Has Japan's Innovative Capacity Declined?[1]

Lee Branstetter
Columbia Business School
and NBER

Yoshiaki Nakamura
Research Institute on Economy, Trade, and Industry

May 29, 2002

[1] (Draft for NBER conference)We thank the conference organizers, the conference participants, Masahiko Aoki, Ashish Arora, Amar Bhide, Hiroyuki Odagiri, David Weinstein, and Akira Goto for extremely helpful comments. We are also grateful to a number of Japanese corporate R&D managers based in Japan and overseas for their candid responses to our questions on Japanese firm R&D activity. By prior agreement, these managers' names must remain confidential. We are grateful to Takuji Saito (Hitotsubashi University) and Masami Imai (University of California, Davis) for excellent research assistance, and to RIETI, the National Science Foundation, and the Columbia Center on Japanese Economy and Business for financial support. All errors remain our own responsibility.

Abstract

This paper examines Japan's R&D performance since the early 1980s using several complementary modes of analysis. First, we examine evidence from aggregate economic statistics concerning changes in Japanese corporate R&D. Second, we analyze comprehensive data on R&D inputs and outputs for a panel of nearly 200 Japanese firms. Microeconometric analysis of this data set allows us to examine where any downturn in R&D activity is concentrated, what Japanese firms are themselves doing to rectify the downturn in performance, and what effects these steps have had to date. Third, we relate the results of interviews with corporate R&D managers and informed industry observers concerning their perceptions of changes in Japanese innovative capacity and the reasons for these changes. We find evidence, at the micro level and the aggregate level, of a slowdown in the growth rate of Japanese research productivity in the 1990s.

I. Introduction

During the 1980s, a major source of Japanese growth – and a major source of concern for Japan's trading partners – was the widely admired innovative capacity of Japanese firms. Over the course of this decade, Japanese firms entered and successfully competed in high-technology industries that had formerly been the preserve of U.S. and European multinationals. Japanese firms' expanding innovative capacity was clearly reflected in aggregate statistics on R&D expenses, patenting, and productivity, all of which showed a steady increase in R&D input and output.[2] Technological leadership in a broad range of critical technologies seemed to be inexorably passing from American to Japanese firms.[3]

This situation changed quite dramatically over the course of the 1990s. R&D spending by the private sector in Japan has stagnated during the course of the *Heisei* recession. Measures of R&D *output* growth in Japan have declined relative to the United States and relative to recent Japanese historical trends. There is also a widespread sense among Japanese R&D managers, industry observers, and government officials that the Japanese approach to technological innovation is no longer working effectively, and fundamental reform of the national innovation system must take place.[4]

The implications of this apparent decline in Japanese innovative capacity are quite serious for Japan's long-run economic prospects. The *Heisei* recession has *not* been driven primarily by technological factors. Rather, the collapse of asset prices, the

---

[2] See Saxonhouse and Okimoto (1987), Arison et. al. (1992), and Mansfield (1988). See also the book length treatment of Goto (1993).

[3] A study by the respected National Academy of Engineering (1987) concluded that Japan was superior to the United States in twenty-five out of thirty-four "critical" technologies.

[4] The *Nihon Keizai Shimbun* published an editorial in September 2000, entitled "Raising the Productivity of R&D," which summarized many of the perceived shortcomings of the Japanese innovation system.

resulting crisis in the banking system, and the inappropriate macroeconomic policy responses of the Japanese government over the last ten years have arguably been the primary cause.[5] However, when normal economic growth resumes in Japan, the maximum rate at which that growth can be sustained will be depend in part on the ability of Japanese firms to develop and deploy new technology. If Japan's innovative capacity is growing at a slower rate than in past decades then this could limit Japan's future prospects.

This paper examines Japan's recent R&D performance using several complementary modes of analysis. First, we examine evidence from aggregate economic statistics concerning changes in Japanese R&D. Second, we analyze comprehensive data on R&D inputs and outputs for a panel of nearly 200 Japanese firms. Microeconometric analysis of this data set allows us to examine where any downturn in R&D activity is concentrated, what Japanese firms are themselves doing to rectify the downturn in performance, and what effects these steps have had to date. Third, we interview several corporate R&D managers at leading Japanese firms – both managers in the central R&D operation in Japan and managers based at Japanese R&D facilities abroad – concerning their perceptions of changes in Japanese innovative capacity and the reasons for these changes.

The main empirical contribution of this paper is to document, at the "micro" level and the aggregate level, a slowdown in Japanese relative innovative performance. We find that after a decade of convergence with the U.S. in terms of R&D inputs and outputs in the 1980s, Japanese and U.S. innovation trends have diverged sharply in the 1990s. Measured in a common currency, real R&D outlays in Japan have grown much more

[5] For recent research which supports this view see Posen (1998).

slowly than in the U.S. The gap in patent output that was closing rapidly in the 1980s began expanding again in the 1990s. Turning to our firm-level data, we find evidence of a slowdown in the growth of R&D productivity in Japan in the 1990s. This slowdown does not affect all firms equally, however. By and large, the research productivity of the electronics industry, broadly defined, has continued to grow in line with the trends of the 1980s and early 1990s. On the other hand, firms outside the electronics industry have performed less well.

Why has Japanese R&D productivity grown more slowly in the 1990s? A full-fledged investigation of this important question is beyond the scope of this paper. However, drawing upon our interviews with Japanese R&D managers and evidence from other economic studies, we are able to present some possible explanations for this striking change. As they have reached the technology frontier, Japanese firms have had to re-orient their R&D efforts from the application and refinement of existing, relatively well-developed technology to the creation of more fundamental breakthroughs. The shortage of Ph.D.-level engineers and the relative weakness of Japanese academic science have inhibited the effectiveness of this more technologically ambitious R&D in Japan. Furthermore, attempts to create large, centralized corporate labs focused on more basic R&D have run into the same problems that large-scale U.S. corporate R&D labs were criticized for in the 1980s, including a lack of focus on the needs of a rapidly evolving marketplace. Finally, the absence of a venture capital industry and the institutions that support start-ups in the U.S. made it more difficult to for established Japanese firms to "partner" in product development with more entrepreneurial and efficient smaller firms.

Having noted these problems, Japanese R&D managers are trying to respond to them. Conversations with Japanese R&D managers revealed several steps Japanese firms are taking to restructure their R&D operations and improve research productivity. This draft presents evidence on the impact of two such steps – the establishment of research facilities abroad and the forging of technology alliances with U.S. firms. We find that both strategies lead to increased flows of technological information to Japanese firms. We also present evidence consistent with the view that these increased flows of knowledge raise overall inventive productivity.

II. Japan's R&D Performance in Comparative Perspective

After nearly a decade of stagnation in Japan, it is sometimes difficult to recall the unease – even fear – that Japan's seemingly unstoppable economic advance over the course of the 1980s once generated among American industrialists and policymakers. To set the stage for our own analysis, it may be worthwhile to review some of the evidence on Japan's expanding technological capability that was generated by the debate over U.S. "competitiveness" and the Japanese "threat."

As the Japanese economy expanded, R&D spending steadily increased. Moreover, the effectiveness with which Japanese firms applied this R&D expenditure to successful generations of useful inventions also seemed to be increasing. Researchers noted that Japanese firms produced more patent applications per R&D dollar than U.S. firms, and that this ratio was not declining, as it seemed to be in the rest of the industrialized world.[6] Scholars familiar with the idiosyncratic features of the Japanese patent system prior to its substantial reform in 1988 were quick to point out that many more patent applications were required to protect the same amount of intellectual

[6] See Okimoto and Saxonhouse (1987) for a discussion of these issues.

property in Japan, and that straightforward comparisons of Japanese and U.S. patent counts were likely to exaggerate Japan's technological prowess.[7]

However, because of the importance of the U.S. market, Japanese firms were also quite aggressive about patenting their inventions in the U.S. as well as in Japan. Over the course of the late 1970s and 1980s, Japanese firms rapidly increased their level of U.S. patenting in absolute numbers and relative to their American counterparts. Given that the two sets of firms were competing under the same patent system with the same set of rules and examiners, this seemed to buttress the case that the Japanese were closing the technological gap with their U.S. rivals.

In addition to these aggregate statistics, careful "micro" studies of Japanese innovation, such as Mansfield (1988), also seemed to suggest that Japan's R&D capacity was formidable, particularly Japanese applied R&D capacity.[8] Furthermore, the comparative analysis of product development in the automobile industry in Japan, Europe, and the United States by Clark and Fujimoto carefully documented Japanese firms' enormous lead over rivals in terms of the resource cost of product development.[9]

However, the picture of expanding relative Japanese technological capability changed substantially in the 1990s. The slow growth of the Japanese economy in that decade was quickly reflected in the aggregate statistics on R&D spending. As shown in Figure 1, real Japanese private sector R&D spending leveled off in the 1990s, declining slightly in the early 1990s before modestly increasing in the late 1990s.[10] In striking

---

7 Again, Okimoto and Saxonhouse (1987) contains a useful discussion of these points.
8 Mansfield's (1988) statistical results suggested that applied R&D expenditure in Japan had a *much* stronger impact on firm-level TFP growth than it did in the United States.
9 For a useful summary of some of the primary results of this research project, see Clark, Fujimoto, and Chew (1987).
10 Posen (2001), arguing that Japanese innovative capacity has been unaffected by the 1990s recession, stresses that the *ratio* of R&D expenditure to GNP has remained high in Japan – in fact, it is higher than in

contrast, U.S. private sector R&D spending grew quite rapidly in real terms in the 1990s, reflecting robust macroeconomic growth and the especially rapid growth of high-technology industries. This difference in the trends in R&D inputs was also reflected in the aggregate statistics on R&D outputs. For instance, the counts of patents taken out by Japanese firms in the United States grew much more slowly after 1990 than they had in the 1980s, whereas the reverse was true for the United States. Figure 2 illustrates this divergence, aggregating across all U.S. patent classes. Throughout the 1980s, one sees rapid growth in U.S. patenting by Japanese firms relative to U.S. inventors. After 1990, the gap between U.S. patent grants to Japanese and American inventors begins growing again.

