Invention, Productivity, and the Evolution of East Asia's Innovation Systems

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Abstract: In the 1980s, the rapid emergence of Japanese firms as technology leaders in a range of industries previously dominated by American firms stunned executives, worried government officials, and prompted a flood of academic studies designed to explain the promethean strength of the Japanese innovation system. Japan today remains a highly developed economy with pockets of innovative strength, but the rapid decline of a number of Japan's most technology-intensive industries and the sharp slowdown in recorded total factor productivity growth and labor productivity growth has raised important questions about the longer run performance of the nation's innovation system. Drawing upon a series of papers that have used firm-level microdata to compare and contrast the innovative performance of Japanese and American firms across the past several decades, this chapter will argue that some of the features of the Japanese innovation system that made it so dynamic and vigorous in the 1970s and early-to-mid 1980s became impediments to success in more recent years as Japan's internal and external conditions changed. Public policies pursued during Japan's rapid growth era reinforced and strengthened some of the aspects of Japan's innovation system that became liabilities in more recent decades. This chapter will focus in particular on policies that exacerbated Japan's "pro-incremental" bias and its "pro-incumbent" bias.

The evolution of innovation systems in South Korea and Taiwan has differed from that of Japan, but this chapter will argue that some of the lessons drawn from the senescence of formerly successful Japanese high-tech industries are useful in explaining the challenges facing the high-tech sectors in South Korea and Taiwan. The chapter will argue that policies adopted in those country's rapid growth eras also reinforced a "pro-incremental" bias and a "pro-incumbent" bias, with similarly negative effects in the longer run.

Chinese industrial policy and industrial policies pursued elsewhere in contemporary Asia bear strong echoes of the policies discussed in this paper. This raises clear concern that the outcome could be the same. Given China's size, the implications for humanity's innovation future are at least somewhat troubling. Let us hope decision-makers can learn from history, and avoid repeating it.

1. The Rise of Innovating Economies in East Asia

Economists of a certain age, on both sides of the Pacific, will recall that there was a time when the world stood in awe of Japan's economic performance. Japan's rapid growth from the 1950s through the early 1970s had many drivers, but among the most impressive to Western observers was the nation's rapid productivity growth, documented by Denison and Chung (1976) in a classic study funded by the Brookings Institution. This careful growth decomposition revealed that Japan had grown faster than any nation in recorded economic history, and that productivity growth in the Japanese economy had been exceptional.

All advanced economies experienced a growth slowdown in the 1970s; Japan was no exception. Nevertheless, Japan grew more rapidly than the other rich Western economies, and its measured productivity growth continued to be high relative to the rest of the OECD member states. In the 1970s and early 1980s, Japan's industrial structure quickly shifted from resource-intensive and labor-intensive manufacturing toward knowledge- and technology-intensive industries. Japanese manufacturers of steel, autos, industrial machines, and, increasingly, electronics began displacing long-established Western manufacturers in industries around the globe. Japan's R&D intensity and the numbers of patents held by Japanese firms and home and abroad surged. By the early 1980s, Japanese firms, long derided as "copycat" imitators of Western technology, had managed to out-engineer their Western rivals in a range of iconic industries. An early series of studies by Edwin Mansfield (1988a,b,c) documented the high productivity of Japan's corporate R&D spending – according to Mansfield, even by the late 1960s, Japanese engineers were generating more patents per R&D dollar than their American rivals. Clark and Fujimoto (1991) focused on Japanese R&D in the automotive industry, presenting compelling evidence that Japanese firms were able to introduce new model cars with fewer engineering hours, and eliminate errors and inefficiencies from the new production lines associated with these new production models much faster than their Western rivals. By the late 1980s, prestigious bodies like the National Academy of Engineering were glumly concluding that Japanese firms were ahead of their American rivals in 25 out of 34 "critical" areas of technology (National Research Council, 1992), and, in 1987, the president of the U.S. Semiconductor Research Corporation conceded, "We may never match Japan's R&D efficiency."

Even at the height of Western infatuation with (and fear of) Japan's technological prowess, thoughtful observers noted both strengths and weaknesses of the Japanese approach to R&D. A useful comparison undertaken by an eminent Stanford engineering professor in Okimoto and Rohlen (1988) is reproduced in Table 1. It is useful to see these differences as reflecting intelligent adaptation to the circumstances Japanese firms found themselves in during the postwar era. One of the few economists who addressed the possible existence of a "Japanese style" of R&D took exactly this approach (Saxonhouse, 1983; Okimoto and Saxonhouse, 1987), and the argument presented below builds on the late Gary Saxonhouse's early insights and on arguments advanced previously in Branstetter and Nakamura (2003).[1]

[1] After writing a first draft of this paper, we discovered the prescient essay penned by Daniel Okimoto and Gary Saxonhouse (1987), and we were struck by the degree to which the arguments in our paper were anticipated by these two astute observers of the Japanese economy more than thirty years ago. Even today, this article is well worth (re)reading.

It was perhaps natural and even inevitable that engineers and firms in a "late developing" state would focus their efforts on effective convergence to a technological frontier largely defined by prior foreign invention, rather than on "fundamental innovation" designed to meaningfully advance that state-of-the-art (Gerschenkron, 1962). Of course, once Japan reached the technological frontier (and lost the cost advantages it had retained through much of the postwar era), it was increasingly necessary for Japanese firms to shift from an innovation system that had been appropriate for Japan's "catch-up" period to one that could generate frontier innovations of its own. The obvious struggle once vaunted Japanese firms and industries have faced in this transition raises questions about the extent to which public policies pursued during the high growth era might have inadvertently hampered this transition. The sections below will argue that this was, in fact, the case. Japanese postwar policy choices in the domains of exchange rate policy, human capital policy, and intellectual property policy powerfully reinforced what may have been a natural tendency for Japanese firms to concentrate on incremental/process engineering at the expense of more radical invention. In other words, policy choices created a strong "pro-incrementalist bias" in the Japanese innovation system. The sections below will also argue that the economic theory of radical invention, such as it is, strongly emphasizes the role of new entrants in speeding the emergence of fundamental new technologies. Postwar Japanese policy choices in the domains of international finance, competition policy, financial market policy, and general regulation of the service sector all worked to limit the entry and mobility opportunities of new, start-up firms. By the time serious policy change in these domains was embraced, the Japanese innovation system had reached a point where positive change was extremely difficult and painful. As the reader will see, South Korean policy choices in these domains were, in some cases, even more extreme, and have produced a South Korean innovation system that is arguably even more subject to a pro-incrementalist bias and a pro-incumbent bias than is the case for Japan. We view Taiwan as taking a different path from that of its two larger East Asian neighbors, but for Taiwan, too, past policies that seemed stunningly successful a couple of decades ago can now be seen in a more skeptical light.

As we develop this argument, we must highlight some important caveats. We do not pretend to develop a general and complete theory of the productivity slowdown in Japan, South Korea, and Taiwan – partly because many of the elements of that slowdown appear common to all industrial countries, and have been investigated thoroughly by other authors (Gordon, 2016; Branstetter and Sichel, 2017; Byrne et al., 2016). We fully acknowledge that all three countries have long harbored service sectors that were less productive and competitive than those in the more advanced Western nations, a point that has been thoroughly explored elsewhere (McKinsey and Co., 2000). We also acknowledge that these nations face acute demographic challenges that constitute an additional growth headwind, another point that has been exhaustively researched by others (IMF, 2016). Instead, we focus our investigation deliberately on those relatively small sectors in the three economies which once inspired the world with their rapid rise – but now appear much less impressive, with a particular focus on electronics and IT. Arithmetic implies that our focus will limit our ability to fully account for the productivity slowdown at the macro level in these economies. On the other hand, our focus sheds new light on the long-term consequences of policy interventions once credited with speeding the development of technology-intensive industries in countries that were once far from the frontier.

That sectoral focus also explains why we focus on Northeast Asia, but not Western Europe. While Western European nations enjoyed rapid productivity convergence vis-à-vis the United States through the early 1990s, with a few exceptions, these nations did not develop indigenous information technology and electronics industries "from scratch" that appeared at one time to be on track to displace American incumbents in these sectors that were essentially invented within the United States.[2] While some European nations engaged in efforts – occasionally ambitious ones – to reshape their industrial structure through government policy, few managed to achieve the degree of success that was once attributed to Japan, South Korea, and Taiwan. While some of the shortcomings of national innovation systems we highlight in this document may also apply to Western Europe, that is not a point that we will seek to develop further in the paragraphs below.

The final caveat we highlight here is an acknowledgment of our intellectual debt to the broad literature on national innovation systems (Nelson, 1993; Lundvall, 2010). Long before venture capitalists began speaking of innovation "ecosystems," researchers in this literature mapped out a systems view of the innovation process that stressed how government policies, public institutions, and private firms of various kinds interacted with one another (and co-evolved with one another) in the pursuit of economically useful new technologies. As researchers within this literature have long noted, the evolution of these systems can lead to pronounced and persistent differences across industries and nations that, once firmly established, can become resistant to change. As in natural ecosystems, the various elements within national innovation systems tend to interact with one another in mutually reinforcing ways. The argument presented below highlights a cautionary lesson: policies embraced at an early point in the development of a national innovation system, which may appear well suited to the circumstances of the time, can constrain and shape the development, and ultimately, the capabilities of that system long after the initial policies cease to be a good match for the needs of the market place.

2. The Evolution of Japanese Innovative Capabilities in the Postwar Policy Environment

Japanese Human Capital Policy Choices , "Pro-Incrementalist Bias," and "Pro-Incumbent Bias"

In a world of globalized supply chains, where it is commonplace for components of even the most sophisticated manufactured products to be assembled in low-wage developing countries, it is easy to forget what a novelty Japan was in the early postwar era. It had been the first and only nonwestern nation to acquire modern manufacturing capabilities on a significant scale in the years prior to World War II. In the postwar era, it continued to grow with surprising vigor, rapidly becoming the first nonwestern nation to join the OECD. These achievements were, in part, the result of Japan's exceptionally successful, decades-long strategy of investing in the acquisition of both general human capital and specific technical capabilities.

Some modern theories of economic growth and development place the acquisition of complementary types of human capital and skill at the heart of the development process (Jones 2014a, 2014b). In these models, modern economies require the acquisition of deep, highly specialized knowledge, but this

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[2] Western Europe's technology-intensive exports have deep historical roots that go back, in some cases, to the era in which continental Western Europe, not the United States, was the global center of science. Germany is sometimes referred to as having the world's most advanced 19th century economy, a somewhat unkind remark that nevertheless acknowledges that the industries in which Germany possesses a revealed comparative advantage today are the same ones that dominated its export structure in the late 19th and early 20th centuries. Some would regard Airbus as postwar Western Europe's great industrial policy success, but industry historians are well aware of the advanced nature of European aircraft industries in the years before World War II. At best, the Airbus experiment has brought about a partial revival of that prewar eminence, and that at considerable cost (USTR, 2012).

expertise is only profitable when individuals reside in labor markets with other possessors of complementary, highly specialized deep expertise. Only when multiple workers with complementary, deep, but different domains of expertise are combined together can sophisticated services be delivered and sophisticated products manufactured. In the absence of such complementary expertise, it instead makes sense for talented individuals to become generalists. But the absence of specialized expertise limits the degree to which individuals can implement (and build upon) the most modern technologies. Japan's highly intentional strategy of building capital and skill was arguably critical to its emergence as a manufacturing and innovating nation.

The strategy took shape after Japan's Meiji Restoration, with the new imperial state moving quickly and decisively to create a modern educational system at all levels and embed state-of-the-art Western expertise into its leading firms and government ministries. To their credit, the Meiji reformers established libraries full of translations of Western thought, science, and engineering throughout the country, subsidized study abroad for thousands of Japanese students, and imported enormous numbers of foreign instructors, consultants, and experts. At least 3,000 foreigners of all types were in government service during the early Meiji period, and a total of 8,000 foreigners were in Japan in public and private positions, all paid for by the Japanese taxpayer or private Japanese investors rather than some foreign-managed program of development aid.[3] In these early years, fully half of the Ministry of Education's budget was spent on foreign experts, and a still higher fraction (two-thirds) of the national public works budget was spent on foreign experts. These foreign experts were expensive, often arrogantly dismissive of Japanese culture, and difficult to manage, and the Japanese institutions employing them had every incentive to replace them as quickly as possible with qualified Japanese citizens. Fortunately, Japan's modernizing educational system was quickly able to prepare its citizens for rapid modernization. In 1891, 26% of the labor force had a primary school education. By 1935, 98% of the population had a primary education. Japan quickly transferred its educational system to its colonies, Taiwan and South Korea.

