**The Progenitors of the Information Age and the Birth of AI: Introducing the "Political Economy of the Fourth Industrial Revolution"**

Victor Menaldo
University of Washington
vmenaldo@uw.edu

This is the introductory chapter to a book manuscript entitled The Political Economy of the Fourth Industrial Revolution—a novel, multidisciplinary account of the origins of the new AI-driven economy. Using the New Institutional Economics framework—which explores economic progress through the prism of changing property rights regimes, contracting patterns, and supply chain dynamics—I situate the Fourth Industrial Revolution within the lineage of its predecessors. This chapter argues that all industrial revolutions exhibit long, uncertain commercialization phases, unique combinations of intangible and tangible capital, and major supply chain reconfigurations. It illuminates how the AI revolution emerged out of a profound transformation of the American political economy. Between the late 1970s and 2000s, a populist-statist consensus that had prevailed since the Progressive Era was supplanted by the "Creative Destruction Paradigm" (CDP). Earning strong bipartisan support, the CDP prioritized evidence-based policymaking and fostered innovation by establishing property rights and liability rules over new asset classes, reducing transaction costs, and solving market failures. These changes transformed contracting relationships, industrial organizations, and firm strategies. Interrelated reforms to intellectual property rights, antitrust regulation, telecommunications, and international trade fostered vertically disintegrated supply chains dominated by American firms specializing in R&D, IP, and design. Evolving in this context, cell phones became platforms that bring together users, manufacturers, developers, and telecommunications providers. Smartphones with complex global supply chains spawned a new economy governed by digital platforms engineered to produce gushers of mobility-enhanced, diverse, and dynamic data exploited by AI researchers.

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## INTRODUCTION

America's economy is increasingly fueled by digital devices, machines, and appliances that communicate with each other over the internet, ever-improving algorithms for driverless cars and virtual reality, and generative Artificial Intelligence (AI) that can process text, images, and videos.[1] In healthcare, AI-driven precision medicine is revolutionizing patient care by tailoring treatments based on individual genetic profiles. In manufacturing, the integration of AI with industrial automation is leading to more efficient and flexible production lines. In finance, advanced algorithmic trading techniques are optimizing trading strategies and improving market liquidity. In education, AI-powered adaptive learning systems increasingly provide personalized learning experiences tailored to individual students' needs.[2]

Its broad applicability, continuous improvement potential, and transformative impact make AI a quintessential General Purpose Technology (GPT): AI-based innovations are transforming firms, empowering workers and consumers, and revolutionizing how we learn, work, and interact.[3] This puts it on par with previous world changing innovations that had broad applications across sectors and spurred further technological advancements. These include the steam engine, electricity, and transistors.

This book manuscript therefore agrees with those individuals and organizations who claim we are living through the early stages of the Fourth Industrial Revolution, a fundamental transformation where AI is reshaping the economy, society, culture, and politics.[4] While in many ways this revolution is unlike anything the world has experienced before, it shares several elements with previous ones, including the simultaneous emergence of groundbreaking technologies with profound economic, social, and political consequences.

The First Industrial Revolution introduced the mechanization of textiles and other consumer goods powered by water and steam power, transforming poor agricultural societies into

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[1] The Gig Economy, represented by companies like Uber, Lyft, and Airbnb, was valued at over $455 billion in 2023. AI could contribute up to $15.7 trillion to the global economy by 2030 and positioning the U.S. as the largest beneficiary (PricewaterhouseCoopers 2020).

[2] The healthcare industry has used AI to personalize medicine, diagnostics, and predictive analytics. For example, IBM's Watson analyzes vast amounts of medical data to inform clinical decision-making. By 2024, smart factories will have added over $2 trillion to the global economy (see Deloitte 2019). Algorithmic trading and AI-driven risk assessment could save the banking industry over $1 trillion by 2030 (Accenture 2018). Adaptive learning platforms have served over 100 million students (see Khan Academy 2023; Coursera 2023).

[3] Companies that have adopted AI are seeing huge productivity improvements, fundamentally changing how they operate and compete (McKinsey & Company 2020). Gig Economy platforms offer workers greater flexibility and control over their work arrangements and provide consumers with more personalized and responsive services. Adaptive learning technologies have furnished students with a tailored, flexible educational experience.

[4] This includes intellectuals such as Schwab (2016) and Brynjolfsson and McAfee (2014), politicians such as Andrew Yang, Xi Jinping, Angela Merkel, and Narendra Modi, and firms such as Siemens, IBM, Deloitte, and Accenture.

prosperous industrial economies. The manufacturing of a wide range of mass-produced goods, from garments to revolvers and tools, often took place in relatively small-scale factories located near their power sources, rivers and mines. Nonetheless, this period eventually saw exponential growth in per capita incomes, allowing societies to escape the Malthusian Trap—a condition where rapid, exponential population growth outpaced linear increases in agricultural production, resulting in recurring famines and disease (McCloskey 2017).

Culminating with the 1852 reforms to the British patent system, relatively strong intellectual property rights (IPRs) incentivized the invention and commercialization of key technologies, such as Boulton and Watt's separate condenser steam engine (Bottomley 2014).[5] The era was marked by extensive collective invention too: Technological innovations were frequently shared and diffused between inventors, entrepreneurs, producers, and distributors through cross-licensing agreements, the exchange of knowledge and knowhow, and industrial fairs (Allen 1983; Nuvolari 2004). This "culture of collaboration" complemented a decentralized production system marked by significant outsourcing and reliance on cottage industries.

The First Industrial Revolution saw global communication (e.g., the telegraph) and transportation networks (e.g., the steam ship) established for the first time in history, which had profound geopolitical impacts. These underwrote mass migrations and an explosion in international trade (see Calomiris and Haber 2014: 39-41). They also made both modern nationalism and democracy possible on a mass scale (Anderson 1983).

The Second Industrial Revolution, which ran from approximately 1870 to the 1930s, harnessed electricity and the internal combustion engine, fueling the mass production of cheaper consumer goods and ushering in an era of unprecedented industrial growth and a reorganization of global politics. This was exemplified by the opening of the Pearl Street Electric Station by Thomas Edison in 1882 and the Fordist production of affordable cars via assembly lines characterized by interchangeable parts, revolutionizing manufacturing efficiency and leading to an unprecedented productivity boom.

This period also saw the rise of vertically integrated firms that dominated key industries by controlling every aspect of innovation and production—from research and development (R&D) to design, manufacturing, and distribution—under one roof (Chandler 1990). [6] And it witnessed the ascendance of American economic—and the beginnings of its eventual military—supremacy starting after the Civil War; by the 1890s, the U.S. had become the world's largest economy and one of its most prosperous nations.[7]

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[5] The Patent Law Amendment Act of 1852 reformed the British patent system by simplifying the application process, reducing fees, and making it easier for inventors to protect their inventions.

[6] This was a marked changed from a vertically disintegrated innovation supply chain that saw large firms outsource their R&D to individual inventors who licensed or sold their patented technologies through patent agents (see Lamoureux and Sokoloff 1999).

[7] On the heels of the mass production of affordable foodstuffs, the availability of cheaper healthcare and medicine, and the spread of air travel, radio, and the telegraph (see Gordon 2018).

The Third Industrial Revolution introduced modern computers and the internet, transforming analog processes into digital ones and reshaping how we communicate and work, while also changing media and politics in the process. It began around 1971 when Intel invented the microprocessor—the programmable computer within a computer chip. This innovation was soon commercialized in various electronic digital devices and services, including personal computers, the world wide web, and eventually smartphones and the digital platform economy.

During this era, U.S. economic leadership consolidated behind big technology firms that pioneered a model of R&D labs generously financed with retained earnings. AT&T's Bell Labs introduced transistors, lasers, the Unix operating system, and the C programming language. Xerox Park pioneered the computer mouse, laser printers and computer-generated graphics.

While the 1990s marked the beginning of a transition towards global, vertically disintegrated supply chains—where production processes were spread across different companies and countries—vertically integrated hardware firms such as those mentioned above, as well as Intel, IBM, Compaq, and Cisco, remained dominant. Even as supply chains began to globalize and fragment after the end of the Cold War, these companies oversaw the development and integration of critical technological components—from microchips to PCs to fiber optic cables—sometimes maintaining control over the entire production process, from R&D to manufacturing and, in some cases, distribution. This comprehensive approach enabled these firms to drive the era's technological advancements while positioning the U.S. as the leader in the digital age. This allowed the U.S. economy to experience another productivity wave on the heels of the internet's commercialization, albeit one that was more muted than previous ones (see Gordon 2018).

Microsoft stands out as a notable exception to the Third Industrial Revolution's prevailing model, presaging the next industrial revolution—the one we are living through today. Challenging IBM, it pioneered the separation of hardware from software and reached supply side economies of scale for an R&D heavy product with near zero marginal costs. Its innovative platform drew in different PC manufacturers, developers, and users. However, during its early phase of dominance, before the advent of cloud computing and generative AI, Microsoft did not yet monetize user data by attracting advertisers nor create a cloud infrastructure and software that could optimize enterprise applications—a contrast to later tech giants.[8]

For its part, the Fourth Industrial Revolution thrives on the continuous generation of over 330 million terabytes of data every day from a multitude of digital activities and platforms. This vast and ever-expanding data pool serves as the lifeblood of today's digital economy, powering everything from Internet of Things (IoT) devices and driverless cars to Virtual Reality (VR) and generative AI. These technologies, and others like them, depend on massive data inputs not only to function effectively but also to personalize user experiences, drive real-time optimization, and spur ongoing innovation. As a result, data has emerged as the most valuable economic resource of our time, often referred to as the "new oil" of the postindustrial age.

