14
Conclusion
Now and Then

> The age of invention has just begun to dawn. . . . [T]he promise is that our children will live in a world that we would not recognize.
>
> —E. B. Moore (1912)[1]

Technological change helped to transform the United States from an undistinguished colony into the global leader in culture and industry, now making investments in orbital architecture to commercialize resources on distant planets. As I write these words, in the spring of 2020, the U.S. Patent Office has recorded a cumulative total of more than ten million patent grants. This rapid and sustained pace of technical advance creates a curious compression of time and perception that makes it difficult to fully appreciate the achievements of the past. Each throng of novel discoveries becomes the necessity of the present, and we regard the breakthroughs of even a decade ago with amused disdain.

The Bowdoin College Yearbook of 1876 noted that "some of our class at times expressed the opinion that it would be a great improvement if a system of water works could be introduced and the buildings piped, so that the students need not have to go out to the well in stormy weather for a pail of water." But, the authors added philosophically, it was probably the case "had they had all of these comforts and conveniences, they would only have wanted more, and would have become so enervated that they would have disliked to do the slightest work themselves." What, one wonders, would they have thought of the experience of current cohorts of Bowdoin students, who are daily served a vast array of gourmet dishes in the most highly rated college dining hall in the country, and who cannot imagine existence without laptops, Wi-Fi access, and their ubiquitous smartphones?

Rapid technological progress creates a certain hubris, where each generation is convinced that their own era is markedly different from all others, and this is particularly true of the age of the internet and information technologies. This

[1] E. B. Moore, "Next Few Years Will Eclipse All Ages in Invention," *Electrician and Mechanic* 24 (1912): 316.

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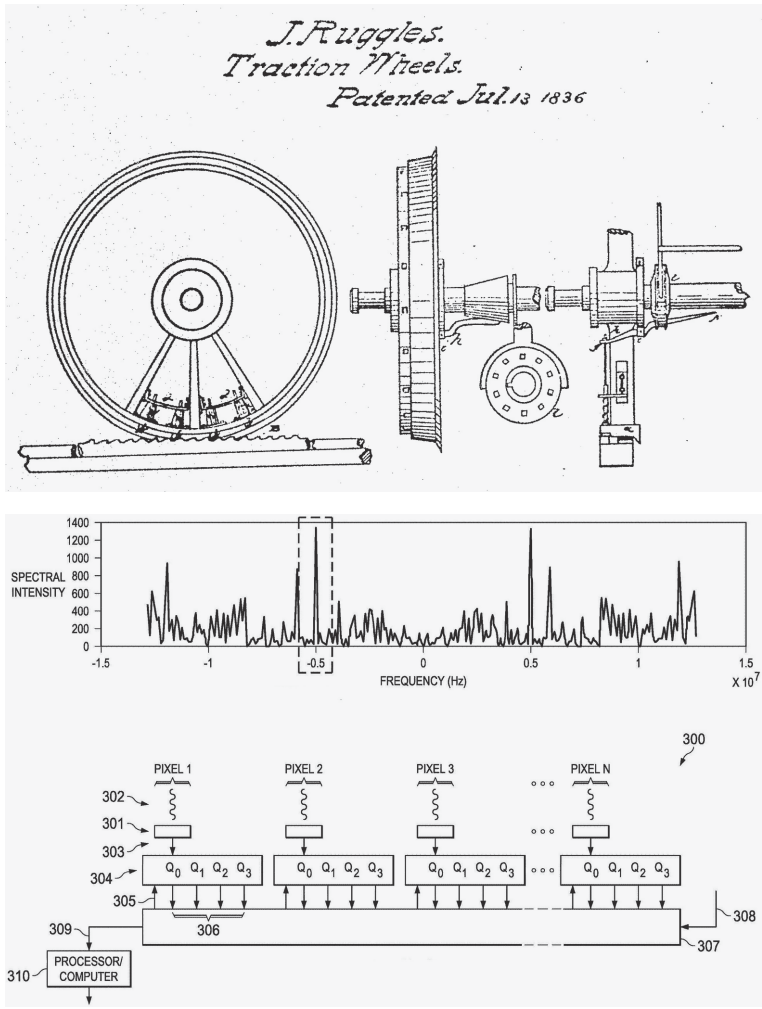

Figure 14.1 Two Centuries of Patented Progress
The first U.S. patent, issued in 1790, was signed by George Washington, Thomas Jefferson, and Edmund Randolph. The official numbering of patents began in 1836. The ten million patents recorded since then provide a valuable index of the progress that resulted from market-oriented innovation institutions.
Source: U.S. Patent Office.

book, however, has emphasized continuities rather than disjuncture. Debates about knowledge, ideas, and growth have been central to economic and political thinking in all cultures. The Pennsylvania Frame of Government in 1683 emphasized the link between universal access to schooling and innovation in its intent

to "erect and order all public schools, and encourage and reward the authors of useful sciences and laudable inventions." George Washington, who gave the first and shortest State of the Union address to Congress in January 1790, was unlikely to encounter any disagreement—even in European parliaments—when he stated that "Knowledge is in every country the surest basis of public happiness." Similarly, writers through the ages from the classical political economists to new growth theorists have speculated about the sorts of ideas, inventions, and inventors, broadly defined, that would best contribute to the wealth or failure of nations.

Nevertheless, controversies have always surrounded specific proposals for the best ways to generate new ideas, and these divergences in opinion have increased in the digital economy. Over the past two centuries, vastly different approaches have been adopted and abandoned among private and public institutions. Early European perspectives—ambivalence or hostility toward accessible property rights in ideas and an enthusiasm for elite administered innovations—are currently experiencing a renaissance. The number, scope, and magnitude of private and state-sponsored prizes have all increased remarkably over the past few decades, motivated by "invented ideas" or mythical historical evidence. European and American governments alike have proposed innovation prize competitions for a vast array of projects including robotics, defense technologies, and environmental research. Developing countries with prohibitively high unemployment and limited fulfillment of basic needs have offered million-dollar bounties for esoteric moonshot inventions and lobbied international organizations to support prize systems as substitutes for patent systems.

Silicon Valley elites have likewise proposed a plethora of grand innovation prizes for dramatic schemes. The Google Lunar X-Prize was typically flamboyant, promising a payout of $30 million for the first successful private effort to land a spacecraft on the moon. "A successful Google Lunar XPRIZE would result in cost-effective and reliable access to the Moon, allowing for the development of new methods of discovering and using space resources, and in the long-term, helping to expand human civilization into space."[2] The competition continued for over a decade (2007–2018) and has been applauded, cited, and studied as a classic example of a successful innovation incentive—but it ultimately failed to achieve the stated objectives and the prize money was withdrawn in 2018 without much fanfare or public notice. Interestingly, a few teams decided to carry on even in the absence of the promised prize, because "the real opportunity is in opening the lunar frontier and the multibillion dollar industry that follows"—that is, in the marketplace.

[2] https://lunar.xprize.org/about/why-the-moon.

Technological prizes make for captivating narratives, but their implementation remains opaque and little is known about their efficacy. Policymakers that investigate the advisability of offering innovation prizes as inducements for technological progress invariably confront a dearth of reliable empirical evidence. They nevertheless invariably conclude that inducement prizes would serve as an effective strategy for ensuring competitiveness in innovation. When one points to cautionary historical outcomes, as I did in a workshop at the National Academies of Sciences, the usual rejoinder is that "this time is different." In the absence of representative data and systematic analysis, the authors of these grand (and often grandiose) schemes, whether at the level of private or national institutions, risk echoing the experiences—and errors—of their elite counterparts in administered systems across time and place.

Part of the reason for deficiencies in our current understanding of the economics of technological change and economic growth owes to a "nirvana approach," where an imperfect institution is deemed inefficient relative to an unexamined ideal.[3] The myopic focus on "optimal" systems has continually failed to penetrate the "black box" of real firms, technological change, and prevailing economic growth processes. This book, by contrast, offers an assessment of real institutional arrangements, including property rights and markets in patented ideas, as well as systematic empirical evidence on how administered innovation institutions have actually functioned in different contexts. The detailed comparisons at the individual level across institutions, place, and time provide novel insights into the sources of long-run innovation and economic development.