This early commitment to educational excellence strengthened in the postwar era in all three countries. Stanford's eminent education expert Thomas Rohlen published his landmark study, *Japan's High Schools*, in 1983. In terms of the mastery of basic skills, Rohlen claimed that the typical Japanese high school graduate in the early 1980s was the equal of the average American college graduate. As early as the mid-1960s, Japanese students were outscoring Europeans and Americans on international standardized tests of mathematics and science. By the 1980s, Japan graduated more than twice as many engineers per capita as the U.S., and its ordinary workers had dramatically higher levels of competence in science and math than their American counterparts. Today, standardized tests of science and mathematics skills suggest that the average levels of skill mastery and the fraction of students scoring one standard deviation above the OECD average are extremely high in Japan, South Korea, and Taiwan (Hanushek and Woessman, 2015).[4] This excellence extends to the city states of Hong Kong and Singapore, who

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[3] Jones (1980) presents a fascinating study of the role of hired foreigners in Meiji Japan, and the facts and figures in this section are taken from her study.

[4] This high level of performance reflects the fact that many East Asian youth participate in not one educational system, but two. Most middle class students attend publicly funded schools, whose curriculum is tightly managed by the national education bureaucracy. But most of these students also attend after-school "cram schools," a vast industry in East Asia that really has no counterpart in the Western world. This cram school industry is highly competitive, and features customized programs of study a parent can purchase that are explicitly designed to compensate for the failures and shortcomings of public school education and pedagogy.

patterned their own educational systems after the "East Asian" model. There can be little doubt that this effective investment in human capital is extremely important in explaining the technological convergence of these nations with the West. Economic research has shown as much. In his own highly cited paper in the *American Economic Review*, Romalis (2004) finds that once one accounts for the expansion observed in East Asia in human and physical capital, there is relatively little left over in the variance of East Asian export flows for "industrial policy" to explain.[5]

However, there were limits to this national human capital strategy, and, in later decades, these limits turned out to be highly consequential; in fact, the consequences reverberated far beyond the borders of Japan. Elementary and secondary education systems in Japan achieved superlative results. On the other hand, the comparative performance of Japanese universities was much less impressive. Japan's universities did a reasonable job of providing a basic engineering education to its technical graduates. However, relative to leading universities in the United States and Western Europe, graduate education was relatively underfunded and institutionally neglected. Okimoto and Saxonhouse (1987) point out that, in the early 1980s, the United States spent six times as much as Japan on doctoral-level training and generated six times as many Ph.D. graduates in the sciences and engineering. Many of these graduates found employment in industry, rather than academia, and most top corporate R&D labs were effectively managed and led by Ph.D. recipients. In Japan, in contrast, advanced training for corporate R&D personnel tended to take place within the larger, technology-intensive firms, which sponsored significant internal training programs for promising technical experts that could even involve lengthy periods of study abroad. While this very different approach to the training of an industrial R&D workforce clearly did not prevent leading Japanese firms from quickly reaching the technology frontier, it made it much more difficult for high-tech start-ups in Japan to quickly acquire the highly skilled researchers they would need to create transformational new advances. Senior technical experts with the requisite skills tended to concentrated within leading companies, in the context of a "lifetime employment system" that strictly limited white collar labor mobility across firms. On the other hand, the armies of Ph.D.-level engineers and scientists emerging from U.S. universities and seeking industrial employment could easily move across firm boundaries – their academic credentials were widely recognized, and their university training did not bind them to particular firm or even a particular industry.

The limited development of graduate education in Japan arguably shaped the nation's technological development in other ways. Basic research funding in Japanese universities was limited, and Japanese academic culture and bureaucratic practices further constrained the degree to which this funding could be concentrated in the hands of promising young scientists. Academic salaries did not adjust to reflect differences in scientific productivity or even differences in the local cost of living, and seniority tended to be the dominant factor in academic incomes.[6] Any critic of the Japanese university system must

[5] Of course, the argument works in the other direction. If we want to understand why aggressive industrial policy has failed in most of the countries that have tried it, we must understand that the weak human capital foundation upon which most of these programs have been built surely contributed to their failure.

[6] A critical element in the rise of American universities to global prominence was the effective self-destruction of German research universities during the Nazi era and the openness of the United States to foreign students, foreign professors, and foreign professionals. Waldinger (2010, 2015) provides compelling empirical evidence on the role of Nazi-era policies in this shift of the global scientific center of gravity. Neither Japan nor South Korea have been historically welcoming to immigrants, further undermining their prospects for scientific leadership. Taiwan has been perhaps more open, but handicapped by its smaller size and diplomatic isolation.

concede that the preeminence of American universities in the postwar global scientific order and the degree to which international scientific discourse became utterly dominated by English language journals presented Japanese universities and scholars with a significant barrier to entry. An effort to make Japan's top universities global contenders would have been expensive and difficult. That being said, the simple fact of the matter is that no real effort was made to position even the top Japanese universities for global scientific leadership. The nation, the Ministry of Education, and even the Japanese universities themselves were content for Japan's universities to play their postwar role as educators of engineers, professionals, and white collar managers. This choice would haunt the nation's technology-intensive industries in later decades. The philosophy and structure of higher education in Japan exerted a profound and lasting influence on its former colonies, Taiwan and South Korea, which tended to reflect the strengths and weaknesses of the Japanese system.

The connection between academic research and frontier innovation in the United States has already been the subject of a large literature (Mansfield, 1991; Rosenberg and Nelson, 1994; Zucker et al., 1998). We will not review that literature here, but will simply note that nations that lack universities where faculty members and graduate students are pursuing frontier science appear to face a profound disadvantage in the global competition for venture capital investment and the global race to implement radical new inventions. Conversely, the ascendancy of American universities in global science exerts a profound gravitational pull on global flows of early-stage venture capital investment. Concentrations of early stage venture capital activity outside the United States, in places like Western Europe or Israel, typically cluster around prestigious universities. We argue that the weakness of the university sector in Japan, South Korea, and Taiwan has limited the ability of firms located in these countries – especially start-up firms – to access frontier knowledge and techniques.

Intellectual Property Policy, Pro-Incrementalist Bias, and Pro-Incumbent Bias

Prewar Japan imported the patent system of Bismarck-era Germany in the 19th century, and this German model remained the basis of Japanese intellectual property policy throughout the 20th century. Notably, the Japanese system, like the German one, provided for a limited degree of IP protection for even modest, incremental inventions. These "petty patents" – known as utility models – do not exist in the American patent system. On the other hand, until the late 1990s, the Japanese system was arguably not as well engineered to protect fundamental innovations as well as the German system on which it was based. Throughout the postwar era into the late 1980s, Japanese firms were constrained to include only one claim per patent application. In addition, Japanese courts had no "doctrine of equivalents," under which minor variations on a patented invention could be ruled as violating the original patent. So, in order to protect their inventions, firms were required to file a large number of patent applications describing all the features and possible permutations of their patents. Even a well-financed large firm would often fail to effectively exclude rivals from using a closely related technology, since Japanese courts interpreted claims broadly when determining whether an invention was sufficiently novel to merit a patent application, but they interpreted them narrowly when it came to determining patent infringement (Sakakibara and Branstetter, 2001). Japan also required the publication of patent applications before patents were granted, and it allowed interested parties to contest the granting of a patent prior to issue. All of this made it difficult and expensive to assemble a Japanese patent portfolio that could effectively exclude rivals from exploiting a fundamental new innovation, and this was especially true for smaller "start-up" firms.

Even firms that had strong patent portfolios found that they did not constitute a very effective weapon against infringement. Until the 1990s, there were almost no cases of Japanese courts awarding large damages to inventors whose intellectual property was infringed. Small firms with brilliant ideas but limited financial resources found themselves in an especially disadvantageous position under this patent system. Even for larger firms, the weakness and narrowness of the Japanese patent system undermined its usefulness as a mechanism for appropriating the returns to R&D. Instead, firms in postwar Japan tended to rely on their manufacturing capabilities, brand names, and quickness to market as the primary mechanisms for appropriating the returns to R&D investment. This, in turn, reinforced the Japanese tendency to focus on incremental innovation, process engineering, and inventions that were close to commercialization.

Japan Exchange Rate Policy and Pro-Incrementalist Bias

As Japan began to reintegrate into the postwar global economy, it found itself possessing a high degree of human capital, an impressive range of manufacturing skill and – given the extent of wartime devastation – much lower factor costs than Western rivals. Japan's economy quickly recovered, but low inflation, rapid productivity convergence, and Japan's participation in the postwar system of fixed exchange rates and limited capital flows kept Japan's cost of production relatively low when measured in Western currencies, especially the U.S. dollar (Ito, 1992). Despite episodic protectionism, Japan generally found open Western markets for its ever-expanding range of export goods. As Japan's real and nominal exchange rates increasingly failed to fully reflect its degree of productivity convergence with the Western world, Japanese firms found that if they could close the quality gap with their Western rivals, they would often outcompete them in the marketplace, thanks to their cost advantage.

As we have already seen, a weak base of fundamental science in Japanese universities and a patent system that offered inadequate protection for significant inventions already worked to bias Japanese firms away from fundamental innovation and towards incremental innovation. A long period of operation under an increasingly undervalued exchange rate reinforced this tendency. As Japanese firms invested in refining the efficiency of their Japanese production base, grinding out incremental improvements in manufacturing efficiency and quality, a consistently favorable exchange rate reinforced the competitiveness of that production base, rewarding these investments. Even after the collapse of the Bretton Woods system in the early 1970s, Japanese macroeconomic policymakers' concerns about the impact of yen appreciation led the Japanese government to take every opportunity to limit exchange rate appreciation, while periods of depreciation were generally welcomed. In real terms, the yen remained much cheaper in the 1970s and 1980s than it was for much of the 1990s.

Labor Market Institutions and Pro-Incumbent Bias

An extensive literature exists on the "lifetime employment" system that developed in postwar Japan (Ito, 1992). While some Western analyses sought to connect the emergence of this system to traditional Japanese cultural values and practices, the reality is that the system was a postwar arrangement designed to buy labor peace and protect firms' investments in worker skills. Prewar labor markets were characterized by high degrees of labor turnover and ruthless mass layoffs in the face of downturns and recessions. Efforts to form labor unions were ruthlessly suppressed by the imperial government. When Japan was occupied by the New Deal Administration of Harry Truman, strong protections for labor were hardwired into the postwar legal regime and union organizers – many of them radicalized by long prison terms and harsh treatment – were set free. Japan's labor movement sought to make up for lost time, and Japanese postwar industrialists viewed frequent strikes and work stoppages as a threat to their prosperity in a growing economy. Since the industrialists could no longer rely on the secret policy to suppress union organizers, they now had to bargain with them. An additional concern for industrialists was the realization that the industrial structure of Japan was changing rapidly, Japan's educational institutions were not keeping up with these changes, and effective adaption would necessitate an extensive investment in workers' skills – but firm's needed some mechanism to ensure that workers trained at the expense of company A would not just "jump ship" and put those skills to work for company B.

The bargain hammered out between industrialists and the Japanese labor movement in the 1950s resulted in what became known in English as the lifetime employment system (Ito, 1992). This system only applied to full-time, male employees in Japan's largest companies. And it only covered these employees through an early "retirement" age, which forced many workers to seek secondary employment after they were "retired" as early as in their 50s. Still, the system offered blue collar and white collar employees a strong guarantee of employment security, a labor representative's presence on the corporate management team, and profit sharing for all rank-and-file workers, not just senior executives. In return, though, workers were expected to complete their entire career in the firm in which they started. Firms generally promoted from within, wages depended heavily on tenure within the firm, and any worker who moved from one firm to another had to start out at the bottom of the wage scale.

While this system helped insure workers against economic shocks, it also drastically limited the flow of workers across firm and industry boundaries. Furthermore, the fact that only the top firms really honored this system had the effect of concentrating Japan's top talent in the leading enterprises and drastically limited the appeal of "start-ups" and "new entrants." Any Japanese executive at a leading firm who left to join a (risky) start-up would have to start all over at the bottom of the wage scale in the (likely) event that the start-up failed.