[8] Later, Microsoft entered the advertising market with acquisitions like aQuantive in 2007 and developed a robust cloud computing infrastructure with Azure, incorporating AI algorithms to optimize applications and services.

The burgeoning IoT consists of interconnected appliances that continuously gather and exchange sensor data, usage statistics, and environmental conditions to automate and enhance various functions in homes and industries. For example, smart thermostats like Nest optimize energy usage. In smart factories, data-driven technologies that monitor machines, production, and supply chains improve the efficiency and flexibility of manufacturing.

Autonomous vehicles, such as those developed by Waymo, process terabytes of dynamic sensor data, GPS information, and traffic data in real time to make split-second driving decisions. Similarly, VR systems, like Oculus Rift, process large datasets to generate immersive experiences that adjust in real time based on user movements.

Finally, generative AI models, such as OpenAI's GPT, are trained on extensive datasets to produce creative outputs in natural language processing and image generation. These models rely on hundreds of gigabytes of text and image data to generate human-like text responses and realistic images. Large language models (LLMs) like GPT function by using deep learning techniques, particularly neural networks, to analyze and understand the patterns within the vast amounts of data they are trained on. By processing this data, the models learn to predict and generate sequences of words, allowing them to create coherent and contextually relevant responses.[9] The ability of LLMs to generate text that closely mimics human writing stems from their exposure to diverse and extensive language data, enabling them to capture nuances in meaning, grammar, and style across different contexts.

To be sure, some critics lambaste generative AI as merely offering incremental improvements over traditional search engines such as Google. Some argue that it's just a glorified autocorrect feature that makes a lot of mistakes (see Davis 2019). This skepticism echoes early criticisms of electricity, when observers dismissed it as inferior to established technologies like steam power, questioning its reliability and cost-effectiveness and lamenting its seemingly intractable deficiencies (Hughes 1983). Critics saw electricity as a luxury good limited to affluent households and niche industries, not a power source that could materially affect everyday life.

Initially, like electricity before it, and AI today, semiconductor technology also was met with significant skepticism. After the invention of the transistor in 1947 by John Bardeen, Walter Brattain, and William Shockley at Bell Labs, its potential applications were not immediately clear. The electronics industry was dominated by clunky vacuum tubes that were used in radios, televisions, and early computers, and many experts doubted that transistors could match their power, reliability, and relatively low cost.

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[9] Deep learning is a subset of machine learning that involves algorithms known as neural networks, which are designed to mimic the structure and function of the human brain. Neural networks consist of layers of interconnected nodes that process input data by assigning varying levels of importance ("weights") to different aspects of the data. As data passes through these layers, the network learns to recognize complex patterns within the data and extracts features that are critical for making predictions and generating outputs. Because deep learning models typically involve multiple ("deep") layers, they can capture the intricate patterns and complex relationships found in large datasets.

Early transistors faced serious technical challenges. They were difficult to manufacture reliably, their performance was inconsistent, and they were more expensive than vacuum tubes. And because the demand for miniaturized electronic components was practically non-existent, their widespread adoption remained limited.

## TO UNDERSTAND THIS REVOLUTION, WE MUST UNDERSTAND PRIOR ONES

The previous industrial revolutions teach us that transformative inventions often require decades to realize their full potential. This extended timeline is primarily due to an uncertain and circuitous commercialization process that only gradually and fitfully transforms novel technologies into practical, timesaving, and productivity-enhancing processes, as well as into valuable final goods and services. Realizing this potential often calls on creating new institutions, regulations, and organizations that can effectively reduce the costs of identifying counterparties, measuring, metering, coordinating, and enforcing agreements, and thus facilitate new patterns of contracting and industrial organization. Indeed, the development of robust, but previously unimaginable, supply chains is always essential to bring groundbreaking products and services to consumers and businesses. That takes a lot of time and experimentation. Many business configurations are tried and many fail.

Electricity's journey from a novel invention to an indispensable utility, which spanned over seven decades, holds lessons for the ongoing AI buildout and a still uncertain commercialization path. Achieving electricity's full potential required extensive reconfiguration of homes, factories, and public facilities. To effectively supplant centralized energy systems such as waterpower or steam engines, the commercialization of electricity called for a comprehensive overhaul of physical infrastructure, including the redesign of transportation networks, buildings, and residences. Early electrification faced significant barriers, including the high costs of retrofitting existing structures, installing intricate wiring systems, and developing stringent safety standards to mitigate electrical hazards.

However, a consistent flow of follow-on innovations and investments gradually ameliorated these obstacles. The development of alternating current (AC) systems by Nikola Tesla and George Westinghouse revolutionized power distribution, enhancing both its efficiency and scalability. The expansion of electrical grids reduced the costs associated with electricity generation and distribution, making it increasingly affordable for a broader population. Concurrently, advancements in electrical appliances and lighting transformed domestic and industrial environments, significantly enhancing productivity and the quality of everyday life. Homes were retrofitted with electrical wiring, public spaces were illuminated with electric lighting, and factories adopted electric machinery.

As documented by Landes (1990) and David (1990), these changes revolutionized how production was organized. Workers could now easily plug in machinery to the ubiquitous electric sockets lining the entirety of factory floors. This optimized space usage, workflow, and logistics, leading to exponential productivity improvements. This is because laborers no longer had to be huddled and crowded together under a centralized power source that hung overhead in the form of a huge leather or rubber belt that they then precariously attached their machines and tools to with pulleys. The reorganization of factory production fueled substantial gains in labor productivity and total factor productivity (TFP); these gains were especially pronounced between 1920 and 1970, during which the U.S. experienced annual compound growth rates in labor productivity of around 3 percent (see Gordon 2018: 17).

Similarly, as Gordon (2018) recounts, the invention of the electric elevator transformed the urban landscape and its functionality: the ability to extend space vertically allowed for higher population densities and the reorganization of offices and some factories. Plus, affordable appliances such as fridges, washing machines, and vacuums became ubiquitous, freeing folks from often tedious, if not backbreaking housework and similar chores.[10]

What ultimately mattered to the Second Industrial Revolution was not the invention of electrical power per se, rather, what made all the difference economically, socially, and politically were its diverse and unimaginable applications. These arose through a meandering, yet profoundly transformative, commercialization process.

Similarly, our digital age was the result of the gradual emergence of markets and firms that introduced innovative patterns of industrial organization and novel business models. It only reached fruition after intricate collaboration and contracting networks took hold and supply chains were drastically transformed. In the semiconductor industry, for example, a fundamental separation of R&D and design from manufacturing and testing and packaging took decades to develop (see Barnett 2021).

The U.S. military and NASA were the primary buyers of early transistors, purchasing them to guide nuclear warheads on missiles and for applications in the space program, such as the Apollo Guidance Computer used during the lunar missions. At first, it was the government's unique needs that drove innovation, not kids who sought transistor radios for beach outings (see O'Mara 2019).

The turning point came with the invention of the integrated circuit. In 1958, Jack Kilby at Texas Instruments and Robert Noyce at Fairchild Semiconductor independently developed these devices. This innovation enabled multiple transistors and other components to be manufactured on a single semiconductor substrate, drastically reducing size and cost while increasing reliability. The integrated circuit demonstrated the immense potential of semiconductor technology for creating complex and compact electronic systems, well beyond transistors that were hitherto soldered together with cumbersome wires.

These advancements began to change industry perceptions. As we shall see later in the book manuscript, strategic collaborations, cross-licensing agreements, and knowledge sharing among companies accelerated progress. As manufacturing techniques improved and economies of scale were achieved, costs decreased, and performance enhanced. Initial skepticism gave way to

[10] The proliferation of "networked" homes and other facilities that were plugged into the electric grid went hand in hand with the advent of widespread telephone access and readily accessible gas and sewage service (Gordon 2018).

enthusiasm as the commercial applications of transistors and integrated circuits expanded into computing, telecommunications, and consumer electronics.

While the U.S. market penetration of incredibly powerful and cheap personal computers is now close to 100%, the process by which this occurred was not preordained. Released in 1971, Intel's 4004 processor, the first commercially available microprocessor, had only 2,300 transistors and was initially designed for calculators. Released in 1978, Intel's 8086 processor had only 29,000 transistors. The first generation of personal computers like the IBM PC, which cost between $1,500 and $3,000 in the early 1980s (equivalent to $4,000 to $8,000 today when adjusted for inflation), offered limited processing power and memory. They eventually evolved, however, into extremely light, portable machines with exponentially greater processing power, memory, and storage and sell for as little as $300 to $500 (2024 dollars). Modern CPU processors like the Intel Core i9 contain billions of transistors.