This research draws on the experiences of over one hundred thousand creative men and women in the United States and Europe, during the first and second Industrial Revolutions. The records document their creative breakthroughs, as well as their participation in mechanics institutes, membership in technical societies, interactions with intermediaries like attorneys and agents, and appearances in bitter court disputes. These inventive pioneers are the ancestors of today's software coders, the teenage entrepreneur who is certain that his patent for an improved coffee cup holder will make his fortune, the scientist whose start-up to produce a new biotech product fails spectacularly in the knowledge economy. They are not all heroic figures, and some are even scoundrels, claiming other people's innovations as their own, and exploiting their political connections

[3] Demsetz (1969). "The view that now pervades much public policy economics implicitly presents the relevant choice as between an ideal norm and an existing 'imperfect' institutional arrangement. This nirvana approach differs considerably from a comparative institutional approach in which the relevant choice is between alternative real institutional arrangements." According to Merrill and Smith (2011), a world of positive transaction costs requires a comparative institutional analysis to make the Coasian approach "more Coasian."

to corner the market. Information about all these extraordinary ordinary innovators allows us to appreciate the incrementalism and individualism of all useful economic activity. This approach establishes a reliable microfoundation for general macroeconomic theories about the role of endogenous innovation in long-run growth processes.

The quest for a consensus regarding the central question of the sources of economic progress has proven to be elusive. Academic economists, pundits, and policymakers alike have reported and circulated numerous competing claims that bear on the relationship between institutions, technology, and growth. When equally qualified commentators differ, how is the interested but nonspecialized observer to differentiate among opposing conclusions? Historical variation across both time and place offers vital clues regarding the validity of conflicting claims. Moreover, the study of the past allows us to identify and orient the discussion around "historical parameters," consisting of fixed events and outcomes that are not subject to individual interpretation. Economic analysis should, at the very least, be consistent with the actual historical facts.

"What Did We Learn?"

Stanley Engerman, an iconic economic historian whose path-breaking empirical research has shed light on the economics of institutions, has a habit of asking at the end of a conference, "Well, what did you learn?" Ventures to countless archives in basements and attics and literal bunkers surrounded by chain link fences, from San Francisco to Kew Gardens in England and uncharted regions outside the Péripherique in Paris, yielded a rich store of detailed original information. These primary sources were then photographed, digitized, and subjected to exhaustive (and exhausting) statistical scrutiny. These extensive datasets together reveal how different institutional arrangements actually worked and the consequences for the global economic and technology leaders in the two centuries of modern economic growth leading up to World War II.

This study shows that the scope of comparative history matters. The usual frame of reference for long-run growth is directed toward the question of why Britain was the first industrial nation. However, scholarship whose standard for comparison or "historical parameter" is limited to the British Industrial Revolution risks arriving at faulty conclusions about the sources of economic growth. A broader time span allows for the analysis of historical parameters that capture the loss of comparative advantage in Europe and the ascendancy of the U.S. economy since the nineteenth century. This wider perspective reveals that technological success or failure did not owe to the European focus on scarce scientific knowledge, the special insights of special social classes, or the heroic

efforts of entrepreneurial government officials to compensate for deficiencies of the "timid private sector." Rather, the capacity for sustained economic progress depended on the degree to which institutions constrained or enabled the ability of ordinary individuals to take advantage of their innovative ideas and creativity.

The political revolution of 1776 paralleled an equally significant American revolution in economic thinking about institutions and useful ideas, and conventional economic theory still needs updating to reflect those insights. Modern macroeconomics has deployed impressive mathematical models and intellectual capital in the quest to improve on Adam Smith. Yet, the data freedom of mathematical modeling and empirical studies of aggregate data both seem to have descended into conclusion anarchy, and mainstream studies still cannot adequately explain why the United States became the wealthiest economy in the world. The research in this book, by contrast, is grounded in the notion that outcomes occurred because individuals responded to specific incentives. The empirical analysis shows how differential institutional rules and incentives actually worked and their consequences for individual behavior and broader aggregate patterns.

Conventional macroeconomic theories mesh very well with early European attitudes and assumptions. The neoclassical school models economic growth as a function of additions to exogenous or inelastic supply factors in the "upper-tails of the distribution," including the knowledge of elites, great inventions, and "general purpose technologies," along with large-scale investments in physical and scarce human capital. This is a good analog of the policies and institutional orientation in Europe, but further analysis is needed to penetrate beyond correlations to determine causal relationships with productivity and long-run growth. Closer inspection of the actual historical details suggests that elites and elite institutions entailed a misallocation of resources, which served to inhibit technological progress and sustained growth. As economists put it, such top-down efforts ran into diminishing returns. Even when it was recognized that existing policies had failed (as in the case of the British patent system and the Royal Society of Arts), the overall governance structure and adjacent institutions proved to be too inflexible to permit effective reforms.

Endogenous growth theorists like Paul Romer emphasize that "the key step in understanding economic growth is to think carefully about ideas," which can be reproduced at low cost, generate spillover benefits, and lead to increasing returns.[4] Innovation growth theorists have further hypothesized about links between institutions and technology and "economic life."[5] This perspective has deep intellectual roots in economic thinking. Adam Smith proposed a virtuous

[4] Romer (1990, 1992).
[5] Aghion et al. (1998).

cycle in which market expansion leads to specialization among individuals, the division of labor, and inventive activity that fueled further expansion, resulting in balanced growth that was evenly distributed throughout the economy. Smith's own commentary on the events in the former British colony (pronounced, according to an indignant American contemporary, "as phlegmatically as he would appraise a bale of cotton") demonstrated his acute understanding of the political economy of the day: "From shopkeepers, tradesmen, and attorneys, [Americans] . . . are employed in contriving a new form of government for an extensive empire, which they flatter themselves, will become, and which, indeed, seems very likely to become, one of the greatest and most formidable that ever was in the world."[6]

Adam Smith's *Wealth of Nations* was first published in 1776 and quickly accorded "bestseller" status in the American colonies.[7] U.S. delegates to Congress, who were drawing up a blueprint for an unprecedented political-economic system, eagerly obtained copies of the book, exchanged reviews, and debated about how Smith's ideas applied to the American context. Thomas Jefferson owned a personal copy in his library and declared, "in political economy I think that it is the best book extant." In 1783, James Madison put Smith on a list of volumes for the proposed congressional library, and his own writings echoed Smithian analysis, including economic faith in ordinary individuals and their divergent ideas, and reservations about elite factions and their qualifications for "instructing the people." The famous American jurist James Kent wrote in 1787 to Nathaniel Lawrence, a delegate at the New York ratifying convention, "I have just been reading Smith on the Wealth of Nations & he has taught me to look with an unfavorable eye on monopolies—But a monopoly of the mental kind I take to be laudable and an exception to the rule."[8]

This book has considered the costs and benefits of markets in ideas relative to administered innovation systems, and the specific mechanisms and incentives that Smithian and non-Smithian institutions created for individual behavior. Mathematical speculations about growth are typically matched with aggregate data, so it is hardly surprising if endogenous growth is found to be inconsistent with calibrations involving variables like "world research output." The complexity of decentralized knowledge and individual responses to incentives can only be detected within such aggregates. Micro-level comparisons of different countries over time helped to shed light on the accumulated effects of incremental adjustments and responses that generated shifts in overall comparative

[6] Smith (1902: 148).

[7] The most popular books in American libraries between 1777 and 1790 were *The Wealth of Nations*, Locke's *Treatises*, and Rousseau's *Emile*. See Lundberg and May (1978).

[8] Kaminski et al. (2003: 247).

advantage. In Britain, France, and the United States, the different rules and standards vested in institutions affected the scale of the population *of inventors*, specialization and the division of labor within and across firms and markets, the presence of spillovers, and the diversity of useful ideas and innovations available in the market.

In the United States, when access to markets improved, the increase in expected profits (which Abraham Lincoln termed the "fuel of interest") created an incentive for rapid technological change ("the fire of genius"). Expansions in market demand induced "shopkeepers, tradesmen, and attorneys" to increase the population of both ordinary and great inventors and encouraged specialization and the division of labor among them. Scale effects were endogenous, not exogenous, and related to the proportion of the population whose responses to incentives increased inventive activity and innovation. The discussion in Chapter 9 on knowledge spillovers further shows that positive external effects depended on the specific institutional mechanisms in place to facilitate the diffusion of ideas. The spread and adoption of inventions then fueled additional market expansion, productivity gains, and higher expected profits in a complex self-sustaining process that would likely defy mathematical modeling. It cannot be overemphasized that the most crucial part of this process related to the diversity of individuals, firms, and ideas that led to a richer and more variable choice set from which the market selected the most highly valued solutions.

The standard textbook analysis of patents as monopolies is also a good match to the European approach, but it fails to comprehend the American model. Patents in Europe were subject to very high fees, which were a good source of revenues for debt-ridden monarchs and for rent-seeking administrators. That the high costs would favor elites and deter the ordinary inventor was counted as an additional benefit. These grants were made in a registration system without any examination for novelty, enabling wealthy patentees to acquire rights to an invention that could have belonged to someone else. The state reserved the arbitrary right to modify this monopoly grant, through expropriation or by stipulating that the patent should be "worked." As a result, European patents were not far removed from the earlier world of arbitrary privileges. These ex post monopoly grants took something away from the public and made it into a pricier private good—or created a deadweight loss, in economic terms—which led to ambivalence about the social value of patent institutions. The emphasis on the higher worth of elite contributions was even more evident in the embrace of prizes and other administered innovation systems, which were regarded as superior to undirected decentralized markets for the ideas of "ordinary" individuals.