Financial Market Policy Choices, Pro-Incrementalist Bias, and Pro-Incumbent Bias

Japan's industrial evolution required not just access to skilled workers but also access to capital. An extensive literature describes the evolution of Japan's highly regulated postwar capital markets (Hoshi and Patrick, 2000; Hoshi and Kashyap, 2001), and the way that it evolved from wartime capital controls and industrial planning. For the purposes of the current argument, it will be sufficient to note that postwar regulatory barriers sharply limited the issuance of stock and bonds into the 1980s. For most firms, it was simply not practical to obtain significant quantities of external financing through direct sales of equity or bonds to investors. Instead, Japan's postwar financial system was dominated by a highly regulated banking cartel. This cartel operated under deposit and commercial lending rates that were set by government fiat rather than the supply and demand of financial capital. To obtain access to sufficient quantities of external finance in Japan's booming postwar economy, most large Japanese manufacturing firms forged a close connection with one of the main commercial banks – one often consummated by the sale of equity to a so-called "main bank" and the presence of bank officials on the corporate board of directors. Academic appraisals of this system generally conclude that it provided large amounts of financial capital to a limited set of "insider" firms at reasonably low interest rates (Hoshi, Kashyap, and Scharfstein, 1991; Hoshi and Kashyap, 2001). On the other hand, new entrants that arose outside of this so-called main bank system were at a significant disadvantage in the postwar race for external finance. Stringent regulation of the stock and bond markets effectively precluded the rise of robust venture capital markets or junk bond markets, as in the U.S., which incentivized investment in highly risky projects and new ventures by offering up very high interest rates to investors with sufficiently high risk tolerance. Financial deregulation in Japan proceeded in stages, with important moves in the early 1980s that enabled blue chip manufacturers to decouple from their historical bank relationships in favor of direct stock and equity issuance. But other important stages of the financial deregulation process were delayed until the 1990s and 2000s, by which time the Japanese economy had been stuck in slow growth for more than a decade (Hoshi and Patrick, 2000). Japan's legacy of heavy financial regulation may have played an underappreciated role in the struggle of its innovation system – a topic to which we shall return.

Japanese Competition Policy and Pro-Incumbent Bias

Japan's postwar development is often mischaracterized as "export-led." In fact, a decomposition of the sources of macroeconomic expansion quickly refutes this idea – Japan did not start running consistent and significant current account surpluses until the 1970s, and these surpluses remained limited in size relative to GDP until the first half of the 1980s. Instead, Japanese growth was driven predominantly by domestic sources of demand, so the openness of Japanese product markets exerted a profound influence on Japan's postwar industrial evolution. In light of that fact, it is interesting to note that one of the first legal changes the Japanese government instituted when it regained full sovereignty from its American occupiers was to substantially weaken the Anti Monopoly Law it inherited from the New Deal government of Harry Truman (Eads and Yamamura, 1987; Uekusa, 1987; Weinstein, 1995). The Japanese government regularly created legal cartels when industries experienced cyclical downturns, with the government itself playing the role of cartel enforcer (Uekusa, 1987; Weinstein, 1995). The market was effectively divided up the basis of pre-recession market shares, a policy that – to the extent that it worked -- powerfully benefitted established incumbents. The postwar Japanese distribution system was fragmented and dominated by small scale, "Mom and Pop" style stores. Such small establishments were not in a position to resist efforts by much larger manufacturers to tie them up into exclusive dealing contracts that would have been a violation of American antitrust law. The difficulty of breaking into the local-incumbent-dominated Japanese retail/distribution system would be regularly cited by foreign sellers of consumer goods in the 1980s as one of the most important barriers to their expansion in the Japanese market (Flath, 2002). Of course, this was an even greater barrier to entry and mobility for Japanese entrants into the market for consumer goods. The market for industrial goods, at least in key sectors like the automotive industry, was dominated by Japan's so-called keiretsu networks. An extensive literature describes Japan's complicated systems of interfirm alliances, and a full treatment of these is beyond the scope of this article (Gerlach, 1992). The main point to be stressed here is that strong alliances between traditional business partners in Japan also constituted a barrier to entry for both foreign and domestic firms. Under U.S. antitrust law, at least some of these ties and connections could have been attacked as unlawful restraints on trade. Under Japan's relatively weak antitrust law and practice, there was no such recourse for would-be entrants. Finally, in much of Japan's service economy (in postwar Japan, as elsewhere, the majority of postwar GDP), heavy handed government regulation strictly restricted entry and competition well into the 1980s. This was true in banking, securities trading, insurance, construction, telecommunications, intercity freight transportation, and airlines. As happens throughout the industrialized world, regulatory capture meant that the regulatory agencies tended to limit competition and ensure rents for incumbents, at the expense of consumers and would-be entrants.

The Decline in Japanese Industrial Research Productivity

To the best of our knowledge, we are among the first researchers to make the argument that the current shortcomings of the Japanese innovation system stem, in part, from features of the postwar policy regime that encouraged a pro-incrementalist and pro-incumbent bias. However, we are certainly not the first researchers to discuss the shortcomings of the Japanese innovation system. These shortcomings were increasingly evident to industrialists and policymakers within Japan by the mid-1990s. At the beginning of the 1990s, Japanese stock and real estate markets plunged, inducing a significant and persistent macroeconomic slowdown. Five years into the decade, the internet revolution was well underway in the United States, but Japanese firms were conspicuously absent from the set of firms – many of them new entrants – that were introducing a fundamental set of new innovations in IT. Even in less technologically dynamic sectors like autos, Japanese firms seemed to be losing ground in the 1990s. Increasingly, Japanese industrialists and policymakers embraced the notion that the innovation system that had served Japan so well during the era of catching up to the industrial West was not able to generate the more significant innovations that Japan's status as an advanced industrial nation on the technology frontier now required.

Recognition of these shortcomings, and of the need for a fundamental reform of the nation's innovation system, was clearly articulated in the so-called Science and Technology Basic Law, implemented in late 1995. In the years since the passage of this law, Japan has continued to strengthen its IP system (Sakakibara and Branstetter, 2001), it has fundamentally reformed its national university system (Amano and Poole, 2005), and undertaken numerous attempts to support the development of a Japanese venture capital market. These reforms specific to Japan's national innovation system complemented efforts to liberalize Japanese financial markets. The so-called "big bang" financial liberalization of the mid-1990s (key components of which were not fully completed until the 2000s) included steps designed to make it easier for innovative firms to motivate employees with stock options, as in the United States. An effort was also made to make Japan's product markets more open to competition. Restrictions on large-scale retailers in Japan, which had the side effect of keeping the balance of power between manufacturers and distributers in favor of the former, were significantly relaxed in the 1990s, and the importance of keiretsu linkages between suppliers and assemblers in key industries declined. Unfortunately, these reforms have not brought about a significant and enduring acceleration of Japanese productivity growth at the macro level, nor have they revived the fortunes of Japan's once-vaunted electronics industry.

Microeconometric research by economists validates the conventional wisdom that Japanese industrial research productivity declined in the 1990s. Branstetter and Nakamura (2003) used firm-level data on patenting and R&D spending to document an apparent decline in R&D productivity outside the electronics sector, and a sharp slowdown in the growth rate of R&D productivity within that sector. They did so by collecting data on R&D inputs and outputs at the level of the firm to estimate a simple "knowledge production function." Following Jaffe (1986) and Sakakibara and Branstetter (2001), Branstetter and Nakamura model innovation for the *i*th firm as a function of its R&D input, such that

$$N_{it} = R_{it}^{\beta}\Phi_{it} \qquad (1)$$

where

$$\Phi_{it} = e^{\sum_c \delta_c D_{ic}} e^{\sum_t \gamma_t T_t} e^{u_i} \quad (2)$$

Here the δ's can be thought of as exogenous differences in the "technological opportunity" across *c* different technological fields that are stable across time. The γ's can be thought of as changes in the overall effectiveness of the R&D process, common to all fields, over time. These latter coefficients are crucial to Branstetter and Nakamura's analysis. They want to observe whether, conditional on R&D spending, the overall effectiveness of private sector innovative activity is increasing, decreasing, or unchanging over time. Their inference concerning this is based on the pattern revealed by the γ coefficients.

Taking the logs of both sides of (2) yields the following log-linear equation

$$n_{it} = \beta r_{it} + \sum_t \gamma_t T_t + \sum_c \delta_c D_{ic} + \varepsilon_{it} \quad (3)$$

In (3), n_{it} is innovation, r_{it} is the firm's own R&D investment, the *D*'s are dummy variables to control for differences in the propensity to generate new knowledge across technological fields (indicated by the subscript *c*) , the T's are year dummies, and ε is an error term. Branstetter and Nakamura proxy innovation with patents and present the patterns sketched out by their year dummies as a statistical description of trends in the productivity of industrial R&D. The key results reported in Branstetter and Nakamura (2003) are reproduced in Figure 1 and represent the differential trends estimated for manufacturing firms outside of electronics and for firms inside that sector. Figure 1 shows an apparent decline in R&D productivity for Japanese firms outside of electronics that sets in during the early 1990s. The electronics sector seems to continue to increase its R&D productivity in the early-to-mid 1990s, but appears to suffer a decline later in that decade.

Branstetter and Nakamura link this decline to important structural changes in the nature of private sector R&D within Japan. As Japanese firms reached the natural limits of what could be accomplished with an R&D strategy that was focused on adaptation of foreign technology, a focus on process and incremental innovation, and a convergence with a technology frontier rather than an effort to go beyond it, these firms were forced to change their approach to R&D. They had to build larger central R&D laboratories with more ambitious agendas, and they had to focus on more fundamental, more science-based research. Unfortunately, the elements of the Japanese innovation system that were needed to make this new emphasis successful were themselves still underdeveloped, and, at least initially, the structural changes within Japanese firms have been unable to forestall a decline, or, at best, a stagnation, in research productivity.

Arora, Branstetter, and Drev (2013) provide a more recent comparative analysis of the productivity of industrial R&D in the electronics and information technology sectors of Japan and the United States. These authors advance the argument that the locus of global technological opportunity in electronics shifted from hardware to software – increasingly, improvements in the performance and functionality of IT equipment was driven by software innovation rather than the creation of new or better physical electronic components or systems of components. The authors use patent data to provide evidence of this global shift, then show that the relative decline in the productivity of Japanese firms' R&D investments appeared to be concentrated in parts of the electronics/IT sector where software was significantly more important. These authors demonstrate this relative decline in Japanese industrial R&D productivity using patent data and data on the stock market's evaluation of the impact of R&D spending on firm profitability, and show that firms that more effectively shifted their R&D strategy to take advantage of these software-based opportunities were more productive by both measures. The authors point out that the U.S. was able to access a large number of software engineers through its immigration system, and suggest that access to human resources was an important component of American firm's ability to out-innovate their Japanese rivals as the shift to software-focused R&D intensified. This line of reasoning points to a complementarity between national innovation systems and immigration systems. Unfortunately, Japan's immigration system remains largely unreformed. The Arora, Branstetter, and Drev focus only on electronics/IT and their sample of firms includes only U.S. and Japan-based firms. Branstetter, Drev, and Kwon (2016) broaden the industry focus to incorporate autos and auto parts, medical devices, pharmaceuticals, and aerospace, and they include European and Korean firms in their sample. These authors conclude that the shift to more software-based innovation extends well beyond the conventional boundaries of IT, and that it is likely to gather momentum over the next decade. National innovation systems that lack the agility to redeploy resources to take advantage of these new opportunities are likely to be at a disadvantage.

3. The Korean Innovation System in Comparative Perspective

South Korea spent roughly the first half of the 20th century as a colony of the Japanese Empire. Shortly after achieving its independence, it was devastated by the civil war on the Korean peninsula. Economic upheaval and political turmoil followed in the wake of this bloody conflict. The Korean economic miracle really dates from the mid-1960s military coup that brought General Park Chung-Hee to power. For better and for worse, General Park left a stamp on Korea's political economy that endures to the present day (Yi, 2006).

The Legacy of Park Chung-Hee: Pro-Incumbent Bias in South Korea

Some of the scholarship seeking to explain the Japanese "miracle economy" of the 1970s and 1980s focused on the role of Japanese industrial policy bureaucrats, but the reality is that the democratic constitution imposed on postwar Japan by the occupying authorities placed tight constraints on the scale and direction of industrial policy (Calder, 1988). A free press, open elections, and the requirement that government policy be based on laws passed by the Diet meant that Japanese industrial policymakers had to stay in line with popular opinion. Businesses were free to lobby against industrial policies with which they disagreed, often successfully. The Japanese financial landscape was dominated by privately owned banks that were subject to government influence, but not direct government control. Administrative authority over the Japanese was divided among fiercely independent agencies who competed with one another for influence and financial resources, and often worked to undermine the power and authority of the other agencies. Careful studies by Japanese and Western scholars reveal that far more government largesse was expended on Japan's less competitive industries (agriculture, mining, etc.) than its emerging industries – because that's what would keep Japan's long-ruling Liberal Democratic Party in office, and, at the end of the day, Japan's politicians were more interested in reelection than the industrial policy visions of MITI bureaucrats. Saxonhouse (1983), Calder (1988), and Beason and Weinstein (1996) all convincing empirical critiques of the notion that industrial policy was the primary driver of changes in Japanese industrial structure.

