i) taxation and ii) spending. Spending was discussed in Chapter 3.2 under Science and Technology Policy. Thus, the focus of this section will be on government taxation broadly and on innovation-related activities in particular.

  Starting with corporate taxes, we can analyze the progression of tax rates and brackets for the relevant period. According to IRS data, the lowest marginal tax bracket has trended lower since the 1950s, coming down from 30% to 15% (see Figure 10). The data also shows the effect of inflation, with the only two taxable brackets in the 1950s set at above or below $25,000.[65] Over time, the total number of taxable brackets would balloon to a high of eight in 1987, after which the Tax Reform Act of 1986 simplified the tax structure to five brackets. However, the Revenue Reconciliation Act of 1993 would again institute eight brackets and increase the top marginal tax bracket to 35%. This structure lasted until the Tax Cuts and Jobs Act in 2017, which reduced all corporate tax rates to a flat 21%.

After adjusting for inflation, the $25,000 lowest marginal bracket cutoff in 1960 would be roughly $184,000 in 2010 dollars.[66] Though there were four graduated brackets at 15%, 25%, 34%, and 39% in 2010 compared to a flat 30% rate in 1960, the tax bills for $25,000 in 1960 dollars and $184,000 in 2010 dollars under each framework are both roughly equal, coming out to $55,000 in 2010 dollars.[67] Thus, after adjusting income for inflation, taxed income (without accounting for deductions or credits) for the lowest marginal tax bracket is generally unchanged today. However, for new firms with little net income, marginal tax rates have decreased since 1960. Thus, a **low-tax regime for firms that are small and/or yet unprofitable** emerges as the first major fiscal policy theme.

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[65] *US Corporation Income Tax: Tax Brackets and Rates, 1909-2010*. Internal Revenue Service, https://www.irs.gov/downloads/irs-soi.
[66] "Inflation Calculator | Find US Dollar's Value from 1913-2022." https://www.usinflationcalculator.com/.
[67] "Historical U.S. Federal Corporate Income Tax Rates & Brackets, 1909-2020." *Tax Foundation*, 24 Aug. 2021, https://taxfoundation.org/historical-corporate-tax-rates-brackets/.

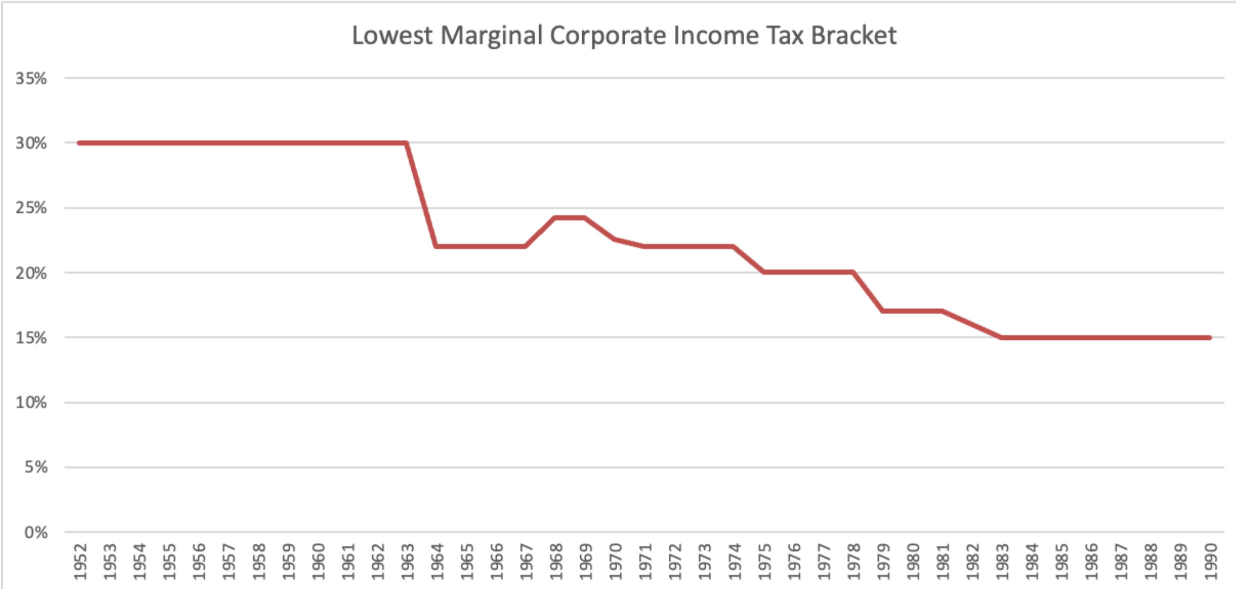


Figure 10: Lowest Marginal Corporate Income Tax Bracket (adapted from Internal Revenue Service data)

Over time, many studies have demonstrated an inverse (i.e., negative) relationship between taxes and innovative activity. Mukherjee, Singh, and Zaldokas (2016) analyzed corporate income tax changes from 1990 to 2006 and found that increases in corporate tax rates lead to "decreases in innovation across every step of the innovation process—R&D, patents, and … new products."[68] Akcigit et al. (2018) used datasets going back to the 1920s to track inventors and their progress over time (e.g., number of patents, places of residence, firms the patents were attributed to, etc.), historical state-level corporate income taxes, personal income tax rates, and innovation outcomes (e.g., patent values, state-level value added, etc.) to draw a relationship between taxes and innovation.[69] They found that, at the state level, both personal and corporate income taxes have "significant negative effects" on number of patents filed and inventors residing in the state. Additionally, the proportion of patents filed by firms relative to individuals is "strongly

[68] Abhiroop Mukherjee, Manpreet Singh, and Alminas Žaldokas. "Do corporate taxes hinder innovation?." *Journal of Financial Economics* 124.1 (2017): 195-221.
[69] Ufuk Akcigit, et al. *Taxation and Innovation in the 20th Century*. No. w24982. National Bureau of Economic Research, 2018.

negatively affected by taxation." For individual inventors, personal income taxes have "significant negative effects" on the likelihood of holding a patent, the number of patents held, the likelihood of producing a valuable patent, and the likelihood of locating in a state with higher taxes. Quality of innovation, proxied by patent citations, was not affected by taxation but rather by quantity.

Implicit in the discussion of the lowest marginal tax bracket is the assumption that innovation is originating from firms in that tax bracket (i.e., usually a startup or newer enterprise). However, this is not always the case. As discussed in Chapter 3.1, some of the largest catalysts for innovation in Silicon Valley of the 1950s and 60s were divisions and research laboratories of large, East Coast electronics firms. Although conclusive data regarding the relationship between firm size and innovation is difficult to find, Goss and Vozikis (1994) tentatively concluded that smaller high-tech firms, *ceteris paribus*, are "more productive" and "innovative" as measured by "value created per worker."[70] High-tech firms, however, can benefit more by locating in densely populated states with greater concentrations of the high-tech industry relative to the national average.

The capital gains tax is also material to the existence of a low tax regime, and Congress recognized this. According to Stanford researcher Kenji Kushida (2015), the lowering of the capital gains tax early on in the Third Industrial Revolution, was a "critical precondition" for the development of firms during the Internet Revolution.[71] Kushida refers to the 1978 Revenue Act, where the federal government slashed the

[70] Ernie Goss and George S. Vozikis. "High tech manufacturing: Firm size, industry and population density." *Small Business Economics* 6.4 (1994): 291-297.
[71] Kushida.

maximum individual marginal capital gains tax from 49.5% to 28.0%.[72] Three provisions entailed this overall reduction: 1) an increase in the fraction of capital gains able to be deducted from taxable income from 50% to 60%, 2) eliminating the untaxed portion of capital gains from being considered as an "add-on" minimum tax, and 3) eliminating the "poisoning of the maximum tax rate on personal service income" by untaxed gains. The bill reduced the corporate capital gains tax rate from 30% to 28% (this rate was decreased further to 20% in the 1981 tax cuts before being raised back up to 28% in 1987[73]). The 1978 Revenue Act was supported by early venture capitalists, who used stock options (and the profits from them, which were taxed as capital gains), to recruit talent to their cash-strapped startups.[74]

[72] *REPORT TO CONGRESS on the CAPITAL GAINS TAX REDUCTIONS OF 1978*. Office of Tax Analysis, Office of the Secretary of the Treasury, Sept. 1985, https://home.treasury.gov/system/files/131/Report-Capial-Gains-Reduction-1978.pdf. https://home.treasury.gov/system/files/131/Report-Capial-Gains-Reduction-1978.pdf.

[73] "Historical Capital Gains and Taxes." *Tax Policy Center Urban Institute & Brookings Institute*, 11 Feb. 2022, https://www.taxpolicycenter.org/statistics/historical-capital-gains-and-taxes.

[74] Zack Wasserman. "How Silicon Valley Hacked the Economy." The Nation. https://www.thenation.com/article/archive/how-silicon-valley-hacked-the-economy/

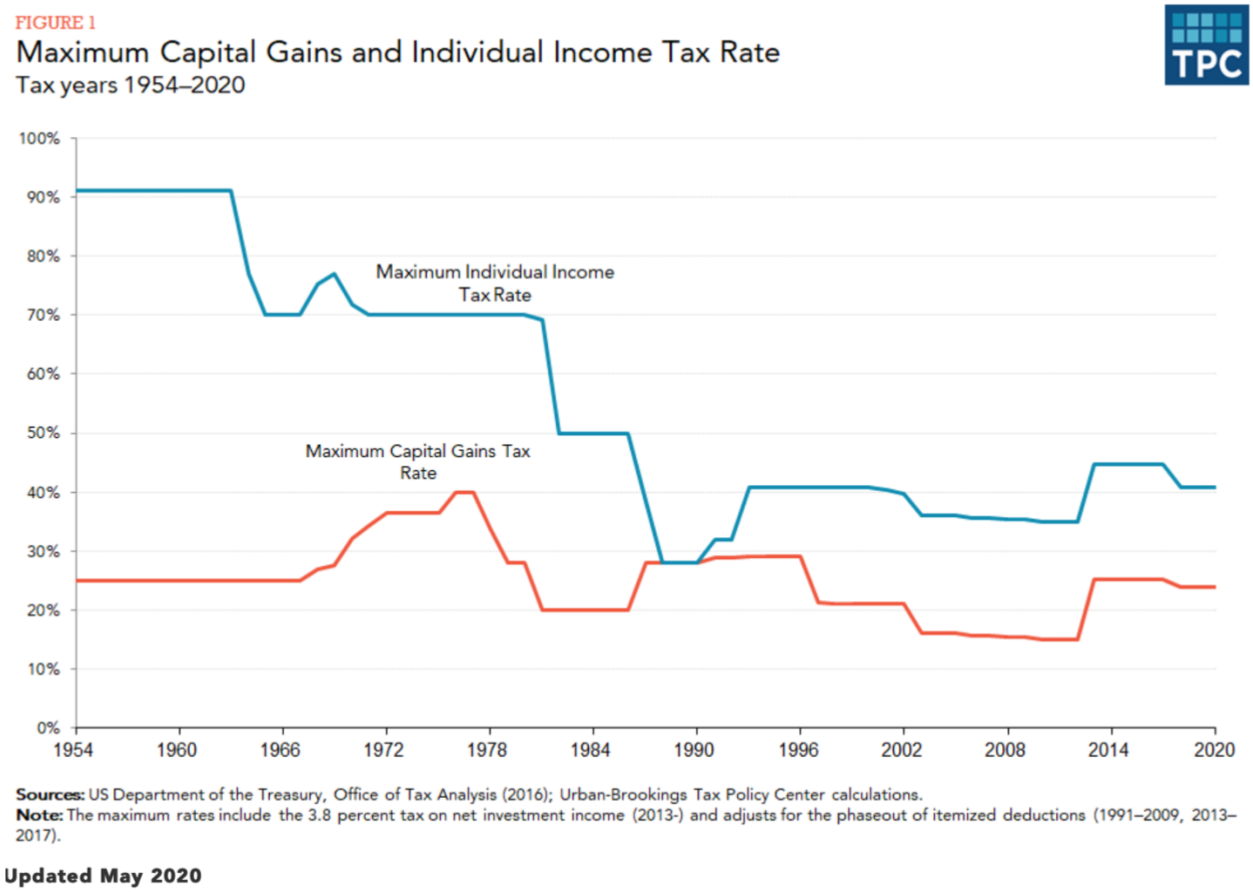


Figure 11 "Maximum Capital Gains and Individual Income Tax Rate" (Urban-Brookings Tax Policy Center, 2020)

There is debate about whether the reduction in capital gains tax had a meaningful effect on innovation. Several researchers, including Kushida (2015), Keuschnigg and Nielsen (2004), and Dimitrova and Eswar (2018), have found an inverse relationship between capital gains taxes and innovation. Keuschnigg and Nielsen used dynamic models that showed that "even a small capital gains tax" involves a "first-order welfare loss" by diminishing incentives for effort by entrepreneurs and managerial support by venture capital backers.[75] This is because of the exploitation of an existing distortion in incentives: with higher capital gains rates, venture capitalists (VCs) are more incentivized to use base salaries to attract entrepreneurs rather than equity contracts. When this occurs,

[75] Christian Keuschnigg and Soren Bo Nielsen. "Start-ups, venture capitalists, and the capital gains tax." *Journal of Public Economics* 88.5 (2004): 1011-1042.

entrepreneurial effort diminishes because base salaries are inherently less performance-based relative to equity.

Dimitrova and Eswar analyzed data on patent production from 12,493 private VC-backed firms to conclude that increases in the capital gains tax rate have negative effects on “both the level and quality of firm innovation,” as measured by number of patents produced and citations per patent, respectively.[76] They did this by conducting a state-by-state analysis of capital gains tax regimes, and found that both the quantity and quality of patent production responded symmetrically to a commensurate change in the capital gains rate (i.e., a linear relationship between the capital gains rate and quantity and quality of patents produced). Study of the demand channel (entrepreneurial willingness to take risk) and the supply channel (VC willingness to provide capital to startups) constituted the central division in their analysis. They were able to conclude that both channels experienced negative relationships with an increase in the capital gains rate. On the demand side, when capital gains rates increased, the standard deviation of patent quality (measured by number of citations per patent) decreased. In other words, entrepreneurs and VCs became less willing to take inventive risks. On the supply side, when capital gains are increased, the number of patents produced remains constant and the quality of patents decreases. The authors reason that this is because VCs, facing new funding constraints and reduced incentives for managerial support, are less likely to fund and support risker and potentially more innovative projects. These findings concur with Keuschnigg and Nielsen.