The economic model of innovation revealed in U.S. policy choices was instead based on four precepts that differed significantly from this patent-as-monopoly trope. First, the primary principle of the American innovation system was that

it placed property rights in useful knowledge at the center of its strategy for promoting progress. According to the American approach, "An invention is property of the highest order." Note that the intellectual property declaration in the U.S. Constitution was the only clause to pass unanimously and without any debate in an otherwise contentious Constitutional Convention. Inventors had a legal and economic right to their own inventive ideas—and this is the only occurrence of the word "right" in the document—which the Constitution "secured." In short,

> the inventor has a property in his invention; a property which is often of very great value, and of which the law intended to give him the absolute enjoyment and possession . . . involving some of the dearest and most valuable rights which society acknowledges, and the constitution itself means to favor.[9]

The second precept relates to U.S. enforcement of these property rights, which was recognized as the strongest in the world. As a nineteenth-century writer wryly noted, U.S. patents constituted a "right to sue." Society was not bestowing property rights for inventions, it was defending them, and federal protection in the Constitution and Supreme Court reduced the scope for individual discretion and arbitrary decisions that prevailed in Europe. The rationale for the defense (as opposed to the grant) was based on the recognition of market failure, where "the most difficult thing in the world is to prove an invasion of property of this character—property protected by patents."[10] Since useful ideas were more readily "assailed" or stolen, enforcement needed to be correspondingly stronger for patent property than for tangible property.

The third principle was that patents were not monopolies. American patents were granted solely for novel ideas that inventors had demonstrably created themselves. As nineteenth-century jurists noted, "a patent is that which brings out from the realm of mind something that never existed before, and gives it to the country."[11] This was a public good—in the sense of a good to the

[9] 15 Fed. Cas. 1018 (D. Mass 1817). The first quote is from the *Annual Report of the Commissioner of Patents* (1871), p. 7.

[10] *Singer v. Walmsley*, 1 Fish. 558 (Md. 1859). A theory of market failure seems irrelevant for explaining why U.S. property rights in ideas existed in the first place, since there is no market failure in land or in houses or most other goods to which property protection attaches. As explained in the first chapter, in standard economic analysis, markets in knowledge are often held to fail because ideas can be replicated at zero cost, and it is impossible to exclude others from obtaining access. The failure of knowledge markets seems somewhat exaggerated on both grounds. For instance, Crawford (1990), who researched archival papers on the Nobel Prize grants, identifies a natural exclusion mechanism to such knowledge: "practically all the materials are in Swedish, which make them as inaccessible to those unfamiliar with this language as if they were encrypted by the National Security Agency." I suspect that the majority of articles in the *American Economic Review* enjoy a comparable natural right of exclusion against the general public.

[11] "When we consider the priceless blessings which have accrued to our land, by the intellect and ingenuity of the country in this department, we feel almost lost in wonder at the vastness of the

public—because patents often opened up new markets or lowered production costs and induced falling prices in the long run. A key analytical question is always, what is the relevant counterfactual, or assumed alternative? The "ex ante perspective" offered a comparison relative to the world *before* the inventor was induced to come up with the idea. Economic models today still fail to appreciate this insight: they are instead based on the European assumption that the invention has already been created, and the alternative is that the idea is in the public domain; as such, the patent "monopoly" to a private entity reduces net social benefits. According to the early U.S. perspective, by contrast, patents were associated with both static and dynamic increases in social welfare over time. Unlike the standard economic view of positive spillover effects as a source of "market failure," early policies celebrated the fact that benefits to the inventor created even greater benefits for society.

In summary, the underlying economic model that informed U.S. technology policies in the nineteenth century highlighted the role of patents as property rights that facilitated markets in ideas.[12] The European monopoly model initially treated patentees with suspicious resentment and hostility but at the same time directed fewer initiatives to curb their excesses in innovation markets through antitrust measures. As I have shown elsewhere, antitrust policies at the state level had been implemented in U.S. courts long before the Sherman Act of 1890. Federal antitrust was adopted as part of an inherently protectionist agenda to shelter firms that were losing out in the competitive process, and after the 1970s antitrust policies became increasingly at odds with patent policies.[13] Today, these continuing protectionist conflicts between antitrust and innovation are becoming all the more manifest and problematic for successful technology-oriented enterprises.

Administered Innovation Systems

Harold Demsetz has long highlighted the need to explicitly gauge the relative costs of market and nonmarket alternatives.[14] This book has empirically tested the assumption in economic theory that innovation prizes were

interests which have been created by the ingenuity of the country and the immense amount now invested, in this department of property." *Singer v. Walmsley*, 1 Fish. 558 (Md. 1859).

[12] Additional implications of this property-based analysis include Hayek's emphasis on access to decentralized knowledge, and Henry Smith's (2008) reminder that property economizes on information costs.

[13] Khan (2011a).

[14] Demsetz (1964).

superior to alternative mechanisms owing to their nice mathematical properties. Administered innovation systems depended on top-down arrangements where elites or bureaucrats made central decisions about prices, values, and the allocation of resources. They typically enshrined the conviction that elites were essential for economic and technical progress and could produce superior outcomes to decentralized knowledge and open markets. As a result, Europeans deliberately designed institutions and implemented strategies that served to reduce the potential population of inventors and the scale of both useful inventive ideas and commercial innovations.

French institutions have long exemplified this technocratic paternalism, in the course of which resources are diverted into wasteful rent-seeking and mercantilist measures to suppress outside competition and disruptive ideas. In England, the scope and depth of markets in patents and inventions was limited because of the conviction that elites and technocrats were best suited to identifying and contributing to important technological choices. Aspects of administered innovation were evident in British patent rules and manifested in many of its adjacent institutions, including the educational and legal systems. Britain was unable to retain its lead for a multitude of reasons that other scholars have identified such as changes in relative factor prices, but a primary contributory factor included institutional obstacles to creative nonelite inventors who were directing their attention to supposedly small incremental improvements in the market.

For mainstream economists, "there is little evidence to suggest that monopsony is important to our economy."[15] Administered innovation systems, by contrast, are best described as monopsonistic, since they consist of a single buyer who sets a fixed price/prize and makes the decisions about who is to benefit. As the empirical results in these pages show, this implies that the price will almost never be right. If the value of the invention is greater than the expected amount of the award (the amount times the probability of winning), then a process of adverse selection will lead to only lemons being submitted for prizes. If the expected award greatly exceeds the value of the invention, this creates a misallocation of resources in the affected market and through diversion from other markets. Moreover, these fixed prices cannot adjust to unanticipated future changes in the market, leading to greater disequilibria over time. When patents and prizes are complementary, returns to inventors can lead to overcompensation and (as the French example shows) create incentives for some applicants to pursue rents by "stacking" grants and other awards rather than through efforts to obtain benefits from the market through satisfying demanders.

[15] Manning (2003: 135).

Monopsony systems led to arbitrary decisions and unfair discrimination, where outcomes reflected the biases of the buyer. Even in the absence of corruption or incompetence, cognitive dissonance among judges resulted in a lack of appreciation for contributions from individuals of different backgrounds, however remarkable their creativity. In Britain, this lack of calibration of awards to the value of inventions was all the more evident in the case of working-class inventors. Wealthier individuals were universally more likely to get prizes, in all of these analyzed samples and in all of these countries, holding the merit of their invention constant. These biases were further distorted by a cascade effect: when judges were not able to objectively determine relative values, they tended to give out awards to those who had already been recognized. This leads to the phenomenon of very skewed distributions of awards, such as the Singer Company, which accumulated over two hundred prizes in the nineteenth century. Multiple awards often reflected the candidate's determination rather than merit.

Women inventors in particular were disadvantaged by the operation of administered institutions, despite official declarations of equality on the books. At the Franklin Institute, prizes were specifically designated for "ingenious men and women," but no women at all were recognized in the antebellum period and just five received any accolades over the entire nineteenth century. Men were universally offered higher amounts of cash and gold and silver medals. As inventors and exhibitors, women generally were granted lesser awards, lower financial sums, and inferior medals—in some instances, women were bestowed with butter knives, ladles, teaspoons, pencils, and thimbles. Even other women with feminist political agendas and higher social status were harsh in their judgments about the flurry of "feminine inventions" for powder puffs, corsets, and kitchen utensils and tried to exclude their inventors from exhibitions, despite the commercial value of these improvements.