In striking contrast, General Park faced few constraints on his exercise of authority. He was not answerable to a constitution, an opposition, or a free press. Park was not limited by bureaucratic infighting, because all bureaucracies were directly answerable to him. One of Park's first economic policy moves was to nationalize Korea's banks – a move that would have been unthinkable in postwar

Japan -- making its financial markets an arm of state policy. The general thus quickly acquired a degree of authority over the allocation of resources in the Korean economy of which Japan's industrial policy bureaucrats could have only dreamed. He did not hesitate to use it (Clifford, 1997).

A complete description of South Korean economic policy during the presidencies of Park and his autocratic successor, Chun Do Hwan, are beyond the scope of this essay. The breathtakingly rapid growth of Korea during this period – a rate of growth even more rapid than that of Japan – attests to the fact that the policy mix pursued during this period had many positive elements. But one of the most important legacies of this period was the rise of the chaebol – Korea's industrial conglomerates (Joh, 2014). Park used his command over the resources of the Korean economy to build up national champions that could eventually compete on a global stage. In practice, this meant awarding low-cost capital, scarce foreign exchange, and industrial licenses to conglomerates headed by business leaders with whom he became closely allied (Clifford, 1997). Of course, awarding special privileges to a small number of favored enterprises tilts the playing field against all others. The legacy of Park's industrial favoritism left South Korea with a degree of industrial concentration that was the highest in the industrial world. This high degree of concentration persisted into the 1990s, despite several rounds of efforts by more democratically oriented governments to reduce the economic power of the chaebol groups. On the eve of the devastating financial crisis of 1997, the Top 4 chaebol groups controlled more than 75% of Korean industrial assets, accounted for two-thirds of gross sales, generated more than 40% of Korean exports, and accounted for most of Korean manufacturing employment (Economist, 1995). In the language of the previous section, this is pro-incumbent bias taken to an extreme level.

Within Korea, public opinion turned against the chaebol groups in the late 1990s; some Koreans placed part of the blame for the economic crisis that gripped the nation in late 1997 on the "reckless" borrowing and investing of these large groups.[7] Other influential commentators criticized the concentration of economic power within the large groups and the collusive ties between these groups and several successive South Korean governments. In addition, the gradual political liberalization and democratization in Korea encouraged politicians to reform the chaebol (Haggard et al, 2003). Since the crisis of 1997, nearly every new South Korean president has promised to check the power of the chaebol groups and encourage entrepreneurship. The results of these repeated campaigns have been disappointing. Figures 2 and 3 depict the concentration of U.S. patent grants and R&D spending, respectively, across Korean firms. A shockingly high fraction of both is concentrated in a single chaebol -- the Samsung Group.

South Koreans refer to their nation, somewhat ruefully, as the Republic of Samsung (Pesek, 2015). In addition to its dominance of South Korean patenting and R&D expenditure, the Samsung Group accounts for a high fraction of South Korean exports and represents a disproportionate fraction of the value of the South Korean stock exchange.[8] When the former chairman, Lee Kun-Hee was convicted of financial wrongdoing and tax evasion, he was pardoned by former president Lee Myung-Bak. The justification offered up to the public was that Samsung was so important to the South Korean economy that it would be destabilizing to jail the head of the firm, even if he were guilty of crimes. Lee Kun-Hee

[7] Twenty percent of all outstanding debt and 75% of all new borrowing in 1998 went to the largest five Chaebol groups -- Samsung, LG, Daewoo, Hyundai and SK (*Economist*, 1999).

[8] The Samsung Group accounts for more than one fifth of the value of the South Korean stock exchange and about 15% to 20% of the GDP of South Korea (LA Times, 2016; CNN, 2017).

has since transferred effective control of Samsung to his son, Lee Jae-Yong. The younger Lee is currently facing charges of bribing Lee Myung-Bak's successor, (and General Park's daughter), Park Gyeun-Hye, who was the first South Korean president to be impeached and removed from office. It remains to be seen whether Korean courts will hold the son to account any more than they did his father. The tangled state of South Korean politics attests to the extreme degree of pro-incumbent bias that Park's industrial policies generated.

Policies and Pro-Incremental Bias in South Korea

South Korea inherited (and built on) the strengths of the Japanese education system. The nation's preeminent university, Seoul National University, was founded as a core part of the Imperial university system. Although the Japanese colonial administration took steps to reserve the highest echelons of Korean commercial, administrative, and academic management for Japanese, the Japanese left Korea a relatively strong educational foundation upon which later governments could build. Once Park took over, the Korean educational system expanded in reach and quality even more rapidly than did the educational system of its former colonial master. Younger Koreans are now the most highly educated people in the industrial world, and Korean students regularly outperform Japanese students on the sorts of internationally comparable standardized tests in which Japanese students regularly outperform Americans (OECD, 2016). Even the Japanese cram school industry has a counterpart in South Korea with an even tighter grip on the lives of its adolescents (Clifford, 1997).

But South Korea also inherited the weaknesses of the Japanese educational system. Like their Japanese counterparts, South Korea's elite universities are better known for the intensity with which high school students compete for admission than for the quality of research or even instruction taking place on their campuses. The same institutional neglect of graduate education, lack of research funding, unwillingness on the part of the education ministry or the universities to concentrate research resources in the hands of innovative scholars rather than senior scholars, and indifference to immigrants limited the research capabilities of South Korean universities. [9] While leading chaebol can set up R&D facilities in Silicon Valley, the weakness of Korean universities drastically limits the access of South Korean start-ups to world class faculty entrepreneurs and graduate students capable of translating laboratory breakthroughs into new products and services.

South Korea inherited the Japanese patent system, and, even after independence, the evolution of the Korean system followed that of Japan's. A long period of weak and narrow protection with indifferent enforcement by courts yielded to stronger patents and enforcement, with reform beginning in the 1980s and patent practices converging to Western standards in the 1990s (La Croix and Kawaura, 1996). Nevertheless, the persistence of weak protection during Korea's high growth period may have reinforced a pro-incrementalist bias in Korea, as it did in Japan.

The evolution of Korean exchange rates and factor prices may have played an even stronger role in shaping South Korea's technological history. Data on the domestic and foreign patents awarded to Korean inventors reveal a sharp trend break in the 1980s. Prior to the mid-1980s, South Korean firms received few domestic patents and almost none from international patent agencies like the U.S. Patent and Trademark Office. After the mid-1980s, the number of international patents granted to South

[9] Only one university from South Korea is on the list of "Top 200 Universities in the World". Retrieved from http://www.4icu.org/top-universities-world/

Korean firms exploded, seemingly marking a surprisingly sudden transition by South Korean firms from imitators to innovators. Work by South Korean economists notes that this patent explosion is broadly coincident in time with the first stages of significant patent reform in South Korea, and these scholars argue that domestic patent reform increased the incentives for R&D. However, research by the current authors (Branstetter and Kwon, 2016) suggests a different interpretation. Careful examination of firm-level patenting and R&D data reveals little immediate growth in chemicals and pharmaceutical patenting, even though this was the technological domain where domestic patent law strengthened the most. In contrast, the rapid expansion of R&D and patenting was actually concentrated in exporting firms for which foreign markets were more important than the domestic market potentially affected by the change in Korean patent law. Furthermore, the increase in patenting and R&D was concentrated in firms whose exports overlapped with those of Japanese rivals.

Branstetter and Kwon (2016) point out that the mid-1980s also saw a sharp change in relative exchange rates of the yen and the won. The yen appreciated sharply against the U.S. dollar after 1985. The won, still pegged to the dollar, effectively depreciated sharply against the yen. Korea-based producers suddenly acquired a large cost advantage over Japanese rivals. By investing in process engineering and other efforts to close the quality gap vis-à-vis Japanese firms, they stood to outsell their rivals in the U.S. and Western Europe. It was the tantalizing prospect of outselling Japanese firms in the world's largest markets, rather than marginally better patent protection in the small South Korea market, that induced a South Korean R&D and patenting explosion.

Readers will note the parallels between South Korea in the 1980s underpricing Japanese rivals and the earlier instances of Japanese firms in the 1970s and early 1980s undercutting American and European rivals. With cheaper factor costs and a favorable exchange rate, South Korean firms could do to Japan what Japan had done to the industrial West. Throughout the 1990s, low cost Korean producers of commodity semiconductor products like DRAM chips were edging out their Japanese rivals in global markets.[10] By the end of the decade, Korean firms were decisively in the lead, and the once vaunted Japanese semiconductor industry was a shadow of its former self (Cho et al, 1998). Japanese firms whose R&D investment strategies had been predicated on their retaining a cost advantage vis-à-vis foreign competitors were increasingly "squeezed" between the rising quality and manufacturing capability of lower cost Asian nations, like South Korea, and the persistently superior product innovation capabilities of their American rivals (Lee, 2013). Indeed, sometimes Japanese firms were competing against both at the same time. American firms struggling to compete with lower cost Japanese rivals began offshoring production to lower cost Asian countries (McKendrick et al., 2000). Early pioneers of this business strategy employed South Korean and Taiwanese firms as contract manufacturers, effectively marrying American brand names and product innovation with low Asian production costs. As educational levels rose elsewhere in the region and advanced manufacturing capabilities diffused to even lower-cost production sites in Southeast Asia and coastal China, production moved there.

The strength of the Korean won ebbed and flowed over the next two decades, with the financial crisis of 1997-1998 leading to a collapse in the value of the won, a long period of relative won weakness, and a revival of South Korean firms' innovation strategies built around relatively low production costs, scale, and strength in process engineering. However, as Chinese manufacturing capabilities grew, it was

[10] In 1993, Samsung produced more DRAM chips than any other firm. In the same year, Hyundai and LG (formerly Goldstar Electron) ranked ninth and tenth on the list of top global DRAM producers (Cho et al, 1998).

increasingly difficult for Korean production sites to compete on price with those based in a country at a fundamentally lower level of economic development. In the 2000s, Korean firms were increasingly subjected to the same kind of "squeeze" that they had helped place on their Japanese rivals in the prior decade (Lee, 2013).

Samsung's prominence in the global smartphone industry is perhaps emblematic of the strengths and weaknesses of South Korea's innovation system. Shortly after the introduction of the iPhone, a revolutionary innovation by Apple, Samsung introduced a very similar product based on the Android operating system and web platform created by Google. The similarities between Samsung's product and Apple's product were so great that they sparked a global round of patent infringement lawsuits by Apple. In the end, these lawsuits did not result in damage judgments large enough to displace Samsung from the market, and Samsung's lower priced products were able to sell in large volumes around the world, boosting Samsung's profits (CNN.com, 2016; Cnet.com, 2015).

Samsung's global market share remains high in terms of handsets sold, but Samsung's share of the global profits earned in smartphones has declined over the three years ending in 2016.[11] Other Asia-based electronics firms began manufacturing even cheaper smartphones, also based on the open Android system. These lower cost firms took market share away from Samsung, which had to respond by cutting prices, since Samsung was offering little the way of product innovation that lower cost Asian rivals could not quickly and closely match.[12] As it turned out, the real innovation that made Samsung phones so attractive – the Android platform – was not Samsung's innovation, but Google's. Google maximized its revenues by offering the platform to as many manufacturers as possible, including low-cost Chinese producers like Huawei, Oppo, and Xiaomi. Press reports in early 2017 suggest that Apple earned at least 80% of total global smartphone profits in 2016. Samsung sells more handsets, but its much less innovative products command much thinner margins (Koreaherald.com, 2017; The Wall Street Journal.com, 2015). The other major revenue driver for Samsung is manufacture of commodity components like DRAM chips. South Korea's innovative strengths appear to be solidly concentrated on the "incremental" side of the spectrum and overwhelmingly concentrated in a small number of chaebol groups whose future is uncertain (IMF, 2014).

We provide confirmation of this concentration from South Korean equity markets. Since the late 1960s (Brainard and Tobin, 1968; Tobin, 1969), Tobin's Q has been widely used to measure the relationship between a firm's market value and its book value. The value of Tobin's Q is affected by a firm's tangible capital and its intangible capital. A firm's intangible capital includes its accumulated stock of technological knowledge. Griliches (1981) estimated this knowledge stock with a cumulated, discounted sum of R&D expenditures, in the same way that the earlier literature had created measures of physical capital stock from a cumulated, discounted sum of investment expenditures. Following Griliches' seminal work, hundreds of academic papers in a variety of industry and national contexts have used a firm's R&D stock as a measure of its intangible capital in order to investigate its relationship with market value.

Following previous work, we assume an additively separable linear specification (Griliches, 1981; Hall

[11] Samsung's share of global smartphone shipments decreased after 2013. However, the share was still over 20% in 2016 (Statistia.com, Retrieved from https://www.statista.com/statistics/271492/global-market-share-held-by-leading-smartphone-vendors/).