The second major theme within fiscal policy is the **government’s use of tax credits to stimulate innovation**. In an effort to encourage broad-based innovation,

[76] Lora Dimitrova and Sapnoti K. Eswar. "Capital Gains Tax and Innovation." *SSRN Electron. J* (2017).

Congress passed, as part of the Economic Recovery Tax Act of 1981, the first federal R&D tax credit. The credit covers four general categories, if used for research or experimentation purposes: wages, raw materials and supplies, sub-contractors, and computer costs.[77] Expenses must also pass the Four Part Test: 1) Permitted Purpose: the technology is related to the "development of a new or improved business component, defined as new or improved products, processes, internal use computer software, techniques, formulas, or inventions to be sold or used in the taxpayer's trade or business," 2) Elimination of Uncertainty: the technology is "intended to resolve technological uncertainty" regarding the viability and feasibility of "developing or improving" the business component, 3) Process of Experimentation: the technology must undergo "testing and evaluation of alternatives to eliminate technological uncertainty," and 4) Technological in Nature: the technology must "rely on a hard science, such as engineering, computer science, biological science, or physical science."[78] However, there are numerous exceptions to qualification for this R&D credit, such as research post-production/implementation, fixed assets used in business activities, and research conducted outside of the United States. Since its inception, the credit expired and was renewed several times until 2015, when Congress made it a permanent part of the tax code.

Studies by the federal government and academic researchers have found positive association between the R&D tax credit and expenditures on research. A study by the General Accounting Office in 1989 of a sample of 800 corporations estimated that the

[77] AlliantGroup. "R&D Tax Credit: How Your Work Qualifies." https://www.alliantgroup.com/services/r-d-tax-credit-2/.
[78] "U.S. Research and Development Tax Credit." The CPA Journal, 30 Oct. 2017, https://www.cpajournal.com/2017/10/30/u-s-research-development-tax-credit/.

new tax credit stimulated $1–2.5bn in additional research spending per year between 1981 and 1985; this came at an estimated cost of $7bn in tax revenues.[79] Baily and Lawrence (1992) estimated that additional research spending came in closer to $2.8bn per year between 1982 and 1989.[80] UC Berkeley's Browyn Hall (1993) came up with a more optimistic investment ratio, estimating that additional spending stimulated in the short run was about $2bn annually against $1bn in foregone tax revenues.[81]

Each of these studies acknowledged the existence of certain "relabeling incentives" (i.e., whether the R&D tax credits actually stimulate new innovation or simply prompt companies to relabel existing/related activities to claim a tax credit) which would diminish the intended purpose of the credit. However, in the early years of the credit, IRS agents who audited the claims determined that attempts at unqualified redemptions remained low. Additionally, Hall posits two reasons for why the R&D increase is real: 1) existing incentives in the tax system to relabel investment expenses as R&D, and 2) accounting for aforementioned relabeling in the base level of R&D before including incremental effects.

According to the OECD, the United States' "generosity of tax incentives" has declined slightly over the last 20 years, though this is attributable to weighting changes in models used.[82] While the United States ranks far below the OECD median for R&D tax subsidy rates, it ranks close to the top for total government support for business R&D as a percentage of GDP after including direct government funding; however, the gap between

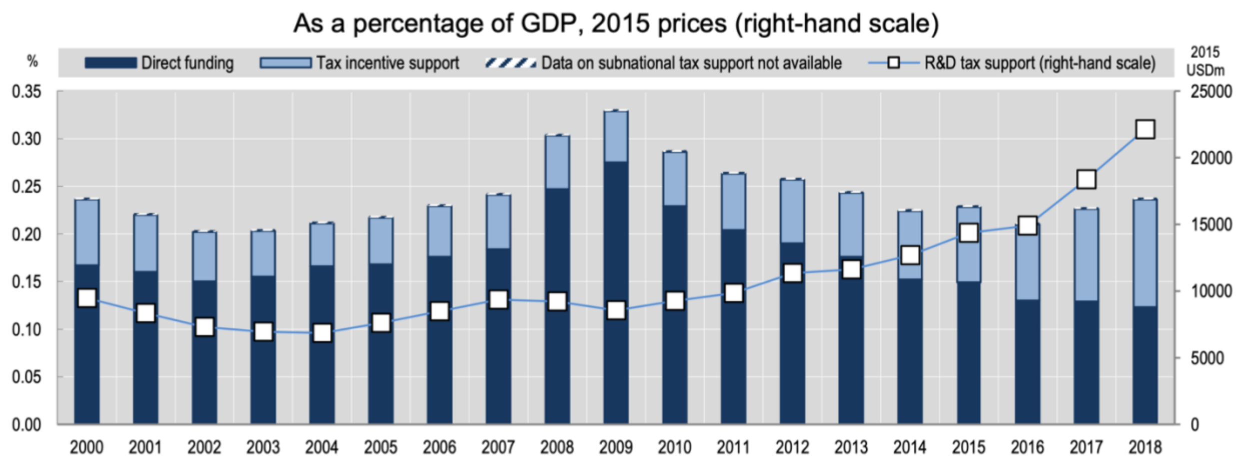
[79] *Tax Policy and Administration: The Research Tax Credit Has Stimulated Some Additional Research Spending*. U.S. Government Accountability Office. https://www.gao.gov/products/ggd-89-114.

[80] Martin Neil Baily and Robert Z. Lawrence. "Tax Policies and Competitiveness." Commissioned for Innovation by the Council on Research and Technology. 1992.

[81] Bronwyn H Hall. "R&D Tax Policy during the 1980s: Success or Failure?" *Tax Policy and the Economy*, vol. 7, Jan. 1993, pp. 1–35. *journals.uchicago.edu (Atypon)*, https://doi.org/10.1086/tpe.7.20060628.

[82] "R&D Tax Incentives: United States, 2021." OECD Directorate for Science, Technology and Innovation, 2021. https://www.oecd.org/sti/rd-tax-stats-united-states.pdf.

tax credits and direct funding has narrowed since 2009 to become nearly even. The mix and benefit of the tax credits varies by size and function. In 2013, Small and Medium Enterprises (SMEs) accounted for 74% of R&D tax credit recipients, but just 9% of tax benefits (relative to large firms). In 2018, services firms represented 68% of recipients while manufacturing firms represented 29% of recipients; each accounted for 49% of total tax benefits distributed.



- <u>Financial Policy</u>

Financial policy can be broken into two central jurisdictions: i) private markets and ii) public markets. Throughout history, both types of markets have played varying roles in the development of new firms. While public markets were more prominent sources of funding during the dot-com bubble, today private markets dominate funding for startups and series-stage companies. During the Third Industrial Revolution, innovations in each of these markets changed the nature of capital access for developing firms; however, the growth of private market financing represented the most dramatic shift in funding structure.

In private markets, the central policy theme to emerge was an **emphasis on returning to and promoting the role of private capital**. This was most apparent with the removal of the prohibition on the ability of pension funds to invest in risker asset classes, such as venture capital, in 1979.[83] This change was enacted by the Labor Department, who relaxed Employment Retirement Income Security Act (ERISA) restrictions under the "prudent man rule," which dictated that fiduciaries shall "discharge his duties with care, skill, prudence and diligence" such that "a prudent man acting in a like capacity and familiar with such matters would use in the conduct of an enterprise of a like character and with like aims."[84] This policy change drastically altered the funding landscape for startups: by the 1980s, pension funds became the "prime funder" of venture capital, going from $100-200mm per year in the 1970s to over $4bn in the 1980s.[85] By 1983, new commitments exceeded $5bn.[86] It is worth noting that university endowment funds did not face ERISA restrictions because they were governed by state laws or charters. This is evidenced by the fact that Yale's endowment fund made its first venture capital investment in 1976, three years before the new Labor Department guidance.[87]

The federal government also played a prominent role in the creation of the venture capital industry. The first known example of a venture capital firm was the American Research and Development Corporation (ARD) in 1946 in Boston, Massachusetts.[88] ARD was created out of the New England Council (NEC), a regional economic committee, with the backing of legislators and university leaders from MIT and

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83 Kushida, 33.
84 "Advisory Council Report of the Working Group on Prudent Investment Process." U.S. Department of Labor. https://www.dol.gov/agencies/ebsa/about-ebsa/about-us/erisa-advisory-council/2006-prudent-investment-process.
85 Kushida, 33.
86 *Venture Economics*, *Venture Capital Yearbook 1988*, p. 17 Entries are presented in 1987 dollars, deflated using the GNP deflator. From NBER Working Paper Series: *Venture Capital and Capital Gains Taxation*, James M. Poterba, Working Paper No. 2832.
87 Dawn Lim. *Yale Endowment's Venture Funds Hit Home Run*. The Wall Street Journal, 7 Apr. 2016, https://www.wsj.com/articles/yale-endowments-venture-funds-hit-home-run-1460073499?mod=article_inline.
88 Tom Nicholas. "The Origins of High-Tech Venture Investing in America." *Financial Market History: Reflections on the Past for Investors Today*, edited by David Chambers and Elroy Dimson, CFA Institute Research Foundation, 2016, pp. 227-242.

Harvard. ARD's focus was "high-tech ventures," and their successful early investment in Digital Equipment Corporation (DEC) in 1957 would eventually set a model for the industry when DEC underwent an IPO in 1966. Around the same time, the Small Business Administration launched the Small Business Investment Company (SBIC) structure.[89] The purpose of SBICs were to act as "federally regulated privately-owned and managed investment funds" to invest in promising startups[90]—essentially, they were a public form of venture capital. Initially, SBICs would provide debt and equity financing to promising companies.[91] Though most of the first SBICs in the 1960s were unsuccessful due to improper management and a focus on real estate, SBICs would make a rebound in the 1970s after a pivot to technology and manufacturing ventures; 300-500 SBICs would be in successful operation by then. However, by the start of the next decade, high interest rates coupled with the flood of venture capital entrants into the market would reduce the relevance of SBICs. By 1990, there were only 180 SBICs in operation, and VCs (backed by pension funds) became the dominant medium of private financing. Today, the SBIC's model is to augment private investments through low cost leverage matching programs.[92]

There is some evidence that SBICs were material to the creation of the modern VC business. Bill Draper, who founded Draper, Gaither and Anderson in 1958, is known as Silicon Valley's first venture capitalist. [93] Draper attested to the role SBICs played in the creation of the VC business, saying that "[without it] I never would have gotten into

[89] Thomas Wade. "The Small Business Investment Company Program: A Primer." *American Action Fund*, https://www.americanactionforum.org/insight/the-small-business-investment-company-program-a-primer/.
[90] "About the SBIC Program." Small Business Investor Alliance. https://www.sbia.org/fund-resources/sbic/.
[91] Thomas Wade, "The Small Business Investment Company Program: A Primer."
[92] "About the SBIC Program."
[93] Piero Scaruffi. "Part 3. The Greybeard Funders: Venture Capital in its Clubby Days (1955-78)." A Timeline of Silicon Valley. https://www.scaruffi.com/svhistory/arun3.html.

venture capital. . . it made the difference between not being able to do it, not having the money." Silicon Valley historian Arun Rao acknowledges that this view—that SBICs "filled a void from 1958 to the early 1970s" until the limited-partnership model could gain traction—was held by many in the industry at the time.

Regarding public markets, no notable research is available that finds that access to public markets to be a significant determinant of innovation or innovation-contributive factors. Additionally, data on IPOs before 1960 is disaggregated and poorly maintained, limiting this paper's ability to compare public market activity leading up to and through the Third Industrial Revolution. Additionally, given the advent of venture capital in the 1970s and its stated purpose,[94] it is unlikely that the public markets would have provided the critical source of funding needed for innovative activities. However, it is useful to examine potential associations between initial public offerings (IPOs) against significant commercial and technological milestones in Third Industrial Revolution history (see Figure 12). When annotating a historical chart of annual IPO volume, it appears "key" technological milestones, such as the invention of the planar circuit in 1959, the invention of the mainframe computer in 1964, and the invention of the microcomputer in 1976, immediately precede tremendous spikes in IPOs. These milestones were each step changes for their respective industries, allowing for the creation of a new ecosystem of competitors, customers, and suppliers, some of which would become publicly traded companies.

[94] Georges Doriot, a HBS professor and president of ARD at its inception, had the following to say about ARD's investment approach: "It should again be emphasized that American Research is a 'venture' or 'risk capital' enterprise. The Corporation does not invest in the ordinary sense. It creates. It risks. Results take more time and the expenses of its operation must be higher, but the potential for ultimate profits is much greater." (Nicholas, 229.)

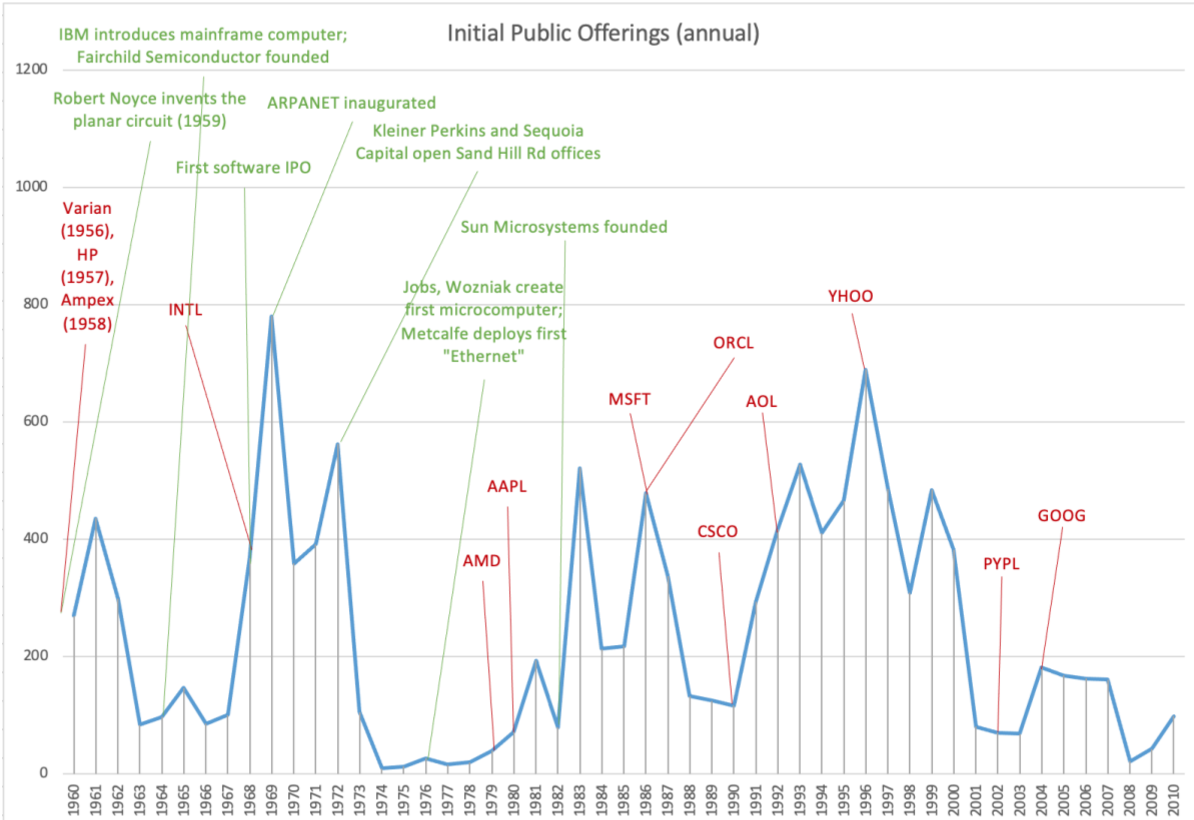

Figure 12: Annual Initial Public Offerings ("Initial Public Offerings: Updated Statistics" by Jay R. Ritter and "A Timeline of Silicon Valley" by Piero Scaruffi[95])

An important non-policy innovation worth mentioning was the development of **new governance structures** at the outset of the Third Industrial Revolution which **promoted employee ownership and control** of the firm, particularly that of founders. In Silicon Valley, law firm Wilson, Sonsini, Goodrich, and Rosati (WSGR) were the pioneers of this new model in Silicon Valley.[96] After becoming frustrated with the management of Fairchild Semiconductor, Robert Noyce and Gordon Moore (both members of the infamous "traitorous eight" who defected from Shockley Semiconductor to found Fairchild Semiconductor in 1957), left to found Intel. Their chief issue with

[95] Jay R. Ritter. *Initial Public Offerings: Updated Statistics*. 1980, p. 74. https://site.warrington.ufl.edu/ritter/files/IPO-Statistics.pdf; Piero Scaruffi. "A Timeline of Silicon Valley."
[96] Kushida, 25.