Another central finding is that governance problems have been integral to all facets of such administered organizations, including the determination of eligibility, nominations, administration, and final decisions. "Nomination nepotism" has been a pervasive feature of science and technology awards, including the Nobel Prizes.[16] Administrators diverted resources away from the disbursement of funds toward expenditures on their own salaries or interests.[17] Despite rules to avoid impropriety, officers of the Franklin Institute were significantly more likely to obtain awards than outsiders, and this was true in several other institutions examined. Between 1731 and 1839, the vast majority of Copley Medals (90%)

[16] Kantha (1991).

[17] Crosland (1979). "Of the annual budget of the Académie des sciences, one finds that nearly all of it was devoted to the salaries, or, more strictly, the honoraria of members, and to general administrative expenses."

went to higher-status gentlemen and professionals, with only 10% given to artisans or tradesmen, owing in part to "internal favoritism" in the selection process.[18] Thus, even in the absence of outright incompetence or corruption, governance difficulties proliferated in administered innovation systems, whether private or state run. These political-economic concerns were compounded at the national level, where inventors had little recourse when states reneged on promises to distribute awards for inventive discoveries. As Jeremy Bentham succinctly observed about such measures, "the province of reward is the last asylum of arbitrary power."[19]

Of course, the prospect of error in decision making is present in all institutions. Effective outcomes over time depend on the operation of feedback mechanisms to censure or impose costs on incorrect choices. Incompetence in the marketplace leads to exit in the long run.[20] However, the norms of administered innovation systems typically tend toward secrecy and a lack of accountability for decisions and outcomes. The Nobel Prize charter explicitly dictates that "Against the decision of the adjudicators in making their award no protest can be lodged."[21] Innovation institutions in Europe and America similarly lacked third-party oversight, there was little or no transparency about processes and outcomes, and decision makers did not bear significant costs or consequences for poor or even disastrous choices. In the absence of effective feedback mechanisms, administered systems faced few or no incentives for change, and those who benefited from inefficiencies had an incentive to block any initiatives for reforms in existing arrangements. Thus, despite early evidence of the failure of its efforts, the practices of the Royal Society of Arts persisted for almost a century before meaningful reforms were implemented, and other prize-granting institutions in Europe were equally slow in adapting to failures and inefficient strategies.

Prizes and Incentives for Inventive Activity

Such research findings were not unknown to the few careful scholars who took the time to actually study the records rather than simply accepting the overblown self-promotion of these administered institutions. Samuel Sidney, an assistant

[18] Bektas and Crosland (1992).

[19] Bentham (1825: 93).

[20] In competitive markets, penalties are imposed for incompetence and rewards for productive outcomes, and profits and losses over time serve as a signal for the reallocation of resources toward their most highly valued use. Contestability (the potential for entry by competitors who are attracted by positive profits) helps to ensure that monopolists in the market cannot long act like textbook monopolists.

[21] Code of Statutes Given at the Royal Palace in Stockholm on the 29th June 1900 (1901), p. 6.

commissioner at the 1851 Crystal Palace Exhibition, spent ten years studying prize systems in exhibitions as well as the incentives that various societies administered.[22] The results of his meticulous researches made him deeply skeptical of these elitist winner-take-all arrangements. In general, outcomes were largely idiosyncratic, although risk-averse or unqualified panels tried to avoid controversy by making the award to the person or the firm with the most established reputation. Over time, the potential for disputed outcomes led to an inflation in the number of prizes and a corresponding fall in their value. His investigations led him to conclude that improvements in market demand and competition provided more successful incentives than prizes.

A central finding of my own extensive empirical analysis is that innovation prizes and other administered systems did not offer effective inducements for inventive activity at appropriate prices. The unmatched strength of a market is in finding the right price, which will reflect the "opportunity cost" or the value of the good or service in other alternative uses. For applicants, the expected value is equal to the probability of winning times the market value of the invention, so prizes are unlikely to serve as an effective incentive unless the stated payout far exceeds the market value of the induced good or service. Prize announcements will obviously have an effect if the promised expected price is excessively high: if you offer a reward of $200 million for breakthroughs in getting your toaster fixed, then it will surely attract a throng of toaster specialists to try to resolve your problem. At the same time, the disproportionate payment will have unforeseen consequences beyond your toaster dilemma, such as inducing oncologists to switch from finding cures for cancer to competing for your blockbuster payout. The problems would be compounded if, at the end of ten years, you were to announce that nobody had satisfied your conditions, and no payouts would be made. In any event, we cannot make inferences about the general efficacy of prize incentives from extreme outliers of this nature or from the usual case studies cited in the literature.

This book instead systematically analyzed large numbers of representative records in decentralized and centralized institutions in Britain, France, and the United States, amounting to over sixty thousand prizes. The samples were drawn from such prominent prize-granting institutions as the Royal Society of Arts, the Franklin Institute, and the Society for the Encouragement of National Industry, among others. A historical parameter that supports the conclusions from my empirical findings is that even these institutions ultimately acknowledged the failure of their attempts at inducing useful inventions. If prizes failed as incentive mechanisms, and administered institutions also acknowledged their own

[22] Sidney (1862).

failure to positively affect the path of technological innovation, why did they proliferate during the eighteenth and nineteenth centuries—and why are they so popular today?

Prize systems clearly provide private benefits to their funders, administrators, and applicants for awards. Many enthusiasts about prizes today still belong to "a large and increasing class in modern society, composed of gentlemen of wealth and position, with a slight knowledge of divers practical pursuits, some enthusiasm, a great love of patronage, and nothing to do."[23] Philanthropists have the satisfaction of an enhanced reputation and are able to draw attention to their own particular or peculiar concerns. Both the funding and award of prizes reflect the self-interest and biases of their administrators, as seen in the dockets of the institutions examined in this book.[24] Administrators and judges boost their status and potential income through their involvement on panels. Some increase their own prospects of gaining a future prize, while others are able to serve as influential patrons for their protégés, if only because they gain inside information about the norms and unwritten procedures. Committee members benefit from networking and opportunities to participate in the elite social circles of members of prize-granting institutions.[25]

In the modern era of teamwork and collective invention, "blockbuster" prizes like the Netflix award provide a focal point to organize and coalesce the attention of different groups, allowing the monopsonistic funder to benefit from all of their investments and the ideas expressed in interim reports, while paying out a fixed price for a single solution to a private problem. Participants in the Netflix contest were well aware of the miniscule probability of winning, but the expected prize payout was merely a windfall. Indeed, for most prize awards, the applicants' investments of time and resources exceed even the absolute value of the award, independently of the probabilities of winning. The Netflix Prize was not a true contest at all, because the contributors were interested in ancillary factors such as the potential to learn from others and the likelihood of securing better jobs. Similarly, the major benefit to Netflix itself was not the algorithm, which proved to be irrelevant in a changing market for its services, but the advertising notoriety and "buzz" that the competition created. In short, prize systems offer diffuse and

[23] Sidney (1862: 377).

[24] Access to historical Nobel Prize information reveals ample evidence of biases, including the research fields that were singled out for prizes relative to important areas that were ignored.

[25] Nonmonetary prizes are especially important as a signal of quality in cultural industries such as books and movies, because the value of these "experience goods" can only be determined by consuming the good. However, even here we observe "long-tailed distributions" where the majority of prizes accrue to a few recipients, and there is an exponential growth in the number of awards. Such prizes also help to validate literal and figurative "moonshots," or ventures based on largely ephemeral claims.

imprecise benefits to both grantors and recipients, largely through diffuse and imprecise means, to achieve equally diffuse and imprecise goals.

European elites were convinced that members of their own class were motivated by honor and eminence, whereas financial prizes merely attracted the lower classes. As Jeremy Bentham satirically expressed it, these institutions assumed "the mechanic or peasant pockets the money. The peer or gentleman ornaments his cabinet with a medal."[26] Peers and gentlemen might have been interested in medals as interior decoration, but honorary prizes also attracted large numbers of manufacturers who chose medals over cash and marked their products with images and tallies of the number of prizes they had obtained. International and national exhibitions mainly provided opportunities for manufacturers to promote and market their products, so it is not surprising that awards for exhibits were largely idiosyncratic and did not reflect inventive value. These "innovation prizes" were not about the technology; they were about the winners and sponsors.

Innovation prizes functioned as a means of signaling and product differentiation, offering winners a relative advantage in the market for customers and potential funding. Manufacturers and retailers accumulated numerous prizes as a useful marketing strategy, comparable to investments in advertisements and enhanced brand name capital. Participation in international exhibitions was especially worthwhile for export-oriented producers who wished to penetrate foreign markets. Since firms attended to obtain prizes in these literal star wars, it was in the interest of organizers to offer larger numbers of low-cost awards, which then reduced the signaling value. Predictably, these events declined in frequency and popularity, as more effective sources of advertisement, mass entertainment, and commercialization developed toward the end of the nineteenth century.