Deliberate and sustained—and quite costly—subsequent efforts are what explain why the number of transistors on a dense integrated circuit (meaning a chip where the components are packed very closely together to maximize the number of transistors in a small area) double approximately every two years. According to Galetovic (2021), Moore's Law was the result of rising R&D investments and continuous experimentation by semiconductor firms that managed, by hook or by crook, to keep cramming more and more transistors onto an integrated circuit's surface area, thereby shrinking electronic devices, improving their processing speed, and inducing constant price reductions.

Firms invested heavily in R&D to overcome technical challenges such as heat dissipation (excess heat generated by electronic components that can impair performance) and electron leakage at smaller scales (unwanted flow of electrons that can cause circuits to malfunction), leading to innovations like strained silicon (silicon that has been stretched at the atomic level to allow electrons to move more easily, improving speed and efficiency), high-κ dielectrics (materials that can store electrical energy more effectively, reducing power loss and allowing for thinner insulating layers in transistors), and FinFET transistor architectures (a specialized design of 3D transistors with thin "fins" that provide better control over electron flow, thus making smaller and more efficient transistors possible).[11]

Now skip ahead to the ongoing evolution of autonomous vehicles. Despite enduring skepticism about the commercial viability of driverless cars, significant progress is really happening. If you've been to San Francisco lately, you may have noticed that driverless cars are a real thing

[11] Universities also greatly contributed to this effort, as Moore's Law was ultimately sustained through significant advances in basic science and intensive R&D across multiple disciplines including solid-state physics, quantum mechanics, and nanotechnology (see O'Mara 2019). The continuous miniaturization of transistors and the enhancement of microprocessor performance required breakthroughs in materials science, including the development of high-purity silicon and the discovery of new semiconductor materials. Electrical engineering breakthroughs led to innovations in circuit design, allowing for more efficient and powerful processors. Advancements in photolithography—the process used to etch intricate patterns onto silicon wafers—were crucial for reducing transistor sizes and increasing chip density.

that's really taking off. Waymo is starting to outcompete Uber there and folks are getting much more comfortable being transported by these vehicles. In fact, many introverts, such as myself, much prefer it.

According to some industry reports, if even 50% of the global vehicle fleet becomes autonomous by 2050, this shift could dramatically transform urban landscapes and transportation systems.[12] Reduced demand for parking spaces could free up valuable real estate for other uses, while interconnected autonomous vehicles may alleviate traffic congestion and enhance road safety and increase fuel economy. Furthermore, the efficiency gains from driverless cars could lead to significant economic benefits, estimated in the trillions of dollars, through increased productivity and reduced transportation costs. These vehicles could also offer individuals more time for work and leisure during commutes, thereby enhancing the overall quality of life. This is just one small silver of the potential efficiencies and improvements that may be associated with driverless cars.

For all this to happen, however, it's going to take a massive sorting of liability rules and safety regulations and new traffic laws and privacy and cybersecurity protocols—not to mention all kinds of new contracting and industrial organization innovations we can't yet imagine. To get these driverless cars to reach their full potential, it's going to take a whole lot of time and effort.

**Digital Platforms are the Fourth Industrial Revolution's Lifeblood**

Today, dynamic U.S. firms specializing in R&D, IP, design, software, algorithms, and marketing occupy the pinnacle of global supply chains, often leaving the assembly of physical devices, including semiconductors and digital devices, to other countries. America's Research-intensive industries—including computers, semiconductors, software, communications, aerospace, pharmaceuticals, scientific instruments, and chemicals—exhibited remarkable growth since their emergence after World War II, culminating in today's mobile digital economy (see Barnett 2021). Ubiquitous, interconnected handheld devices such as smartphones, and the app economy they spawned—including mobile-enhanced search and social media platforms and the growth of the gig economy—have transformed the larger economy, society, and politics.

Big Tech's big spending means continued smartphone innovation. The early generation of mobile phones were exceedingly expensive, costing over $10,000 in today's dollars after adjusting for inflation, and limited in number—only about 12,000 units were sold in 1983, the first year after their introduction (see Murray 2001). Today's smartphone prices range from $100 to $1,000 and have eliminated consumers' need to purchase separate devices such as cameras, GPS units, and music players. This has been a boon to consumers and made technological advancements accessible to a broader population, if not the entire world's inhabitants (see Galetovic and Haber 2017). Technological progress around foldable displays, 5G connectivity, enhanced camera capabilities, biometric security, extended battery life, and AI-powered personal assistants continues apace. However, the smartphone's most profound innovation lies in how it serves as a foundation for the mobility-enhanced app economy that generates huge amounts of data.

[12] McKinsey & Company 2023; Boston Consulting Group 2023; PricewaterhouseCoopers 2023.

The most instrumental players in generating, refining, organizing, and distributing the data that drives the Fourth Industrial Revolution are digital platforms embedded within these mobile devices. They specialize in searching for information and data, social media, e-commerce, and matching and continue to strive to keep an ever-expanding user base immersed and engaged, as the data they generate underwrites a range of free products and services for consumers who, in exchange for creating and sharing their digital footprints, receive personalized ads tailored to their interests and behaviors. To achieve this delicate balance, platforms like Google, Facebook (Meta), Amazon, and Twitter/X have established appealing, multi-sided markets that attract a global audience and countless advertisers, developers, and device manufacturers—all benefiting from network effects. The first type of network effect is direct, where the utility for existing users increases as more users join the platform. The second is indirect, where the value for advertisers, developers, and device makers grows with the expanding user base.

To sustain these network effects and the market share and profits they enable, digital platforms make appreciable investments in R&D and continue to innovate. In 2023, Alphabet (Google's parent company) spent approximately $45.4 billion on R&D (Statista 2023), while Meta (formerly Facebook) invested about $38.48 billion (MacroTrends 2023). In surveys measuring consumer surplus—the difference between what users would be willing to pay for goods and services versus what they actually pay—Americans value their use of search engines like Google at nearly $20,000 annually, highlighting significant savings for a service that is free (Brynjolfsson et al. 2019).[13]

As GPS-enabled digital devices have proliferated and their digital platforms have mushroomed, this has disrupted traditional industries, casting a long shadow from which the Fourth Industrial Revolution emerged. Ridesharing and delivery services, independent contracting platforms, and e-shopping sites have revolutionized commerce. By underwriting the rapid spread of information across global search engines, social networks, matching apps, and video-sharing websites have profoundly changed quotidian social interactions, dating, and culture, as well as political landscapes. These digital juggernauts continue to churn out vast amounts of diverse and dynamic data that fuels AI models.

Digital platforms depend on massive volumes of raw data to personalize user experiences, optimize content delivery, and power targeted advertising. For instance, Facebook collects extensive data on user activities to tailor news feeds and ads to individual preferences. In turn, this same data is used by researchers to train generative AI models, enabling them to understand and produce coherent, contextually relevant text.[14] Likewise, user-generated content from

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[13] Modern smartphones possess processing power that rivals that of desktop computers from the 1990s and early 2000s; their System on a Chip (SoC)—which integrates the Central Processing Unit (CPU), Graphics Processing Unit (GPU), memory controllers, modems, and other specialized processors—contains billions of transistors that enable high performance within a compact, energy-efficient design made possible by significant advancements in semiconductor technology, even though smartphones prioritize portability and power efficiency over sustained performance.

[14] While social media, e-commerce platforms, and digital forums are major sources of data for training generative AI models, researchers have also utilized other data sources, including large-

platforms like Twitter/X is invaluable for teaching AI models to generate human-like responses, enhancing their ability to engage in meaningful conversations.

**The Book Manuscript's Key Questions and its General Strategy**

How did the U.S. arrive at the point where its leading firms' most valuable capital is intangible while remaining at the bleeding edge of technological innovation? How did these firms revolutionize the innovation process, become more productive and profitable, and fundamentally transform the American economy in the process? What political, legal, and regulatory frameworks fostered the technological advancements that transformed mobile devices into the data-gathering engines that now power the Fourth Industrial Revolution?

In other words, how were mobile phones transformed from bulky devices with limited functionality—primarily handling voice calls and plagued by short battery lives—into powerful computing devices with high-resolution touchscreens, cameras, internet connectivity, GPS, audio-video capabilities, and AI assistants? How did smartphones evolve into platforms connecting users, handset manufacturers, developers, software providers, and payment processors, therefore spawning an app economy dominated by geo-coded digital platforms deploying personalized recommendations and interactive features? How did these GPS-enhanced digital platforms achieve and maintain dominance through both direct and indirect network effects, locking in massive global user bases numbering in the billions? What measures allowed them to build ecosystems that seamlessly integrate hardware, software, and user profiles while providing bundled services from search engines to cloud storage? How did they cultivate user-generated content and personalize experiences through engagement-increasing algorithms, sophisticated recommendation systems, targeted advertising, and bespoke services?

To address these questions and thus uncover the foundational changes that drove the Fourth Industrial Revolution, I employ a New Institutional Economics (NIE) approach. By leveraging the tools of rational choice theory, NIE examines how institutions mediate the relationship between individuals' preferences and their actions.[15] NIE explores how institutions, norms, laws, and regulations shape the formation of markets and organizations and thus influence both individual behaviors and collective actions. It can therefore be used to understand how institutional differences and changes influence economic, political, and social outcomes, making it relevant to economists, political scientists, and sociologists alike (see Levi and Menaldo 2015).