Fairchild was the management's reluctance to provide employees with ownership stakes in the company.[97] Working with WSGR, the Intel founders devised a system that gave the founders significant equity and control of the company as well as greater license to distribute stock options, while also preserving protections for venture capitalists. This legal structure would go on to become the de-facto model for later startups throughout Silicon Valley and established the limited partnership as the Valley's "dominant investment vehicle." As a result, cash-strapped startups found it easier to recruit talented employees through the use of equity compensation.

Chapter 3.5: Education Policy

As outlined in the policy lever description, education policy concerns the development and operation of systems and organizations of instruction to develop a skilled and knowledgeable populace. The relationship between societal levels of education and per capita GDP is generally understood to be positive. However, in the United States, fundamental disagreements about the role of government in education, emphasized subject areas in secondary and higher education, and the definition of education itself have all affected historical policy formation and execution in the past.

World War II's mass mobilization of women in the labor force also forced changes in the way education and childcare were administered throughout the country. Broadly, the wartime and post-war environment saw an **increase in federal involvement in public education efforts**. Firstly, during wartime, new federal education spending initiatives were justified by the reported strains on local communities from rapidly growing population centers around military bases as

[97] Martin Kenney and Richard Florida. *Venture Capital in Silicon Valley: Fueling New Firm Formation.* 2009.

well as the reduction in mothers serving as caretakers.[98] The result was the Lanham Act of 1941, which was eventually expanded through subsequent amendments to total over $125 million in federal assistance to approximately 1000 school systems across the country. This assistance came in two main forms: 1) direct assistance for the construction and operation of additional educational facilities and 2) expanded childcare assistance for mothers working in industries critical to the war effort. Both types of assistance were unprecedented in American history, largely due to unfavorable public views on the involvement of the federal government in education. At its height, Lanham Act childcare programs (educational programs for children ages 0-12) were administered in "over 635 communities in every state except New Mexico."[99] A study by Christopher Herbst from Arizona State University found that the childcare program in particular yielded several positive, long-run effects on child development: children in the program were "more likely to be employed, have higher earnings, and be less likely to [depend on welfare] as adults" as well as possess "long-run improvements in educational attainment."

After the war, U.S. presidents and policymakers came to view education as a national security imperative, which justified even greater federal intervention than ever before. STEM education, in particular, came under greater scrutiny. Motivated by the USSR's launch of Sputnik, the National Defense Education Act (NDEA) of 1958 was the federal government's first response to building technical talent. The NDEA provided loan support for "college students, improvements to STEM education in grade-schools, graduate fellowships … and vocational-technical training."[100] The policy was successful in expanding the reach of higher education to

[98] Harry W. Porter. "The Lanham Act." *History of Education Journal*, vol. 3, no. 1, 1951, pp. 1–6, http://www.jstor.org/stable/3659219.
[99] Chris M. Herbst. "Universal child care, maternal employment, and children's long-run outcomes: Evidence from the US Lanham Act of 1940." *Journal of Labor Economics* 35.2 (2017): 519-564.
[100] *Federal Role in Education*. US Department of Education, 15 June 2021, https://www2.ed.gov/about/overview/fed/role.html.

underprivileged populations, establishing the National Defense Student Loan Program (continued today as National Direct Student Loans) and contributing "nine-tenths of loan capital" to needy students and counting on institutions to make up the rest.[101] By 1960, the NDEA had authorized a total of $222 million in assistance ($2.16 billion in 2022 dollars). There is evidence that the NDEA directly contributed to the rise in college enrollments over the next decade, which more than doubled from 3.6 million in 1960 to 7.5 million by 1970.

As of 2017, the outstanding federal loan portfolio reached $1.4tn.[102] In that year, $96bn in new loans were granted to 8.6 million students, an increase from $36bn over 4.1 million students in 1995. According to the CBO, these increases are because "the number of borrowers increased, the average amount they borrowed increased, and the rate at which they repaid their loans slowed." The reasons behind these drivers are 1) increases in total college enrollment and 2) higher average cost of tuition.

It is impossible to discuss post-war education without mentioning the popularly-known "G.I. Bill" of 1944. This act provided "tuition, subsistence, books and supplies, equipment, and counseling services for veterans to continue their education in school or college."[103] The act allowed 2.3 million veterans to attend universities, 3.5 million to receive school training, and 3.4 million to receive on-the-job training. The results on national educational attainment levels were direct: the number of degrees awarded by U.S. higher education institutions doubled between 1940 and 1950. The percentage of bachelor's degrees nationally would increase from 4.6% in 1945 to 25% by the end of the century (see Figure 13). The G.I. Bill was extended in 1984 as an

[101] John S. Schwegler. *Academic Freedom And The Disclaimer Affidavit Of The National Defense Education Act: The Response Of Higher Education*, Teachers College, Columbia University, Ann Arbor, 1982.
[102] "The Volume and Repayment of Federal Student Loans: 1995 to 2017." Congressional Budget Office. https://www.cbo.gov/publication/56754.
[103] "Servicemen's Readjustment Act (1944)." U.S. National Archives. 22 Sept. 2021, https://www.archives.gov/milestone-documents/servicemens-readjustment-act.

enduring benefits program for veterans during peacetime, especially those who had served during the Vietnam War.[104] Benefits were expanded with the passage of the Post-9/11 Veterans Educational Assistance Act of 2008 and created the Yellow Ribbon Program, which allowed the Department of Veterans affairs to match university scholarships for veterans. In 2017, the 15-year deadline for veterans to use or transfer their benefits under the "Post-9/11 G.I. Bill" was eliminated.

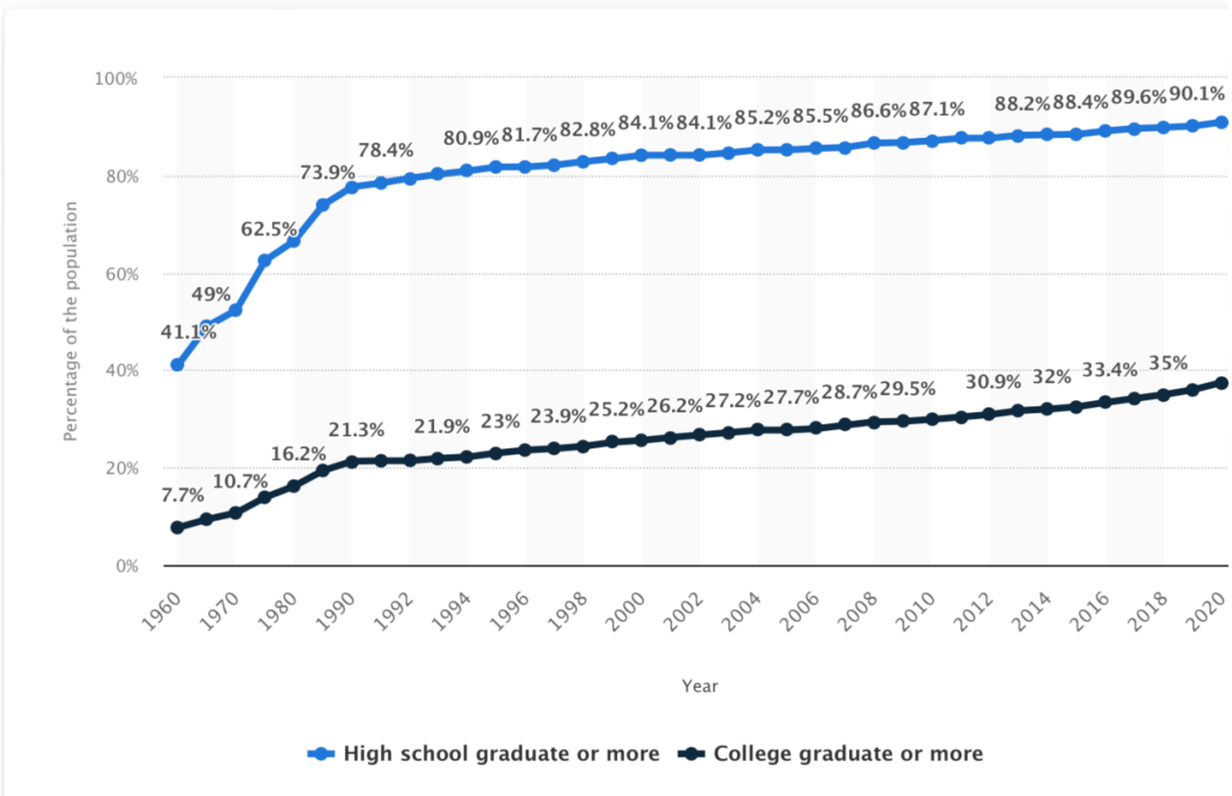

Figure 13: "Educational attainment distribution in the United States from 1960 to 2020" (Statista)

The federal government's commitment to directing additional resources towards education was again highlighted during President Johnson's Great Society efforts in the 1960s. In 1965, the Elementary and Secondary Education Act (ESEA) and the Higher Education Act (HEA) were signed into law to provide greater support for low-income students. The HEA

[104] Caitlin, O'Brien. "A Brief History of the GI Bill." https://www.militarytimes.com/education-transition/2021/03/10/a-brief-history-of-the-gi-bill/.

established direct student loans, Pell Grants, TRIO programs, and work study programs,[105] while the ESEA distributed additional funding to school districts with high percentages of low-income students. The goals of both legislative efforts were to expand access to and quality of education nationally with the goal of improving employee productivity in the long run. Pell Grants, the largest source of federal grants for postsecondary education, totaled $27bn over 6.3 million undergraduate students in FY2020.[106] These grants are need-based and are not repaid. Federal funding for the K-12 education of low-income students via ESEA has more than doubled since 1980 in constant FY2017 dollars, totaling approximately $15.5 million in 2017.[107]

There may be evidence to suggest that the federal government's support of higher education, including the GI Bill, NDEA, and HEA, positively influenced both the breadth and depth of educational attainment in the United States. The 1950s and 60s saw a dramatic uptake in new college enrollments (see Figure 14). By the end of the 1950s, college enrollments had risen by 49% over the preceding 10 years.[108] Enrollment rose 120% in the 1960s, and, by the end of the decade, 35% of the 18- to 24-year old population was enrolled in college. Enrollment slowed a bit in the 1970s to a 45% increase over the decade and again in the 1980s to a 17% increase over the decade.

[105] *The Higher Education Act (HEA): A Primer.* Congressional Research Service, 17 Aug. 2021. https://sgp.fas.org/crs/misc/R43351.pdf
[106] *Federal Pell Grant Program of the Higher Education Act: Primer.* Congressional Research Service, 09 Sep., 2021. https://crsreports.congress.gov/product/pdf/R/R45418
[107] *History of the ESEA Title I-A Formulas.* Congressional Research Service, 17 Aug. 2021. https://crsreports.congress.gov/product/pdf/R/R44898
[108] Thomas D. Snyder. *120 Years of American Education: A Statistical Portrait.* National Center for Educational Statistics, U.S. Department of Education, Jan 1993. https://nces.ed.gov/pubs93/93442.pdf