Figure 3 illustrates a similar pattern of convergence followed by divergence within the cluster of patent classes that are most closely connected to computers and information technologies – what we might refer to as "IT patents." As this figure clearly shows, by the end of the 1980s, Japanese firms had reached a level of patenting in the United States in these patent classes that nearly equaled that of their U.S. counterparts.[11] Over the next 10 years, however, American firms' patenting in these fields exploded, dramatically outstripping the growth in Japanese patents.[12]

Finally, it is important to point out that the decline in patents is not merely seen in the U.S. patent system, which, important though it is, is only one part of the global intellectual property protection system. Figure 4 illustrates recent trends in worldwide

---

the United States. Unfortunately, this reflects the fact that the Japanese economy has scarcely grown over the 1990s.

[11] Posen (2001) stresses that many of the top 10 patenting firms in the United States are Japanese multinationals. Unfortunately, the strong performance of these elite firms is not necessarily representative of the innovative performance of their industries.

[12] Figures 2 and 3 show a dramatic jump in patenting in 1997. This relates to a change in U.S. patent law which brought the U.S. into compliance with the international standard in patent length. The law included a clause which allowed patents filed before a certain date to receive certain procedural advantages.

patent applications by applicants based in the U.S., Japan, and Europe. Obviously, there have been striking increases in the quantity of applications from inventors based in the U.S. and Europe, but not in Japan.

This review of the aggregate evidence suggests that there is something real behind the steadily more insistent concerns being raised in Japan about the Japanese national innovation system and its comparative performance.[13] However, this quick review of the aggregate statistics raises an important question. Is the relative decline in Japanese innovative output simply a function of relative declines in R&D spending, or has there been a slowdown in the growth of Japanese firms' innovative capacity, even after controlling for changes in R&D spending? This question is addressed in the next sections.

III. Japanese Private Sector R&D Productivity: A Micro Analysis

In this section, we utilize data collected on R&D inputs and outputs at the level of the firm to estimate a simple "knowledge production function."[14] Let innovation for the *i*th firm be a function of its R&D input, such that

$$N_{it} = R_{it}^{b}\Phi_{it} \tag{1}$$

where

$$\Phi_{it} = e^{\sum_c d_c D_{ic}} e^{\sum_t g_t T_t} e^{u_i} \tag{2}$$

[13] For a forceful presentation of the view that Japan's relative innovative performance has not changed since the 1980s, see Posen (2001). While we strongly agree with Posen's main point – that Japan's poor macroeconomic performance in the 1990s has little direct connection with the efficiency of its R&D activity – we believe his rather optimistic view of the Japanese innovation system is not consistent with some of the evidence presented in this paper.

[14] We note that the empirical methodology in this section borrows heavily from Branstetter (2001), and the exposition of this section follows that earlier paper quite closely.

Here the d 's can be thought of as exogenous differences in the "technological opportunity" across c different technological fields that are stable across time. The g '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 will be crucial to our analysis. We want to observe whether, conditional on R&D spending, the overall effectiveness of private sector innovative activity is increasing, decreasing, or unchanging over time. Our inference concerning this will be based on the pattern revealed by the g coefficients.

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

$$n_{it} = br_{it} + \sum_t g_t T_t + \sum_c d_c D_{ic} + e_{it} \tag{3}$$

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 e is an error term.

Now we come to a pivotal question: how do we measure innovation? In fact, there are no direct measures of innovation, so tracking "innovation" will require the use of indirect and noisy empirical proxies. If some fraction of new knowledge is patented, such that the number of new patents generated by the ith firm is an exponential function of its new knowledge,

$$P_{it} = e^{\sum_c a_c D_{ic}} e^{x_i} N_{it} \tag{4}$$

then the production of new knowledge can be proxied by examining the generation of new patents. We take the logs of both sides of (4) and substituting into (3), we get

$$p_{it} = br_{it} + \sum_t g_t T_t + \sum_c d_c D_{ic} + m_{it} \tag{5}$$

where p_{it} is the log of the number of new patents and the other variables are as before, except for the error term which is defined below. Note that we can also allow for firm fixed effects, such that there can be time-invariant differences in the propensity to patent among firms within industries. Because firms in our sample do not change their primary industry affiliation over time, the industry effect will "fall out" with the firm fixed effect.

As written, equation (5) suggests that the log of patent counts should be our dependent variable. Because some firms in our sample are observed to take out zero patents in a given year, this creates an obvious problem – one cannot take the log of zero. In the earlier micro "R&D/Patents" literature, it was customary to take the log of the count of patents plus 1, in order to get around this problem. However, this somewhat arbitrary transformation of the dependent variable could bias the results.

Rather than adopt this questionable approach, we have used count data statistical models to conduct our analysis. In particular, we use the fixed effects negative binomial estimator developed by Hausman, Hall, and Griliches (1984), to estimate a version of (5) in which a 0 realization of the dependent variable does not pose any kind of mathematical problem.[15]

To implement this approach, we collected data on the patents granted to Japanese firms in the United States (dated by year of patent application), patents applied for by Japanese firms in Japan, R&D spending, and industry affiliation. Data on U.S. patents come from the NBER patent database. Data on Japanese firm R&D spending come primarily from the annual R&D surveys published by Toyo Keizai in the Japan Company

[15] A sketch derivation of this estimator is provided in a longer version of this paper, available from the authors upon request. For a more complete development, see Hausman, Hall, and Griliches (1984).

Handbook. Data on Japanese firms' patent applications in Japan come from the PATOLIS database.[16]

An immediate question arises as to the representativeness of our sample. In Japan, R&D spending and patenting have historically been highly concentrated in the larger industrial firms, and this pattern has not changed over the past decade. A balanced panel of large industrial firms in the U.S. would become steadily less representative of U.S. patenting over the 1990s because of the rising role of universities and high-tech start-up firms in U.S. inventive activity. In Japan, there is no evidence of a similar shift. Our sample includes most of the leading innovative firms in Japan.[17]

For our purposes, the use of U.S. patents is actually the preferred metric of innovative output. A major patent reform in Japan in 1988 allowed Japanese firms to change the number of claims per patent, making it at least theoretically possible for Japanese firms to protect the same amount of intellectual property with a smaller number of patents. It is thus difficult to draw long-term inference about changes in research productivity using Japanese patent application counts because the relationship between innovations and patents has shifted over time.[18] There was no such change in the U.S. patent system over our sample period. Furthermore, we know that Japanese firms tended to submit patent applications to the U.S. Patent and Trademark Office for the ideas which they perceived, at least *ex ante*, to have the most promise, so that a U.S. patent count series represents a "quality-adjusted" measure of innovative output. Finally, thanks to the availability of U.S. patent data in electronic form, it is possible to conduct an additional

[16] Further information on data sources and construction is provided in the attached Data Appendix.
[17] A complete list of the firms in the sample is available from the authors upon request.
[18] For an empirical study of the effects of this patent reform on Japanese innovation, see Sakakibara and Branstetter (2001).

"quality adjustment" by measuring the number of citations received by a patent from subsequently granted patents over some fixed time period – in our case, four years.

The first column of Table 1 presents results of a fixed effects negative binomial regression of U.S. patent counts on firm R&D spending and our year dummy variables. Controlling for R&D spending at the firm level, the coefficients on the time dummies trace out changes in the level of R&D output that are common to all firms. In other words, it gives us a sense of how innovative output is changing, on average, after we have controlled for inputs. Figure 5 graphs the pattern traced out by the time dummies, along with the 95% confidence bounds. The picture that emerges is fairly striking. From the mid-to-late 1980s, one sees a sharp increase in average innovative output. This growth largely ceases in the early 90s, suggesting that R&D productivity reached a plateau around 1990 and grew little thereafter.[19]

Is this cessation of R&D productivity growth real or an artifact of the data? The substitution of observable patents for unobservable innovation creates some problems for our statistical inference. The g coefficients measure not just changes in the productivity of R&D activity over time, but also changes in the propensity to patent in the United States over time. It could be, for instance, that Japanese firms are generating larger numbers of innovations over time, but that, in order to economize on the costs of protecting their intellectual property rights, they are being more selective about which patents they take out in the U.S. In other words, a count-based output measure would show a flattening of innovative productivity, where there was none.[20]

[19] Including deflated sales as an additional regressor yields results qualitatively similar to those presented here.

[20] We thank Hiroyuki Odagiri for stressing this point.

To try to get around this possibility, we constructed a measure of patent output in which we adjusted for the number of citations received by each patent up to four years after it was granted. If the number of patents taken out in the U.S. is going down because only the upper tail of the quality distribution of innovations is actually being patented, then an outcomes measure that controls for innovation quality would be less likely to generate a spurious result of flat productivity growth.