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scale web crawls that gather text data from various websites, digital libraries containing books and academic papers, publicly available datasets like Common Crawl, government databases, news archives, and user contributions to collaborative projects like Wikipedia.

[15] Rational choice theory posits that individuals make decisions by systematically evaluating available options to maximize their utility. It assumes that preferences are linear and transitive, and that individuals engage in cost-benefit comparisons and expected value calculations to choose the most favorable outcome: the one closest to their ideal point. This may include engaging in strategic behavior: when pursuing their preferences, individuals condition their behavior on what they believe others will do—it acts as a constraint on their actions.

The NIE paradigm is premised on the idea that as individuals and organizations pursue their interests and attempt to benefit from gains from trade, they encounter various challenges and frictions. Transaction costs may impede their ability to secure property rights over tangible and intangible assets or their labor (see Alston et al. 2018). Transaction costs are the expenses associated with finding counterparties to transact with, assessing and measuring relevant features of the transaction, negotiating agreements, and enforcing their terms. Information asymmetries (such as adverse selection) and principal-agent problems (such as moral hazards) may derail, or at least seriously distort, market exchanges and complicate relationships within organizations.[16] Collective action issues, including coordination difficulties (Olson 1967), and attempts to safeguard against opportunistic behavior (Williamson 1985), further impact how institutions function and affect the ability of individuals and groups to achieve their objectives.

NIE is helpful for understanding how the assignment and enforcement of new property rights and the contracts that activate these rights contribute to the creation of new networks of exchange, competition, and collaboration between individuals, firms, and other organizations. It is also helpful for deciphering the logic behind the industrial organization of new supply chains, including how firms within the same supply chain relate to each other or how potential rivals compete and cooperate. Finally, NIE helps gain purchase on why and how governments may or may not reduce transaction costs and address market failures in the quest to satisfy their political and economic objectives.[17]

More specifically, this book manuscript draws on NIE to help make sense of how shifts in ideological, institutional, and regulatory landscapes can establish property rights regimes, lubricate contracting relationships, and promote new industrial organizations. It exploits the lessons of NIE to theorize about how previously prohibitive transaction costs may appreciably decline, allowing new markets for manufactured products and intangible assets and information and services to materialize and previously unrealizable gains from trade to be realized.

THE ARGUMENT

To understand the origins of the Fourth Industrial Revolution, this book manuscript outlines the causes and mechanics of the twilight of the Third Industrial Revolution. The key technological

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[16] Adverse selection refers to a situation where one party possesses more or better information than the other before a transaction occurs, leading to the selection of suboptimal or higher-risk participants. This hidden information problem can result in markets being dominated by those with less desirable characteristics, driving up costs and inefficiencies, like in insurance markets where individuals with higher risk are more likely to seek coverage. Moral hazard occurs after a transaction has taken place, where one party may take hidden actions that affect the outcome of the agreement, often to the detriment of the other party. For example, an insured individual may take greater risks than they otherwise would because they do not bear the full consequences of their actions. On these points see Alston et al. (2018).

[17] Market failures occur when markets "go missing"—not because there is a lack of potential gains from trade, but because property rights are not well-defined or transaction costs are prohibitively high, despite buyers' willingness to pay and producers' willingness to sell (see Coase 1960).

advancements that this book seeks to explain came about as the result of profound reforms to IPRs, trade policy, telecommunications, and antitrust regulations between the late 1970s and the early 2000s. I hasten to emphasize, however, that these changes are not best understood as embodying so-called Neoliberalism or the "Washington Consensus."

Neoliberalism is an ideology that emerged prominently in the late 20th century, advocating for free-market capitalism as the primary means to achieve economic growth and social welfare. It emphasizes the efficiency of market mechanisms in allocating resources and reducing the state's role in the economy by promoting privatization, deregulation, and globalization (see Harvey 2005; Mirowski and Plehwe 2009). Key tenets of neoliberalism include deregulation of industries, privatization of state-owned enterprises, introducing means-testing to the government's safety net, and the promotion of individual entrepreneurship. Neoliberal policies often involve lowering trade barriers to encourage international trade, reducing taxes to stimulate investment and consumption, and limiting regulations that are excessively distortionary.

Similarly, the Washington Consensus refers to a set of ten economic policy prescriptions formulated by economist John Williamson (see Williamson 1990). These prescriptions were promoted by Washington, D.C.-based institutions like the International Monetary Fund (IMF), the World Bank, and the U.S. Treasury, particularly for developing countries facing economic crises. The policies emphasized fiscal discipline, reordering public expenditure priorities, tax reform, liberalizing interest rates, adopting competitive exchange rates, trade liberalization, encouraging foreign direct investment, privatization of state enterprises, deregulation, and securing property rights. The overarching goal was to stabilize economies that had suffered macroeconomic crises due to trade or fiscal imbalances and reform them in a more market-oriented direction, including integrating them into the global economy.

This book manuscript challenges the view that neoliberalism or the Washington Consensus birthed today's globalized knowledge economy, instead attributing the groundwork for the AI revolution to a distinctly bipartisan agenda that prioritized globalization and innovation through evidence-based policy. Over several decades, a series of often unheralded laws, regulations, and court decisions, endorsed by both parties, shifted from a populist-statist focus to a pragmatic, technocratic emphasis on innovation and global integration. This culminated in a political economy fundamentally centered on intangible capital, where digital ecosystems formed around interoperable devices and multisided platforms.

### A Technocratic Approach Displaced a Populist One

The Progressive—or perhaps better put, populist and statist—era spanned between the 1890s and 1920s. It was the first period to see a significant, coherent expansion of government intervention in America's economy and society. Presidents Theodore Roosevelt and Woodrow Wilson championed policies that increased federal oversight to address several challenges engendered by industrialization, urbanization, and increased economic inequality. These policies included aggressive antitrust actions against alleged monopolies, embodied in the establishment of regulatory bodies like the Federal Trade Commission (FTC), and legislation such as the Clayton Antitrust Act.

By introducing extensive federal programs aimed at economic recovery and social welfare in response to the Great Depression during the 1930s, President Franklin D. Roosevelt's (FDRs) New Deal further entrenched this statist approach. The New Deal's "Three Rs"—Relief, Recovery, and Reform—inspired legislation and launched executive level agencies that centralized economic planning and increased federal regulation of the economy.[18] The Social Security Act (SSA) established a federal safety net for the elderly and unemployed. The National Industrial Recovery Act (NIRA) attempted to manage industrial production and pricing through codes of so-called fair competition, while the Agricultural Adjustment Act (AAA) sought to manage agricultural production by introducing price floors aimed at raising crop prices. The creation of the Securities and Exchange Commission (SEC) exemplified a strong federal presence in the regulation of financial markets.

This statist, populist trajectory continued with President Lyndon B. Johnson's (LBJs) "Great Society" programs in the 1960s, which expanded federal involvement in education, healthcare, and civil rights. Johnson's initiatives aimed to eliminate poverty and racial injustice, leading to the creation of Medicare and Medicaid, federal funding for education through the Elementary and Secondary Education Act (ESEA), and the enactment of civil rights legislation like the Civil Rights Act of 1964 and the Voting Rights Act of 1965. President Richard Nixon, LBJ's successor, continued in his predecessor's footsteps in terms of embracing price controls in a bid to tame inflation and indulging in more muscular regulation; for example, by introducing the Environmental Protection Agency (EPA).

The longstanding populist and statist consensus that spanned the long 20th century condoned significant government intervention to address social, economic, and environmental problems. However, it often prioritized aggressive regulatory action over the empirical assessment of policies' effectiveness. And it often culminated in regulatory overreach that introduced serious economic distortions and encouraged rent-seeking (see Buchanan and Tullock 1962; Stigler 1971; Peltzman 1976).

**The Creative Destruction Paradigm**

But populism and statism for the sake of statism was not to last. A new approach, which I will henceforth refer to as the Creative Destruction Paradigm (CDP), internalized Joseph Schumpeter's concept of "creative destruction"—the process by which profit-seeking firms innovate and disrupt and displace old industries and incumbents to make way for new technologies and goods and services and economic growth. The CDP prioritized the government's role in promoting innovation by helping to create entirely new markets by first establishing property rights and reducing transaction costs, solving market failures, and establishing international rules of the road to help firms globalize supply chains and foster the worldwide circulation of ideas and technologies. This fueled an innovation-driven transformation that endowed the U.S. with an intangible capital centric, digital economy that would ultimately culminate in the Fourth Industrial Revolution.

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[18] Moreover, programs like the Works Progress Administration (WPA) and the Civilian Conservation Corps (CCC) provided government-funded employment to millions of Americans.