[12] The market shares of Chinese phone makers such as Huawei, Xiaomi, OPPO and Vivo have been increasing. Fortune.com, Retrieved from http://fortune.com/2017/01/24/china-smartphones-oppo-vivo-huawei-xiaomi/

and Kim, 2000).[13] Let V_{it} and A_{it} be the market value and the replacement cost of tangible assets of firm i at time t, respectively. Then the relationship between the two variables can be written as follows:

$$V_{it}(A,K) = q_t(A_{it} + \gamma_t K_{it})^{\sigma_t} \tag{4}$$

where K_{it} represents the replacement cost of the firm's stock of knowledge, typically measured by stocks of R&D expenditures, q_t represents the average market valuation coefficient of the firm's total assets, γ_t is the shadow value of the firm's technological knowledge measuring the firm's private returns to R&D, and σ_t determines returns to scale. Following standard practice in the literature, we transform the above equation by taking natural logarithms (e.g. Hall and Oriani, 2006) as follows:

$$ln\, V_{it} = ln\, q_t + \sigma_t\, ln\, A_{it} + \sigma_t ln\,(1 + \frac{\gamma_t K_{it}}{A_{it}}) \tag{5}$$

By assuming σ_t equals one (constant returns to scale) and subtracting $ln\, A_{it}$ on both sides, we can obtain the following equation:

$$ln(V_{it}/A_{it}) = ln\, q_t + ln\,(1 + \frac{\gamma_t K_{it}}{A_{it}}) \tag{6}$$

Finally, we define Tobin's Q as the ratio of the market value to the replacement cost of tangible assets and rewrite the equation as follows:

$$ln(Q_{it}) = ln\, q_t + ln\,[1 + \gamma_t\left(\frac{K_{it}}{A_{it}}\right)] \tag{7}$$

Following Hall and Kim (2000) and Arora, Branstetter, and Drev (2013), we estimate equation (7) using a nonlinear least squares (NLS) approach. Equipped with this methodological tool, we can explore the hypothesis that South Korean engineering and research talent is disproportionately concentrated in a handful of chaebol firms. We do this by running equation (7) on a variety of subsamples of publicly traded Korean firms, where we first include all firms, then selectively include or omit top chaebol-affiliated firms. The results are provided in Tables 2 and 3. Table 2 draws upon equity market data from 2007-2016. Table 3 omits the first two years as a robustness check, on the grounds that global financial uncertainty in 2007-2008 may cloud the inference that could be drawn from those years. As it turns out, both tables deliver a broadly consistent message, which can be read directly from the estimates of γ obtained for different subsamples. The stock market's evaluation of the profitability of R&D spending is much higher for the top chaebol-affiliated firms than it is for the whole sample, and this is especially true for the Samsung group. Aggregating over the years 2009-2016, the South Korean equity market values the R&D investment of the Samsung group some 4.36 times as much as it values the R&D investment of other South Korean firms. More broadly, the R&D investment of the top 30 chaebol firms is valued at a 171% premium over the rest of the market. This is fully consistent with the conventional wisdom that the chaebols in general, and Samsung in particular, have managed to hire a disproportionate share of Korea's technical and engineering talent.[14]

4. The Taiwanese Innovation System in Comparative Perspective

[13] Our notation follows Hall and Kim (2000).

[14] In results not reported here for reasons of space, we estimate patent production functions, and show that R&D productivity, as measured by (citation-adjusted) counts of patent per R&D dollar, is much higher within chaebol-affiliated firms, and it is especially high within firms in the Samsung group, though these differentials are generally not as extreme as those indicated by our Tobin's Q regressions. These results are available from the authors upon request.

Like Korea, Taiwan was a colony of the Japanese Empire from 1895 until the defeat of Imperial Japan in 1945. While brutal, exploitative, and authoritarian in many ways, Japanese colonial rule was markedly less harsh in Taiwan than in Korea. The Japanese left Taiwan with the physical and institutional infrastructure of a modern economy. When it was ceded to Chiang Kai-Shek's Republic of China by the Allied Powers at the end of the Second World War, it was the richest province in the nation by a large margin. Initially welcomed by the Taiwanese, Chiang's army and provincial government quickly demonstrated a remarkable combination of corruption, brutality, and incompetence. A popular uprising against mainland authority in 1947 was brutally suppressed, and when Chiang Kai-Shek relocated his Nationalist government to Taiwan in 1949, he presided over an authoritarian regime characterized by martial law, systematic oppression of any political dissent, and a concentration of economic policymaking authority in his own hands. Like his contemporary, Park Chung-hee, Chiang Kai-Shek possessed almost unlimited power to remake the political economy of Taiwan in accordance with his vision. When he died in 1975, power devolved to his son, Chiang Ching-kuo.

Like South Korea, Taiwan inherited an educational system that downplayed research and graduate education and an intellectual property system that offered, at best, narrow protection that was weakly enforced. Like South Korea, Taiwan's much lower factor prices fostered an orientation toward process-oriented, cost-reduction, incremental R&D, and, like South Korea, Taiwan faced an important moment of opportunity in the mid-1980s, when the sharp appreciation of the Japanese yen gifted Taiwanese producers with the opportunity to undercut their traditional Japanese rivals in the world's most important export markets. As in the case of South Korean firms, Taiwanese firms responded to this opportunity with a surge of investment in R&D, a surge of international patents, and an export boom. But many of the forces channeling innovative effort into an incrementalist direction were as present in Taiwan as in South Korea.

However, the directions in which the Chiang dynasty moved Taiwan differed in important ways from that of Park's South Korea. First, Chiang Kai-Shek's economic planners came to believe that the devastating bouts of inflation that wracked the Chinese mainland were one of the chief reasons his Nationalist Party (Kuo Min Tang or KMT) lost the Chinese civil war to the Communists. Mindful of repeating this fatal error, the technocrats in charge of monetary and financial policy adopted the so-called "high interest rate" policy (Wade, 1990). This meant that the formal banking system charged sufficiently high interest rates to keep inflationary pressure under control. Incidentally, this meant that Taiwanese savers were rewarded for placing funds in the financial system. This, in turn, implied that savings were high (generally equal – or more than equal to – national investment), Taiwan tended to run current account surpluses, even early in its postwar history, and the nation avoided the burden of foreign debt that plagued South Korea in the aftermath of the oil crises of the 1970s and ultimately triggered the financial crisis of 1997. Because all firms, even large ones favored by the government-run banking system, paid relatively high interest rates, the financial playing field was never tilted in the direction of favored conglomerates to the same extent as in South Korea. Taiwanese authorities tolerated the existence of a "gray market" for capital that leaked out of the formal banking system to fund highly profitable enterprises that could not secure formal bank loans. In fact, the authorities monitored the interest rates charged in this gray market, and used it as a benchmark for setting official interest rates. This tolerance allowed smaller firms outside favored corporate groups and sectors to get much easier access to capital than was possible in South Korea under the Park regime. While some degree of official favoritism existed, the government of Taiwan was not nearly as attached to the idea of building national champions as was the government of South Korea, and Taiwan's level of industrial concentration was much lower. As the Taiwanese economy matured, Taiwan came to host a fairly robust domestic venture capital market, in which local firms were able to find sufficient financing to enter even reasonably complex industries. The pro-incumbent bias that was so overwhelming in South Korea was not a significant feature of the economic landscape in Taiwan.

Traditional explanations for this difference in industrial structure have also stressed the entrepreneurial character of Taiwanese managers, and the greater openness and flexibility of Taiwanese markets for electronics products, labor, and capital. The Taiwanese electronics industry, which eventually became the mainstay of Taiwanese manufacturing, is characterized by a very high degree of entry and exit, as is documented in the Aw, Chen, and Roberts (2001), which gives some empirical grounding to the notion of flexible Taiwanese markets. However, we speculate that extensive government involvement in Taiwan, of a different sort than in Korea or Japan, may have also played a role in explaining the differences in industrial structure. In Japan, government subsidization of R&D was quite limited; firms were left to fend for themselves. Only larger enterprises may have had the private resources necessary to make large, risky investments in adopting and modifying (or creating) technology new to the firm and construct the mechanisms that would enable them to appropriate the returns from such investments. In Taiwan, a considerable fraction of the fixed costs of technology adoption and refinement were undertaken by the state, and the results were provided on favorable terms to local firms. As it turns out, these efforts had a strong industry focus and, at least to some extent, a pro-incremental bias.

Taiwan is substantially smaller in geographic size and population than South Korea, so it is perhaps inevitable that its economy would be less diversified than that of its larger neighbor. South Korea has emerged as a significant global player in capital-intensive sectors including autos, shipbuilding, and steel, as well as electronics. In contrast, Taiwan's exports and industrial structure are more concentrated in electronics and IT. While this concentration reflects, to some extent, the natural response of entrepreneurs to market opportunities, it also reflects the emphasis of government industrial policy. The promotion of the electronics industry has been a key priority of the Taiwanese government for decades. Historical studies have emphasized the role of the Industrial Technology Research Institute (ITRI), established in 1973 with the goal of increasing national R&D capacity in technologically advanced sectors. By 1987, one study suggested that this single institute accounted for roughly 25% of the government's total R&D expenditures – a research budget of some U.S. $215 million.[15] This is significant, because, in Taiwan, the government historically accounted for a much larger share of total R&D expenditure than in Japan and a much larger share of total R&D expenditure in Taiwan than private industry. While ITRI's name does not necessarily suggest a focus on electronics, such a focus did exist. In 1974, the Electronic Research and Service Organization (ERSO) was established under ITRI with the responsibility of recruiting foreign partners to develop and commercialize semiconductor fabrication technology. The government was heavily involved in the 1986 formation of the Taiwan Semiconductor Manufacturing Corporation (TSMC), initially a joint venture between Philips and several domestic public and private firms, which has become a highly successful enterprise. ERSO was deeply involved in international technology transfer through the 1980s, often identifying key technologies itself, then sublicensing them to firms.[16] Thus, the Taiwanese government was involved in directing and subsidizing international technology transfer to a substantial degree in this industry, with considerable

[15] See Wade (1990), p. 98.
[16] Wade (1990), pp. 103-107. This practice of sublicensing could mean that our plant-level data fail to capture all "effective" foreign technology purchases.

success.[17] Given the special favors showered on electronics, it is perhaps not surprising that, as Taiwan's industrial structure shifted from labor-intensive goods to more knowledge-intensive goods, it became increasingly concentrated in that sector. Figure 4 reveals the high concentration of Taiwanese firms' U.S. patents in classes associated with electronics hardware.

ITRI/ERSO was not the only source of Taiwanese government largesse for electronics relative to other industries. Taiwanese industrial planners sought to build an electronics-based industrial park south of the capital, Taipei, in Hsinchu, that would become the island's answer to Silicon Valley. First proposed in 1976, the park was initially opened in 1980 and grew rapidly over the next two decades. The government made massive investments in infrastructure, offered special financing deals to new firms moving into the park, and even constructed American-style schools for the families of the expatriate Taiwanese they hoped to lure back to Taiwan from the United States. Fortunately for these recruitment efforts, Taiwan's drive to build out Hsinchu Science Park kicked into high gear just as rising living standards and a shift to democracy were making Taiwan a more attractive place for those expatriates to seek career advancement. As American high-tech companies began to offshore their manufacturing to Asia, reducing demand for in-house manufacturing experts and engineers specialized in process innovation, Taiwanese expatriate engineers facing stagnating career prospects (or layoffs) in the U.S. were increasingly inclined to move "home" to Hsinchu. By the mid-1990s, social scientists and international investors were hailing the success of the park. Saxenian and Hsu (2001) provide a typically positive assessment of the venture in an article tellingly titled "The Silicon Valley-Hsinchu Connection."

As the years have passed, however, the limitations of Hsinchu's success, and of the more general nexus of policies that nurtured Taiwan's high-tech industries, have become more apparent. Relatively small firms that historically relied on ITRI/ERSO to do the "heavy lifting" of identifying key foreign technologies and underwriting assimilative R&D were naturally focused on implementing and refining technologies developed by others, rather than breaking fundamental new ground. The new firms taking shape in Hsinchu were more focused on the efficient contract manufacturing of Silicon Valley designs than the creation of "breakthrough" new products. Like a "helicopter parent" that does too much to position their children for success, the institutions and policies designed to nurture Taiwan's high-tech sector may have inadvertently undermined the incentives for these firms to develop within themselves more fundamental capabilities for research. The industry that took root in Hsinchu was focused on hardware, not software, and incremental, rather than transformative R&D. And as mainland China began to emerge as an alternative site for large-scale manufacturing of sophisticated electronics products, Taiwan's vaunted high-tech sector began to experience fears of a "hollowing out."