The second column of Table 1 presents results from such a regression. Figure 6 graphs the coefficients along with their 95% confidence bounds. The picture that emerges is remarkably similar to that in Figure 5. Note that, in the last years of our sample, measured productivity declines sharply. This is an artifact of our data. Detailed studies of patent citations show that it takes several years for patent citations to a particular invention to peak. A patent applied for in 1996 would not be granted, on average, until 1997 or 1998 – possibly even later. Thus, we would only pick up less than four years' worth of patent citations. For this reason, coefficients on year dummies for years later than 1995 in this graph should be viewed with caution.

The next set of regression results segmented our sample into industry groups, to see how research productivity trends differed among industries.[21] Figure 7 displays some results from these regressions. The top line traces out measured increases in research productivity for electronics firms. The bottom line traces out the measured path for non-electronics firms. These results indicate that the research productivity of the electronics industry, broadly defined, has continued to grow through the 1990s more or less in line with the trends of the 1980s. However, the results suggest a *decline* in research productivity for manufacturing firms outside the electronics industry. That is, controlling

[21] A table reporting all of the coefficients from this regression is available from the authors upon request.

for innovative inputs, these firms are generating less innovative output, on average, then they were in the late 1980s. Regression results based on citation-adjusted patent output measures indicate a similar pattern.

Table 2 presents results based on Japanese patent applications. If one pools data across all firms, the Japanese patent application data suggest a continuing rise in innovative productivity through the mid 1990s, but a slowdown in that growth relative to the trends of the 1980s. Splitting the sample along industry lines indicates electronics firms have outperformed firms in other industries. In both cases, a slowdown in productivity growth is evident, occurring sooner among the firms outside of electronics. While there were substantial increases in R&D productivity in the early 1990s for electronics firms, the increase is much less impressive outside that sector.[22] A similar breakdown of R&D productivity trends by size category suggests that, outside the electronics sector, relatively smaller firms are more likely to show progress in research productivity than the larger firms. This finding was confirmed using U.S. patent output data as well.[23]

What can we conclude from our preliminary exploration of the firm-level data? Our results suggest that changes in Japan's absolute and relative performance are not simply or solely the result of a decline in firms' R&D spending. Although we find some evidence of an actual *decline* in research productivity in some sectors, the more robust result is that the broad-based increase in Japanese research productivity that was so

---

[22] One could make the argument that the evidence from Japanese patent applications could be consistent with increased innovation in both categories if the number of claims was rising fast enough to offset the slowdown in the growth of patent applications. This possibility indicates the need for caution in interpreting results based on Japanese patent data. For a study of Japanese innovation trends in the immediate aftermath of the 1988 patent reform, see Sakakibara and Branstetter (2001).

[23] These regression results are available from the authors upon request.

striking in the 1980s has largely faded in the 1990s. The exception to this general trend is the electronics sector, which has continued to increase its innovative output, controlling for input, more or less in line with earlier trends. However, the continued progress in R&D productivity in this sector has not prevented Japanese firms from falling well behind their American rivals in such key patent categories as IT. This may reflect Japanese firms' inability to match their rivals' expanding investments in R&D.

IV. Why has research productivity growth slowed and what should be done? A Managerial Perspective

At this point, we relate some of the results of our interviews with Japanese R&D managers, conducted in the U.S. and Japan in 2000 and 2001. These were fascinating exchanges, and we regret that the space constraints for this paper and the confidential nature of some of the material restrict what we can pass on to the reader. Each interviewed company had made, over the last two decades, a substantial commitment to R&D at the technological frontier within its industry. A large central R&D operation had been built up with the aim of creating important technical breakthroughs that could be incorporated into future generations of products. While our interviewees tended to be corporations recognized as technological leaders within their fields, this change in focus from applied to more basic R&D is broadly reflected in larger, more representative surveys.[24] A change in the focus of R&D was inevitable – at one time, Japanese firms were the global low-cost suppliers of standardized products, but manufacturers in South

---

[24] The stereotype of Japanese firms as being effective imitators and implementers rather than innovators may have been an accurate description of Japanese R&D activity in the late 1970s or early 1980s, but by the late 1980s, Japanese firms had reached the technological frontier and their continued success increasingly depended on their ability to advance that frontier. See Goto and Nagata (1995) and the statistics presented in *Gijutsu Yoran* (2000 edition) for evidence that the distribution of R&D effort across the categories of basic versus applied R&D in the U.S. and Japan had essentially converged by the mid-1990s.

Korea, Taiwan, and China are increasingly able to undercut Japanese firms. This means that Japanese firms have to compete on the basis of innovative products.

Despite this investment in frontier research, the interviewed R&D managers are universally dissatisfied with the results. The view within firms seems to be that the central R&D laboratories have become bureaucratic, insular, and unresponsive to the needs of the firm. R&D management has been unable to effectively translate the basic and frontier research conducted by the central R&D laboratories into effective new products. To a surprising extent, the critiques of the central R&D operations seem to echo criticism made in the 1980s by American firms of their own central R&D operations, which were also maligned as being unable to translate research advances effectively into new products. In other words, managerial perception confirms the findings of our statistical analysis – managers think their relative R&D performance has declined.

Our interviewees spoke admiringly of the way their American counterparts had restructured their R&D operations over the last decade, and most of the interviewed firms were also trying to restructure their own R&D operations along the lines of the "new" U.S. model. While the characteristics of the new structure of R&D are still emerging, conversations with Japanese corporate R&D managers suggest that these features include: 1) greater reliance on R&D partnerships *outside* the traditional vertical keiretsu networks within Japan, 2) greater reliance on foreign (especially U.S.) R&D partnerships and acquisitions of high-tech firms, 3) greater emphasis on cooperation with universities, at home and abroad, 4) a de-emphasis on centralized "in-house" R&D and a gradual downsizing of resources invested in central R&D facilities, and 5) increased interest and investment in "corporate venturing" programs.

If there is a single theme that guides all of these departures from the "traditional" model of research, it might be a move from a focus on in-house research and development toward a focus on increased "R&D outsourcing." Essentially, the expensive experiment with trying to create technical breakthroughs inside Japanese corporate laboratories has had only limited success. So, Japanese firms, in conscious imitation of their U.S. counterparts, are placing increased emphasis on sourcing useful technologies from outside the firm, which can then be combined with the firm's own technical strengths to generate important new products.[25] Because Japan still has, despite extensive efforts by the government to promote them, relatively few high-tech start-ups, and because the quality and level of academic research in Japan typically lags that of the U.S., Japanese firms have moved aggressively to expand their efforts to "tap into" U.S. technology networks.

However, both prior research and comments from our interviewees suggest that Japanese firms may have faced special challenges as they moved from a focus on applied R&D and development toward a concentration on research at the technology frontier. First, as Gary Saxonhouse has pointed out for decades, the Japanese higher education system produces far fewer Ph.D.s in the sciences and engineering than does the U.S. educational system.[26] This is true not only in terms of absolute numbers but also in per capita terms. While Japan has produced many more engineering graduates at the

---

[25] One interviewee cited statistics indicating that such leading U.S. technology firms as IBM, Microsoft, and Cisco were spending large sums of money (equivalent to substantial fractions of their corporate R&D budgets) on ideas generated outside the firm.
[26] Again, see Okimoto and Saxonhouse (1987).

bachelors degree level per capita, and this may have been sufficient to propel Japan's technical advance while it was still behind the technology frontier, it is reasonable to think that, as Japanese firms have reached the frontier, it has become more important to have technical personnel with highly specialized training. These individuals are far less numerous in Japan than in the United States. In some fields, such as software engineering, the shortage of engineers with advanced degrees is so acute that there have been references to the "soft crisis" for fifteen years.[27] Even in the U.S., demand for software engineers dramatically outstripped supply in the 1990s – but U.S. immigration law allowed the "import" of hundreds of thousands of foreign engineers to bridge the gap.[28]

Second, U.S. high technology firms are able to work with and build upon the research of the world's most celebrated research universities and institutions. Despite important advances over the postwar period, the quantity and quality of publicly funded research in Japanese universities and research institutes typically lags behind that conducted in the U.S. While the results of this kind of "public science" are generally published in easily accessible scientific journals, understanding and applying the most recent scientific developments may require a degree of familiarity with and connection to that recent science that is harder to come by in Japan than in the United States.

As Figures 3-6 made clear, there has been a surge of patenting and a sharp increase in R&D spending in the U.S. over the course of the 1990s. While there is not yet a consensus regarding the causes of this increase, recent research suggests several potentially important factors. Some component of the increase has probably been driven

---

[27] See Finan and Williams (1992).

[28] We thank Amar Bhide and Ashish Aurora for discussions on the role of immigration (especially from India) in propelling the U.S. high-tech boom of the 1990s.

by changes in "scientific and technological opportunity." Important fundamental scientific breakthroughs in molecular biology, genetics, and, more recently, genomics, have helped fuel a sharp increase in the number of patents granted in fields associated with "biotechnology." Likewise, recent advances in telecommunications and computer networking have probably helped drive a sharp increase in patenting in the "IT" classes.[29] Consistent with this "science-driven" view of increased innovation, corporate patents are increasingly citing scientific papers, suggesting that the link between science and innovation is tighter than in the past.[30] It is uncertain whether these breakthroughs will continue to generate opportunities for industrial application, or whether they will eventually "play themselves out" as the opportunities for commercial application of these new discoveries are exhausted.