The CDP was exemplified by Executive Order 12866 in 1993 and the Office of Management and Budget's Circular A-4 in 2003. Both required executive agencies to spell out a proposed regulation's anticipated economic costs and benefits, explain the logic behind their interventions, and compare them to a "no regulation" alternative. They sought to ensure that federal government interventions were justified, efficient, and conducive to economic growth (see Executive Order No. 12866. 1993). In turn, they contributed to an environment where innovation could flourish. These directives were the culmination of earlier efforts begun by Presidents Carter, Reagan, and Clinton to ensure that Washington, D.C. consider the potential effects of federal regulations on the economy and society, and that these efforts promote greater efficiency and innovation.

Jimmy Carter, whose tenure spanned from 1977 to 1981, played a pivotal yet often underappreciated role in shaping America's new political economy. His administration undertook significant deregulation efforts across various industries, including airlines, trucking, railroads, energy, and communications. The Airline Deregulation Act of 1978, the Motor Carrier Act of 1980, and the Staggers Rail Act of 1980 unleashed competition and spurred innovation, resulting in a more efficient transportation and distribution system. Air travel costs declined by half (Morrison and Winston 1995), making commercial flight a mainstay of American life, while the logistical cost of moving goods shrank by 50% as a share of GDP (Winston 1998), enabling the U.S. to diversify its economy and take the pole position in high-tech sectors even as its postwar manufacturing dominance waned, reflecting the ascendance of intangible capital and IP.[19]

Consider some of the key regulatory areas that eventually made the Fourth Industrial Revolution possible. In communications, reforms initiated by the Federal Communications Commission (FCC) during the Carter administration made telecommunications markets more competitive and fostered innovation. Also, Carter's IP policies set the stage for recognizing the importance of property rights in promoting innovation: the Bayh-Dole Act of 1980 revolutionized the management and commercialization of federally funded research and improvements to the patent system enhanced the efficiency and effectiveness of the patent examination process and IP enforcement (see Barnett 2021). Finally, competition policy became far less populist and more grounded in price theory and insights from industrial organization, as well as evidence-based: its central goal continued to trend towards promoting consumer welfare, both statically and dynamically, instead of shielding competitors from their dominant rivals or punishing bigness or success per se. These dramatic changes to telecommunications, IP, and antitrust are topics we will explore in greater detail later in the book manuscript.

Building on Carter's foundation, Presidents Ronald Reagan, George H.W. Bush, and Bill Clinton further advanced deregulation, freer trade, and the globalization of supply chains. Reagan's administration championed free-market policies, reducing government intervention and promoting competition across multiple sectors. This included significant tax reforms—such as the Economic Recovery Tax Act of 1981 and the Tax Reform Act of 1986—that lowered marginal income tax rates and simplified the tax code. Beyond tax policy, Reagan continued

[19] The Carter administration also initiated the deregulation of oil and natural gas prices, which, along with subsequent efforts by President Ronald Reagan, led to abundant energy supplies.

deregulation efforts in the financial sector with the Garn-St. Germain Depository Institutions Act of 1982. He also built upon Carter's efforts to strengthen IPRs—notably through the establishment of the Court of Appeals for the Federal Circuit in 1982—and consolidated a more technocratic approach to antitrust policy focused on improving consumer welfare.

While under George H.W. Bush, the U.S. pursued free trade agreements, initiating negotiations for the North American Free Trade Agreement (NAFTA), the Clinton administration secured NAFTA's passage through Congress, leading to its implementation in 1994, and played a pivotal role in establishing the World Trade Organization (WTO) in 1995. Clinton also worked towards granting Permanent Normal Trade Relations status to China, facilitating its entry into the WTO in 2001. These agreements and policies lowered trade barriers, encouraged the expansion of global supply chains, and allowed U.S. companies to access international markets more effectively. This is a topic we will explore later in the book manuscript.

President Clinton's administration especially embraced globalization and technological advancement, promoting policies that facilitated the growth of the internet and digital technologies. The Telecommunications Act of 1996 overhauled regulations to promote competition and reduce barriers to entry in the telecommunications industry, leading to increased innovation and consumer choices in telecommunications and internet services. This legislation also ushered in the so-called E-Rate program to expand internet access in schools and libraries.

Clinton also promoted the rise of the internet through other initiatives, sometimes indirectly. The 1997 "Framework for Global Electronic Commerce" advocated for minimal government intervention and the private sector's lead in internet development. The Digital Millennium Copyright Act of 1998 updated copyright law for the digital age. More permissive antitrust policies eventually allowed digital platforms to grow organically and then grow some more via acquisitions, reaching demand side economies of scale and establishing ecosystems of bundled, highly integrated services that maximized user engagement. Lesser-known regulations and laws paved the way for electronic signatures and digital contracts that reduced barriers to negotiation and simplified digital payments.[20]

Clinton's support for the World Trade Organization (WTO) and the establishment of permanent, normal trade relations with China further integrated the U.S. into the global economy. These actions facilitated global trade liberalization, expanded markets for U.S. companies, and

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[20] The Electronic Signatures in Global and National Commerce Act (E-SIGN Act) of 2000 and the Uniform Electronic Transactions Act (UETA) of 1999 facilitated the use of electronic signatures and digital contracts. The E-SIGN Act established the validity of electronic records and signatures, ensuring they have the same legal standing as traditional paper documents. Similarly, the UETA standardized state laws related to electronic transactions, significantly reducing barriers to digital transactions. Moreover, court decisions reinforced these statutes: Specht v. Netscape Communications Corp. (2002) highlighted the importance of conspicuous terms and user assent and Nguyen v. Barnes & Noble Inc. (2014) reinforced the principle that users must have actual or constructive notice of terms for them to be binding.

contributed to the globalization of supply chains. We will explore this phenomenon further ahead in the book manuscript.

That the Creative Destruction Paradigm (CDP) transcended several administrations—both Democrat and Republican—demonstrates the widespread consensus that this approach obtained. Policymakers from both sides of the aisle believed it would make America more prosperous, stronger, and more influential (Block and Keller 2011; O'Mara 2019). They supported not only market-oriented reforms and deregulation, but also proactive government involvement in fostering innovation and addressing market failures (see Mazzucato 2013; Block 2008). Therefore, terms such as neoliberalism or the Washington Consensus, which predominantly emphasize minimal state intervention and broad deregulation, simply do not do this era justice. What's missing is the critical role for government in promoting research, spurring technological advancement, and helping create and consolidate new markets.

To be sure, the private sector is nonetheless the dynamo that propels the commercialization of innovation. Profit-seeking firms drive forward new goods and services that embody technological advancements, as well as introduce and hone the processes that bring them to life. They also foster new ecosystems of complementary products and applications. They may also coordinate with other firms to expand market reach, perhaps by setting standards that reduce redundancy, certify quality, and promote interoperability. However, for the private sector to play such a crucial role, it must first rely on the government providing a robust foundation.

**The Government Sets up a Commercialization Framework**

The invention and commercialization of new technologies during the CDP era was facilitated by legislation that established property rights and assigned liability. The Bayh-Dole Act of 1980 allowed universities and small businesses to own patents on inventions resulting from federally funded research, spurring innovation in biotechnology and computing by incentivizing commercialization. Section 230 of the Communications Decency Act, passed in 1996, provided online platforms with immunity from liability for user-generated content, enabling them to host and manage vast amounts of information without fear of legal repercussions and stimulating the growth of vibrant digital communities and the rise of social media.[21] In 1998, the Digital Millennium Copyright Act (DMCA) Safe Harbor provisions introduced protections for online service providers against copyright infringement claims for user-generated content. This reduced potential legal costs for platforms hosting user content, encouraging the growth of services like YouTube and fostering greater content sharing by users.

The invention and commercialization of new technologies during the CDP era was also a byproduct of the federal government's deregulation of industries previously governed by strict

[21] This is not to say that Section 230 did not ultimately blur the lines between digital platforms and publishers; moreover, there are ongoing debates about its scope—particularly regarding so-called algorithmic amplification: algorithms that target selected content to viewers based on their search or viewing history. Proponents argue that algorithmic curation enhances the user experience by delivering relevant content, while critics contend that it can create echo chambers and propagate misinformation (see Langvardt 2022).

regulations. For example, the 1996 Telecommunications Act overhauled the telecommunications industry by reducing barriers to entry and incentivizing and enabling new companies to challenge established providers.[22] This legislation prompted both incumbents and newcomers to expand, improve, and accelerate the deployment of their communications networks—whether broadband, wireless, or mobile. These efforts were further facilitated by multiple spectrum auctions conducted by the FCC that efficiently allocated wireless frequencies to the network providers best suited to supply the market. This, in turn, encouraged significant growth and innovation in internet services and cellular coverage.

Additionally, throughout the CDP era the federal government nurtured new markets associated with all manner of innovations through supportive regulations, subsidies, and favorable tax policies. A sounder fiscal environment, in particular, stimulated invention by making it more financially viable for companies to engage in high-risk, high-reward research projects. Reductions in capital gains tax rates encouraged venture capital financing by increasing after-tax returns on investments in startups and innovative firms. This influx of venture capital was instrumental in funding emerging companies in the high-tech sector (see O'Mara 2019: Chapter 3). Furthermore, fiscal policies such as the Research and Experimentation Tax Credit (introduced in 1981) and accelerated depreciation allowances for R&D expenditures reduced the effective cost of investment in innovation. These incentives allowed firms to deduct a larger portion of their R&D expenses from their taxable income more quickly, thereby encouraging increased invention efforts.