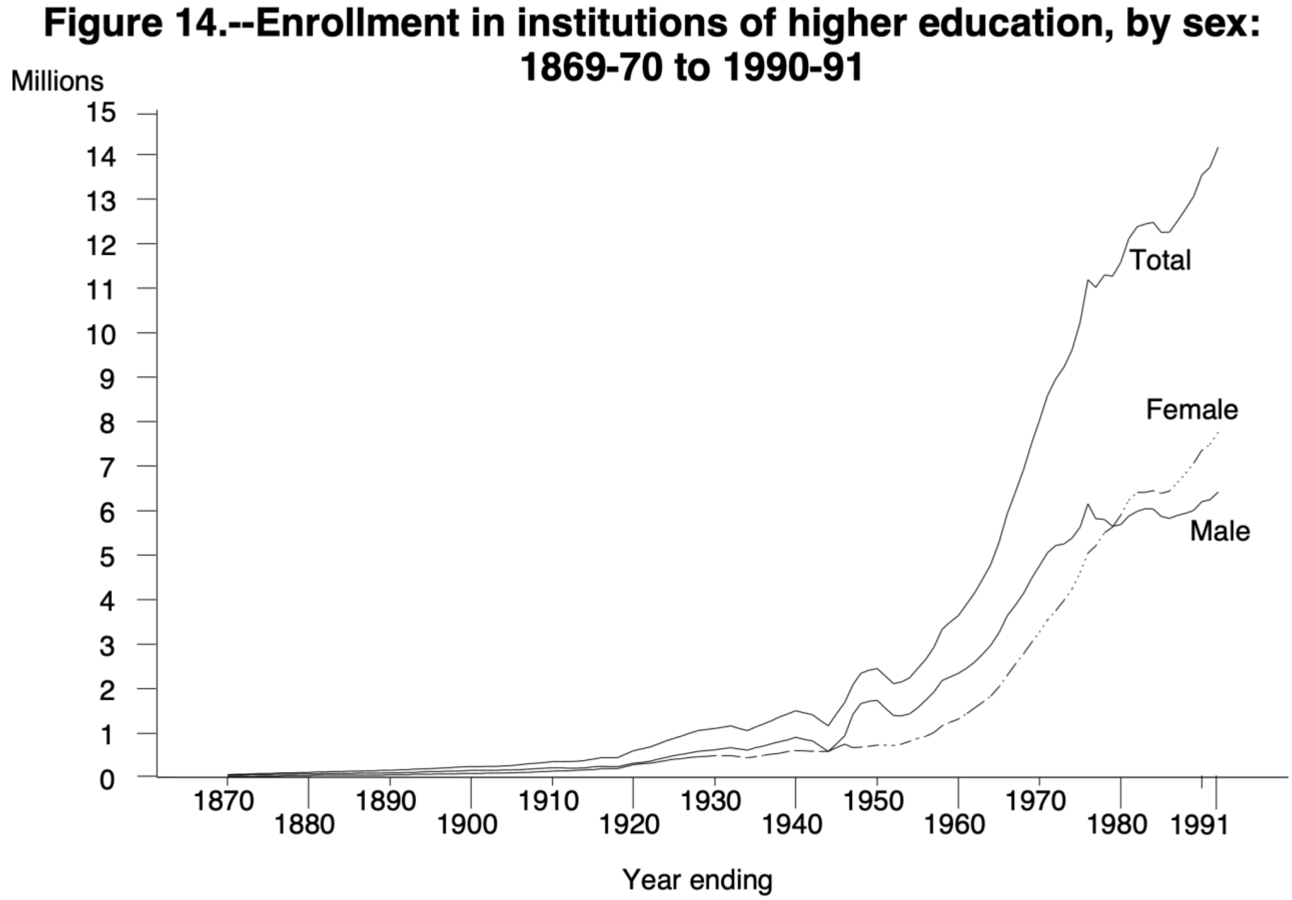

Figure 14: Enrollment in institutions of higher education, by sex: 1869-70 to 1990-91 (U.S. Department of Education)

For master's and doctor's degrees, the 1960s was similarly transformational: by the end of the decade, the ratio of doctor's degrees per 1,000 bachelor's degrees shot up 239% to 78, while the ratio of master's degrees per 100 bachelor's degrees rose to 33. This surge in total educational attainment translated to STEM degrees, which were conferred at historically high shares of total degree conferrals (no less than 35%).[109] According to data by the National Science Foundation, the absolute number of bachelor's degrees awarded in science and engineering (S&E) increased by 77% from 1966 (the earliest date data is available) to 1974, topping out at 326,230 awards that year before plateauing. This metric would not be surpassed again until 1990, when 329,094 awards were conferred.

[109] Mark Fiegener. *Science and Engineering Degrees: 1966–2010*. National Center for Science and Engineering Statistics, National Science Foundation, Jun. 2013. https://www.nsf.gov/statistics/nsf13327/pdf/nsf13327.pdf.

In contrast to the surge in STEM-degrees conferred at the leadup to the Third Industrial Revolution, the growth of STEM degree conferrals throughout the duration of the revolution have lagged in comparison. It would take another 30 years for annual S&E degrees to rise by the same amount, reaching 470,214 awards (+44% annual increase) in 2005. This rise in S&E degrees largely coincided with a rise in total bachelor's degrees awarded; as a percentage of total bachelor's degrees, S&E degrees have remained between 31% and 36% since 1966 (the high of 35.7% occurred in 1969). A slightly different dataset from the National Center for Education Statistics reveals generally the same trend throughout the duration of the Third Industrial Revolution, with the percentage of total degrees conferred across bachelor's, master's, and doctor's levels in natural sciences, computer sciences, and engineering either at the same or lower share than in 1970 (see Figure 15).[110] Thus, there has been no outsized increase in STEM majors relative to the college-educated population throughout the Third Industrial Revolution.

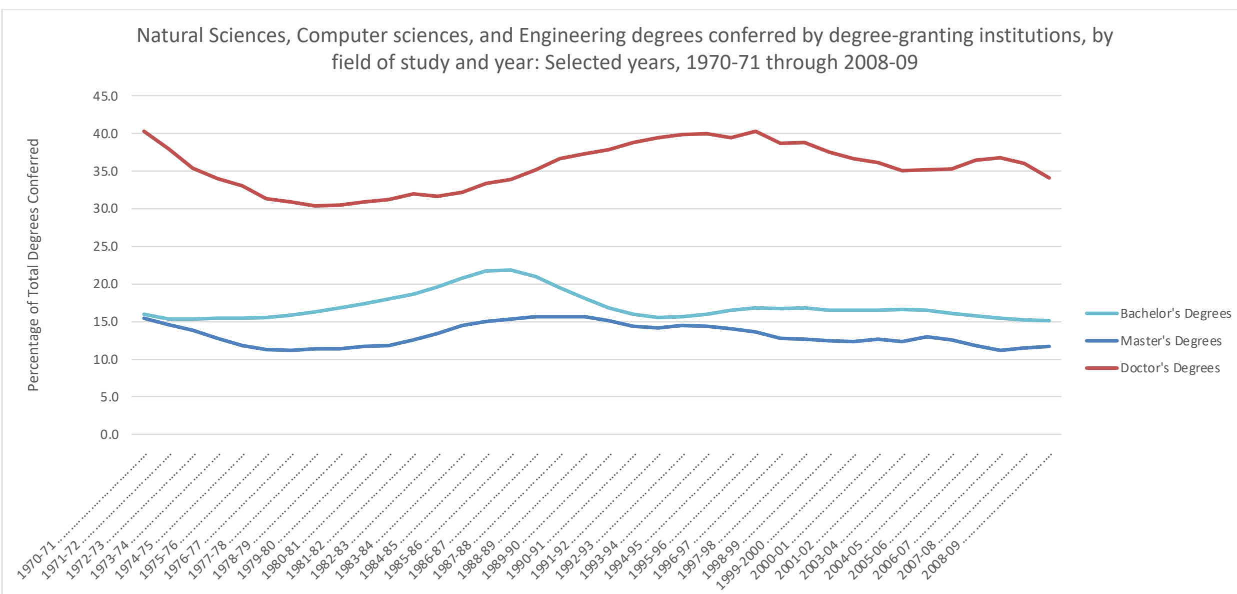

Figure 15: Relative share of STEM-degree conferrals, 1970-2009 (adapted from U.S. Department of Education data)

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[110] *Digest of Education Statistics, 2010*. National Center for Education Statistics, https://nces.ed.gov/programs/digest/d10/tables/dt10_285.asp.

Specific to Silicon Valley, the Third Industrial Revolution saw the region transform into a locus for East Coast electronic firms' research and development centers. The rise of Stanford University as a center for advanced technological excellence, both in theoretical and applied research, was central to this phenomenon. Zucker, Brewer, and Darby (1998) showed that firms locate near universities where access to star scientific talent is available.[111] While not a result of public policy, this rise was largely the result of Frederick Terman's academic entrepreneurialism. Terman's "steeple strategy," as he termed it, was focused on developing Stanford into a leader in advanced technological areas of relevance to industry.[112] Rather than simply directing research faculty to act as effective subcontractors for industry, Terman focused aggressively on building an insurmountable lead in research, building a large PhD program and rejecting industry contracts narrowly focused on application. However, to supplement the exchange flow already occurring between campus and local industry, he committed to building excellence in theory rather than application. By getting ahead of the curve, per se, Stanford's faculty and researchers were able to produce grounding breaking innovations that were then transferred to industry. Terman would then make deals with promising companies (e.g., Varian's klystron project) to commercialize this competitive advantage. Although Terman's "steeple strategy" was not a product of public policy, it provides an important indicator of an effective strategy to promote the formation of a sustainable innovation cluster.

The effect of this generational increase in educational attainment is reflected in the greater numbers of researchers per capita in the United States since 1981, which has grown from

[111] John Van Reenen. *Innovation and Human Capital Policy.* National Bureau of Education Statistics, Apr. 2021. https://www.nber.org/system/files/chapters/c14423/c14423.pdf.
[112] Kushida, 44.

5.3 to 9.2 researchers per 1,000 workers in 2017.[113] While this growth is slower than other advanced technology economies (e.g., Korea, Germany, France, and Japan, which have overtaken the United States in per capita researchers) over the same time period. As of 2018, Korea stands out with 15.3 researchers per 1,000 workers, Japan and Germany now exceed the United States with 9.9 and 9.7, respectively, and China lags behind at 2.4 (a +100% increase since 2001).[114] The causality between researcher density and innovative activity is unclear; however, present-day indicators of innovative-production seem correlated with the aforementioned rise. Since 1980, both Korea and the European Patent Office have seen dramatic rises in their aggregate and per capita patent filing rates, while China now receives more than double the number of patent applications than the USPTO.[115] As of 2019, per unit of GDP, Korea files the greatest number of patent applications at 7,779 per $100bn in GDP, followed by China (5,520), Japan (4,691), Germany (1,642), Switzerland (1,634), and the United States (1,389).

An important non-policy activity that merits note are the **deliberate exchanges between research universities and industry,** which became a central driver for innovation. Industry employees would enroll in university programs to gain theoretical knowledge pertinent to their technical specialty, while faculty were encouraged to join or found startups near the university and bring former students with them.[116] This "bidirectional exchange" manifested itself in sabbatical programs for professors, meetings by university deans with heads of local companies, and resource collaborations with local companies on innovative projects. Stanford University

[113] *Main Science and Technology Indicators*. OECD, 08 May 2022. https://stats.oecd.org/index.aspx?DataSetCode=msti_pub#downloaded11.21.20.
[114] These figures are likely impacted by the wider economic and educational access disparities in both societies, which affects the distribution of educational attainment.
[115] *World Intellectual Property Indicators 2020*. World Intellectual Property Organization, 2020. https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2020.pdf
[116] Kushida, 41.

(and UC Berkeley to a slightly lesser degree) served as a hub for this exchange.[117] Stanford's innovations in microwave tubes, for example, were eventually commercialized and exploited by local corporations, while the university's own research efforts benefited by appropriating advanced manufacturing technology in klystrons and solid-state electronics. The development of the klystron in 1937 in conjunction with the Varian brothers was one Stanford's most influential electronics contributions; the brothers would go on to found Varian Associates in 1948, becoming one of the military's key suppliers for klystrons and microwave tubes in the post-war development spree.[118] Other famous indigenous firms in Silicon Valley to benefit from the university-industry exchange model (either founded by or recruited a significant number of Stanford graduates) were Hewlett Packard, Huggins Laboratories, Litton Industries, and Watkins-Johnson. Additionally, according to Leslie, Stanford's "honors cooperative program" was a centerpiece of bidirectional talent exchange between industry and the university.[119] A brainchild of legendary Stanford engineering dean Frederick Terman, this program attracted the likes of Hewlett Packard, General Electric, and Sylvania, who enrolled significant numbers of their young, talented researchers in the program "part-time for advanced degrees."

Rotation between private research labs and university faculty positions was another important form of exchange between industry and academia. In the immediate post-war electronics environment, most of the electronics industry's R&D activity was located on the East Coast in the labs of the largest electronics corporations.[120] Many of Silicon Valley's early advanced electronics founders would actually spent time conducting research and training in

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[117] Lécuyer, 8.

[118] Leslie, 78–81. Varian was provided "an unusual contract with the university, the Varians were granted access to faculty, laboratory space, and modest funding for materials in return for a half interest in any resulting patents." The company's relationship with Stanford was deep: its "first board meeting was held on campus, its board of directors included several faculty members, and its first successful product, a tiny reflex klystron for guided missiles, was designed by a faculty consultant."

[119] Ibid.

[120] Ibid.

these East Coast laboratories before bringing the knowledge back to the West Coast.[121] Terman spent the duration of the war directing the Radio Research Laboratory (RRL), focusing on radar and communications technology, at Harvard University.[122] He brought 30 Stanford students and colleagues to the RRL through his time there, ensuring that each of them studied practical skills which would assist in their commercial efforts back on the West Coast. Charles Litton of Litton Industrial spent the duration of the war at Federal Telephone's New Jersey plant working on radar tubes before returning to the Bay Area to found Litton Industries, which build a successful business around manufacturing cheaper, high-quality magnetrons (a power tube input). William Shockley's Shockley Semiconductor and the Fairchild Semiconductor experiment are other famous examples of the transfer of East Coast capital and know-how to talent centers in California.

Chapter 3.6: Immigration Policy

Immigration policy concerns the statutes and regulations that influence the entrance of persons, particularly those who wish to reside temporarily or permanently, into a state.[123] Immigration and innovation are known to be closely related due to the importance of human capital to a state's innovative potential. As discussed in the education lever, there are two general ways to create high-skill talent: 1) develop existing talent within a state or 2) bring in high-skill

[121] For a discussion on the differences in success between East Coast innovation centers like MIT/Boston and West Coast innovation centers like Stanford/San Francisco, see Anna Lee-Saxenian's *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Harvard, 1994). Saxenian finds that Silicon Valley's advantage derives from its fragmented and highly competitive economy, the decentralized nature of industrial and organizational structures, and its free-flowing adaptive culture.
[122] Ibid.
[123] Sofia Perez. *Immigration Policy - an Overview*. International Encyclopedia of the Social & Behavioral Sciences, *ScienceDirect Topics*, 2015. https://www.sciencedirect.com/topics/social-sciences/immigration-policy#:~:text=The%20term%20immigration%20policy%20encompasses,territory%20either%20temporarily%20or%20permanently.

talent from outside of the state. The immigration lever primarily concerns policies with intentions or effects towards the second aim. In the United States, immigration policy has changed throughout history to favor groups of different backgrounds, national origins, races, skills, and ideologies. Unlike other policy levers, which are characterized by often frequent, complex policy changes, immigration policy has a fairly linear change history.