Kortum and Lerner (1998) point out that the increase in patenting is not confined to those clusters of technologies that have seen recent fundamental breakthroughs. Instead, they argue that the management of R&D has undergone an institutional change – they argue that a system of small start-up firms financed by venture capital partnerships is more productive than the traditional "big corporate R&D system," and they present evidence that the increase in innovation has been highest where venture capital investment is most concentrated. The recent collapse of the IT sector and the large-scale bankruptcies of venture-backed high tech firms over the last two years suggest that the ultimate power of this institutional innovation to propel increased innovation in the long run may have been overstated, but it is almost certain to have played an important role in the late 1990s.

---

[29] See Cockburn and Henderson (2000) and Hicks et. al. (2001) for recent studies touching on these issues.
[30] For studies of this expanding linkage, see Narin et. al. (1997) and Branstetter (2001).

Of course, a more cynical review of the recent surge in innovation would regard it as more of a mirage than a reality – a mirror image of the surge in physical capital investment during Japan's "bubble economy." Due to increases in the breadth and length of intellectual property protection afforded by patents – and in an effort to ward off patent lawsuits – firms have simply sharply increased their propensity to patent. Perhaps the most disturbing study along these lines is the work of Hall and Ziedonis (2001), who show that there has been a sharp increase in the propensity to patent in the semiconductor industry for reasons that have little to do with a real increase in innovation. We do not hold the view that the recent surge in U.S. innovation is entirely a mirage, but, clearly, Japanese firms should exercise caution in borrowing from the "new U.S. model," when it is still unclear what features of this model have really played a significant role.

While we eventually hope to explore *all* of the dimensions of the Japanese industrial R&D restructuring outlined in the paragraphs above as part of a long-term research project, in this draft we focus on the international dimension of Japanese firms' R&D restructuring. In doing so, we seek to answer two questions. First, how and to what extent are Japanese firms seeking to obtain useful technological information from U.S. sources? Second, is this strategy working? In other words, have Japanese firms that have made the effort to tap into U.S. technology networks benefited, in terms of raising their R&D productivity? Drawing upon recent research by one of the authors, we seek to shed light on these questions in the next section.

V. Tapping into U.S. technology networks: Has it worked?

As much prior research has documented, Japanese firms have historically been enthusiastic licensees of U.S. technology. However, the concept of "tapping into" U.S.

technology networks that we attempt to measure in this section is not a passive implementation of technology developed by another firm, but rather, the incorporation of ideas developed outside the firm into the firm's own R&D operation. It is much more pro-active than simple licensing, and there seem to be two primary modes by which it takes place.

Establishment of research facilities abroad. Japanese investment abroad is tracked by both public and private databases. Using the *Kaigai Kigyou Shihon Shinshutsu* database, one can track Japanese investment in foreign R&D/product development facilities and acquisitions of U.S. firms at the level of the Japanese parent firm. Prior research on the overseas R&D of Japanese firms has emphasized that the fraction of the firms' total R&D effort expended by these overseas research facilities has been relatively modest. They collectively account for only a tiny fraction of overall firm R&D spending and overall firm patenting.[31] However, they may play an important role as a "bridge" between in-house R&D resources and useful U.S. technology, despite their relatively small size. Drawing upon results from Branstetter (2001), we will present evidence on this issue.

Research alliances. Japanese firms have also been aggressive about forming technology-sharing and technology-development alliances with U.S. firms. Two data sources track these alliances over time, identifying the Japanese and U.S. partners. The SDC alliance database uses contemporary press accounts to track corporate alliances, of which the "technology" alliances that are the focus of this section are a subset. Unfortunately, the extent of coverage of this database tends to be rather thin prior to the early 1990s. A more comprehensive database, focusing specifically in technology

[31] Evidence on these points is provided by Odagiri and Yasuda (1997) and by Belderbos (1999).

alliances, has been assembled over the years by a team of researchers at the University of Maastricht. This "CATI" database, developed under the supervision of John Hagedoorn, is arguably the most comprehensive and detailed database available. While the results in this draft are based on the SDC database results, the final draft will incorporate data from the CATI database.

Do alliances and U.S. R&D facilities promote flows of knowledge from U.S. to Japanese firms? We assess this using data on the citations to prior American inventions found in the U.S. patents of Japanese firms. We are careful to exclude all Japanese-invented U.S. patents from this set of "American" inventions. Using an empirical methodology developed in Branstetter (2001), we presume that the flow of patent citations is proportional to the flow of knowledge.[32]

Let C_{Jit} be the number of citations made by the patent applications Japanese firm i filed in year t to the cumulated stock of "indigenous" U.S.-invented patents granted as of year t.[33] We can then write the expectation of C_{Jit} as a function of several other observables

$$E[C_{Jit}] = (N_{Jit})^{b_1}(N_{At})^{b_2}[e^{b_3 FDI_{it}}][e^{b_4 Alliance_{it}}][e^{b_5 PROX_i}]R_{it}^{b_6}a_i a_t \quad (6)$$

Let E be the expectations operator. Here E[C_{Jit}] is a function of the number of patents Japanese firm i has taken out in the U.S. in year t (N_{Jit}), the number of potentially cited indigenous U.S. patents which exist as of year t (N_{At}), the level of firm i's "FDI presence" in the U.S. in year t (FDI_{it}), the level of firm i's alliance activity with U.S. firms in year t, and the extent to which firm i is at a point in the technology space which

---

32 This framework builds heavily on the methodology of Jaffe and Trajtenberg (1996) and the citations data are taken from Hall, Jaffe, and Trajtenberg (2001).

33 Note that the U.S. Patent and Trademark Office only makes available data on patent applications that are eventually *granted*. In this paper, patents are dated by year of application rather than year of grant, because it takes on average two years – sometimes much longer – for the patent office to grant a patent.

is "densely populated" by other indigenous U.S. patents ($PROX_i$). Some Japanese firms might cite U.S. patents more frequently simply because they happen to be working on technologies in which a large number of indigenous U.S. inventors are active.

If one wishes to control for this "technological proximity," the existing literature suggests a way in which it could be done. The typical Japanese firm in this data set conducts R&D in a number of technological fields simultaneously. One could obtain a measure of a firm's location in "technology space" by measuring the distribution of its R&D effort across various technological fields. Let firm *i*'s R&D program be described by the vector *F*, where

$$F_i = (f_1, ..., f_k) \tag{7}$$

and each of the *k* elements of *F* represent the firm's research resources and expertise in the *k*th technological area.[34] From the number of patents taken out in different technological areas, we can infer what the distribution of R&D investment and technological expertise across different technical fields has been.

In the same way, we can also compute a vector of location in technology space for the aggregate of all U.S. inventors, treating them as though they belonged to a single giant enterprise, and denoting that F_{US}. This suggests that $PROX_i$ might be measured as:

$$PROX_i = \frac{F_i F_{US}'}{[(F_i F_i')(F_{US} F_{US}')]^{1/2}} \tag{8}$$

This is a technological proximity coefficient in the spirit of Jaffe (1986).

[34] The *k* different technological clusters are constructed by aggregating the hundreds of patent classes in the U.S. Patent and Trademark Office classification system into 50 distinct categories of technology. I then count the number of patents taken out by firm *i* in each of these 50 categories over full length of my sample period.

One may also wish to allow citations to be influenced by the firms' R&D spending (R_{it}) and by vectors of multiplicative "fixed effects" associated with the citing firm (a_i) and the (application) year in which the citation takes place (a_t). Including these fixed effects actually simplifies the equation, provided one is willing to make some assumptions. The stock of cumulated potentially citable "indigenous" U.S. patents will be the same for all Japanese citing firms in each year, so that the N_{At} terms are effectively absorbed into the time dummies. One may also want to assume that a firm's location in technology space relative to aggregate American inventive activity is relatively fixed over time. In that case, the effect of the *PROX* measure is absorbed into the firm fixed effects.[35] The fact that I cannot separately identify it from the firm effects is of little concern, as my primary focus is on the impact of changes in FDI on citations.

Taking the log of (6) and implementing these assumptions gives us a simple, log-linear estimation equation

$$c_{Jit} = b_0 + b_1 p_{it} + b_2 FDI_{it} + b_3 r_{it} + b_4 Alliance_{it} + \sum_t a_t T_t + a_i + e_{it} \qquad (9)$$

where c_{Jit} is the log of the number of citations made by the U.S. patent applications of Japanese firm i in year t to indigenous U.S. patents, p is the log of the count of U.S. patent applications of Japanese firm i in year t, FDI is one of a number of alternative measures of the FDI stock of firm i in year t, r is the log of R&D spending of firm i in year t, *Alliance* measures alliance activity, the a_t's are time dummies, and a_i is a "firm effect," reflecting firm-specific research productivity and, perhaps, firm-specific but time

[35] "Industry effects" will also be absorbed into the firm effects, because firms in my sample do not change their primary industry affiliation over time.

invariant differences in the "connectedness" of the Japanese firm's research team to current developments in U.S. research that might affect its tendency to cite U.S. patents.