Despite government fears of excessive economic dependence on mainland China, the gravitational attraction of China's low costs and apparently limitless quantities of increasingly skilled labor proved irresistible to Taiwanese electronics firms. Government restrictions on cross-straits investment were liberalized at the beginning of the controversial Chen Shui-Bian Administration in Taiwan, and a tidal

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[17] In contrast, the Japanese government began the postwar period with a policy of *limiting* foreign technology purchases, as is shown by Wakasugi (1997). As the Japanese economy developed and the potential benefits of technology imports became clear to government authorities, these limits were progressively relaxed. Wakasugi (1997) has argued that the government allowed only "favored" firms to bid for foreign technology as a way of preventing competition among potential Japanese purchasers from driving up the price of the license. This may have lowered the price of foreign technology for these firms, but it effectively *increased* the price (to infinity) for the firms that were not favored, and, in Wakasugi's view, it is unlikely that this intervention was welfare-enhancing.

wave of investment ensured. Branstetter, Chen, and Glennon (2017) offer a careful dissection of the impact of this relocation of manufacturing on the R&D of Taiwanese firms in the technological domains related to the products and components that were offshored – finding a statistically robust negative effect. Taiwan's trade flows to and from China first rose sharply, then fell substantially as an increasingly large fraction of the entire value chain moved to China. Taiwan's leading contract manufacturing firms have managed to stay one step ahead of their "indigenous" Chinese competitors on the mainland, but the Taiwanese economy has slowed sharply from the go-go 1990s, incomes have stagnated, and the notion that Hsinchu Science Park is going to become a real analog to Silicon Valley seems increasingly at variance with the facts on the ground. Like Japan and South Korea, Taiwan seems increasingly squeezed between Silicon Valley and China. American firms continue to generate a stream of fundamental innovations Taiwan cannot match. China continues to offer a mix of lower costs and rising skills that Taiwanese manufactures cannot resist. For Taiwan, the increasingly tight economic embrace of the Chinese mainland raises existential political questions about the future of the island as a *de facto* independent state.

5. The Economic Theory of Radical Innovation and the Consequences of Pro-Incumbent and Pro-Incrementalist Bias

An impressively robust stream of empirical research demonstrates that the outcomes of R&D are characterized by highly skewed returns, with the preponderance of private profit and social value emerging from a small minority of inventions of outsized importance (Harhoff, Scherer, and Vopel, 2003; Scherer and Harhoff, 2000). Of course, healthy innovation systems require a balance of radical and incremental innovation. The theory of general purpose technologies recognizes that even transformative new innovations (like electricity) require incremental inventions to adapt them to their full range of potential uses (Helpman and Trajtenberg, 1995). Fundamentally new ideas rarely come into the marketplace fully formed. The majority of innovative activity in any economy at any point in time is incremental (Harhoff, Scherer, and Vopel, 2003). So, the reader should not construe the arguments presented here as a denigration of incremental innovation. But it is also true that incremental invention within a tightly circumscribed technological paradigm generally runs into diminishing returns. By bringing fundamentally new ideas into the marketplace, radical innovation can bring to fore a new technological paradigm in which the (initial) returns to refinement and improvement are high. This is an old idea in the economics of innovation, arguably first given mathematical form by Evenson and Kislev (1976) and revived in the context of a modern growth model by Kortum (1997).

In this section, we will define radical innovation as the kind of technological breakthroughs that result in fundamental transformation of existing products, new product categories, or even whole new industries. The existing economic theory of "radical" technological change suggests that the birth of new industries is often abetted by the rapid entry of large numbers of new firms, all trying new approaches to a new technology. Finding ones way through a rapidly evolving and uncertain technological landscape requires running many experiments. Empirical evidence and theory suggest that established incumbents will often resist investment in experiments that render existing business models obsolete.

In management theory, the classic reference is the book, *The Innovator's Dilemma,* by Clayton Christensen (1997). In this enormously influential book, Christensen points out that successful incumbents face a double bind when seeking to engage in radical innovation. Successful incumbents typically arrive at their position after years, even decades, of successful refinement of existing products and business practices. Precisely because organizational capabilities and business practices are so closely tied to the existing state-of-the-art, the firm's engineers may be poorly equipped to succeed in a radically different approach to the same product class or service. Given this reality, the chances of success in radical innovation are low. Furthermore, even if these firms "succeed" in coming up with a fundamental innovation that works better than their existing model, their success will undermine the existing business model that has brought the firm profits and prestige. It is even possible that firms will "succeed" in disrupting their business model, but then fail to retain the lead in the ensuing race to refine the new products and techniques. For this reason, radical innovation is generally resisted by incumbents and championed by new entrants.

Christensen put forward a plausible story, and motivated it with anecdotes drawn from the disk drive industry and other industries, but he stopped short of producing either a formal economic model of radical innovation or strong empirical evidence in favor of his idea.[18] However, there is an economic theory of the process by which whole new industries come into being, and the classic paper was authored by the late Steven Klepper (1996). This paper set forth a theory of industry evolution that starts with the rapid entry of a number of new firms, offering competing business and product models. Eventually, a small number of these entrants hit upon business and product models that succeed in garnering a significant share of sales in the emergent industry. Upon achieving this success, the small number of especially successful entrants invests in cost-reducing, process R&D to cement the ascendancy of their new products. Paradoxically, this successful ascendancy of a small number of dominant firms crowds out further radical experimentation, and leads to a shakeout, with large scale exit and an eventual equilibrium with a much smaller set of players and a much-reduced range of product models and designs. At this point, the pace of technological change in the industry tends to slow substantially, and the focus of innovation shifts from radical experimentation with new designs to incremental improvements of existing designs.

Historical and econometric investigations into the history of a number of new industries – autos, tires, televisions, lasers, and semiconductors – reveal common patterns consistent with this theory (Klepper, 2010; Buenstorf and Klepper, 2009). In all cases, rapid progress to practical and usable designs and business models requires the rapid entry of large numbers of new firms. Economic research highlights, in particular, the importance of labor mobility into and among these new firms. One common pattern in nearly all new industries is the early emergence of an important set of leading firms, which then "seed" the industry with a large number of "spinoffs." At an early stage in the history of a new industry, a small number of firms establish themselves as market leaders, and they attract a large number of especially talented pioneers who want to make their fortunes in this new domain. Eventually, disagreements arise within the management team regarding which new business models and product designs to pursue. Managers convinced that the "seed" firm is pursuing the wrong model leave to start their own firms. The experimentation undertaken by these spin-offs tends to have a particularly significant impact on the subsequent evolution of the new industry.

In the past few decades, the process of new industry creation in the United States has taken on some characteristics not shared by the earlier historic episodes discussed in the work of Klepper and his coauthors. Recent waves of industry creation in the life sciences and information technology have emerged in response to new breakthroughs at the scientific frontier that create the potential for the emergence of new industries (Zucker et al., 1998). Several waves of firm entry in biotechnology have been sparked by the emergence of new sciences, such as genetic engineering and bioinformatics.

[18] Igami (2017) provides empirical evidence that validates Christensen's hypothesis in his original setting, the disk drive industry.

Similarly, in information technology, the rise of analytics and machine learning has prompted recent waves of firm formation and startup activity. New industry creation in the 21st century appears to be more science-based and more closely connected to frontier university research than in the past. The development of successful products based on these discoveries often requires "human bridges" – entrepreneurial faculty and graduate students conversant in the new technology who can partner with experienced managers and engineers to embed the new ideas in successful firms and products (Agrawal and Henderson, 2003). The local absence of first-rate universities with adequate stocks of faculty entrepreneurs and mobile graduate students schooled at the technological frontier are therefore a growing liability in some technical domains. Success also requires that experienced R&D managers and engineers be willing to leave the comfort and security of an established firm with established routines and take a risk on something that is new and unproven.

The odds are always against the success of any one entrepreneurial venture, but, in the United States, strong protection for intellectual property rights and the willingness of American courts to levy significant damages or even issue injunctions when inventions are infringed by financially stronger manufactures has helped level the playing field to some extent (Hochberg et al., 2017; Jaffe and Lerner, 2003). Strong IP rights also create a legal environment in which holders of patents protecting important innovations can bargain with contract manufacturers and other business partners without fear of expropriation (Hall and Ziedonis, 2001). That raises the chances of success by loosening the historical requirement that firms excel in both product and process innovation. America's open capital markets allow new start-ups to offer investors the prospects of outsized returns to compensate them for high risk, further upping the odds of success. America's historically open product markets for consumer and industrial goods enable new innovators to compete with established sellers. In America's fluid labor markets for top managers and engineers, past association with an ambitious start-up – even if it fails – is viewed as a useful career experience. By contrast, the repeated waves of downsizing and chronic competitive woes of traditional American manufacturers in more technologically quiescent industries lessens the appeal of spending an entire career as an engineer or manager in a more established firm. For talented young American managers and engineers, the balance of risks and rewards tilts toward smaller firms in technologically dynamic sectors, and this induces such individuals to join the flood of talent that a 21st century wave of new firm formation in a technologically dynamic sector requires. Frontier research continues to point to the importance of new firms as channels for the most fundamental, socially beneficial innovations (Acemoglu, Akcigit, Bloom, and Kerr, 2013). In America, these firms receive the flows of talent and financing, the access to downstream markets, and the IP protection they need to grow and thrive.

For talented young Japanese and Korean engineers, the balance of risks has long tilted in the opposite direction. Keiretsu (or chaebol) linkages, weak antitrust policy, a heavily regulated service sector, and a fragmented and vertically foreclosed distribution system have made it hard for new entrants to get traction in the product markets of Japan or South Korea. The weakness of Japanese and Korean research universities means that small firms have had limited access to faculty entrepreneurs or mobile graduate students. A history of weak IP rights has led to an overwhelming concentration of technical talent in a limited number of established firms, most of whom are pursuing incrementalist business strategies. Few foreigners can name more than one truly new Japanese or Korean firm that has ascended to the upper tier of corporate success in recent years.

In the 1990s and 2000s, governments in both countries have tried to adopt a more "Silicon Valley" approach to innovation. Both countries have tried to strengthen their patent systems, upgrade their universities, promote venture capital investment, and level the playing field for start-up firms.[19] But these efforts at reform were generally adopted in the context of rapidly aging populations, slowing growth, and rising concern over the declining efficacy of the traditional R&D system. The conspicuous absence of past success in grafting a "Silicon Valley" model onto Japanese and Korean innovation systems undermines the willingness of investors to support such efforts with their dollars or talented young engineers to support such efforts with their careers. As we noted in the previous section, Taiwan took a different path – one that was more consciously inspired by and imitative of the Silicon Valley model than was the case in South Korea and Japan, and Taiwanese economic planners were clearly less guilty of a pro-incumbent bias in their policymaking that was true in Korea or Japan. But if Taiwan's policymakers managed to avoid an excessive focus on a small number of local firms, they proved unable to resist what may turn out to be an excessive focus on a particular sector – IT hardware. And the way Taiwan created its own answer to Silicon Valley appears to have reinforced the incrementalist inclinations of Taiwanese firms' approach to R&D. Like Korea and Japan, Taiwan has tried to reform its R&D system in response to the increasingly apparent limitations of the system it created. Like Japan and Korea, Taiwan has had, at best, limited success. It is hard to avoid the conclusion that, had they adopted these reforms during their high-growth eras, South Korea, Taiwan, and Japan might have had a better chance of success.

6. Alternative Explanations for an Innovation Slowdown in Northeast Asia

This paper has argued that Japan, South Korea, and Taiwan have all suffered, to varying degrees, from a decline in their R&D productivity, because the national innovation systems engineered to meet the circumstances of their high growth periods have proven less effective as these economies have reached economic maturity. Our argument has also stressed the degree to which government policies created or reinforced pro-incrementalist and pro-incumbent biases in these countries that have made the necessary transition in these innovation systems more difficult to achieve.

Are there other plausible explanations for the evident slowdown in R&D productivity that are largely disconnected from past policy choices? This section briefly considers two: the aging of these three societies' populations and the apparent shift in the locus of technological opportunity from "hardware" to "software." Conventional wisdom and Silicon Valley's tendency to lionize the technological contributions of young entrepreneurs might suggest that a nation's technological progress rests disproportionately on the efforts of younger scientists and engineers. As the number of students in Japan's universities has dropped sharply in recent years (a decline of roughly 20% in the decade from 2000 to 2010), this could raise concerns that the shrinking cohorts of younger scientists and engineers graduating from these universities and entering Japanese firms would have undermined technological progress, even if the structure of Japan's national innovation system was ideally suited to its changing circumstances. A similar demographic shift has led to declines in university enrollment in South Korea and Taiwan, raising the possibility that the slowdown common to all three countries has its roots in a

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[19] The challenges facing such efforts are clear, and progress to date has been limited. Based on the fierceness of the competition among domestic students to obtain admission, the top universities in Japan, South Korea, and Taiwan are easily the peers (or near-peers) of America's Ivy League Institutions. But Japan's top university was ranked 43rd in the world by one of the widely read indices of comparative university quality. Korea's top university was ranked 85th according to the same index, and well below the top 100 according to others. Taiwan's top university was ranked 195th in the world. Interestingly, all of these institutions were originally created as part of the Japanese imperial university system during the prewar era.

common demographic shift.[20] Indeed, some scholars have sought to attribute part of America's productivity slowdown over the past decade to the effects of an aging population. Karahan et al. (2017) find a statistical link between population aging and the widely observed decline in firm formation rates.