Before the end of World War II, the most common motives behind immigration policy concerned the race and national origin of the immigrants as well as potential economic effects on the domestic labor market. In the late 1800s as the federal government sought to populate largely sparse western states, immigrants as a share of the existing population rose to about 15%.[124] This culminated in the "Great Wave" of immigration, in which the foreign-born population more than doubled from 1880 to 1930.[125] However, after 1915, immigration began steadily declining as economic instability and global conflicts encouraged the passage of restrictive measures. The national origins quota system installed in 1921 limited immigration according to quotas that corresponded to existing levels of population share in the United States; by default, this system favored immigrants from Northwestern Europe and discouraged immigration from Asia.[126] This system would remain in place through the early 1950s until the Immigration Act of 1952, which revised the 1924 regime to permit national quotas at a "rate of one-sixth of one percent of each nationality's population in the United States as of 1920."[127] Although the law eliminated prohibitions on Asian immigration and established a minimum quota of 100 visas per year, the

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[124] MPI Data Hub. "Immigrants in the US_1850-Present." *Tableau Public,* https://public.tableau.com/app/profile/mpi.data.hub/viz/ImmigrantsintheUS_1850-Present/Dashboard1.
[125] Elizabeth Grieco. "The "Second Great Wave" of Immigration: Growth of the Foreign-Born Population Since 1970." *U.S. Census Bureau,* 26 Feb. 2014. https://www.census.gov/newsroom/blogs/random-samplings/2014/02/the-second-great-wave-of-immigration-growth-of-the-foreign-born-population-since-1970.html.
[126] "Historical Overview of Immigration Policy." *Center for Immigration Studies*. https://cis.org/Historical-Overview-Immigration-Policy
[127] "The Immigration and Nationality Act of 1952 (The McCarran-Walter Act)." *Office of the Historian U.S. Department of State*. https://history.state.gov/milestones/1945-1952/immigration-act

nature of the admittance structure ensured that immigration from minority countries of origin remained low. By 1970, the percentage of immigrants as a share of the United States population would plunge to under 5% (see Figure 16).[128]

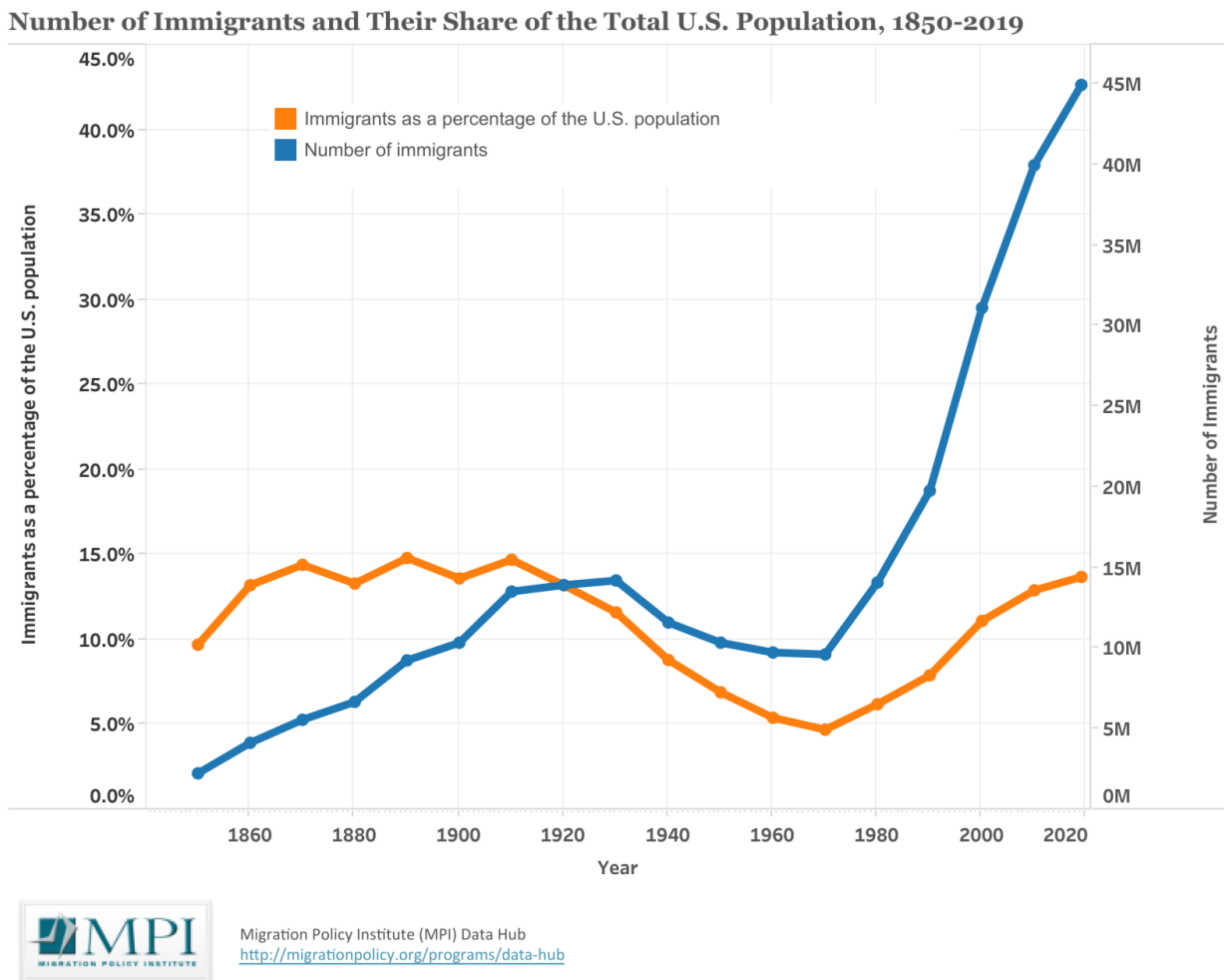

Figure 16: US Immigrant Population and Share over Time, 1850-Present (MPI Data Hub)

The turning point for modern immigration policy came in 1965 with the passage of the landmark Immigration Act of 1965. This act eliminated the national origin quota system in favor of new categories of immigrants, including "unmarried and married sons and daughters of U.S. citizens; siblings of U.S. citizens; spouses and unmarried sons and daughters of green card holders" and professions including but not limited to "architects, engineers, lawyers, physicians,

[128] MPI Data Hub. "Immigrants in the US_1850-Present."

surgeons, and teachers; scientists and artists of exceptional ability; skilled and unskilled workers in occupations for which labor was in short supply."[129] The law also established provisions for refugee admittance. The division between family-based migration, employment-based migration, and refugee migration was 74%, 20%, and 6% respectively. Though early versions of the legislation included a greater share of green cards for workers, supporters of a European-centric immigration regime pushed for a system that favored family migration and, consequently, the existing majority population. The law limited immigration from both the Eastern and Western hemispheres to 290,000 annually (170,00 from the East, 120,000 from the West) and no more than 20,000 from an individual country in the East. For employment-based green cards, immigrants had to prove that their presence was not "adversely affecting the wages and working conditions of the workers in the United States similarly employed."[130] The additional burden this clause placed on immigrants would increase denial rates.[131]

Despite the hurdles that remained, the 1965 Immigration Act was a turning point in the history of American immigration.[132] By 1980, the average number of annual immigrants had increased by approximately 150,000 over the average from 1952-65, and the percentage of immigrants as a share of the United States population rebounded to 6.2%. In 2019, the foreign-born population reached 45 million or a 13.7% share of the total United States' population. Such immigration shares have not been seen since the 1910s. This act and subsequent policies are emblematic of the Third Industrial Revolution's theme of **liberalization of non-European**

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[129] Andrew Baxter and Alex Nowrasteh. "A Brief History of U.S. Immigration Policy from the Colonial Period to the Present Day." *Cato Institute,* 3 Aug. 2021. https://www.cato.org/policy-analysis/brief-history-us-immigration-policy-colonial-period-present-day#immigration-nationality-act-1965
[130] 1965 Immigration and Nationality Act, 89th Cong., October 3, 1965.
[131] Briggs, *Immigration Policy and the American Labor Force*, p. 63; and 1952 Immigration and Nationality Act, 82nd Cong., June 27, 1952.
[132] Andrew Baxter and Alex Nowrasteh.

immigration, which would, despite the intent of some members of Congress, drastically increase immigration from Asia and Latin America to the United States.

The only other major immigration reform act during the Third Industrial Revolution was the Immigration Act of 1990.[133] This act made several changes to the 1965 Act. Most pertinent to innovative activities, the act established the H1-B non-immigrant visa for skilled workers and the O-1 non-immigrant visa for individuals of exceptional talent.[134] The H-1B program was established to help American firms deal with labor shortages in industries and functions of specialized expertise, such as "research, engineering, and computer programming," all core innovation sectors of the Third Industrial Revolution.[135] The O-1 program was meant to selectively lure exceptional talent to the United States, from those in the arts, athletics, or business to great scientific minds.[136]

The 1990 Act also changed green card admittance quotas. It provided minimums for family-based green cards (226,000) and employment-based green cards (140,000), increased the total number of green cards issued annually to 675,000, and increased per-country caps to 7% of the total familial and employment-based allowance (25,620).[137] Finally, the Diversity Visa program was created in an effort to revive immigration from European countries, which had not seen the intended benefits from the 1965 Act's family-centric green card allocation.

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[133] During the 1980s, President Reagan signed the Immigration Reform and Control Act (IRCA) which provided amnesty for illegal immigrants residing in the country illegally since 1982. However, this act had no discernable direct or indirect effect on innovation-related activities.
[134] Andrew Baxter and Alex Nowrasteh.
[135] D'Souza, Deborah. "The H-1B Visa Issue Explained." *Investopedia*, https://www.investopedia.com/news/h1b-visa-issue-explained-msft-goog/.
[136] "O-1 Visa: Individuals with Extraordinary Ability or Achievement." USCIS. 20 Apr. 2022, https://www.uscis.gov/working-in-the-united-states/temporary-workers/o-1-visa-individuals-with-extraordinary-ability-or-achievement.
[137] Andrew Baxter and Alex Nowrasteh. The 7% per-country cap does not apply to uncapped categories, such as immediate relatives of US citizens (Julia Gelatt. "Explainer: How the U.S. Legal Immigration System Works." *Migrationpolicy.Org*, 26 Apr. 2019, https://www.migrationpolicy.org/content/explainer-how-us-legal-immigration-system-works.)

A few additional modifications to high skill talent migration would occur in the early 2000s. Under the American Competitiveness in the Twenty-First Century Act in 2000, the annual H-1B cap of 65,000 established in 1990 was temporarily increased to 195,000 for three years to handle the backlog facing the system.[138] Additionally (and critically), universities and non-profit research institutions were permanently exempted from the visa cap.[139] These changes somewhat reversed to normal in 2004, when Congress passed the H-1B Visa Reform Act. This act returned the H-1B visa cap to 65,000 but provided an exemption for the first 20,000 H-1B visas granted if the recipient was a high-skilled temporary worker with an advanced degree (master's degree or higher) from an American university.

The broader immigration environment has had direct effects on modern innovative production in the United States. Kushida (2015) notes that immigration to Silicon Valley was higher than average; as of 2012, the foreign-born population in Silicon Valley was 36%, a relatively higher share total than the surrounding state of California (27%) and the United States' average (13%).[140] Other immigration researchers, like Anna-Lee Saxenian, have argued that the benefit of Silicon Valley's direct ties to productive production and talent centers like Israel, Taiwan, India, and China created important international bridges that facilitated the development and proliferation of modern technological and process innovations, such as computer software, fab-less semiconductor plants, IT outsourcing, and advanced component production.

In general, the majority of academic research available seems to agree that **high-skill immigration to the United States is positive for innovation and the broader economy.** Burchardi, et al. (2020) found that "immigration to the US between 1975 and 2010 had a positive

[138] "American Competitiveness in the Twenty-first Century Act of 2000." *U.S. Congress*, 17 Oct. 2000. https://www.govinfo.gov/content/pkg/PLAW-106publ313/pdf/PLAW-106publ313.pdf
[139] Andrew Baxter and Alex Nowrasteh.
[140] Kushida, 28.

causal effect on local innovation, local economic dynamism, and average wages of natives" and, since 1965, may have contributed to an "additional 8% growth in innovation and 5% growth in wages."[141] The authors attempt to prove causality by constructing datasets of exogeneous county-level immigration and regional models of endogenous innovation and migrations to "estimate the local elasticity of innovation to research labor." The impact on innovation, as measured by patenting activity, was direct: 1% increase in immigration to a given county on average increased the number of patents filed by local residents by 1.7% over a five-year period. For every 10,000 additional immigrants in a county, the flow of patents over a five-year period increases by 1.15 per 100,000 residents (a 21% increase from the mean). The influx of residents increases wage growth by 15% annually, on average. Second, immigrants to a particular county created spillover effects in the patenting rate of surrounding areas; however, this spillover is undetectable beyond 150 miles. Finally, the authors found that "low education migrants (bottom third of the distribution of schooling among migrants) have no detectable impact on local innovation, the impact of medium educated migrants (middle third) is about half of that for the average migrant, and the impact of high education migrants (top third) is an order of magnitude larger than for the average migrant"—specifically, 11 more local patents per 100,000 residents compared to 2.6 more local patents per 100,000 residents for migrants of average education.[142] Based on the study's date range of 1975 onwards coupled with knowledge of immigration liberalization beginning in 1965, it is unlikely that immigrant migration significantly contributed to the foundational innovations of the Digital Revolution from the 1970s-90s. However, there is a plausible case to be made that skilled immigrant labor allowed America's largest Internet

[141] Konrad Burchardi, et al. *Immigration, innovation, and growth*. No. w27075. National Bureau of Economic Research, 2020.
[142] Average education is defined as roughly 11 years of total schooling, while high education is one standard deviation higher (roughly 4 additional years).

companies (also the largest users of H-1B allotments) to scale rapidly during the Internet Revolution from the 1990s-2010s.