This was particularly the case with the commercialization of the internet's physical backbone. Accelerated depreciation schedules enabled telecommunications firms to deduct the cost of infrastructure investments at a faster rate, improving their cash flow and making it more attractive to invest in broadband networks. Additionally, investment tax credits directly reduced the amount of taxes owed by companies that invested in digital infrastructure. By lowering the effective cost of investment, companies were incentivized to deploy advanced technologies and expand their networks.

Furthermore, these fiscal incentives also encouraged investments in other critical components of the digital infrastructure, such as servers, data centers, and networking hardware—routers,

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[22] It therefore overhauled and superseded the Communications Act of 1934, which had established a regulatory framework imposing strict common carrier obligations on telecommunications providers. These obligations required providers to offer services to all customers without discrimination and at government-regulated rates, enforcing price controls through rate-of-return regulations. Additionally, the 1934 Act created significant barriers to entry. These included granting exclusive franchises to incumbent providers; imposing strict licensing requirements through the FCC; prohibiting cross-market entry; restricting companies from offering multiple types of services such as local and long-distance telephone service. Furthermore, the lack of mandates for network interconnection—while incumbents couldn't deny service to customers, they could (and did) deny access to potential competitors to their networks—and the high capital requirements for building independent infrastructure made it nearly impossible for new entrants to compete effectively.

switches, and other equipment essential for directing internet traffic efficiently. For example, accelerated depreciation allowances enabled companies to more rapidly recover the costs of purchasing and upgrading servers and establishing data centers, which are essential for processing, storing, and managing the vast amounts of data transmitted over the internet. This not only enhanced the capabilities of the worldwide web's backbone, but also supported the growth of cloud computing services and content delivery networks that rely heavily on extensive server infrastructure.

During the CDP era, the federal government also encouraged the formation of private, voluntary organizations that brought together various players in the digital device supply chain, including potential rivals. These included standard-setting organizations (SSOs), which establish technical standards to ensure compatibility and interoperability among products and technologies. By determining which patented technologies are incorporated into new products, SSOs help unify the industry around common platforms. As we shall see in greater detail later in the book manuscript, when we explore the 3rd Generation Partnership Project (3GPP), SSOs played a pivotal role in standardizing mobile telecommunications technologies—including 3G, 4G, and 5G standards—and were critical to the development and commercialization of smartphones and similar digital devices. The government also supported research consortia like SEMATECH, in which U.S. semiconductor manufacturers collaborated on R&D: they pooled resources and expertise and jointly invested in more advanced manufacturing processes for both logic and memory chips.[23]

By facilitating collaboration among firms to standardize and improve products and reduce effort duplication, initiatives such as 3GPP and SEMATECH helped build new markets centered on product and process innovation. By promoting and supporting these collaborative efforts, the government played a crucial role in uniting industry players toward common goals. This accelerated technological advancement, helped commercialize innovation, and enhanced the global competitiveness of U.S. high-tech industries.

**Going Beyond Providing a Framework—the Government's Direct Support**

During the CDP era, the federal government also solved an array of market failures. For example, due to several intertwined factors, existing market players lacked sufficient incentives to provide the entire infrastructural backbone supporting the internet or cellular networks. First, private firms were reluctant to bear the high costs and risk the uncertain returns associated with independently developing the foundational technologies behind these systems. Second, these infrastructures are governed by the logic of public goods.[24] Therefore, to ensure that both the internet and cellular networks would achieve interoperability and widespread adoption,

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[23] SEMATECH (Semiconductor Manufacturing Technology) is a non-profit consortium established in 1987 by the U.S. government and 14 leading U.S. semiconductor firms, including companies such as Intel, IBM, Texas Instruments, and Motorola.

[24] They provide widespread benefits that are non-excludable and non-rivalrous. On the one hand, the social gains far exceed any profits accruing to any one firm. On the other hand, each firm has an incentive to free ride on the efforts of others, disincentivizing investment even from those who might capture a relatively high share of the value.

government involvement was crucial in terms of bankrolling research and setting protocols, standards, and facilitating coordination.

By promoting basic and applied science through substantial R&D funding via agencies like the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA), the federal government was instrumental in developing the internet's foundational architecture (see O'Mara 2019). These initiatives led to the creation of ARPANET (Advanced Research Projects Agency Network) in the late 1960s, which aimed to facilitate the sharing of resources and information among scientists and military personnel. It was the first operational packet-switching network—a method of breaking data into small packets for efficient transmission—and connected a few universities and research institutions. Building on ARPANET's success, the NSF established NSFNET (National Science Foundation Network) in the mid-1980s to create a high-speed network linking U.S. research institutions with supercomputing centers, thereby accelerating scientific collaboration.

While private companies undertook subsequent expansions of the internet network motivated by financial gain—deploying fiber optic networks, undersea cables, and satellite systems—the federal government promoted the widespread adoption of these distribution channels by facilitating standardization and coordination. By establishing foundational technologies and supporting the standardization of protocols such as the Transmission Control Protocol/Internet Protocol (TCP/IP) and reinforcing web standards like HTTP and HTML, the government underwrote compatibility. Additionally, its role in creating organizations like ICANN ensured the stable and unified management of critical internet resources.[25]

To further buttress the private provision of an internet network distributed by broadband, municipal governments often partnered with telecommunications firms to develop city-wide fiber-optic networks. In doing so, they combined public funding or assets (like access to rights-of-way) with private sector expertise and capital. Through initiatives like the High-Performance Computing and Communication Act of 1991, the federal government funded significant advancements in network speeds and computing power, expanding the internet backbone. The federal government also undertook repeated attempts to narrow the digital divide separating urban from rural areas.[26]

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[25] The Internet Corporation for Assigned Names and Numbers (ICANN) is a non-profit organization formed in 1998 to help maintain the security, stability, and interoperability of the internet. Supported by the U.S. government, ICANN is responsible for coordinating critical internet resources, including the global domain name system (DNS) and the allocation of Internet Protocol (IP) addresses. By managing the assignment of domain names like .com, .org, and country codes, as well as ensuring each internet-connected device has a unique IP address, ICANN plays a vital role in facilitating internet connectivity and communication: Its oversight of protocol parameters and root server management ensures that different systems and networks can function together seamlessly.

[26] Under the American Recovery and Reinvestment Act of 2009, the Broadband Technology Opportunities Program (BTOP) provided approximately $4.7 billion in grants to expand broadband access and adoption in unserved and underserved areas. This program supported the

**Indirect and Direct Government Actions Reduced Transaction Costs**

The CDP's legal, policy, and judicial transformations worked to appreciably reduce transaction costs in the digital economy in general. This enabled buyers, sellers, brokers, and users to find each other in cyberspace with greater ease and exchange new goods, services, information, and knowledge at declining cost.

Key legal reforms and judicial decisions enhanced legal certainty and standardized regulations, thereby facilitating more efficient and secure online transactions and encouraging businesses to expand and intensify their operations. The enactment of the Electronic Signatures in Global and National Commerce Act (ESIGN Act) in 2000 gave legal validity to electronic signatures and records, eliminating the need for physical documents and in-person signatures, making online transactions more efficient and secure. The adoption of the Uniform Computer Information Transactions Act (UCITA) aimed to standardize laws concerning software licensing and computer information transactions across states, making it easier for companies to operate within a single market. Regulations facilitating online payment systems established legal guidelines for electronic transactions, boosting consumer confidence in e-commerce. Judicial decisions clarifying e-commerce jurisdiction and applicable law provided legal certainty, reducing the risks and costs associated with interstate and international online transactions. This encouraged businesses to expand their digital operations across borders.

Privacy and data protection regulations, the legitimization of electronic records, the advent of online dispute resolution mechanisms, and the harmonization of international e-commerce laws significantly increased trust, enabling businesses to operate more efficiently and expansively. The implementation of privacy and data protection regulations, such as the Gramm-Leach-Bliley Act and FTC guidelines, increased user and business confidence in online transactions and thus bolstered e-commerce. The facilitation of electronic record-keeping laws recognized electronic records as legal documents in business and government transactions. This reduced the need for paper records, lowering storage and retrieval costs, and made it easier for private and public actors to manage and exchange information digitally. Support for online alternative dispute resolution (ADR) mechanisms provided cost-effective means for buyers and sellers to resolve issues without resorting to costly litigation. Finally, international agreements on e-commerce and digital trade harmonized international e-commerce laws, making it easier for businesses to operate globally.

**A Virtuous Circle of Transaction Cost Reduction**

By assigning and enforcing a new set of property rights, reducing transaction costs associated with standardization, coordination, negotiation, and contract enforcement, and solving an array

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deployment of infrastructure, enhancement of public computer centers, and promotion of sustainable broadband adoption projects. The Broadband Initiatives Program (BIP), another component of the 2009 stimulus package, allocated about $2.5 billion in grants and loans specifically for rural broadband infrastructure projects. The Connect America Fund (CAF) provides financial support to service providers to expand broadband services to rural and high-cost areas where the market alone may not make those investments worthwhile.

of market failures, the Creative Destruction Paradigm profoundly transformed America's political economy. It birthed new networks of firms contracting with each other. It drastically changed supply chains and business strategies. As a result, new markets, firms, patterns of industrial organization, business models, products, and digital services proliferated. In a virtuous circle, these innovations further reduced transaction costs.