With some of the lowest birthrates in the advanced industrial world, there is no question that Japan, Taiwan, and South Korea will all face significant challenges in adapting to slower population growth and the fiscal challenge of supporting a large cohort of retirees with the labor of smaller generations of workers. However, recent research calls into question the impact of these shifts on innovation and research productivity. Azoulay et al. (2017) link U.S. census data on firm formation to data on tax returns and business owners, creating a comprehensive data window through which to examine the distribution of high-impact entrepreneurial activity across worker age groups. In a surprising refutation of the conventional wisdom that high impact entrepreneurship is a young person's game, they find that the probability of founding a "high-impact" firm tends to peak at the ages 45-59. Despite a rapid aging of its population, Japan's median age is still only 46.1 – the same as Germany, a nation which is enjoying something of an innovation renaissance (Breznitz, 2014). In addition, Guzman and Stern (2016) present compelling evidence that the widely noted decline in firm formation has not significantly affected the founding and growth of America's most impactful start-ups. Instead, the decline in firm formation seems to principally reflect a decline in the founding of marginal firms that were destined to grow slowly, innovate little, and make only modest contributions to overall growth and industrial development. The formation of high-impact firms proceeds apace. Indeed, it has accelerated in recent years, in spite of adverse demographic shifts. This strengthens the argument that demographic shifts, *per se*, are an insufficient explanation of the apparent slowdown in East Asian innovation.

A more compelling alternative argument may be the one explored in Arora, Branstetter, and Drev (2013) and Branstetter, Drew, and Kwon (2016): the shift from hardware- to software-centered innovation. As already noted in this paper, prior research documents a significant shift across virtually the entire industry space toward greater reliance on software, rather than traditional mechanical, electrical, or chemical engineering, as a way of enhancing product performance. To exploit the opportunities created by this shift, firms need to develop a broad range of software innovation capabilities, and this can be challenging in countries that graduate relatively few computer scientists and software engineers and have limited pathways through which skilled foreigners can immigrate. This line of reasoning suggests that national innovation systems that had insufficiently invested in software expertise and skills prior to this shift in the locus of technological opportunity would have been disadvantaged, even if they were well calibrated in every other dimension and did not also suffer from a pro-incrementalist and pro-incumbent bias.

Given that both authors have invested considerable intellectual energy in building the case that the shift to software-centric innovation constitutes a consequential shift in the locus of inventive opportunity, it is difficult for us to discount the point advanced in the previous paragraph. Yet, at another level, it actually reinforces our broader argument. One of the most important features one would wish in the national innovation system of an advanced economy at the technological frontier is the ability to create, recognize, and exploit fundamental shifts that open up new domains for more applied research. The U.S. innovation system has not only played a disproportionate role in driving the software revolution – it has also played a dominant role in biotechnology-related innovations that are transforming medicine, and in the creation of the "fracking" technologies that have upended the world of hydrocarbon energy

[20] Reports cited in the popular press suggest that Taiwanese university student enrollment could decline by 30% in the coming decade and South Korean enrollment could decline by as much as 40% incoming years.

extraction. Start-up enterprises have played a disproportionately important role in driving these important developments. The struggles in Japan, Taiwan, and South Korea to adapt to these changes, as well as the software revolution, point to the relative rigidity of their once highly praised innovation systems. At some point, the current furor over artificial intelligence and machine learning is likely to die out, and some other domain will emerge as the new locus of technological opportunity. The agility and flexibility displayed by the American system over the long run provides grounds for hope – even confidence – that American firms will be at the center of these new developments, even if we cannot forecast what they might be. Does anyone harbor the same optimism about Japanese firms?

7. Lessons for the Rest of Asia – and the World

At one level, it seems churlish to question the success of Japan, South Korea, and Taiwan. These economies have successfully climbed the development ladder from its lower levels to its uppermost rungs. They are among the most R&D intensive economies on the planet. They generate an impressive number of international patents per capita. They remain important manufacturers and exporters of the kinds of products generally associated with high-tech dynamism. They exceed nearly all other nations in terms of educational attainment and skill acquisition within their populations. In fact, along most usual metrics of innovative output, these three nations outshine nearly all member states of the OECD. Any growth analyst that grades "on the curve" would have to give these three Northeast Asian economies full marks.

And yet, when we measure these nations by their own past performance, one cannot help but be struck by the degree to which they have each fallen short of what might have been reasonably expected a decade or two ago. As recent research by the IMF has shown, Japan's overall total factor productivity level relative to the United States has actually *declined* substantially over the past twenty years, even as it has become a much more R&D-intensive economy than the U.S. South Korea's level of productivity relative to the U.S. has essentially not changed in the past 20 years – it remains stuck at around 60% of the U.S. aggregate TFP level – in spite of South Korea's emergence as the most R&D intensive nation in the OECD. All three nations face the specter of aging and shrinking populations, stagnating real incomes, and slow growth amid a conspicuous absence of the kind of fundamental innovation we might have expected from a set of wealthy nations whose innovation systems had reached full economic maturity. Israel provides a galling counter example of an even smaller (and, in some ways, poorer) state whose innovation system nevertheless appears to be generating much more ambitious innovations via a mechanism that seems much more in tune with the Silicon Valley model than exists in East Asia. Israel has more firms listed on the NASDAQ than Japan, South Korea, and Taiwan put together. Intel recently spent more than $15 billion purchasing the machine vision technology of an Israeli start-up. When was the last time a young Japanese, South Korean, or Taiwanese start-up firm received such attention? Given the important role high-tech American entrepreneurs of East Asian descent have played in the most fundamental innovations emerging from Silicon Valley, it is hard to escape the conclusion that the national innovation systems of Japan, South Korea, and Taiwan have failed to achieve their full potential. Somehow, these systems have not succeeded in moving beyond the incremental approach to invention that was their hallmark during their years of rapid growth. At a time when the entire industrial world seems stuck in a persistent period of slower productivity growth, despite the best efforts of Silicon Valley, this disappointing failure may have global ramifications.

The economic literature on national innovation systems stresses the degree to which the elements within this system co-evolve to fit one another, making fundamental change within the system increasingly hard as the system matures. Germany and the United States have both been at the technological frontier in science-related industries for more than a century. Each country possesses elements of its innovation system that the other has tried to copy. Yet, multiple attempts by American policymakers to adopt German-style apprenticeship systems or set up organizations like Germany's Fraunhofer Institutes have failed. Likewise, Germany's efforts to graft the Silicon Valley model onto its own innovation system have yielded, at best, limited success.

Given this dynamic, the authors of the current paper look with some misgivings on the technology policies being adopted in mainland China. Much has been made in the media of the success of Chinese firms in the ecommerce space. Yet, this success owes much to a conscious policy of digital protectionism that has created a large domestic market inside China from which the foreign digital innovators are effectively excluded, allowing indigenous Chinese firms to copy (or modify only slightly) Western business models and technology. The government of Xi Jinping seems quite determined to script out for the nation the pathway of future economic development, and maintains a chokehold on financial development that prevents capital from flowing to the most novel entrepreneurs. The powerful apparatus of the state reinforces the role of large incumbents, many of them state-owned, state-connected, or state-influenced. Intellectual property rights are, at best, imperfectly enforced. And a long period of deliberate intervention to keep China's exchange rate artificially cheap has clearly influenced the allocation of innovative resources in China along the spectrum of "incremental versus fundamental." The degree to which this is true is reflected in the paradox of China's great wall of patents. China now generates more domestic patent applications and grants than any other nation, yet only a tiny fraction of these are patented anywhere in the world outside of China. In response to the bidding of its emperor, China generates a tsunami of patents that even the inventors do not consider to be worth patenting elsewhere in the world – a powerful indictment of Chinese invention quality under the current model. If anything, China's current rulers appear to be pursuing the industrial policies of their East Asian predecessors with even more enthusiasm than the nations that pioneered them. There is little doubt that these policies have met with some success, in the short run.

But aging industrial nations are increasingly being forced to recognize the fact that economic development is a very long game. China's immense size means that the achievable technological trajectory of the human race will depend, to some extent, on how well China plays that long game. Will the immense human resources of the Middle Kingdom be mobilized within a system that can deploy them to create the sorts of fundamental innovations humanity will need to sustain healthy growth in the 21st century and beyond? Will the "Chinese Dream" create a true peer of Silicon Valley, with transformative innovations that will support rising living standards long after the authors of the current paper lie in the dust? Or it is possible that future economic historians will view China as a nation that repeated the mistakes of its East Asian predecessors, and emerged with an innovation system that shared their limitations? We will not attempt even a provisional answer to this question. But the future technological trajectory of Asia – and, indeed, the world – likely hinges on that answer.

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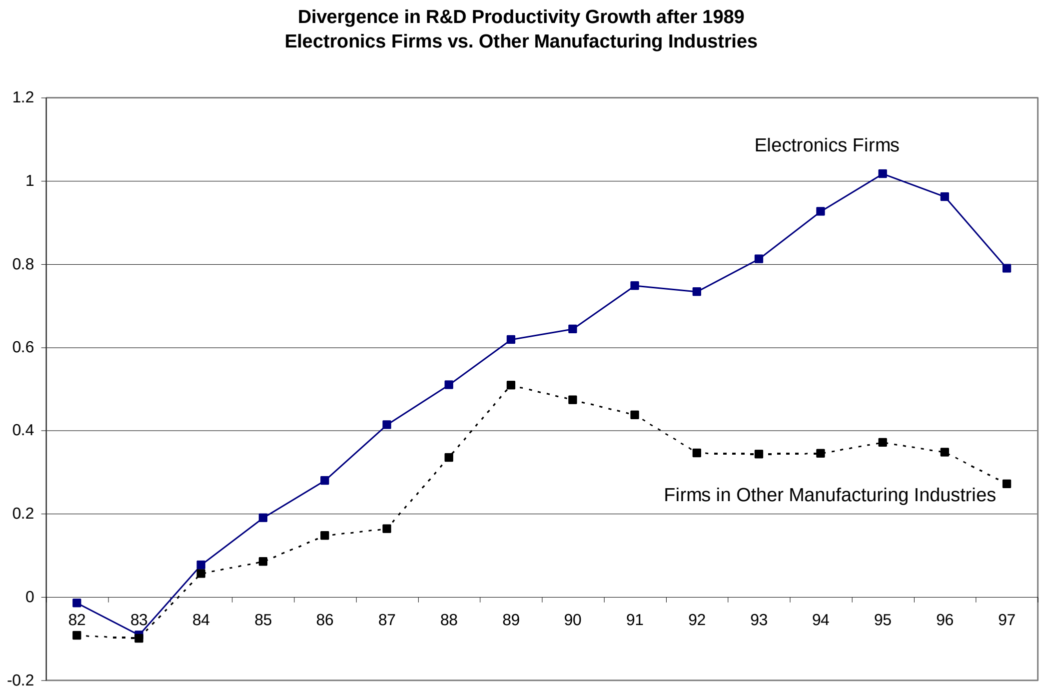
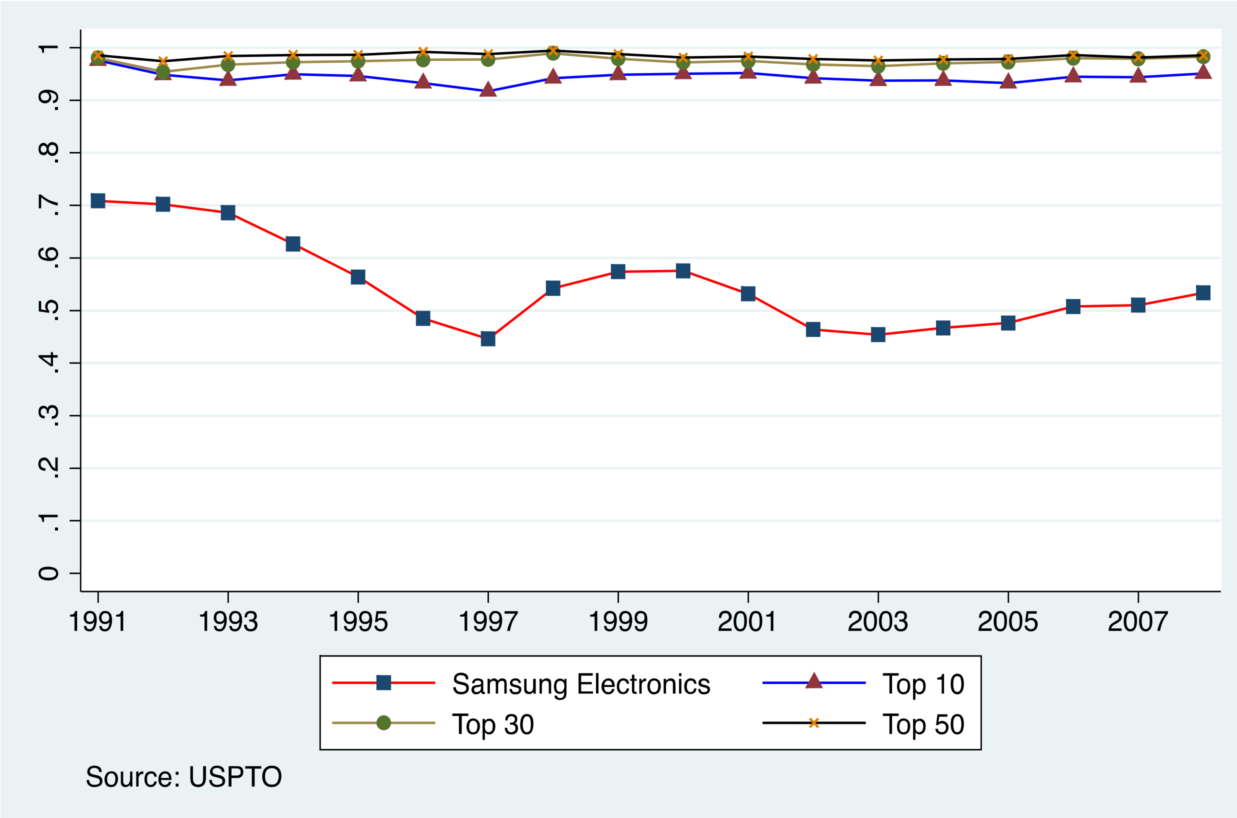
Figure 1: Trends in Japanese R&D Productivity Growth