Hunt and Gauthier-Loiselle (2008) affirmed the 2003 National Survey on College Graduates, which showed that immigrants are more likely to patent than native citizens—specifically, at double the rate—and that this phenomenon was "entirely accounted for by their disproportionately holding degrees in science and engineering." They concluded that native innovators are not crowded out by immigrants and that a 1% increase in immigrant college graduates increases patents per capita by approximately 15% due to positive spillover effects.[143] Additionally, the positive impacts of post-college graduates are larger than college graduates. Hunt and Gauthier-Loiselle also note numerous observational studies that, while not establishing a causal relationship between immigration and innovation, provide important signals for the relationship between the two:

> Compared to a foreign–born population of 12% in 2000, 26% of U.S.–based Nobel Prize recipients from 1990–2000 were immigrants (Peri 2007), as were 25% of founders of public venture–backed U.S. companies in 1990–2005 (Anderson and Platzer 2006), and founders of 25% of new high–tech companies with more than one million dollars in sales in 2006 (Wadhwa et al. 2007). Immigrants are over–represented among members of the National Academy of Sciences and the National Academy of Engineering, among authors of highly–cited science and engineering journal articles, and among founders of bio–tech companies undergoing IPOs (Stephan and Levin 2001). Kerr (2007) documents the surge in the share of U.S. patents awarded to U.S.–based inventors with Chinese and Indian

[143] Jennifer Hunt and Marjolaine Gauthier-Loiselle. "How much does immigration boost innovation?." *American Economic Journal: Macroeconomics* 2.2 (2010): 31-56.

names to 12% of the total by 2004, and Wadhwa et al. (2007) find that non–U.S. citizens account for 24% of international patent applications from the United States. (Hunt 1)

Regarding the disproportionate focus on science and engineering disciplines, Hanson and Slaughter (2016) concur with Hunt and Gauthier-Loiselle: when controlling for fields of study, "the foreign-native born differential in patenting disappears."[144] Thus, the immigrant impact on innovation as measured by patenting can be explained by immigrants' "strong revealed comparative advantage in STEM."

In a study of global talent flows, Harvard Business School's William Kerr (2019) noted that the H-1B program's flexibility with regards to functional allocation allows it to adapt to industry needs. For example, visa share for computer-related occupations was "25% in 1995, 57% in 1998, 28% in 2002, and over 70% in 2012;" these numbers largely tracked the proportion of visas obtained by Indian workers over the same time period.[145] Broadly, the study noted that nearly 30% of all STEM workers today are immigrants, up from approximately 7% in 1960.

However, today's general policy attitude towards high-skill immigration can be characterized as outmoded, restrictive, and inefficient. In 2019, the United States issued about 1 million green cards, of which 63% were family-based, 32% were humanitarian or based on the diversity lottery, and just 5% were employment-based.[146] The impact of employment-based immigration's low relative priority is reflected in the excessively long waiting periods for workers from countries that are large suppliers of high-skill talent, such as India and China. As of 2020, a record 1.2 million foreign workers and their families were waiting for employment-

[144] Gordon Hanson and Matthew J. Slaughter. "High-skilled immigration and the rise of STEM occupations in US employment." *Education, Skills, and Technical Change* (2016): 465.
[145] Sari Kerr, William Kerr, and William Lincoln. 2015a. "Firms and the Economics of Skilled Migration." *Innovation Policy and the Economy* 15 (1): 115-152.
[146] Andrew Baxter and Alex Nowrasteh.

based green cards.[147] The central culprit for these wait times are the 7% per-country caps instituted in the 1990 Act. As a result of these caps, waiting times for immigrants from high-supply countries have stretched into the decades. For example, Indian employer-sponsored applicants currently face an 80 year wait for green cards; this waiting period is expected to outlast the lifetimes of approximately 200,000 of these applicants. Indian workers constitute 68% of employment-based backlog (over 800,000 applicants), followed by Chinese workers at 14% and 18% from the rest of the world. According to projections by the CATO Institute, after accounting for death and abandonment, only half of Indian applicants in the employment-related backlog are expected to actually receive employment-based green cards. Demand for H-1B visas remains extremely high: since 2008, "the annual H-1B cap was reached within the first five business days on eight occasions." Another side effect is that many of the 600,000 international students who enroll in American universities each year have been unable to obtain green cards.

A study by Congressional Research Service analyst William Kandel (2020) analyzes the potential impact of eliminating the 7% per-country caps without increasing the current limit of approximately 120,000 green cards across the three employment-based immigration categories (EB1, EB2, and EB3).[148] He finds that replacing the quota system with a first-come-first served system would drastically reduce wait times for Indian and Chinese nationals. Indian nationals, who currently face the longest wait times, would see projected FY2030 wait times across the three green card categories would drop from 18, 436, and 48 years, respectively, to 7, 37, and 11 years, respectively. Similar, yet smaller, wait time decreases would apply for Chinese nationals. Since, under this scenario, the system would discard national origin as a criteria for queue status,

[147] David Bier."Employment-Based Green Card Backlog Hits 1.2 Million in 2020." *Cato Institute,* 20 Nov. 2020. https://www.cato.org/blog/employment-based-green-card-backlog-hits-12-million-2020.
[148] William A. Kandel, "The Employment-Based Immigration Backlog," R46291, Congressional Research Service, March 20, 2020.

applicants from the rest of the world—who currently face little to no wait times—would see their wait times increase to the aforementioned 7, 37, and 11 years, respectively, across the three green card categories. Currently, Kandel notes that, to the extent that Indian and Chinese nationals tend to "concentrate in particular industrial sectors," per-country caps impose "constraints on some industries and allows other [countries] to access that worker pool." The resulting backlog has the potential to disadvantage American employers in recruiting high-skill labor.

Chapter 3.7: Other Relevant Policy Catalysts

- California's Non-Compete Prohibition

  Although state-level policies are generally avoided in this paper's analysis to prevent state-by-state comparisons, one would be remiss to not give greater scrutiny to the policy environment in California, and Silicon Valley specifically, leading up to and through the Third Industrial Revolution. For a variety of reasons, some more deliberate than others, Silicon Valley is the global epicenter for the Third Industrial Revolution and promises to be an influential actor in the Fourth Industrial Revolution. One such policy innovation that had a material effect on the region's innovative output was California's prohibition on non-compete legislation during the 20th century.

  A non-compete agreement is an agreement typically issued by employers to employees with significant proprietary expertise critical to a business' product portfolio (but could be issued to all strategic employees) that prevents them from engaging in future business activities that would interfere with the commercial activities of the employer.[149] They are meant to prevent an employer's brightest minds from leaving the company and starting an identical enterprise with identical or superior product offerings to compete with the employer. Today, three states have outright bans on non-compete agreements: California, North Dakota, and Oklahoma.

California's aversion to non-compete agreements is a longstanding tradition; its ban on the agreements was first passed in 1872 in an effort to stimulate "open competition" amongst enterprises.[150] This prohibition, along with others made in a similar spirit, helped former IBM employees in 1964 leave the company to form enterprises that constructed components to supply the IBM System/360 mainframe computer.[151] Initially, the employees feared retaliatory action from IBM; however, the prohibition on non-compete agreements allowed them to take advanced technical knowledge and deploy it in the pursuit of the same product (potentially in a more efficient production method) or a new use.

Intuitively, such a legal provision would have a few potential consequences, distinct for employers and for employees (or, broadly, the labor pool). For employees, non-compete prohibitions are an incentive to i) work diligently at their current stations to produce superior output and subsequently ii) start new enterprises. Employees who are aware that their technical skills and knowhow are essentially being subsidized by their current employer via labs, equipment, etc. would naturally be incentivized to be as productive as possible. Given that upfront research and development costs for nascent technologies represent substantial barriers to entry for new firms, an employee hoping to

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[149] Eric Larson. "How Do Non-Compete Agreements Work." *ExpertLaw*, 7 Apr. 2018. https://www.expertlaw.com/library/employment-and-labor-law/how-do-non-compete-agreements-work.
[150] *Edwards v. Arthur Andersen LLP*, 44 Cal. 4th 937, 945. 2008. https://scholar.google.com/scholar_case?case=969445912817466674&hl=en&as_sdt=6&as_vis=1&oi=scholarr.
[151] Kushida, 36.

profit off of nascent technology would be interested in maximizing the resources available to them at their current employer to reach a point of reasonable technological proof before they depart.

Numerous studies have confirmed these intuitive outcomes.[152] Samila and Sorensen (2011) measured the effect of a non-compete environment on the relationship between venture capital supply and entrepreneurship, patent rates, employment, and the total wage bill.[153] Their analysis found that an active non-compete environment actually "limit[s] entrepreneurship" and "impedes innovation." However, under an "'employee-friendly' regime"—defined by the authors as a regime which, at minimum, does not enforce non-compete agreements—an average region that experiences a doubling in venture capital investment would see the creation of 17 to 41 more firms and 4,273 to 6,767 additional jobs. Additionally, venture capital returns and patenting rates both improved under such regimes. The authors' analyses controlled for endogenous variables in venture capital supply by using national average university endowment returns as an instrumental variable,[154] and their results were consistent when California and Silicon Valley were excluded from the analysis. Samila and Sorenson's results implied that the "fluidity of labor markets" was material to the development of a region's economy as well as its innovative output. Their results concurred with findings from a similar study

[152] Ronald J. Gilson. "The legal infrastructure of high technology industrial districts: Silicon Valley, Route 128, and covenants not to compete." *NYUl Rev.* 74 (1999): 575.; Matt Marx and Lee Fleming. "Non-compete agreements: Barriers to Entry… and Exit?." *Innovation policy and the economy* 12.1 (2012): 39-64.

[153] Sampsa Samila and Olav Sorenson. "Noncompete covenants: Incentives to innovate or impediments to growth." *Management Science* 57.3 (2011): 425-438.

[154] "An instrumental variable (sometimes called an "instrument" variable) is a third variable, Z, used in regression analysis when you have endogenous variables—variables that are influenced by other variables in the model. In other words, you use it to account for unexpected behavior between variables. Using an instrumental variable to identify the hidden (unobserved) correlation allows you to see the true correlation between the explanatory variable and response variable, Y." Stephanie. "Instrumental Variable: Definition & Overview." *Statistics How To*, 26 Dec. 2016, https://www.statisticshowto.com/instrumental-variable/.

by Garmaise (2009) which concluded that firms invest less in research and development activities under active non-compete environments.[155]

Broadly, the positive effect of non-competes on innovation, employment, enterprise creation, and venture capital returns among other metrics suggests that there are substantial spillover effects to economies without non-compete enforcement. Given the substantial pull factors in favor of new/small firms, these effects would theoretically apply to both incumbent firms and startups. High labor fluidity coupled with incentives to commercialize inventions, supportive economic conditions, and a willing supply of capital suggest the key ingredients necessary for an innovation cluster, in which capital (human and financial), ideas, and operational best practices continually mix at a rapid pace. Additionally, the ability of employees to freely move about within an innovation cluster allows for the "rapid reallocation of resources toward firms with the best innovations."[156]

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[155] Mark J. Garmaise. "Ties That Truly Bind: Noncompetition Agreements, Executive Compensation, and Firm Investment." *Journal of Law, Economics, & Organization*, vol. 27, no. 2, 2011, pp. 376–425, http://www.jstor.org/stable/41261726.

[156] Bruce Fallick, Charles A. Fleischman, and James B. Rebitzer. "Job-hopping in Silicon Valley: some evidence concerning the microfoundations of a high-technology cluster." *The review of economics and statistics* 88.3 (2006): 472-481.

Chapter IV: Policy That Matters

Chapter 4.1: Third Industrial Revolution Policy Scorecard

Arriving at a Score

Thus far, this paper has attempted to survey and catalogue the most innovation-positive federal policies leading up to and through the initial stages of the Third Industrial Revolution to determine their relevance to and impact on innovative output of Third Industrial Revolution technologies (all technologies that replace *physical* labor). To isolate and identify innovation-relevant policies, the policy universe was first categorized by thematic policy levers, such as education policy or labor policy, modeled after existing federal agencies of the United States government. 15 such levers were identified. Given the vastness of federal policy history over the 40-to-60-year analytical scope of this paper, it was necessary to subsequently narrow down policy levers subject to analysis according to the predicted relevance to innovative production during the Fourth Industrial Revolution. After narrowing the analytical scope to five primary policy levers, each policy lever was subsequently surveyed to determine its prevailing policy attitude towards innovative activities leading up to and through the initial stages of the Third Industrial Revolution.

After categorizing policies based on thematic verticals, it became necessary to understand the nature of policy actions taken within those verticals. In Chapter 2, a rudimentary analytical framework, the Innovation Contribution Scorecard, was presented (see Figure 1) to classify policy actions by their effect (i.e., their actual impact on innovation via their respective policy lever). This framework serves as a "scoring criteria" to determine the *nature* of each enacted policy with relation to its impact on innovative output during the Third Industrial Revolution. Scores are assigned from a -2 to 3 scale, with -2 representing policies that explicitly prohibit innovative activity or its antecedents and 3 representing policies that explicitly mandate innovative activity or its antecedents. This scale allows for an accounting of policies that hindered or were detrimental to innovative output or the existence of its necessary antecedents (e.g., trained human capital).

A determination of the policy's *efficacy* on innovative output during the Third Industrial Revolution is achieved through use of Lowi's "Four Systems of Policy, Politics, and Choice" model (see Figure 17). This model classifies policy along a matrix of applicability of coercion and likelihood of coercion to gain a sense of a policy's direct impact on its intended outcome. Lowi's model yields four policy impact quadrants: Quadrant 1 (environment-remote), Quadrant 2 (individual-remote), Quadrant 3 (individual-immediate), and Quadrant 4 (environment-immediate).