The assumption that the technological proximity of a Japanese firm to U.S. inventive activity stays fixed over a long period is a strong one. The data permit us to allow this proximity measure to vary within firms over time, although we lack sufficiently rich patent data to do this for all firms or all years. If firms are simultaneously increasing their FDI in the U.S. and moving "closer" to U.S. firms in technology space, this new specification allows us to control for the latter effect, picking up only the partial effect of an increase in FDI or alliance activity on "spillovers" as measured by citations.[36] This imposes a much more stringent statistical test of the impact of FDI (or the impact of alliance activity) on knowledge spillovers. After all, it is possible some of the movement of Japanese firms in "technology space" is *induced* by spillovers from American firms, which they receive either through their network of subsidiaries or their network of alliances. However, if a positive effect of FDI and/or alliance activity remains even after controlling for this movement, this is even stronger evidence in favor of the view that FDI and/or alliances function as a channel of knowledge spillovers. The specification suggested by this line of thinking would be:

$$c_{Jit} = b_0 + b_1 p_{it} + b_2 FDI_{it} + b_3 r_{it} + b_4 Alliance_{it} + b_5 PROX_{it} + \sum_t a_t T_t + a_i + e_{it} \qquad (10)$$

[36] Suppose Fujitsu decides to become a world leader in "wireless modems." Fujitsu will need to establish distribution and, possibly, manufacturing facilities in America because it is a leading national market for this kind of product. At the same time, Fujitsu will begin to conduct more research on technologies related to wireless modems and take out more patents protecting its research in this area. Since many American firms have been active in this technology, Fujitsu's new patents will inevitably cite American patents quite frequently. In this case, a change in firm strategy generates both an increase in U.S. FDI and an increase in citations to U.S. patents, though there is no direct causal relationship between the two variables. Without controlling for the firm's movement in technology space, one could overestimate the impact of FDI on knowledge spillovers.

The focus of interest will be on the coefficients b_2 and b_4. Do firms that increase their levels of FDI in the United States experience an increased tendency to cite U.S. patents?[37] Do firms that engage in more frequent technology alliances and R&D joint ventures with U.S. experience an increased tendency to cite U.S. patents? Positive, significant coefficients would suggest the answer is yes in both cases. The reason why one might expect a positive coefficient is straightforward. To monitor and understand other firms' R&D can be a difficult task – particularly when the other firms' R&D activities are located on the opposite side of the Pacific Ocean. It may be facilitated enormously by the geographical proximity attained through FDI, through which the cost of accessing foreign firms' knowledge assets is reduced. This effect may occur regardless of whether or not the FDI by the Japanese firm takes the form of "greenfield" new investment or acquisition of existing U.S. firms.[38] Obviously, this monitoring can also be facilitated by R&D alliances, and the alliances may foster spillover benefits that go beyond the technology targeted by the alliance and even beyond the direct alliance partners.

Results of an estimation of (10) are given in Table 6. We see clearly that both alliances and R&D subsidiaries have a positive, statistically significant impact on the measured flow of technological knowledge from U.S. to Japanese firms. While the coefficients are small in magnitude, the reader should recall that the coefficients give the increase in knowledge flows associated with the establishment of an additional subsidiary

---

[37] It may be that an acquisition or greenfield investment might not have an immediate impact on the research of the Japanese parent firm, so various lags of the FDI "stock" will be considered.

[38] Because technological knowledge could flow through Japanese subsidiaries, even if they are not primarily established for the purpose of tracking U.S. technology trends, Branstetter (2001) examines the effect of the *total* subsidiary network and of *acquisitions*, as well as the establishment of R&D centers *per se*, on the impact of knowledge flows from U.S. to Japanese firms.

or an additional alliance. Because some firms in our data set went from zero subsidiaries (or alliances) to several dozen, the cumulative effect implied by the regression coefficients could be quite substantial.

Our conversations with Japanese R&D managers suggest an important complementarity between overseas R&D facilities and R&D alliances. Often, overseas R&D centers are used as a base from which to search out alliance partners, and, in many cases, the site of R&D centers was selected with current or potential alliance partners in mind. In future work, we hope to explore our microdata for evidence of this complementarity.

Does this strategy work? The finding that the establishment of overseas R&D facilities and research alliances enhance knowledge flows is of limited interest unless it is the case that firms which receive greater knowledge flows from the U.S. are able to translate that into greater innovative productivity. Of course, firmly establishing a causal linkage between enhanced knowledge flows and greater innovative productivity is difficult, but in the Table 7, we present evidence that is at least consistent with this view. The first column of the table reports the results of a fixed effects negative binomial regression. In this case, the dependent variable is our citation-adjusted measure of U.S. patent output. We regress this on firm-level R&D spending and two separate measures of knowledge flows from the U.S. The first measure is the count of citations to U.S. patents – the dependent variable from our previous set of regression results. We see clearly that U.S. knowledge flows are positively associated with higher quality patent output, and that this association is robust to the inclusion of a control for patent counts.[39] The coefficient is very small, but the reader should recall that the statistical interpretation of this coefficient is the increase in patent quality associated with an additional citation. Because some firms make hundreds of such citations in a single year's cohort of patent applications, the cumulative effects of a substantial increase in such citations could be quite substantial.

This point is demonstrated by the results in the second column of Table 7. The measure of knowledge flow used in this column is a simple dummy variable equal to 1 if the firm in question receives higher than the median level of citations over the sample period. A random effects negative binomial regression shows that this variable is highly significant and large in magnitude, suggesting that there is a strong correlation in the cross section between high levels of knowledge flow and high levels of quality-adjusted patent output. Frequently-citing firms generate patents that are nearly 90% "better," as measured by their *ex-post* citations. We cannot interpret this as strong *causal* evidence of a linkage between knowledge flows from the U.S. and invention quality, because there are likely to be important unmeasured differences in the research quality of firms which may be correlated with the frequency with which they cite U.S. patents. Nevertheless, these results offer large sample statistical evidence consistent with the view expressed by our interviewees that "tapping into U.S. technology networks" can be a useful component of an R&D reform strategy.

VI. Conclusion

[39] The obvious relationship between counts of citations to prior U.S. patents and the number of successful Japanese patent applications requires the use of this control. This implies that our innovative output measure is, in effect, measuring the *average* quality of patents in a given cohort.

Less than a decade ago, Japanese firms were held up as exemplars of strength in technological innovation. Today, leaders in government and industry are calling for a reform of the national innovation system in order to raise the long-run sustainable growth rate of the Japanese economy. This paper has demonstrated that there are reasonable grounds for concern about the relative performance of Japanese manufacturing firms in technology-intensive industries. To answer the question posed by our title, we do not find strong evidence that Japanese innovative capacity has actually declined. However, that capacity has failed to grow at the rate of the 1980s. As a result, U.S. and worldwide patent statistics suggest that Japanese firms have fallen behind their American counterparts, even in areas where Japanese firms were formerly relatively quite strong and rapidly converging on U.S. levels of inventive output.

Microeconometric analysis suggests that this decline in relative performance cannot be entirely ascribed to a relative reduction in R&D inputs, though such a relative reduction has occurred. We find evidence consistent with the view that, outside the electronics sector, R&D productivity growth has stagnated in the 1990s – perhaps even declined. This view is strongly reflected in the U.S. patent data, and the results are robust to an adjustment for the quality of individual U.S. patents. Japanese patent data do not provide as strong a confirmation of this view, but the shortcomings of Japanese patent applications as consistent measures of inventive output over time have been noted in the text.

Anecdotal evidence from R&D manager interviews is strongly consistent with a slowdown/decline in Japanese R&D productivity relative to the firms' American competitors and relative to their own experience in the 1980s. Firms are taking steps to increase the efficiency of their R&D operations, and one key strategy adopted to varying degrees by all interviewed firms includes an increased emphasis on "tapping into U.S. technology networks." We provide a microeconometric assessment of the impact of steps taken to accomplish these strategic goals, finding that the establishment of R&D centers in the U.S. *and* the formation of technology-sharing alliances with U.S. firms have a positive impact on knowledge flow from U.S. to Japanese firms. Finally, we show that increased international knowledge flows are strongly correlated with higher levels of innovative performance, at least in the firm cross-section.

In future work, we plan to conduct a more comprehensive examination of Japanese firm R&D restructuring which considers all aspects of the restructuring process. We believe that this more comprehensive study could shed useful light on the extent of the restructuring, the degree to which different components have had positive effects on research productivity, and the role that public policy could play in enhancing the evolution of the Japanese innovation system. Furthermore, our interviews strongly suggested that the move toward partial outsourcing of R&D is not a purely Japanese phenomenon, but rather a conscious imitation of a shift that is already well underway in the U.S. A Japanese perspective on the global process of "vertical disintegration of R&D" may offer useful lessons on this process for the rest of the world.

Bibliography

Arison, T., C. Fred Bergsten, E. Graham, and M. C. Harris (eds.), 1992, *Japan's Growing Technological Capability: Implications for the U.S. Economy*, National Academy Press.

Belderbos, R., 1999, "Overseas Innovations by Japanese Firms: A Micro-Econometrical Analysis of Patent and Subsidiary Data," working paper 99-1, Hitotsubashi University, Institute of Innovation Research.

Clark, Chew, and Fujimoto, 1987.

Cockburn, I. and R. Henderson, 1998, "The Organization of Research in Drug Discovery,"*Journal of Industrial Economics*, Vol. 46, No. 2, pp. 157-182

Cohen, W., A. Goto, A. Nagata, R. Nelson, and J. Walsh, "R&D Spillovers, Patents, and the Incentives to Innovate in Japan and the United States," working paper, Carnegie Mellon University, 1998.