From the broader perspective of national technology policy, using prizes as inducements is the equivalent of pushing on a string, given the lack of predictable connection between the objectives of the grantors and the objectives of competitors. Prizes can be effective for private entities who are able to free-ride off the efforts of the entire cohort striving for the award, while only paying for one successful solution; however, social welfare is reduced by the lost resources and investments made by the many losers in the prize competitions. This is especially true if the objective of the competition is highly specific to the grantor and

[26] Bentham (1825: 85). The notion that honorary prizes are necessary because certain cultural norms are antithetical to monetization seems flawed. After all, courts and juries routinely assign dollar values for far more fraught intangibles such as injuries and emotional distress, and even compute and pay out compensation for loss of life. Rather, honorary prizes seem to be effective in situations where the award sidesteps informational problems, where the income elasticity of the recipient is low, or where the award enables parallel returns such as more consulting opportunities.

results cannot readily be transferred to other projects. Moreover, the secrecy involved in most prize systems tends to inhibit the diffusion of useful information, especially for outsiders. These net social losses suggest that prize competitions are inappropriate policy instruments for government agencies that should be promoting overall welfare. The prize-granting institutions in all three countries studied here uniformly abandoned attempts at inducing inventions by these means, and switched to other activities such as research grants to facilitate inventive activity and efforts to improve their patent systems.

By contrast, the deficiencies of administered systems highlighted the net advantages of markets in patented ideas. Patent incentives were aligned with productivity because financial rewards would accrue only for contributions that were valued in the marketplace. Jeremy Bentham pointed to the lower social cost of the market for patents, which "adapts itself with the utmost nicety to those rules of proportion to which it is most difficult for reward artificially instituted by the legislator to conform. . . . [I]t unites every property which can be wished for in a reward."[27] Moreover, as Friedrich Hayek pointed out, the market mechanism coordinates and taps into decentralized knowledge in a manner that cannot be readily replicated by even the most adept administrators, especially in the dynamic and rapidly changing environment for novel technologies.

Markets for Patented Ideas Redux

The greatest divergence in history was the rise of the United States and its continued leadership in the global economy from the nineteenth century onward. American achievements through the second Industrial Revolution owed little to specialized elites, the dictates and decisions of special committees to judge inventions, or ambitious measures by the government to simulate entrepreneurial functions. Instead, private property rights in inventive ideas and supportive adjacent institutions were at the core of American technological policy initiatives. Knowledge has been recognized as central to progress in all societies; the innovation of the American approach was to further designate knowledge as an economic good that would be best produced and exchanged through an open market in ideas, in a benign Smithian process. The ultimate arbiter of rewards and the allocation of resources would be the consumer, rather than the arbitrary decisions of groups with the power to bestow or withhold benefits. Some observers of patent laws pointed to "the extremely liberal propositions of the United States, which one could only recognize as approaching the ideal of the future."[28]

[27] Bentham (1825: 92).
[28] Cited in Penrose (1951: 81).

The chapters in this book show at a very granular level that inventors responded to, and benefited from, the ability to protect their ideas with patents. Skeptics point out, as an implied or explicit indictment of the benefits of patent systems, that many inventors do not obtain patents for their discoveries. The argument rests on a non sequitur: some firms are able to benefit from lead time, firstcomer advantages, private rights of exclusion, or trade secrecy; therefore, patents are unnecessary for all firms. The relevant concern, however, is not the truism that all inventions are not patented. Creative individuals have always pursued diverse means of benefiting from their ideas. Most educators do not copyright their lectures, because they obtain compensation from their colleges and from correlates with their reputation; this does not imply that copyrights for professors are irrelevant or unimportant. The American model was based on the right of all creative individuals to freely choose among alternatives means of benefiting from their discoveries, including whether or not to patent, or whether or not to "work" their patented idea.

What is decidedly beyond debate is that the framers, the U.S. Constitution, and the Supreme Court put property rights in ideas at the center of American economic growth strategy. The nineteenth century was the age of patented invention in the United States, which had the world's largest population of productive inventors. The U.S. Patent Office was deluged with applications from across the country and from inventors of every social and economic background. Americans obtained the largest number of patents in the entire world, both before and after adjusting for population and the size of the economy. As shown elsewhere in this book, prior to 1870, U.S. patents totaled almost half of all the patents filed in the rest of the world, and that numerical gap increased during the second half of the nineteenth century. American patentees were so eager to protect their ideas that they filed caveats with the Patent Office to give advance notice of their intention to obtain property rights. Patents continue to matter greatly to certain inventors and industries, as the ten millionth patent filing in 2018 demonstrates (Table 14.1). In accordance with endogenous growth models, networks of patented ideas accumulated and contributed to increasing returns in the knowledge economy.

Indeed, one of the constant complaints about the patent system has always been that *too many* patents were being claimed and commercialized.[29] One of the authors of these sentiments acknowledged the "insuperable difficulties" of

[29] "Every lady is enveloped in patents, from the crown of her head to the soles of her feet, each of which is of as much importance in itself as the patent for a tooth-pick, or a toy popgun. . . . And such is also the fact with respect to the numerous or rather the innumerable host of patents for trivial inventions in kitchen utensils and those used in dwelling-houses in the ordinary course of domestic uses and economy." *United States Congressional Record: Proceedings and Debates of the 45th Congress* (1879), p. 308. The other cited quotes in the paragraph are from the same source.

Table 14.1 Progress of Useful Knowledge in the United States

Patent Number	Date	Inventors	Subject Matter
First ("1X")	July 1790	Samuel Hopkins	Method of making potash
No. 1	July 1836	John Ruggles	Cog for locomotive wheels
No. 1,000,000	August 1911	Francis H. Holton	Vehicle tire durability
No. 2,000,000	April 1935	Joseph Ledwinka	Pneumatic tires for railways
No. 3,000,000	September 1961	Kenneth Eldredge	Automatic reading system for data processors
No. 4,000,000	December 1976	Robert Mendenhall	Process to recycle asphalt compositions
No. 5,000,000	March 1991	L. Ingram et al.	Method of using bacteria to produce ethanol
No. 6,000,000	December 1999	Jeffrey C. Hawkins and Michael Albanese	Synchronization of data across devices
No. 7,000,000	February 2006	John P. O'Brien	Improvement in polysaccharide fibers
No. 8,000,000	August 2011	Robert J. Greenberg et al.	Visual prosthesis for retinal degeneration
No. 9,000,000	March 2012	Matthew Carroll	Windshield wiper fuel reservoir
No. 10,000,000	June 2018	Joseph Marron	Laser detection

Source: U.S. Patent Office.

determining which inventions were of low worth but expressed an admirable faith in the "judgment and discretion" of Congress to establish itself as the final arbiter of economic value. Congress, of course, declined to take up this mandate, to the great relief of cooks everywhere whose necessities include four different types of patented lemon zesters. However, even this critic "freely admitted" that, by creating incentives for everyone in the population,

> our patent laws have operated to stimulate the inventive faculties of our people, and . . . placed us in the front rank of nations, if not in advance of all. . . . Such inventors and discoverers are the great benefactors, not only of our own people,

but of mankind. Their inventions and discoveries have revolutionized the world and advanced the progress of the human race.

Patentees pursued their claims all the way to the U.S. Supreme Court, secure in the knowledge that the rights to property in new ideas were enshrined in the Constitution itself. Litigation about every aspect of business has always been central to the economy, involving firms, their competitors, consumers and other stakeholders, and the state and federal governments. Disruptive technologies by definition would engender disputes about torts, contracts, real property, and crime. Hostility against "patent sharks" (the nineteenth-century version of today's troll) was part of a broader populism directed to large corporations and their wealthy owners, a populism that was leveraged by other competitors who would benefit from free access to patented ideas. Their orchestrated outrage about patent litigation led to continual demands for congressional action, but these bills failed to persuade and were never translated into legislative measures during the second Industrial Revolution.

A final incontrovertible historical parameter is that countries that wished to emulate American economic achievements openly recognized and voluntarily began to adopt the distinctive U.S. rules and standards toward property rights in patents. The central role of patents and the market for technology in American policy was acknowledged by prominent and influential foreign observers and policymakers. Sir William Thomson (Lord Kelvin), a renowned British inventor and scientist, was a judge at the 1876 Centennial Exhibition in Philadelphia, which featured displays of Bell's telephone, the Westinghouse air brake, Edison's improved telegraph, sewing machines, refrigerator cars, and numerous other patented discoveries. He observed that, "judged by its results in benefiting the public, . . . the American patent law must be admitted to be most successful. . . . [I]t seemed that every good thing deserving a patent was patented."[30] Switzerland may have been able to make excellent artisanal chocolate and music boxes in the absence of patent laws, but when they wished to become competitive in global innovation markets, they voluntarily introduced a patent system. Countries like Switzerland, Britain, and Germany reformed their intellectual property laws in direct response to the American experience.