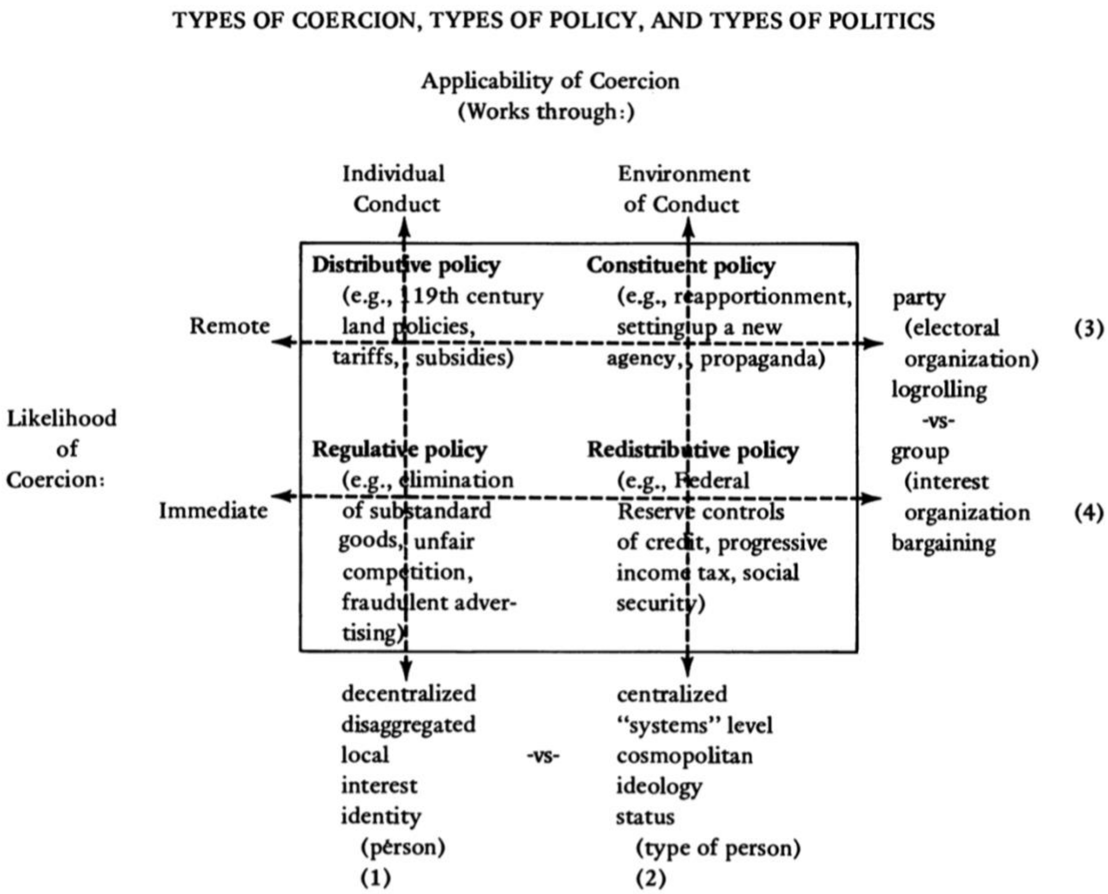

Figure 17: Theodore Lowi's Four Systems of Policy, Politics, and Choice (Lowi)

Lowi does not explicitly outline the causality of each quadrant. Thus, this paper makes an assumption by assigning greater weights to "individual" and "immediate" impacts on innovation-inducing activities than "remote" and "environmental" impacts on innovation-inducing activities due to their greater likelihood of inducing innovation-productive output. Quadrant 3 policies are assigned a multiplier of 1.5 (implied 50% premium), Quadrants 2 and 4 policies are assigned a multiplier of 1.25 (implied 25% premium), and Quadrant 1 policies are assigned a multiplier of 1 (no premium).

Finally, because later-stage technological developments are dependent upon the invention of earlier, foundational technologies, greater weight is placed on policy actions before the advent of the Third Industrial Revolution and early in its lifecycle. This paper assigns a "Foundational

Policy Premium” via an additional 1.5 multiplier (50% premium) for policy actions enacted in or before 1979, the end of the first decade of the Third Industrial Revolution.

Thus, the following equation is used to produce an aggregate score for each policy lever:

$$\boldsymbol{TIR\ Innovation\ Score} =$$
$$(\boldsymbol{Innovation\ Contribution\ Score})(\boldsymbol{Lowi\ Impact\ Multiplier})(\boldsymbol{Foundational\ Policy\ Premium}).$$

Innovation Contribution Scorecard

Below, the Innovation Contribution Scorecard classifies each of the policy actions catalogued in this paper by decade and nature:

Third Industrial Revolution Innovation Contribution Scorecard					
	Prohibit (-2)	**Discourage/Tax (-1)**	**Neutral/Permit (1)**	**Encourage/Subsidize (2)**	**Require (3)**
Pre-1950s			• Lanham Act of 1940	• Antitrust: "Golden Era of Antitrust" • GI Bill of 1944	• DoD sponsorship of advanced electronics R&D; DoD electronics procurement contracts
1950s		• IP: Patent Act of 1952 • Immigration Act of 1952		• Antitrust: "Golden Era of Antitrust" • National Defense Education Act of 1958	• DoD sponsorship of advanced electronics R&D; DoD electronics contracts
1960s			• Immigration Act of 1965 • Elementary and Secondary Education Act of 1965 • International Trade: Trade Act of 1962	• Fiscal: Reduction in corporate income tax rates • Financial: Small Business Investment Corporations (1966) • Higher Education Act of 1965	• "McNamara Depression" - forced commercialization

1970s			• International Trade: Trade Expansion Act of 1974 • IP: Patent Cooperation Treaty entered into force (1978)	• Fiscal: Lowering capital gains tax from 49.5 to 28 (1978) • Financial: relaxed ERISA restrictions on pension funds (1979) • Industry-University Cooperative Research Centers (1973)	
1980s			• IP: *Diamond v. Diehr (1981)* • Creation of Federal Circuit Court of Appeals (1982)	• IP: Stevenson-Wydler Act (1980)[2] • IP: Bayh-Dole Act (1985) • Fiscal: Lower marginal tax rates for small/unprofitable companies • Fiscal: Economic Recovery Tax Act of 1981 - R&D tax credits • Small Business Innovation Development Act (1982) • Omnibus Trade and Competitiveness Act of 1988	
1990s		• Antitrust: "Waning Era of Antitrust" • R&D funding share for advanced electronics programs stagnates	• Immigration Act of 1990[1]		

Policy Lever Color Key:
Commerce
Science & Technology
Fiscal & Financial
Education
Immigration

[1]The American Competitiveness in the Twenty-First Century Act and the H-1B Visa Reform Act are considered derivative modifications to this act.
[2]The Federal Technology Transfer Act of 1986 is considered a derivative modification to this act.

Policy actions are categorized by quadrant according to the Lowi model below:

Lowi Impact Multiplier				
	Quadrant 1 (environment-remote) – 1	**Quadrant 2 (individual-remote) – 1.25**	**Quadrant 3 (individual-immediate) – 1.5**	**Quadrant 4 (environment-immediate) – 1.25**
Commerce	• International Trade: Trade Act of 1962 • International Trade: Trade Expansion Act of 1974 • Creation of Federal Circuit Court of Appeals (1982) • IP: Patent Cooperation Treaty entered into force (1978)	• IP: *Diamond v. Diehr (1981)*	• Antitrust: "Golden Era of Antitrust" • IP: Patent Act of 1952 • IP: Stevenson-Wydler Act (1980)[2] • IP: Bayh-Dole Act (1985) • Antitrust: "Waning Era of Antitrust"	
Science & Technology		• Small Business Innovation Development Act (1982) • Omnibus Trade and Competitivenes s Act of 1988 • Industry-University Cooperative Research Centers (1973)	• DoD sponsorship of advanced electronics R&D; DoD electronics procurement contracts (1940s-1960s) • "McNamara Depression" - forced commercialization (1960s) • R&D funding share for advanced electronics programs stagnates (1990s)	
Fiscal & Financial		• Financial: Small Business Investment Corporations (1966) • Fiscal: Economic Recovery Tax Act of 1981 - R&D tax credits		• Fiscal: Reduction in corporate income tax rates (1960s) • Fiscal: Lowering capital gains tax from 49.5 to 28 (1978) • Financial: relaxed ERISA restrictions on

				pension funds (1979) • Fiscal: Lower marginal tax rates for small/unprofitable companies (1980s)
Education	• Lanham Act of 1940 • Elementary and Secondary Education Act of 1965			• GI Bill of 1944 • National Defense Education Act of 1958 • Higher Education Act of 1965
Immigration			• Immigration Act of 1990[1]	• Immigration Act of 1952 • Immigration Act of 1965

Using the TIR Innovation Score equation, an aggregated score for each policy action is produced below:

Aggregate Third Industrial Revolution Policy Innovation Scores					
Policy Lever	**Policy Action**	**Innovation Contribution Score**	**Lowi Impact Multiplier**	**Foundational Policy Premium**	**TIR Innovation Score**
Commerce					
	Antitrust: "Golden Era of Antitrust"	2	1.5	1.5	4.5
	IP: Patent Act of 1952	-1	1.5	1.5	-2.25
	International Trade: Trade Act of 1962	1	1	1.5	1.5
	International Trade: Trade Expansion Act of 1974	1	1	1.5	1.5
	IP: Patent Cooperation Treaty entered into force (1978)	1	1	1.5	1.5
	IP: Stevenson-Wydler Act (1980)	2	1.5	1	3
	IP: Diamond v. Diehr	1	1.25	1	1.25

	(1981)				
	Creation of Federal Circuit Court of Appeals (1982)	1	1	1	1
	IP: Bayh-Dole Act (1985)	2	1.5	1	3
	Antitrust: “Waning Era of Antitrust”	-1	1.5	1	-1.5
AVERAGE					**1.35**
Science & Technology					
	DoD sponsorship of advanced electronics R&D; DoD electronics procurement contracts (1940s-1960s)	3	1.5	1.5	6.75
	"McNamara Depression" - forced commercialization (1960s)	3	1.5	1.5	6.75
	Industry-University Cooperative Research Centers (1973)	2	1.25	1.5	3.75
	Small Business Innovation Development Act (1982)	2	1.25	1	2.5
	Omnibus Trade and Competitiveness Act of 1988	2	1.25	1	2.5
	R&D funding share for advanced electronics programs stagnates	-1	1.5	1	-1.5
AVERAGE					**3.46**
Fiscal & Financial					
	Fiscal: Reduction in corporate income tax rates (1960s)	2	1.25	1.5	3.75
	Financial: Small Business Investment Corporations (1966)	2	1.25	1.5	3.75
	Fiscal: Lowering capital gains tax from 49.5 to 28 (1978)	2	1.25	1.5	3.75

	Financial: relaxed ERISA restrictions on pension funds (1979)	2	1.25	1.5	3.75
	Fiscal: Lower marginal tax rates for small/unprofitable companies (1980s)	2	1.25	1	2.5
	Fiscal: Economic Recovery Tax Act of 1981 - R&D tax credits	2	1.25	1	2.5
AVERAGE					**3.33**
Education					
	Lanham Act of 1940	1	1	1.5	1.5
	GI Bill of 1944	2	1.25	1.5	3.75
	National Defense Education Act of 1958	2	1.25	1.5	3.75
	Elementary and Secondary Education Act of 1965	1	1	1.5	1.5
	Higher Education Act of 1965	2	1.25	1.5	3.75
AVERAGE					**2.85**
Immigration					
	Immigration Act of 1952	-1	1.25	1.5	-1.875
	Immigration Act of 1965	1	1.25	1.5	1.875
	Immigration Act of 1990	1	1.5	1	1.5
AVERAGE					**0.50**

Thus, the final ranking of the policy levers most material to the development of the Third Industrial Revolution is as follows:

1. **Science & Technology**
2. **Fiscal & Financial**
3. **Education**
4. **Commerce**
5. **Immigration**

The ranking of these levers signifies the **degree to which each lever supported Third Industrial Revolution-related innovative output during the Third Industrial Revolution**. According to the results of this analysis, federal Science & Technology policy was the most influential policy lever for Third Industrial Revolution innovative output, while Immigration policy was the least influential. These results make sense if taken at face value. The United States federal government, especially after the launch of Sputnik, adopted a public science and technology readiness posture unlike any seen in American history. The impetus was not for any purely innovation-driven or education-motivated goals; science and technology became a national security imperative in the race for military advantage, global credibility, and domestic morale. The most visible aspect of this public charge was the Space Race, which led to the founding of NASA and countless spinoff technologies.[157] In contrast, immigration as a source of innovation from the 1950s to the end of the 1970s was essentially a non-factor; it was not until the Immigration Act of 1965 that immigration was opened up to employment-based criteria and to immigrants from the Eastern Hemisphere, and it was not until the Immigration Act of 1990 that high-skill immigration was included as a priority item in statute.

This policy ranking does not attempt to prove causality. Analytical social science studies in history all face the same problem: there can be no "control" against which to analyze the behavior(s) of interest. This analysis will never be able to determine whether federal policy caused, or was central to inducing, critical Third Industrial Revolution technologies like the integrated chip, for example. However, at a minimum, we can determine that the policy environment, outlined by the status of the five levers above, *permitted* the advent of the Third Industrial Revolution and its constituent innovations. We know this because the Third Industrial Revolution occurred.

[157] "This Day in History, July 29." *History*. https://www.history.com/this-day-in-history/nasa-created.

It is true that there might have been greater innovative output had the levers been positioned differently. That is something this paper cannot take a position on. However, it is possible to *analyze* the effects of certain policy actions (e.g., the effect of public R&D "spillover effects" on innovation) to *infer* that such actions are likely innovation-promoting, and, consequently, would be associated with greater aggregate innovative output.

Chapter 4.2: Levers in the Present Day

Naturally, with the passage of time, each of the five policy levers and their material components have changed since the mid-to-late 20th century. A brief snapshot highlighting the status of the policy components analyzed in this paper in the present-day is augmented from information in Chapter 3 and provided below.

1. Science & Technology
    a. After a decade of declines under the Obama administration, public R&D funding is making a rebound. In constant dollars, public R&D spending levels have generally risen over the long term; currently, they are nearly double what they were at the advent of the Third Industrial Revolution.
    b. In contrast to the early years of the Third Industrial Revolution when public R&D made up more than a majority of total R&D outlays, today public R&D expenditures make up less than a third of total R&D spending in the United States. Additionally, within public R&D spending, the share of science, space, and technology-related outlays has declined the most, dropping from an average of 31.9% in the years 1965-1971 to an average of 16.0% in the years 2014-2020.[158]

[158] "Table 9.8—Composition of Outlays for the Conduct of Research and Development: 1949–2023."

The largest beneficiary in its place has been health-related R&D (directed overwhelmingly to the NIH), which saw its share increase from 6.0% to 26.7% over the same period. Defense-related R&D has remained largely the same, seeing a slight drop from a 51.5% share to a 48.7% share.

2. Fiscal & Financial
    a. For new firms with little net income, marginal tax rates have decreased since 1960.
    b. The maximum capital gains tax rate is at pre-Third Industrial Revolution levels (approximately 25%).
    c. The R&D tax credit was made a permanent part of the tax code in 2015.
    d. Government support for business R&D is nearly even between tax credits and direct funding.
3. Education
    a. As of 2017, the outstanding federal loan portfolio reached $1.4tn. In that year, $96bn in new loans were granted to 8.6 million students, an increase from $36bn over 4.1 million students in 1995.
    b. The G.I. Bill has been extended since 1984 as an enduring benefits program for veterans during peacetime, especially those who had served during the Vietnam War.
    c. Pell Grants, the largest source of federal grants for postsecondary education, totaled $27bn over 6.3 million undergraduate students in FY2020.
    d. Federal funding for the K-12 education of low-income students via ESEA has more than doubled since 1980 in constant FY2017 dollars, totaling approximately $15.5 million in 2017.