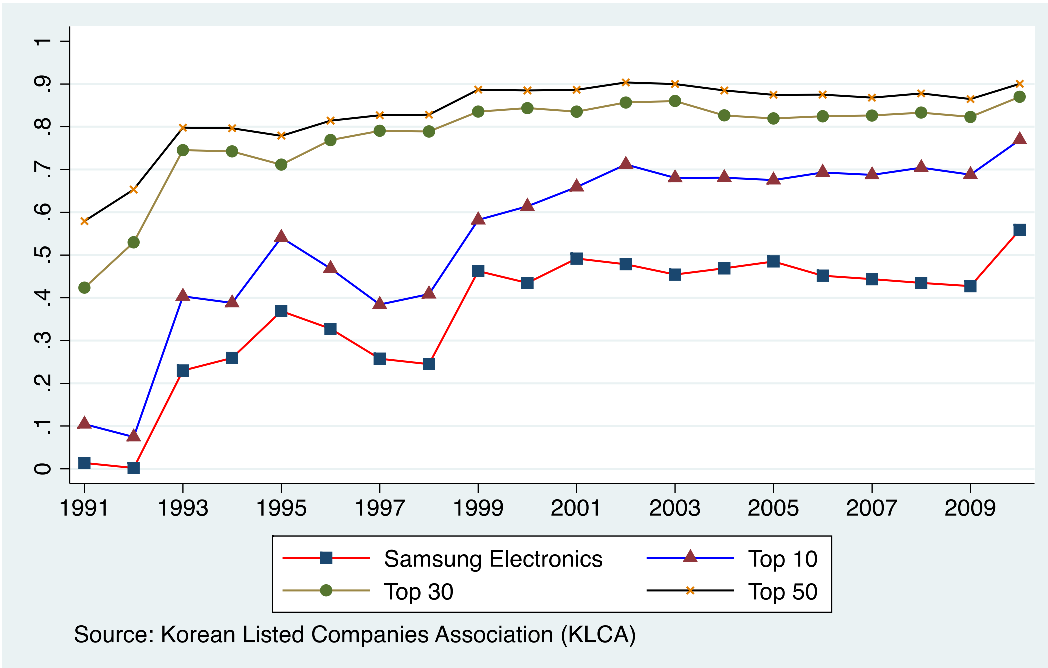
Source: Branstetter and Nakamura (2003). This figure graphs the estimated coefficients on year dummy variables obtained by regression of a "patent production function," as described in equation (3) in the text. Equation (3) is separately estimated for firms inside and outside of the electronics industry, and the time dummy coefficients from these separate regressions are superimposed onto one another. The dependent variable is U.S. patent grants dated by year of patent application. Independent variables include firm-level R&D spending (taken from firm-level survey data reported in various issues of Toyo Keizai's Kaisha Shiki Ho) and industry dummy variables (to control for time-invariant differences across industries in the propensity to patent). The results are qualitative robust to the use of data on Japanese patent applications, to the weighting of U.S. patent grants by forward citations, and to the use of firm fixed effects. See Branstetter and Nakamura (2003) for details.

Figure 2: Concentration of U.S. Patent Grants Among South Korean Firms



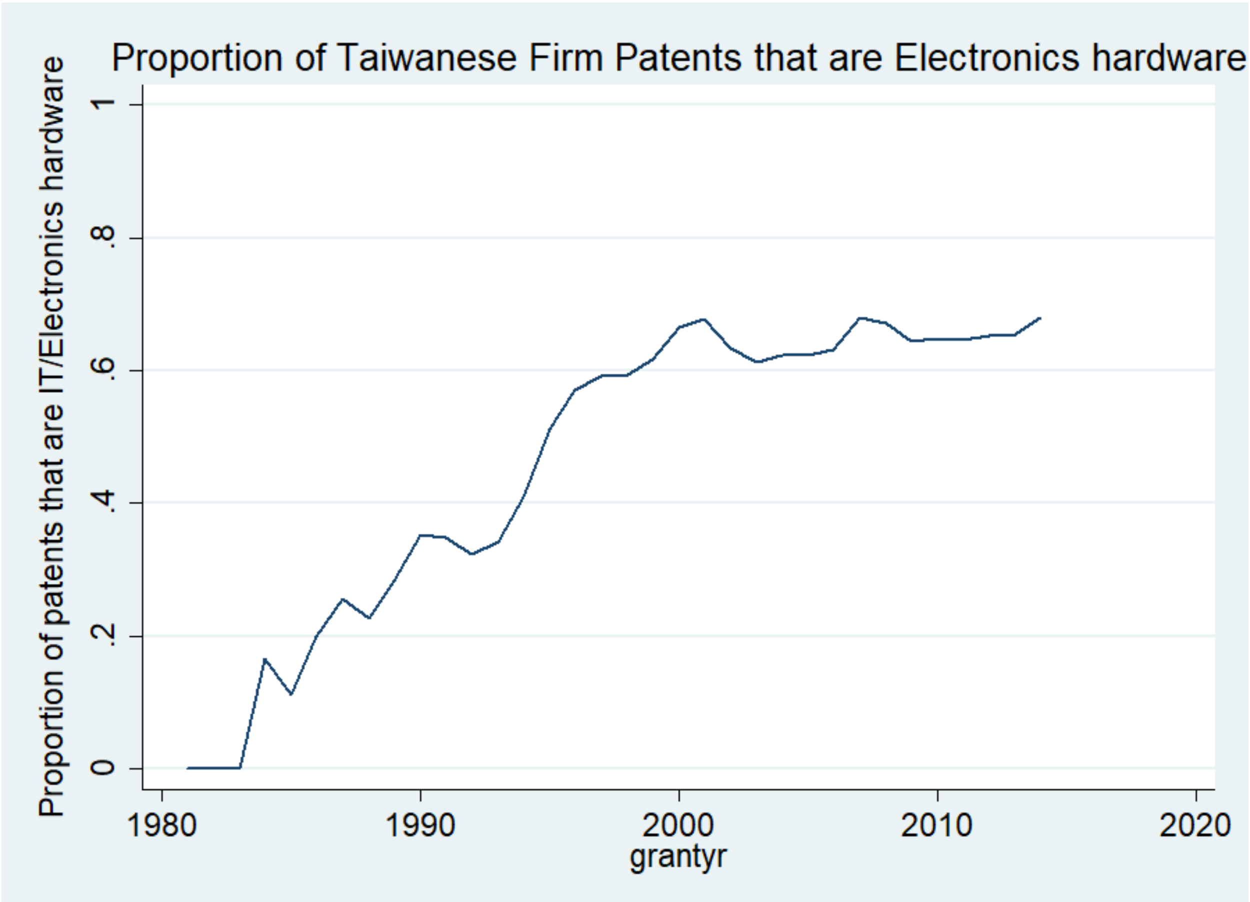
This figure measures the fraction of total U.S. patent grants awarded to South Korean inventors that are accounted for by Samsung Electronics, and by firms affiliated with the top 10, top 30, and top 50 chaebol groups, respectively. Patents are assigned a date based on year of application. South Korean patent data also indicate a significant concentration of patenting in the portfolios of these chaebol firms. Samsung Electronics alone accounts for more than 50% of all U.S. patent grants received by South Korean firms in recent years.

Figure 3: Concentration of R&D Spending Among South Korean Firms



This figure uses data on total R&D expenditure, as reported by the publicly traded firms listed on South Korean equity markets, to calculate the fraction of annual expenditure accounted for by Samsung Electronics, the top 10 chaebol groups, the top 30 chaebol groups, and the top 50 chaebol groups. In 2010, Samsung Electronics accounted for more than 50% of total R&D expenditure reported by these firms. Data are taken from the Korean Listed Companies Association.

Figure 4: Concentration of Taiwanese Patenting in Electronics Hardware



This graph uses data from the U.S. PTO to calculate the fraction of patents awarded to Taiwanese inventors that are in patent classes associated with electronics and IT hardware. Software-related patents are omitted. Since the late 1990s, patents in these classes have accounted for more than 60% of the total. Taiwanese patents and data on Taiwanese R&D spending also point to a strong concentration of activity in the electronics industry (Branstetter and Chen, 2006).

TABLE 1 COMPARISON OF RELATIVE STRENGTHS IN THE JAPANESE AND AMERICAN INNOVATION SYSTEMS

United States	Japan
Basic research	Applied development
Software	Hardware
Fundamental new products	Miniaturization
High-technology systems	Process equipment and technology
New industry creation	Product variety
Advanced development	Process engineering

Source: Henry Riggs, Professor of Industrial Engineering, Stanford University, reproduced from Okimoto and Rohlen, 1988.

Table 2 South Korea's Innovative Resources are Concentrated in Chaebol Firms: Evidence from Tobin's Q Regressions: 2007-2016

lnQ	Full Sample	Only Samsung group	Except Samsung group	Except Samsung Electronics	Only Top 30: Sales	Except Top 30: Sales
RD/Assets	**0.830*** **	**2.323*** **	**0.743*** **	**0.738*** **	**1.350*** **	**0.793** **
	(0.261)	(0.589)	(0.282)	(0.265)	(0.387)	(0.330)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs	762	62	700	752	235	527
Adj R-Squared	0.319	0.697	0.295	0.311	0.527	0.123

This table presents estimates of the stock market's valuation of R&D investment for different groups of South Korean firms, obtained from regression specification (7) in the text. Data are taken from the KLCA database (TS2000 and COINS). Regression estimates suggest that the stock market values R&D undertaken by the Samsung Group far more highly than R&D investment undertaken by other South Korean firms.

Table 3 **South Korea's Innovative Resources are Concentrated in Chaebol Firms: Evidence from Tobin's Q Regressions: 2009-2016**

lnQ	Full Sample	Only Samsung group	Except Samsung group	Except Samsung Electronics	Only Top 30: Sales	Except Top 30: Sales
RD/Assets	**0.793*****	**3.050*****	**0.700****	**0.700****	**1.298*****	**0.759****
	(0.279)	(0.674)	(0.298)	(0.283)	(0.402)	(0.354)
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Number of Obs	602	49	553	594	192	410
Adj R-Squared	0.331	0.744	0.313	0.322	0.530	0.111

This table presents estimates of the stock market's valuation of R&D investment for different groups of South Korean firms, obtained from regression specification (7) in the text. Data are taken from the KLCA database (TS2000 and COINS). Regression estimates suggest that the stock market values R&D undertaken by the Samsung Group nearly four times more than R&D investment undertaken by all firms other than Samsung Group firms. Since the global financial crisis of 2007-2008 roiled equity markets around the world, regression results reported in this table omit data from those years.