Finan, W. and C. Williams, 1992, "Implications of Japan's 'Soft Crisis': Forcing New Directions for Japanese Electronics Companies," in Arison, T., C. Fred Bergsten, E. Graham, and M. C. Harris (eds.), 1992, *Japan's Growing Technological Capability: Implications for the U.S. Economy*, National Academy Press.

Gijutsu Yoran 2000 [Indicators of Science and Technology], published by the Science and Technology Policy Bureau of the Science and Technology Agency, Government of Japan.

Goto, A., 1993, *Nihon no Gijutsu Kakushin to Sangyou Soshiki*, University of Tokyo Press.

Hausman, Hall, and Z. Griliches, 1984, "Econometric Models for Count Data with an Application to the Patents – R&D Relationship," *Econometrica*, 52 (4), pp. 909-938.

Hall, B., A. B. Jaffe, and M. Trajtenberg, 2001, "The NBER Patent Citation Data File: Lessons, Insights, and Methodological Tools" NBER Working Paper no. 8498.

Hall, B. and R. Ziedonis, 2001, "The Patent Paradox Revisited," *The RAND Journal of Economics*, spring 2001.

Henderson, R., A. B. Jaffe, and M. Trajtenberg, 1998, "Universities as a Source of Commercial Technology: A Detailed Analysis of University Patenting, 1965-1988," *Review of Economics and Statistics*, Vol. 80, No. 1, pp. 119-127.

Kortum, S. and J. Lerner, 1997, "Stronger Protection or Technological Revolution: Which is Behind the Recent Surge in Patenting?" *Carnegie-Rochester Conference Series on Public Policy*, Vol. 48, pp. 247-304.

Mansfield, E., 1988, "Industrial R&D in Japan and the United States: A Comparative Study," *American Economic Review Papers and Proceedings*, May 1988

Montalvo, J., and Y. Yafeh, 1994, "A Micro-econometric Analysis of Technology Transfer: The Case of Licensing Agreements of Japanese Firms," *International Journal of Industrial Organization*, 12 (2).

Odagiri, H. and H. Yasuda, 1997, "Overseas R&D Activities of Japanese Firms," in *Innovation in Japan*, (A. Goto and H. Odagiri, Eds.), Clarendon Press, Oxford.

Okimoto, D. and G. Saxonhouse, 1987, "Technology and the Future of the Economy" in *The Political Economy of Japan, Volume 1: The Domestic Transformation*, K. Yamamura and Y. Yasuba (eds.), Stanford University Press.

Posen, A., 1998, *Restoring Japan's Economic Growth*, Institute for International Economics.

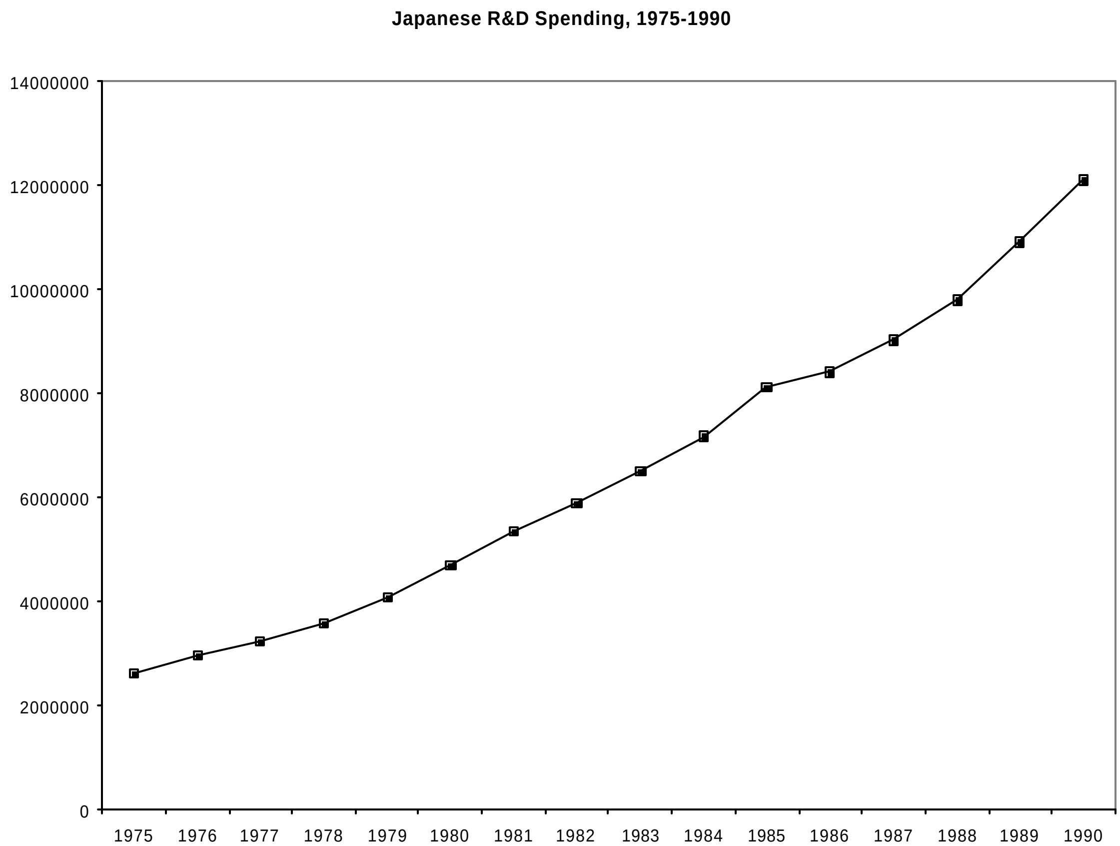
Posen, A., 2001, "Unchanging Innovation and Changing Economic Performance in Japan," in *Technological Innovation and National Economic Performance*, Princeton.

Saxenian, Annalee, 2000, "The Silicon Valley – Taiwan Hsinchu Connection," in M. Aoki and J. Teranishi (eds.), *Tenkanki no Tou Ajia to Nihon Kigyou* [The East Asian Economies and the Japanese Company at a Turning Point], Touyou Keizai Press.

Sakakibara, M. and L. Branstetter, 2001, "Do Stronger Patents Induce More Innovation? Evidence from the Japanese 1988 Patent Reforms," *RAND Journal of Economics*, Spring 2001.

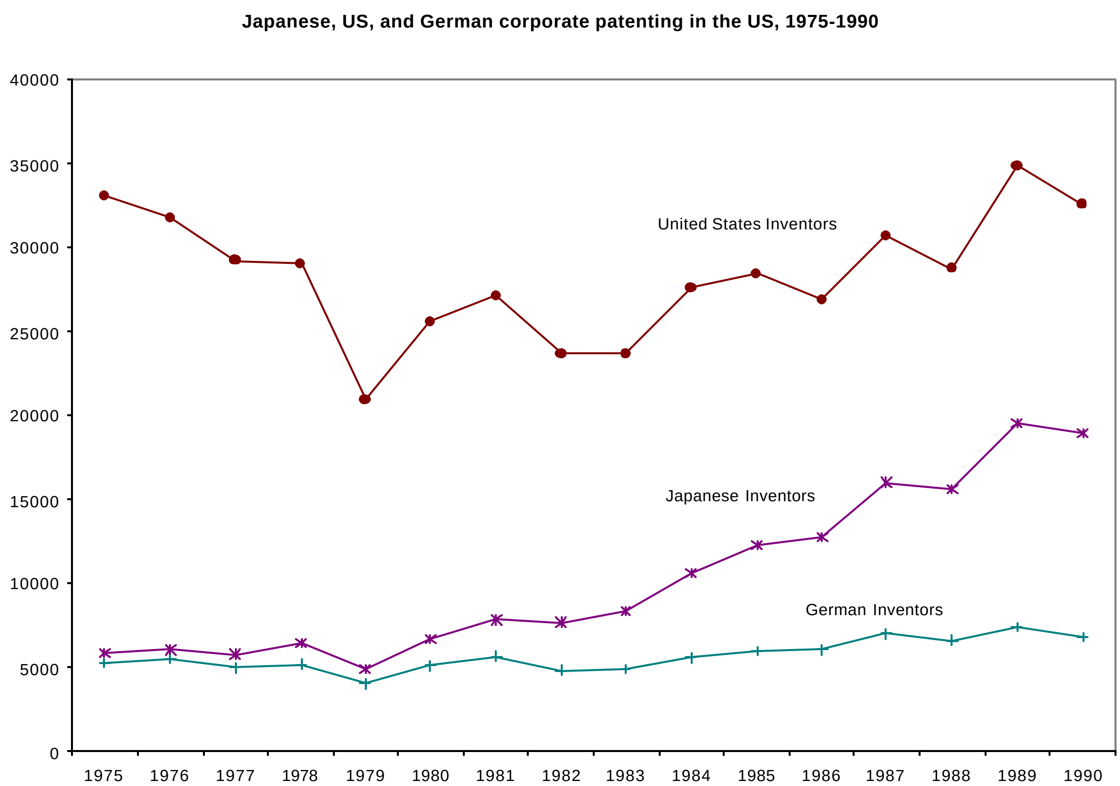
Wakasugi, R. and F. Koyata, 1997, "R&D, Firm Size and Innovation Outputs: Are Japanese Firms Efficient in Product Development?" the *Journal of Product Innovation Management*, Vol. 14, pp. 383-392.