4. <u>Commerce</u>

a. Since Bayh-Dole's enactment, the legislation has led to the creation of over $1.3tn in economic growth, 4.2 million jobs, and assisted the success of over 11,000 university-originated startups.

b. Fourth Industrial Revolution-relevant patent areas, such as machine learning and drones, show that newer firms lead incumbents in patent grants. This shift is geographic as well; traditional incumbents (and current leaders) are primarily American and Japanese, while Chinese and American firms lead in Fourth Industrial Revolution-relevant spaces.

c. Several studies have concluded that, since the 1970s, market power (and concentration) of companies has increased due to increased profitability, which is in turn a result of higher operating margins. Observers have termed the cause of this to be our entrance into the "Waning Era of Antitrust."

d. *Diamond v. Diehr*, the Supreme Court decision which ruled that software used for industrial purposes could be patentable if it "transformed the process into an inventive application of the [mathematical] formula" (i.e., applied abstract code to improve an industry process), was modified slightly in *Mayo v. Prometheus* and *Alice v. CLS Bank*, though its core interpretation still applies.

e. The United States currently has free trade agreements with 20 countries, including the recently negotiated US-Mexico-Canada Agreement (USMCA) which substituted NAFTA.[159] After the COVID pandemic disrupted global supply chains in 2020, the United States has devoted increased attention to decoupling critical

[159] "Free Trade Agreements." *Office of the United States Trade Representative*. http://ustr.gov/trade-agreements/free-trade-agreements.

advanced technological inputs and manufacturing processes from global supply chains.

5. Immigration

   a. The last change to the immigration regime concerning high-skill talent was the H-1B Visa Reform Act in 2004. This act returned the H-1B visa cap to 65,000 annually but provided an exemption for the first 20,000 H-1B visas granted if the recipient was a high-skilled temporary worker with an advanced degree (master's degree or higher) from an American university.

   b. The H-1B Visa Reform Act of 2004 modified the Immigration Act of 1990, which provided minimums for family-based green cards (226,000) and employment-based green cards (140,000), increased the total number of green cards issued annually to 675,000, and increased per-country caps to 7% of the total familial and employment-based allowance (25,620). Additionally, it instituted the Diversity Visa program in an effort to revive immigration from European countries.

   c. In 2019, the United States issued about 1 million green cards, of which 63% were family-based, 32% were humanitarian or based on the diversity lottery, and just 5% were employment-based.

   d. As of 2020, a record 1.2 million foreign workers and their families were waiting for employment-based green cards. The central cause for these wait times are the 7% per-country caps instituted in the 1990 Act. As a result of these caps, waiting times for immigrants from high-supply countries, particularly India, have stretched into the decades.

Chapter V: A Roadmap for the Fourth Industrial Revolution

Chapter 5.1: Defining the Fourth Industrial Revolution

Broadly, the role of the federal government in innovation-related activities from the mid-to-late 20th century to today has generally decreased. This is attributable to reasons exogeneous and endogenous to the United States. Externally, competition from the USSR during the Cold War necessitated a coordinated response to innovation in computing and space which the federal government was better positioned to coordinate. However, after this threat dissipated, policy attention turned away from advanced technology research in favor of biological research and other spending priorities, such as public healthcare coverage. Internally, the massive growth of technology companies during the Digital Revolution and the Internet Revolution incentivized the privatization of most advanced technology research, as competitors sought to retain and protect inventions rather than collaborate with universities or public institutions. These companies benefited from knowledge economies that accrue with scale, allowing a smaller number of technology companies to dominate their service offering.

Today, the federal government has decreased latitude to promote innovation-related activities but has shown greater willingness to do so. This is induced by both resources and capabilities. Today, the federal government spends a far greater percentage of its budget on mandatory spending items, which account for two-thirds of all federal spending, than it did in the 1960s.[160] The biggest share change in federal outlays lies with entitlement programs: as of 2011, Social Security, Medicare, Medicaid, and other entitlement programs accounted for roughly 56% of federal outlays compared to 18% in 1962 (when Medicare and Medicaid didn't exist).[161] In

[160] "Mandatory Spending in Fiscal Year 2020: An Infographic." *Congressional Budget Office*, 30 Apr. 2021. https://www.cbo.gov/publication/57171.
[161] Thuy Vo Lam. "50 Years of Government Spending, in 1 Graph." *NPR*, 14 May 2012. https://www.npr.org/sections/money/2012/05/14/152671813/50-years-of-government-spending-in-1-graph.

contrast, “defense” and “other agency spending” (which includes NASA, education, and science among other unrelated agencies) have seen their shares drop from 52% and 15% to 23% and 12%, respectively, over the same time period. On the other hand, lawmakers’ increased attention on Chinese parity in fields of advanced technology has finally prompted legislative action. Both the House and the Senate passed spending bills in the 117th Congress earmarking roughly $250bn for investments in scientific research, semiconductor and robotics investments, supply chain resiliency, and emerging technologies (AI, quantum computing, etc.); however, a consensus version has yet to formally pass. [162]

However, the trends shaping innovation-inducing activities are unique today as well. First, unlike the 1950s, **human capital and its components are decentralized**. Remote work has made it possible for innovation, particularly in software, to develop amongst remote teams from across the world. This dramatically expands the potential pace for innovation by increasing labor productivity and employee mobility. In the Information Age, input components of human capital, such as education and skills development, have also decentralized from the university centers that predominated in the 1960s and proliferated across the Internet. Institutional education is no longer necessary to build natural language processing or artificial intelligence algorithms.

Second, just as computing power became the de-facto progress metric of the Third Industrial Revolution, the classification accuracy of Artificial General Intelligence (AGI) systems will become the de-facto progress metric of the Fourth.[163] In order to improve their accuracy, systems will need to train on immeasurably large amounts of data. Thus, **the acquisition, quality, and usefulness of data will become a linchpin resource for the**

[162] Deirdre Walsh. “The House passed a bill aimed at boosting U.S. competitiveness with China.” *NPR*, 4 Feb. 2022. https://www.npr.org/2022/02/04/1078226282/u-s-house-passes-china-competition-bill.
[163] Ajitesh Kumar. “Different Success / Evaluation Metrics for AI / ML Products.” *Data Analytics*, 19 Jan. 2022. https://vitalflux.com/different-success-metrics-for-ai-ml-initiatives/.

development of artificial intelligence systems. Organizations (businesses, governments, etc.) with the greatest access to useful, good-quality data will be able to gain significant technological advantages over their competitors.

The expected nature of innovations during the Fourth Industrial Revolution provides leading indications about factors that might contribute to their creation. First, as Klaus Schwab predicts, we will begin to see the convergence of the "physical, digital, and biological worlds."[164] **Integrated digital platform systems, such as the "metaverse,"** is the most visible example. Such systems require incredible amounts of resources to build and operate, limiting their possession to the handful of companies with the resources available. Conceivably, in the future, a considerable amount of citizens' daily activities (e.g., banking, entertainment) will reside in the metaverse. As one metaverse cements a lead, the government will have to balance the scale and efficiency afforded by one, central metaverse against the risks of giving one company the key to the one, central metaverse (analogous to Twitter's function as the 'modern town square'). On the other hand, should multiple metaverses become viable (as is becoming the case between Meta and Roblox), the government would need to weigh the costs of regulating, connecting, and duplicating services for multiple metaverses against the upside of free market competition.

The advent of metaverses highlight the significance of the **Internet of Things (IoT)** to the Fourth Industrial Revolution. As the physical and digital world become more integrated, significant amounts of investment will be required to embed the thousands of sensors required for IoT's functioning within physical infrastructure. In an IoT-functional world, fully autonomous transportation services, smart infrastructure, and health systems will produce efficiency gains on a level never before seen.

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[164] Schwab, 1.

Finally, the automation of exchange systems (financial and legal) will dramatically improve the operating speed and accuracy of exchange mediums. The implications of **cryptocurrency/decentralized finance ("de-fi")**—transforming the nature of commerce by automating its inefficient functions—is understood by many. However, in order to perform, these technologies rely upon secure, low sources of energy as well as more efficient processing capabilities. Securing access to these resources and facilitating continued processing power improvements will be important.

Chapter 5.2: A Policy Roadmap for Success

Introduction and Caveats

This paper began with a central assumption: the best place to start formulating the most optimal policy environment conducive to the creation of innovation for the Fourth Industrial Revolution was to start with our implemented policy environment during the Third. This paper's analysis found that, of the five levers deemed most material to innovation, the federal government's Science & Technology policy, Fiscal & Financial policy, and Education policies were the most influential in facilitating the Third Industrial Revolution. Commerce policy and Immigration policy were deemed to be less influential in facilitating the Third Industrial Revolution.

These results can be interpreted in two ways. First, they can be interpreted as "what mattered and what did not matter" for innovative output. For example: "Commerce policy ranked lower on influence. Thus, reforming antitrust posture will not provide the greatest value add to future innovation." Such a view attempts to determine materiality to innovation and inherently assumes that what transpired over the Third Industrial Revolution was the best result possible or as close to it as we would likely have gotten. Second, the rankings can be interpreted as “the federal government’s particular method of promoting innovation for that era.” This view does not assume that the United States’ performance is optimal. For example, although Immigration was not an influential policy lever during the Third Industrial Revolution, studies have demonstrated that high-skill immigrants have a positive effect on innovation as measured by patenting. A policymaker might take the view that the federal government did not properly harness a potentially material lever, and that doing so would have improved aggregate innovative output.

For policymakers looking to formulate a policy framework, these results provide a starting point that can be modified to fit the available resources, capabilities, and objectives of the era. The goal should be to formulate a policy roadmap that will, at minimum, *permit* the successful advent of the Fourth Industrial Revolution. At best, it will *optimize* innovative output through the Fourth Industrial Revolution. Such a roadmap would be a forecast, and, consequently, inherently uncertain. Additionally, this roadmap would be founded on inherent assumptions about the nature of innovation across eras, namely, that “this time is the same as last time.” This paper recognizes that such simplifying assumptions, while important for the policymaking exercise, limit confidence in a final product.

Looking Forward to the Fourth

<u>SUGGESTED POLICY ACTIONS</u>

1. **Science & Technology Policy**

a. <u>“Public Steeples”</u>: combine Terman’s “steeple strategy” with increased public R&D, focusing resources with the greatest spillover potential to theoretical areas of future relevance to industry

b. <u>Government as a Lead Consumer</u>: reestablishing the federal government’s role as a promoter of nascent fields of innovation through procurement programs for defense, education, or public health applications

2. **Fiscal & Financial**

a. <u>Maintain Low Tax Regimes</u>: reducing the capital gains tax and corporate income tax burdens, particularly for smaller enterprises

b. <u>Capital Tranche #2</u>: explore avenues to unlock untapped sources of capital (similar to the ERISA-rule relaxation for pension funds) and/or more efficiently allocate available capital via digital assets, which might include regulation to speed their adoption and proliferation

3. **Education**

a. <u>Accelerated Education Directorate</u>: provide matching funds to states to promote the creation of future-skills programs (heavy emphasis on STEM and computer science education) via specialized magnet schools and/or a digitally accessible curriculum

b. <u>Cluster Building</u>: prioritize the cultivation of innovation clusters centered around larger research universities via bidirectional exchange models between universities and local industry

4. **Commerce**

a. Balanced Antitrust Posture: promoting consumer preference in platform systems (metaverses, automated transportation services) by promoting systems compatibility between services

b. Employee Mobility: examining the implications of a federal statute restricting the use of non-compete contracts

5. Immigration

a. Targeted Immigration: promoting high-skill immigration by easing unreasonable visa and green card burdens

Chapter VI: Conclusion

The Fourth Industrial Revolution promises to be the next great advancement humanity will face. It will change the very nature of our everyday existence, bringing our daily lives closer to the digital world than ever before. It will decrease costs and improve performance by drastically reducing decision and processing times. Most significantly, this revolution will see the rise of technologies that effectuate the replacement of mental labor, a capability that will free up millions of hours worth of productive capacity that can be put to better use.

Societies must be prepared to guard against the risks posed by this era. As with any industrial revolution, labor markets are a key concern. This revolution will first make redundant many lower-level forms of mental labor. From fast food clerks to line workers to paralegals to truck drivers, the advent of an artificial intelligence nearing parity with human intelligence signals the end of humans occupying jobs of lower-level mental labor in the medium-term. This circumstance promises to increase the division between high and low paying jobs, exacerbating income inequality in developed nations. It is incumbent upon policymakers to heed the lessons of the Third Industrial Revolution, which put thousands of American factory workers out of jobs, and begin planning for this employment displacement over the next two decades. By the end of this industrial era, if they are not already partially displaced, the threat to labor markets will extend to higher levels of mental labor.

As alluded to in Chapter 1, leadership through industrial revolutions is critical to much more than technological superiority. The “winners” of each of the last industrial revolutions have proceeded to become the world’s preeminent economic growth engines and, consequently, global hegemons. The United States can ill-afford to lose this technological race, for the alternative would be a victory by communist China. Such a scenario would pose a serious threat to the West. Unlike prior industrial revolutions, which conferred on a nation superior means of production that could then be leveraged in trade against other nations, the Fourth Industrial Revolution does not confine its means of production to one country. Rather, the Fourth is about *standard setting*—setting the digital protocols and standards for artificial intelligence, the metaverse, digital currencies, and so much more. Whoever is able to get ahead in this race will be able to dictate the standards of this new technological environment that we will all live in and interact with. The United States' principal priority over the next 10-20 years must be to develop, launch, and scale a successful and adoptable standard for Fourth Industrial Revolution technologies to offer a powerful alternative to the Chinese Communist Party's digital police state. Such a demand is not trite nor seasonal, but existential; the future of the United States and the democratic world at large could very well be decided by the quality of our computer code in the early 21st century.

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Biography

Ashish Dave is a senior at UT Austin majoring in Business Honors, Plan II Honors, and Finance with a certificate in Business Spanish. He is a recipient of the Forty Acres Scholarship, UT Austin's premier full-ride merit scholarship. At UT, Ashish has served as a Senior Consultant for Texas Consulting, the Head of Finance & Strategy for the Texas Rocket Engineering Lab, Senior Undergraduate Fellow for the Clements Center for National Security, and First Year Representative in UT Austin's Student Government Assembly. Ashish also served as Co-Founder/CEO of his own startup, Politiq, a digital platform that matches talented volunteers and political professionals with local, state, and federal political campaigns. Ashish is a member of the McCombs Dean's Undergraduate Student Advisory Council and the Titans of Investing network under Britt Harris. Ashish is an Eagle Scout from BSA Troop 404 in Pearland, Texas.

Ashish's professional experiences include internships as a Summer Analyst in Goldman Sachs' Executive Office, a Program Integration Intern in Boeing's Defense, Space & Security division, a Consulting Fellow for an "open innovation" consulting firm in Madrid, Spain, and a Legislative Intern for the Texas Senate. After graduation, Ashish plans to start his career as a Business Analyst at McKinsey & Co.