At this point, we might indulge ourselves by speculating about a largely unanswerable question. If all technological achievements over the past two centuries of American history were obliterated except for the universe of patented inventions, how close would we be to today's standard of living? My own view is that we would not be far from the current frontier, given a substitution effect

[30] Great Britain, *Parliamentary Papers*, House of Commons, vol. 34 (1877), p. 271.

where markets for ideas responded to perceived needs and shortfalls in supply and demand. But, with greater certainty, another historical parameter is that the lives of ordinary people were transformed by the creativity of a *populous* army of equally ordinary peers in pursuit of returns in the marketplace—from the patentees of paper clips (one of the truly great inventions, in my view) and paper bags to windshield wiper reservoirs. In the race for prizes, there could be only one first-place winner, whereas in the democratic open market for ideas, all participants with useful inventions could be winners.

Now and Then

The mark of a successful project in economics—as opposed to one in engineering—is that it excites (provokes) further questions. In the case of economic history, this "whataboutism" inevitably prompts inquiries about the relevance to the present. The twentieth century introduced changes in the organization of technology, research and development, markets for finance and venture capital, and the role of the government. I have stressed that this book adheres to a sort of academic Smithian principle, where the scope of objective observations is limited by the extent of the original datasets. Although the caveat does not limit my liability, this brief section will venture beyond those data to speculate about the relevance of my results to modern developments in human capital and education, centralized administered systems and government support for technology, and markets in invention. Finally, I return to the specific questions about institutions and growth with which this book started, now phrased as "Why not China?"

Several chapters in this book considered how human capital was related to the production of new ideas and inventions and the population of inventors. The timing of educational investments and the cross-country patterns suggest that "upper tail knowledge" and costly specialized human capital was neither necessary nor sufficient for sustained economic growth. The effectiveness of such factors depended, as always, on the details, including the quality and appropriateness of science and technology training (rote learning vs. problem solving; pure signaling vs. a rigorous curriculum; theoretical vs. pragmatic orientations). Engineers in the United States benefited society enormously by facilitating access to markets through improvements in infrastructure. However, they were significantly less likely to appear in the rosters of "great" and "ordinary" inventors than their counterparts in the lower ends of the distribution of technical knowledge.

Commercially successful inventions were not necessarily the most scientifically or technically advanced technologies.

French technocratic paternalism, in particular, illustrated how an emphasis on the special insights and contributions of technical elites could actually divert a society from technological and economic advance. The French model enshrined the conviction that the graduates of elite universities possessed the most appropriate knowledge and insights into the optimal course for technology and industry. Narrow technocratic training in exclusive programs largely served as a filter that guaranteed an influential position on graduation and encouraged the perspective that certified elites should direct outcomes rather than respond to the shifting, unpredictable needs of the mass market. The potentially arbitrary nature of "exclusive" (in the dual sense of elite and closed) systems is still evident in France today, in both minor and significant dimensions, ranging from archives where access depends on the patronage of an insider to "flagrant example[s] of government incompetence in promoting innovative activities" that have resulted in "unmitigated disaster."[31]

More broadly, the results of administered systems lead to doubts about government policies to support or substitute for the efforts of private entrepreneurs and to "nudge" market outcomes. Among economists, the French approach to economic development has re-emerged in the guise of Richard Thaler's "libertarian paternalism," now dressed in elegant outfits of mathematical formulae, dedicated to the "attempt to steer people's choices in welfare-promoting directions without eliminating freedom of choice."[32] Case studies that focus on successes tend to overlook countervailing evidence. Government research and development initiatives in the major industrial countries still tend to be highly concentrated in the military and defense industries and a handful of high-technology sectors. Josh Lerner offers a balanced and perceptive survey of the role of the government in promoting technological innovation through direct interventions and indirect support for venture capital and entrepreneurship. In the United States, he identifies effective contributions from such public sector initiatives as the Small Business Investment Company and the American research development programs, as well as a modicum of public subsidies and funding for venture capital. However, Lerner's overall evaluation is far more mixed, as the title of his

[31] Lerner (2009); Cohen and Noll (1991).

[32] Thaler and Sunstein (2008). Thaler, winner of the Nobel Prize in 2017 for his formative contributions to the field of behavioral economics, suggests that ordinary individuals systematically make choices that they themselves often identify as suboptimal. This implies the need for "choice architects," who not only provide accurate information but also help to shape choices toward outcomes that individuals themselves would have chosen. The empirical evidence in these chapters shows that enlightened administered innovation systems generally fail in the attempt to "nudge" or direct those whom elites perceive to be misguided and uninformed.

book suggests, because of the many caveats and counterexamples that can also be drawn from other case studies.[33]

Numerous studies have shown that firms' responses to government measures to remedy market failure can lead to further unanticipated social costs. The French example (Chapter 6) similarly indicated how benefits can be outmatched by the potential for overcompensation, distortions, and a misallocation of resources, especially when little attention is paid to the alternatives that are sacrificed. In the biopharmaceutical field today, one observes similar efforts to accumulate returns from multiple sources, such as viral gene therapy treatments that received federal research grants, tax credits for half of research and development expenditures, exclusive rights accorded to biologic therapies, and patent protection and other benefits, along with costly market prices for the final product. Government regulations at times reflect the bias that "known lives" are typically valued more highly than "unknown lives."[34] The Orphan Drug Acts in the United States and in Europe, in particular, succeeded in their objectives, in part by shifting spending by pharmaceutical companies from broader classes of diseases toward discoveries for diseases affecting small numbers of patients in the population, including "ultra-orphan" problems (affecting fewer than a thousand individuals). Medical researchers have questioned the resulting increased burden on health care budgets as well as the costs in terms of other treatments sacrificed.

The discussion of national innovation systems in Chapter 13 highlighted the importance of adjacent institutions that interact with any given institution in a manner that can reinforce or undermine desired objectives. Patentees were unlikely to flourish if the legal system persistently overturned property rights in ideas. Negative interaction effects of "crony capitalism," according to some political economic studies, reduce or eliminate the benefits from state and corporate expenditures and efforts to promote financial ventures and innovation.[35] In modern Russia, China, and parts of Latin America, for example, collusion among elites in privileged positions in the state and business sectors allow the diversion of large sums to enrich a few, under the guise of investments to improve infrastructure and innovative capacity.[36]

[33] A book review of "The Entrepreneurial State," in *The Economist*, August 13, 2013, notes that committed advocates of public sector entrepreneurship typically fail to concede "how often would-be entrepreneurial states end up pouring money down ratholes. The world is littered with imitation Silicon Valleys that produce nothing but debt. Yes, private-sector ventures also frequently fail, but their investors know when to stop: their own money runs out."

[34] Such issues are discussed in McCabe et al. (2005).

[35] Haber (2013); Pei (2016).

[36] By contrast, more positive outcomes for state policies have been recorded in smaller economies such as Singapore, Taiwan, and Ireland. Hobday (1995) highlights incentives from expansions in export markets that initially generated incremental improvements and minor product innovations.

A growing amount of research in transition economies as well as in developed countries reports the tendency for politically connected enterprises to exhibit inefficiencies and significantly underperform their peers.[37] A further concern is the degree to which government efforts to aid innovation and technology "crowd out" private sector activity. Crowding out by government funding provides a windfall for favored businesses but also creates distortions because tax revenues are diverted to subsidize ventures that would still have occurred in the absence of the transfer. Several research surveys remain ambivalent about the overall net effects, but a number of studies have found severe crowding out in such examples as the U.S. Small Business program.[38]

The scope and depth of markets in ideas and inventions in the nineteenth relative to the twenty-first century have also been raised in discussions of the applicability of insights from the historical record. Property rights in ideas through the patent system helped to promote deep and active markets in inventions. Flourishing markets for both patented and unpatented ideas still serve to allocate resources today toward higher-valued uses, through a division of labor and specialization among "outside" and "inside" inventors, intermediaries, and firms. Licensing of patents in secondary and tertiary markets and cross-licensing (the mutual exchange of related patent rights) have always been a significant aspect of such transactions, as shown by business records, litigation, and archival assignment documents, although more research is needed to estimate the scope and scale of private contracts. During the 1980s, American universities responded to legal rules by significantly increasing their efforts to extract returns from their research through higher patenting and licensing. A large-scale survey of American companies showed that almost half of innovative firms had acquired technological innovations from the market, including customers, suppliers, independent inventors, and other outsiders.[39] The authors concluded that "external sources of invention make a significant contribution to the overall rate of innovation in the economy."[40]

In modern markets for invention, as in the past, the distinction between "insiders" and "outsiders" is frequently blurred. "Independent" inventors often include an employee acting as a principal on his or her own behalf (such as a corporate software engineer who has come up with an idea on his own time), rather than one who is unattached to a firm. A fascinating series of case studies show how firms treat outside submission of ideas, including internal submissions that are outside the inventor's regular job description.[41] In corporations like Yamaha,

[37] Shirley et al. (1995).
[38] Wallsten (2000); David et al. (2000).
[39] Arora et al. (2016).
[40] Arora et al. (2004).
[41] Holte (2016).