Figure 1



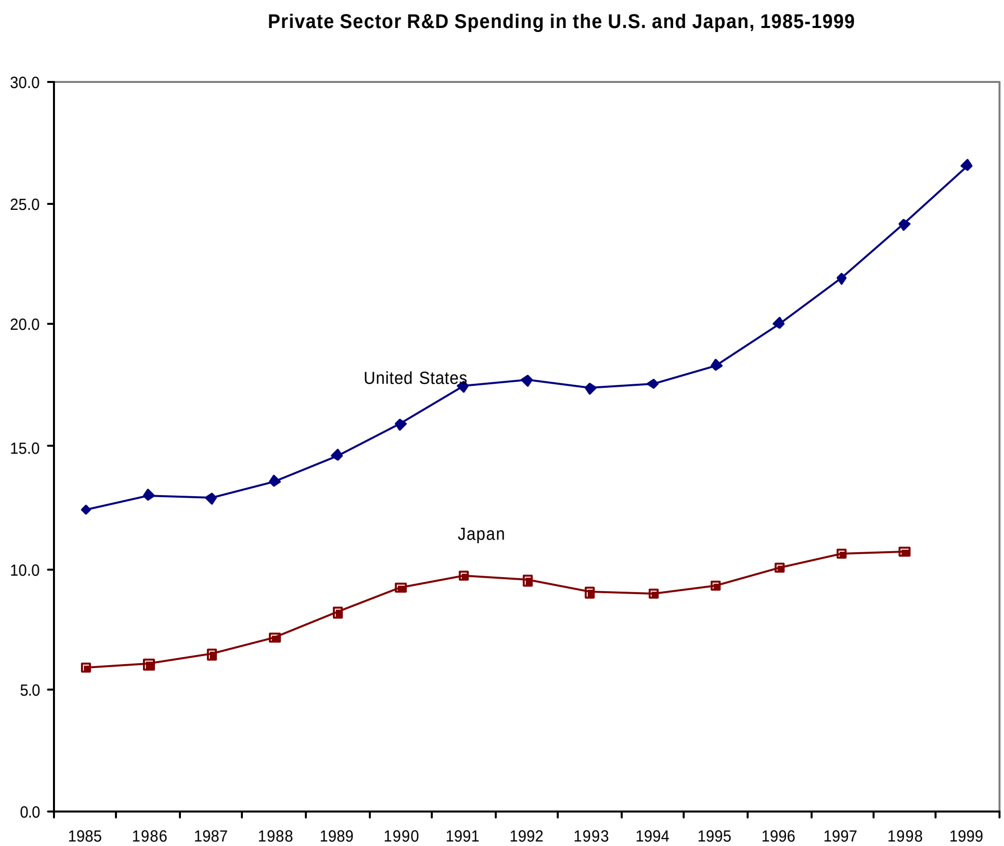
Source: *Gijutsu Yoran*, 2000. Graph shows real R&D expenditures in millions of yen.

Figure 2



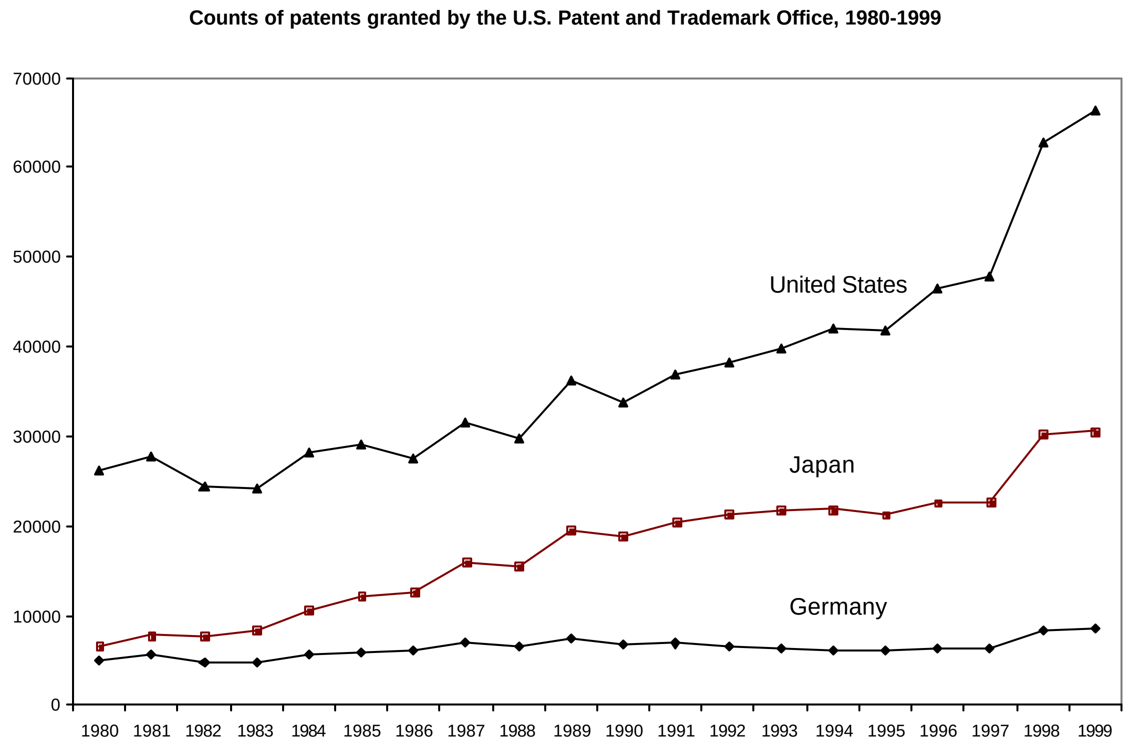
Source: Authors' calculations using the NBER Patent Database described in Hall, Jaffe, and Trajtenberg (2001).

Figure 3



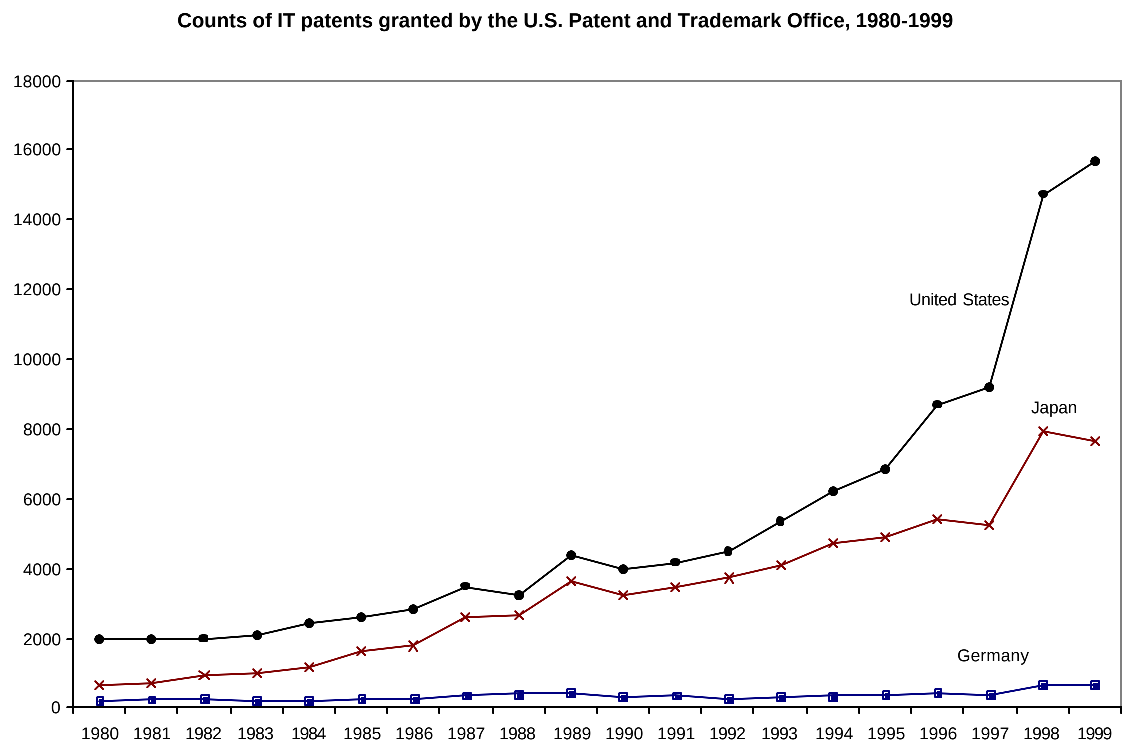
Source: *Gijutsu Yoran*, 2000. Graph measures real private sector R&D spending, converted into trillions of yen, using the OECD purchasing power parity exchange rates.