This facilitated the globalization of supply chains and outsourcing became the dominant strategy across industries. For example, Eastman Kodak hired IBM to manage its data center in 1989. General Electric outsourced support jobs to India in 1996, while Nike shifted virtually all its shoe production to contract manufacturers in Asia, focusing instead on design, marketing, and sales. IBM sold its personal computer business to Lenovo in 2005, redirecting its focus to services and software. Dell outsourced the production of many computer components, concentrating on assembly and direct sales. Boeing sold its Wichita and Tulsa operations to Onex, a Canadian private-equity firm, in 2005, leading to the creation of Spirit AeroSystems. Indeed, during the 2000s, Boeing outsourced over 70% of the production process for the 787 Dreamliner, taking on the role of assembler rather than manufacturer.

Other major companies embraced similar strategies. Motorola outsourced much of its manufacturing to Flextronics and other contract manufacturers in the 2000s. Cisco Systems outsourced most of its manufacturing and assembly to firms like Foxconn and Jabil Circuit. In 2004, Xerox outsourced its IT infrastructure to IBM, allowing it to focus more on core business services and document technology. Procter & Gamble outsourced its IT services to HP in 2003, including data center operations, desktop support, and network management. Ford Motor Company spun off its parts division in 2000 to reduce costs and concentrate on core automotive manufacturing and sales.

The evolution of the smartphone exemplifies the culmination of vertical disintegration in supply chains. The separation of design, component manufacturing, software development, assembly, and application creation embodies specialization and global collaboration. The assembly of smartphones—including Apple's iPhones and devices, such as Motorola and Sony phones, running the Android platform—became largely separated from the manufacturing of semiconductors and other key components like Gorilla Glass.

Apple, for instance, outsources the assembly of its devices to contract manufacturers such as Foxconn and Pegatron, allowing the company to concentrate on design, software development, and marketing. Component production is handled by specialized firms: Corning supplies Gorilla Glass; Qualcomm designs processors and modems; Sony manufactures camera sensors; and TSMC fabricates custom-designed chips.

Fabless chip designers such as Qualcomm and NVIDIA focus on designing complete chips, while ARM specializes in developing and licensing processor architectures and instruction sets that serve as fundamental blueprints for CPU cores and other semiconductor IP (see Barnett

2021).[27] These companies rely heavily on specialized Electronic Design Automation (EDA) firms like Synopsys, Cadence Design Systems, and Siemens EDA (formerly Mentor Graphics). These EDA companies provide the type of advanced software tools that allow the fabless industry to design increasingly complex chips and verify chip designs to ensure they meet specifications and can be efficiently manufactured.[28]

The chip designs created by fabless companies are then sent to pure-play foundries run by companies such as Taiwan's TSMC, Samsung, and Global Foundries; they boast advanced fabrication facilities and processes required to manufacture semiconductor wafers at scale based on the designs provided by the chip design firms.[29] The Dutch firm ASML focuses specifically on producing the advanced EUV lithography equipment necessary for chip manufacturing, as do Nikon and Canon in Japan. These machines enable the precise etching of circuit patterns onto silicon wafers, which is essential for creating the complex and miniaturized features of modern semiconductor chips. After fabrication, companies such as ASE Technology and Amkor Technology handle testing and packaging, often with facilities in China and other countries.

Vertical disintegration is also embodied in the software that runs mobile devices. In the case of Android smartphones, manufacturers like Samsung, Huawei, and Xiaomi often rely on Google's Android operating system, which they may customize but did not develop from scratch. Moreover, most applications for both iOS and Android platforms are developed by third-party developers worldwide, contributing to rich and diverse app ecosystems without direct involvement from the device manufacturers.

In the wake of these developments, digital Platforms such as Google, Facebook, Amazon, and Twitter managed to establish appealing, many-sided markets with a global reach that brings together consumers, advertisers, developers, and handset manufacturers. They provide free services to users by capitalizing—after first acquiring consent—on their users' digital footprint, serving both personalized content and targeted ads. As more users join, their appeal to new users, advertisers, and developers only mushrooms, creating a self-reinforcing cycle of growth.

This resulted in essential, and often addictive, products and services that have become integral to daily life and have increased social welfare. With over 2.91 billion monthly users on the platform (Business News Daily, 2024), Facebook has facilitated an explosion of exchanges between businesses—many of them small or family run—and consumers. Amazon offers over 353 million products on its platform, providing consumers with a vast array of choices, often at very competitive prices (VanAkker 2024).

While this globalized supply chain made affordable mobile devices that utilize GPS technology possible, they also indirectly contributed to the AI revolution. By enabling applications that

[27] ARM's licensees, which include companies like Qualcomm, NVIDIA, Apple, and Samsung, use ARM's architectures or pre-designed cores as components in their own chip designs.
[28] While ARM doesn't typically design complete chips, it does use EDA tools to develop and validate their architectures and core designs.
[29] ARM, while not directly involved in chip production, works closely with foundries to ensure their designs are optimized for various manufacturing processes.

provide geographic data for location-based services, these devices have spawned a new geo-locational economy. Users employ maps, search engines, and comparison platforms to quickly find and evaluate products and services, significantly lowering search costs and increasing market efficiency. The result is an explosion of gig economy platforms such as Airbnb for real estate rentals, Uber and Lyft for ride-sharing, and various matching markets like TaskRabbit, as well as geo-coded social networks like Snapchat and location-aware online marketplaces. In turn, advertising has become better targeted and more effective than ever before, as businesses leverage data analytics and AI to tailor ads to individual consumer preferences, reducing marketing costs and increasing conversion rates.

Several ancillary innovations have allowed transactions to proceed more quickly, reducing delays associated with negotiation and contracting. Standardized Clickwrap Agreements, requiring users to affirmatively click an "I agree" button after being presented with terms of service, and Browsewrap Agreements, where terms are available via hyperlink with assent implied, reduce legal transaction costs by simplifying the contract formation process. Additionally, the online reviews and ratings provided by platforms like Yelp reduce information asymmetries, enabling consumers to make better-informed and less risky e-commerce purchases.

Meanwhile, automated payment systems such as digital wallets and payment platforms like PayPal and Stripe minimize policing and enforcement costs by ensuring transactions are executed accurately and promptly. They incorporate advanced fraud detection algorithms, reducing the risk of errors, fraud, and non-payment issues. These systems also provide transparent transaction records, making it easier to track and verify payments. Furthermore, encryption technologies secure sensitive financial and personal data during transactions, which is crucial in building consumer trust in digital marketplaces.

**The Virtuous Circle Helped Generate the Data that Fuels AI**

Collectively, these hardware advancements, innovative software solutions, and novel business models have not only reduced transaction costs across the board—they have also generated a Cambrian-like explosion of data. This surge in data availability has, in turn, fueled advancements in big data analytics and AI. A greater amount of improved and diverse data has bankrolled the more sophisticated and powerful AI models behind the Fourth Industrial Revolution.

First, a constant flow of social media posts, search history, and purchase behavior has helped train LLMs to recognize grammatical structures, semantic relationships, and contextual understanding. These rivers of geolocational data have allowed these models to improve their ability to generalize, learn from edge cases, reduce bias, and sound more human-like. This has allowed LLMs to better understand and predict consumer patterns and personalize interactions. By detecting shifts in user behavior and providing timely information and recommendations, they've made their experience more dynamic and relevant.

Second, digital platforms need to process and store vast amounts of geo-coded and dynamic user-generated data, which has spurred the expansion of cloud infrastructure essential for handling AI algorithms' computational demands. Cloud computing provides scalable, on-demand computing power and storage solutions, which has enabled the efficient processing of large datasets necessary for training and refining AI models. Services like Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform offer advanced machine learning tools that allow organizations to develop and deploy AI applications without substantial investment in physical infrastructure. Their accessibility and increasing affordability have supported AI applications such as natural language processing, image recognition, and predictive analytics. The democratization of powerful computational resources has enabled even the smallest organizations to leverage AI technologies.

Third, the rise of the geo-locational economy fueled by GPS-enabled smartphones requires much more computational power than stationary applications could provide: digital platforms need to process and analyze sophisticated data in real-time. This has fed massive demand for more innovative, powerful, and energy-efficient processors. In response, companies like Nvidia developed more advanced Graphics Processing Units (GPUs), which, beyond graphics rendering, proved highly effective for the parallel processing tasks essential in AI computations.