National Geographic, Nexon, eBay, Hershey, and General Electric, the stated policies toward the submission of unsolicited ideas range from complete openness, to invitations to submit that are limited to patented inventions, to the refusal to consider any submissions.[42] Many firms echo Under Armor, which describes itself as "an idea house" based on an "open platform of innovation," since "we are entrepreneurs and innovators and understand that great innovation can come from both inside and outside our company."[43] As discussed in Chapter 3, innovative crowdsourcing platforms like Innocentive act as brokers for idea submissions from networks of hundreds of thousands of solvers.[44] Technological innovations such as blockchain ledgers are likely to facilitate decentralized exchanges of ideas and inventive solutions. In short, the market in both patented and unpatented ideas has expanded in scale and scope in the current incarnation of the knowledge economy but retains its central characteristics.

Follow the Leader

Today's developing countries encounter very different circumstances and concerns than Britain, France, or the United States in the nineteenth century. Nevertheless, an approach that highlights distinctions between markets in ideas and administered systems still holds crucial lessons for interpreting current patterns. As the first chapter discussed, studies of early British economic achievements directed attention to other possible candidates for early industrial leadership, including debates about "Why not China?" Now, attention has again been drawn to this region, and to the remarkable transformation of the Chinese economy that accelerated toward the end of the twentieth century. Economic development in China over the very long run has followed a complex pattern perhaps best described by a (sino?) sine-curve. Historically unprecedented economic growth rates have raised the possibility that China might surpass all other nations and attain its declared ambitions to overtake global competitors in Europe and the United States.

Over the first two decades of the twenty-first century, growth rates in China surged to the extent that the total size of its economy surpassed that of the United States, adjusted for purchasing power or relative prices in the two countries. The

[42] Yamaha, for instance, only considers patented submissions: "if you send us any Idea that is not granted as a patent, Yamaha shall return your Idea without any review or evaluation. If an Idea you sent is officially registered as a patent, Intellectual Property Division will review and give you a feedback." Atlas Copco encourages "ideas that are product- or service related, of a technical or marketing nature, that relate to Atlas Copco's technologies or the way we do business. Atlas Copco welcomes them all." These quotes are from the companies' websites.

[43] https://uaideas.force.com/.

[44] https://www.innocentive.com/.

current steep drive to convergence in China dates from the market reforms in the 1980s ("it doesn't matter whether a cat is black or white, as long as it catches mice") that partially liberalized the nonstate sector.[45] Some economists credit this growth to a reduction in inefficiencies, which might imply that the observed changes reflect a movement toward the efficient frontier rather than an expansion in production possibilities.[46] Despite the historically high growth rates, Chinese total factor productivity and the level of output per person are still significantly below the corresponding U.S. rates, and it is not clear when or even whether China might achieve convergence in these key measures of economic welfare.

China offers a fascinating case study of a centralized administered system that is attempting to create a top-down market in ideas, and also illustrates how individual responses to incentives can lead to unintended consequences. State bureaucrats have drawn up a list of correlates with technological change and directed significant resources to boosting each category, from investments in scarce human capital, science and technology, and university infrastructure to intellectual property institutions.[47] As a result, China is now among the global leaders in almost every measure of science and technology inputs. The number of scientists and engineers jumped from 1.2 million in 1982 to 3.2 million in 2010, and some 1.1 million undergraduate degrees in these subjects were granted in 2010. Chinese citizens make up the largest group of foreign students in U.S. doctoral programs, and the quantity of scientific publications by Chinese scholars is second only to the United States. Wealthy businessmen and elite scientists have even founded the Future Science Awards, a domestic version of the Nobel Prize.

The Chinese experience in intellectual property rights aptly illustrates some of the complexities behind generalities about innovation and institutions. One of the most memorable experiences in my professional life was in Wuzhen, China, a historic town crisscrossed with canals, which is the permanent site for the World Internet Conference. I was invited there to lead an intensive workshop on the evolution of the U.S. patent and copyright system, and numerous members of the Chinese media listened intently to live translation of the lengthy presentation, and later asked detailed questions about the graphs and tables illustrating

[45] Deng Xiaoping's statement is often stated as a rationale for the shift away from planning toward the mixed "socialist market economy."

[46] Zhu (2012).

[47] Xie et al. (2014). The film industry in China similarly illustrates how their intellectual property policies have endogenously responded to changing economic realities. During the period when the market for domestic films was not well developed in China, there was little incentive to offer protection for movies. In recent years, however, Chinese-made films have become more profitable, leading to a significant increase in concern about reducing piracy. The 2017 Film Industry Promotion Law allows for stiff penalties for infringement. The government has also committed to supporting the industry through measures such as fiscal policies, and state funding of 1 billion yuan each year.

the costs and benefits of intellectual property policies. Some economists suppose that this sort of enlightened interest in intellectual property rights by such "follower countries" as China and India helps to explain their rapid convergence toward the growth paths of the early industrializers.

Quantitative measures, however, need to be adjusted to incorporate an assessment of the institutional details associated with the aggregate patterns. The World Intellectual Property Organization notes that the Chinese corporations Huawei and ZTE have risen to the top of the list for international patent applications. There was also a corresponding increase in total patent applications for China (Figure 14.2).[48] However, the rapid run-up in patent statistics does not entirely reflect market-oriented processes. Rather, the patterns owe in large part to administered efforts by the state to boost the numbers through an extensive array of incentives that may be termed "prizes for patents." Patentees can increase their chances of academic tenure, obtain coveted residence permits in attractive locations, or get cash payments and other types of bonuses. Firms leverage inflated patent portfolios to acquire windfall benefits from the authorities that range from large credits and subsidies to profitable state contracts.

Domestic patenting in China seems to be of lower (but increasing) quality relative to comparable foreign patents. Information about the quality of technological capabilities is revealed, for instance, in the percentage of applications that are actually granted, evidence from patent renewals, and other indicators of patent quality.[49] Similar questions have been raised about the quality of scientific output and about questionable practices to manipulate citations and other quality indices in a black-market "publication bazaar."[50] The Chinese example therefore mirrors the historical experience of countries like France and highlights the potential costs of a centralized administered innovation system that fosters unintended consequences including incentives for corruption and unethical conduct. Empirical studies in the political economy of China point to the need for efficiency gains in the form of a decentralized approach to governance, and the evidence in this book suggests that such benefits would also apply to technology markets.[51] Economic progress in a country of over one billion residents is necessarily contingent on private initiative and incentives for productivity, entrepreneurship, and innovation across the entire population. To

[48] The first modern patent law of 1984 has been amended several times, in the direction of enhancing the value of property rights and the functioning of markets in those rights. Statutory enforcement is relatively stringent, including criminal sanctions for infringement, but intellectual property piracy is still pervasive.

[49] Hu and Jefferson (2009). Patent protection may have had a stronger effect through the incentives for foreign investment. According to the World Economic Forum, China's technological standing largely owed to the efforts of foreign direct investors (http://reports.weforum.org/).

[50] Hvistendahl (2013).

[51] Stromseth et al. (2017).