Meanwhile, the creation of specialized mobile processors optimized for energy efficiency and performance has made an indirect impact on AI progress. Companies such as Qualcomm, with their Snapdragon processors, Apple's A-series chips featuring integrated Neural Processing Units (NPUs), and Samsung's Exynos chips have all helped democratize AI by bringing its capabilities to consumer devices. They have also facilitated the growth of edge computing, where data processing occurs on the device rather than in centralized servers, enabling faster response times and reducing bandwidth usage. In turn, the availability of on-device AI processing has spurred innovation among app developers and companies: they have rolled out more personalized and responsive AI services.[30]

## THE BOOK MANUSCRIPT'S OTHER CONTRIBUTIONS

Understanding the etiology of the smartphone as both a hardware device and a software-run platform that nests digital platforms within it requires a deeper exploration of the U.S. economy's evolution. Leveraging strengths in invention and the commercialization of innovation, American industries shifted toward intangible capital, focusing not on traditional manufacturing but on R&D, intellectual property (IP), design, marketing, and distribution. Legal and technological changes fostered highly decentralized supply chains governed by arm's-length exchanges and extreme specialization along the lines of comparative advantage. As the economy became more globalized this meant more outsourcing of labor-intensive manufacturing to countries that paid relatively lower wages (see Autor, Dorn, and Hanson 2016).

From 1972 to 1992, R&D-intensive, intangible-capital-rich industries grew at an average rate twice that of real GDP, led by computers, semiconductors, and software. With export shares significantly higher than the national average, these sectors became not only economic drivers domestically but also formidable players in global trade (see FTC 1996). The rapid ascent of these industries from their nascent stages after World War II to positions of global prominence

[30] For instance, augmented reality (AR) applications, real-time language translation, and intelligent personal assistants rely on edge computing to deliver seamless and instantaneous user experiences.

by the early 1990s is a testament to the transformative power of U.S.-led technological and regulatory shifts.

This robust growth pattern persisted post-1992. Between 1992 and 2020, these sectors frequently outpaced real GDP growth, doubling or even tripling it. While the U.S. real GDP grew at an average annual rate of about 2.5% during this period (Bureau of Economic Analysis 2021), sectors like information technology (IT) averaged growth rates between 5% and 7% annually (National Science Board 2020). For example, the global semiconductor industry saw sales grow from approximately $60 billion in 1992 to over $440 billion in 2020, reflecting an annual compound growth rate of 8% (Semiconductor Industry Association 2021). The software market similarly expanded, rising from around $60 billion to over $500 billion (Gartner 2020). These sectors also saw a global reach, with exports of U.S. semiconductor production consistently above 80% (Semiconductor Industry Association 2020).[31]

The trajectory of the American economy along these lines contextualizes the rise of the Fourth Industrial Revolution. The smartphone, representing the pinnacle of digital innovation, is a culmination of decades of technology transfer across and within the type of supply chains that are emblematic of these changes. This process catalyzed a shift from vertically integrated manufacturing toward a decentralized model, facilitating rapid innovation and specialization across the economy. Technology transfer began with devices like personal computers and was characterized by continuous knowledge exchanges between rival firms and along the supply chain. It then continued with subsequent technological advancements like the smartphone.

Another key contribution of this book manuscript is examining how, over decades, the vibrant transfer of technology across supply chains' vertical and horizontal dimensions reshaped the high-technology sector and the U.S. economy at large. I first focus on semiconductor industry dynamics during the Third Industrial Revolution, between the 1970s and early 2000s. While dominant companies like Intel and Texas Instruments historically designed and manufactured their own CPUs and memory chips, they now coexist within a highly specialized, disintegrated supply chain for semiconductors. Industry leaders readily shared technology and know-how during this period with both their rivals and suppliers—firms that provided them with key inputs, machinery, and complementary services such as software and consulting services. By selling and licensing patents and setting industry standards they fostered a collaborative ecosystem that fractionalized supply chains and accelerated innovation in the semiconductor industry.

To make sense of this pattern, I theorize that strong industry innovation leaders serve as focal points that help set technological standards and commercialize innovation. They engage in the lion's share of their sector's R&D and patenting to dictate the pace of technological change and uptake, bespeaking the dynamics of a Pareto Distribution. As this book manuscript will argue and show, R&D and patenting are not evenly spread across firms; rather roughly 20% of firms generate 80% of innovations. Therefore, unlike a Normal Distribution (bell curve), where most

[31] This pattern applies to non-computing industries that are R&D and design heavy as well, e.g., the aerospace industry's exports account for over 60% of its production (Aerospace Industries Association 2020).

observations cluster around the mean, technological progress obeys a "power law" whereby a small number of participants account for a disproportionate share of outcomes.

These leaders also create and support institutions that codify best practices and distribute valuable information, shaping the competitive landscape in ways that reinforce their bleeding edge positions. However, while industry innovation leaders clearly outwork their rivals on this dimension, they also help build them up, as they are not stingy when it comes to sharing ideas, knowledge, and know-how with them. Nor do they withhold their supply chain partners from gaining access to these assets.

This book manuscript empirically examines this process since the 1970s to reach several conclusions.

First, high-tech firms are important hubs inside dense networks of patent licensing arrangements and general technology sharing patterns. Notably, leading firms in sectors such as semiconductors and telecommunications hold influential patents with numerous forward citations, reinforcing their status as technological leaders. Moreover, dominant firms are more frequently cited for their GPT contributions, while follower firms predominantly cite these leaders in the process of adopting standardized innovations. This asymmetric structure of knowledge flows fosters both vertical and horizontal technology transfer, enabling the broad dissemination of standardized innovations across a given sector.

I also find that technology transfer impacts productivity differently across firms. While patent forward citation leaders sit at the productivity frontier, follower firms (that cite leaders' patents) experience significant TFP gains as they absorb leaders' innovations. This leads to greater convergence within sectors over time as productivity differences across firms are compressed.

This phenomenon in turn narrows industry price markups. As best practices are diffused and firms' cost differentials are attenuated, this engenders a more compressed distribution of Ricardian Rents. However, patent forward citation leaders in high-tech sectors nonetheless maintain some competitive advantages in the face of the equalizing effects of strong technology diffusion due to their ability to sustain the spearhead position in terms of process and product innovation. This is, after all, one of the main attractions of obtaining and defending their leadership position through prolific patenting and harvesting citations.

## HOW THIS BOOK DIFFERS FROM SIMILAR ONES

There have been many works on the effects of digital platforms. And, for good reason: they are, after all, grand psychological experiments, social laboratories, and public squares that influence what people across the world see, read, and believe (Gillespie 2018; Vaidhyanathan 2018). They shape our preferences, interests, and identity—and how we express ourselves politically (Zuboff 2019; Tufekci 2017). This may even occur in ways that individuals are not aware of (Parisier 2011). And it may have real-world impacts, perhaps fueling conspiracy theories that would otherwise not spread beyond hardcore adherents (Donovan & Friedberg 2019), exacerbating polarization (Sunstein 2017), and impacting elections (Benkler, Faris, and Roberts 2018).[32] Conversely, users' social-media activity has provided (true) information about candidates, promoted voter education, and offered corrections to misinformation about election integrity (Guess et al. 2020; Tucker et al. 2018). And even though controversial, social-media platforms allow politicians to identify and target voters; more surgical pitches increase electoral turnout and political engagement (Baldwin-Philippi 2019).

There is no definitive take on how digital platforms specifically gave birth to AI, however. To be sure, other works have taken up the genesis of these platforms, but only in a piecemeal manner. Some discuss the catalyzing impact of Section 230 (Klonick 2017; Balkin 2020). Others focus exclusively on the consolidation of the international supply chain that undergirds mobile devices (Curry and Kenney 2020), or the semiconductor industry (see Barnett 2021). This book manuscript also differs significantly from Margaret O'Mara's "The Code," which offers a detailed historical narrative of Silicon Valley's rise, examining the cultural, political, and institutional factors that fostered its success.

WHAT'S NEXT

Ahead, this book manuscript explores several of the laws, regulations, and court decisions that reduced transaction costs in ways that helped birth digital platforms and AI. It examines how stronger IPRs coupled with liberalized trade and capital flows, fostered vertically disintegrated markets with global supply chains, thus allowing the design of semiconductors to be separated from their fabrication and ultimately ushering in increasingly powerful and more affordable mobile devices. In parallel, I relay how standards created and sustained by private standard setting organizations allowed digital devices to become interoperable, with mobile phone standards being the most important one. I also explore how a reformed telecommunications regime created the infrastructure that undergirded the wireless internet and allowed it to become mobile. And I flesh out how an increasingly restrained and innovation focused antitrust policy allowed digital platforms to get quite big and achieve massive network effects, as well as to create ecosystems of bundled products and experiment with novel data monetization strategies.

The rest of this book manuscript also introduces and systematically tests a new view of how firms and organizations engage in decentralized innovation networks. This story differs from the conventional narrative of atomized firms that invest in R&D unilaterally and in isolation. I instead argue that when making R&D decisions and all other aspects of innovation, including invention, standardization, and the commercialization of new technologies, leading firms will cultivate "innovation commons": ecosystems of experimentation, design, production, and knowhow that link governments, firms and other actors together within nascent supply chains for new goods and services. To do so I construct several original datasets and exploit network analysis and firm level data that observes their patents, productivity, and profits.

[32] Digital platforms have responded to criticism. They have sometimes become more aggressive content moderators; or consider Google's decision to stop tracking users across websites, which they used to hoover up their data and better personalize ads.

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