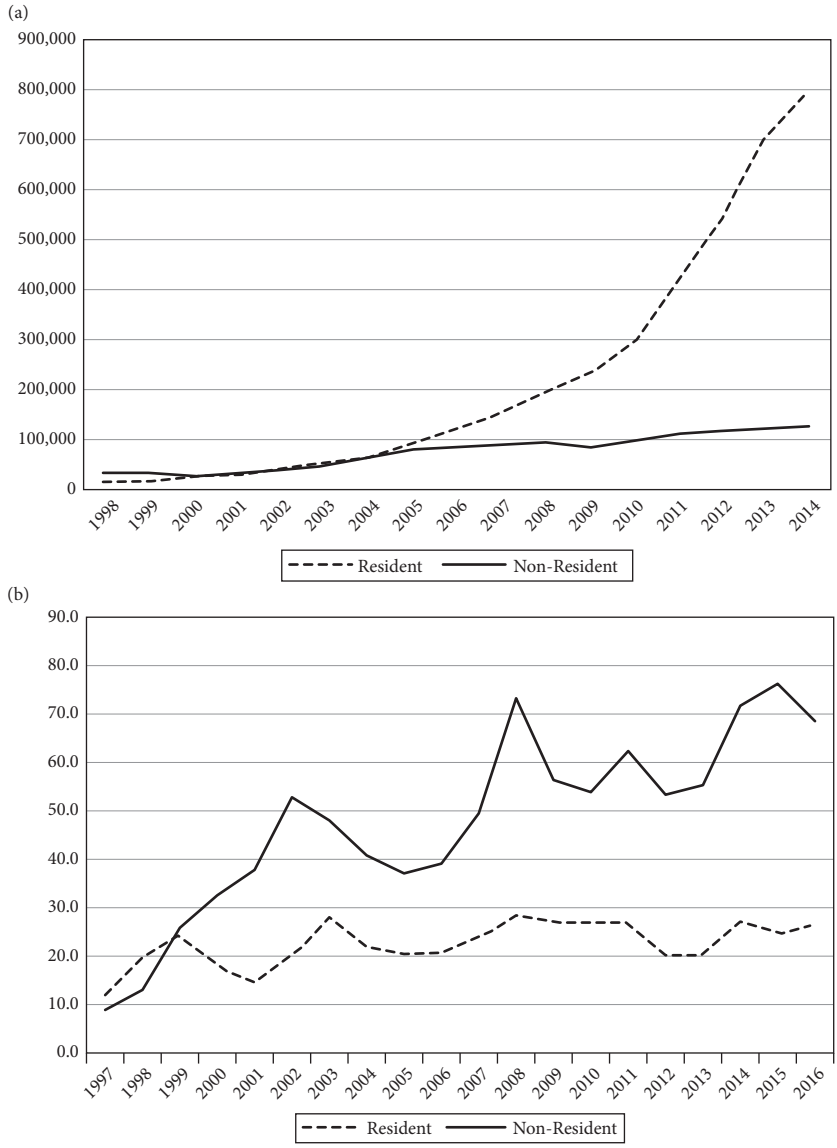

Figure 14.2 Patenting in China
(a) Patent applications in China, by residency. (b) Percentage of patent applications granted in China, by residency.
Source: World Intellectual Property Organization.

date, China has experienced the benefits of removing constraints on markets, but until its administrators acknowledge that decentralization and "spontaneous coordination" are an essential prerequisite for self-sustaining growth,

China is likely to fall short of its goal to overtake the United States as the global economic leader.

Future Perfect?

Popular and academic perspectives on technology have always ranged along a spectrum from fulsome wonder at an age of "infinite progress" to despair about the potential to revert to "a new dark age."[52] According to some dismal economists, we have entered an age of diminishing returns because of the end of the era of great inventions, or because of the inherent nature of science and technological change.[53] Their pessimism implicitly owes to the conviction that inventive activity arises from rare supply factors such as genius, and exogenous general purpose technologies that do not respond elastically to expansions in market demand. Or perhaps, like Edward Bellamy's hero in the futurist 1888 novel *Looking Backward*, pessimists feel that "if we could have devised an arrangement for providing everybody with music in their homes, perfect in quality, unlimited in quantity, suited to every mood, and beginning and ceasing at will, we should have considered the limit of human felicity already attained, and ceased to strive for further improvements."[54]

By contrast, observers who have documented the propensity of market-oriented incentives to induce relatively ordinary inventors to solve emerging problems have tended to be notably more optimistic about society's ability to elicit the sort of creativity that would exceed our best expectations. This link between markets and optimism about the future was evident in the reports of the Commissioners of Patents, especially at the end of the nineteenth century, when American residents contemplated a world that patented innovations had dramatically transformed over the course of their own lifetime. The head of the Patent Office, John S. Seymour, observed that "the relation which exists between industrial demand and inventive activity is very close. . . . [S]hould any change or advance in industrial conditions cause a sudden increased demand for some article, means for producing that article or its equivalent will be created very rapidly in the brains of ambitious inventors."[55] This elastic response was evident in inventions involving simple innovations through to complex technologies. The introduction of home delivery of mail induced hundreds of patents for letter boxes. The beginning of "big digs" for new canal projects

[52] Bridle (2018); Reese (2013).
[53] Gordon (2017); Cowen and Dutton (2011); Jones (2009).
[54] Bellamy (1888: 157–158).
[55] *Annual Report of Commissioner of Patents* (1895), p. xiii.

promptly stimulated numerous patents for excavators, newspaper articles about the need for a specific kind of bottle led to a thousand patent applications to meet the demand, and new systems of voting resulted in spikes in voting machine inventions.

Charles H. Duell, the son of a former Commissioner of Patents, was head of the U.S. Patent Office at the start of the twentieth century, by which time inventors were filing applications for some fifty thousand inventions, and over twenty thousand assignments were being recorded each year. Duell is often falsely identified as a technological pessimist who thought everything had already been invented, but he was adamant in his belief that the patent system would ensure the continuity of progress.[56] His successor, Edward B. Moore, was equally hyperbolic in his expectations about the ability of market incentives to generate unimaginable future advances, which he attributed to the favorable American patent institutions: "The accomplishments of the last half-century, while marvelous almost beyond conception, will not begin to compare with what will be done in the next half-century."[57]

In the twenty-first century, the sources of inventive activity include more scientific training and technical human capital, and greater investments in research and development by large corporations, relative to the early industrial era. At the same time, these supply factors reflect differences in scale and degree for specific industries, rather than in the underlying fundamentals for productive technological discovery.[58] After all, many of the most transformative features of the digital economy were devised by college dropouts or by liberal arts graduates whose training mimics the wholistic and flexible creativity of great thinkers and inventors of the nineteenth century.[59] Just as in the second Industrial Revolution, an apprenticeship in a high-technology startup can in some instances offer more valuable and relevant training than an advanced degree in science and

[56] He wrote in the *Annual Report of the Commissioner of Patents* (1900), p. xii: "The world owes as much to inventors as to statesmen or warriors. To them the United States is the greatest debtor. . . . [I]n this century the debt will be piled still higher, for inventors never rest."

[57] E. B. Moore, "Next Few Years Will Eclipse All Ages in Invention," *Electrician and Mechanic* 24 (1912): 316. "The patent laws of this country have been a greater protection to the inventor than have those of any of the other nations and are being widely adopted."

[58] Capital market imperfections helped to induce "in house" innovation within firms, so we might expect that technological change that reduces such transactions costs will lead to a shift back to innovations in the market. Today, science accelerators like Indiebio.com provide lab equipment and other fixed assets that enable independent scientists to become entrepreneurs.

[59] Entrepreneurs who never went beyond high school or dropped out of undergraduate colleges include Bill Gates and Paul Allen (Microsoft), Larry Ellison (Oracle), Steve Jobs (Apple), Mark Zuckerberg (Facebook), David Karp (Tumblr), Peter Cashmore (Mashable), Michael Lazaridis (Research in Motion), Jack Dorsey and Evan Williams (Twitter), Shawn Fanning and Sean Parker (Napster), Michael Dell (Dell Computers), Travis Kalanick (Uber), Jan Koum (WhatsApp), and Daniel Elk (Spotify). The legendary Chinese entrepreneur Jack Ma never wrote a line of code and merely obtained an undistinguished undergraduate degree in English. Bureaucrats are unlikely to identify or elicit such radically disruptive contributions from seemingly unqualified individuals.

engineering.[60] As Thomas Edison showed, deficiencies in technical education can be resolved by tapping into labor markets or collaborations in teams. Indeed, the promise of blockchains and "decentralized autonomous organizations" lie in a reversion to the nineteenth-century world of independent market interactions, in which this alchemy of diverse ideas and individual creativity resulted in discoveries that generated enormous value for all of society.[61]

The twentieth century has been characterized as "the American century," but at this critical juncture, new global competitors are adopting economic policies and institutions that have the potential to outpace U.S. achievements. Whether the twenty-first century will remain the American century will largely depend on the extent to which the lessons of the past are kept to the forefront. American technological and industrial progress owed to democratic open-access markets in ideas where entrepreneurial innovators succeeded, not by decree of administrators, but because their creations satisfied the ultimate judges—consumers in the marketplace. The evolution of administered innovation systems over the past three centuries largely serves as a cautionary tale rather than as a success story. The economic history of innovations instead suggests that the best incentive for necessary changes is failure in the marketplace; while the best prize for creative contributions to the knowledge economy is success in the marketplace.

[60] Marc Benioff, the CEO of Salesforce, calls for "a moonshot goal to create five million apprenticeships in the next five years." One of these tech billionaires offers thirty fellowships of $100,000 every year to induce young people to drop out of college. Switzerland is a leader in global competitiveness, in part because of its apprenticeship system, where the majority of high school graduates enter apprenticeships, many attached to jobs in innovative industries.

[61] Buterin (2014).