Figure 4



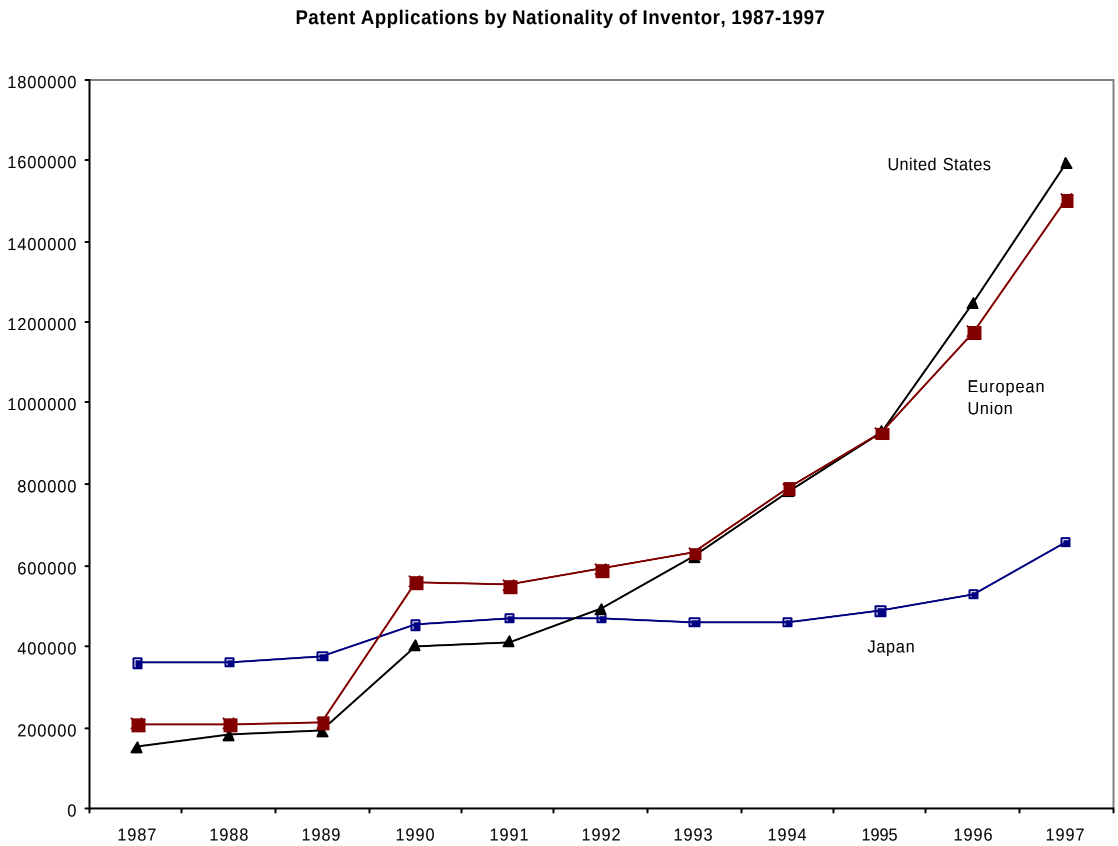
Source: Author's calculations based on the NBER Patent Database.

Figure 5



Source: Author's calculations using the NBER Patent Database.

Figure 6

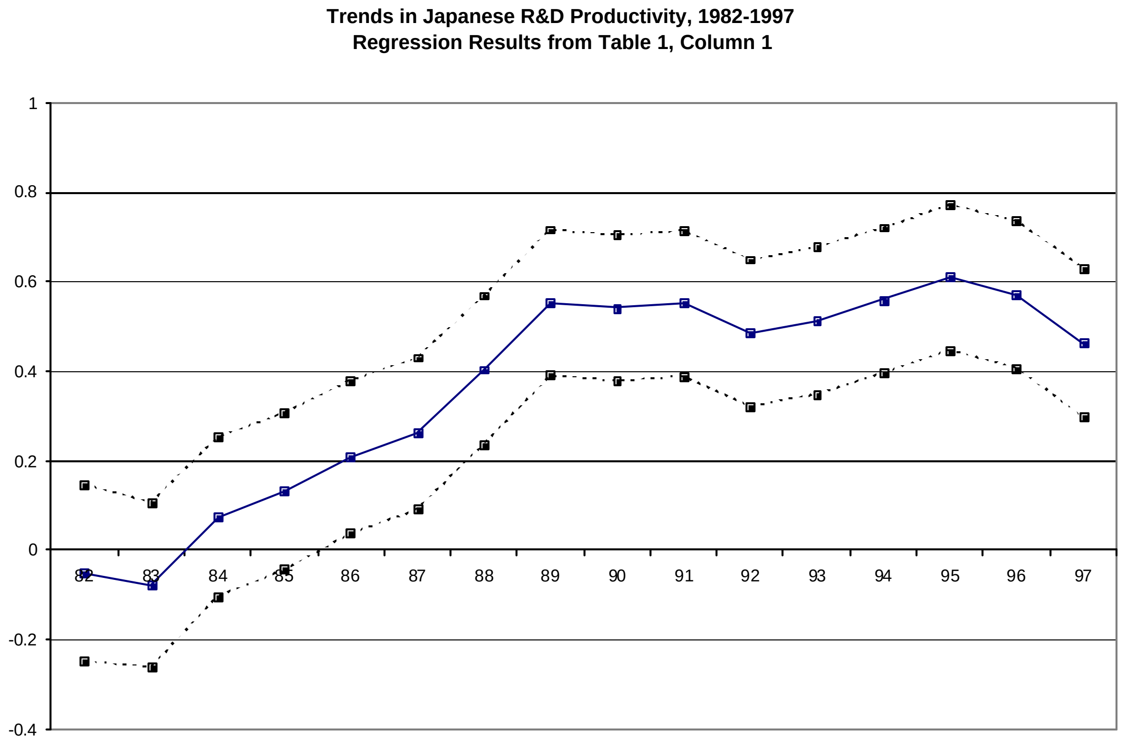


Source: *Gijutsu Yoran*, 2000. This measures patent applications generated by inventors in the indicated country and submitted worldwide.

Table 1 Japanese R&D Productivity Trends
Fixed effects negative binomial regression models

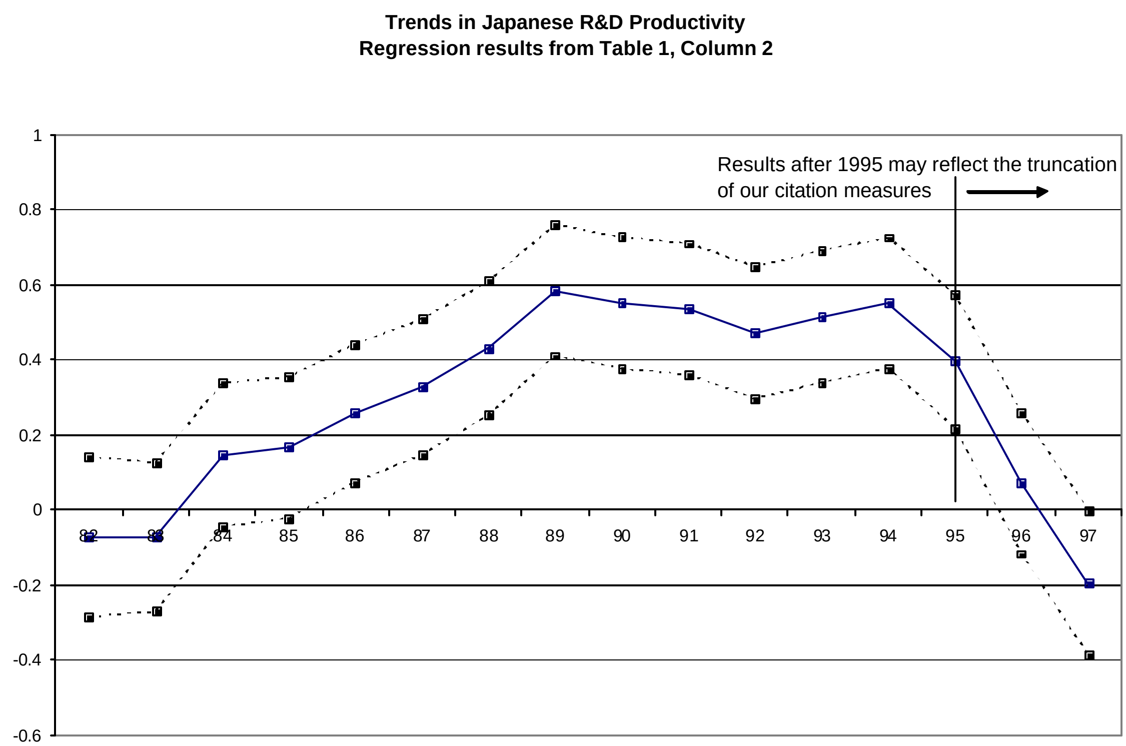
Variable	Patent counts	Citation-adjusted patent counts
new_lrnd	0.294	0.385
	(0.0206)	(0.0190)
82	-0.0501	-0.0706
	(0.100)	(0.109)
83	-0.0776	-0.0714
	(0.0940)	(0.101)
84	0.0751	0.146
	(0.0907)	(0.0972)
85	0.131	0.167
	(0.0894)	(0.0962)
86	0.208	0.259
	(0.0873)	(0.0936)
87	0.261	0.328
	(0.0863)	(0.0923)
88	0.403	0.431
	0.0844	(0.0907)
89	0.553	0.586
	(0.0830)	(0.0891)
90	0.541	0.552
	(0.0832)	(0.0894)
91	0.552	0.535
	(0.0830)	(0.0890)
92	0.486	0.473
	(0.0836)	(0.0896)
93	0.513	0.516
	(0.0840)	(0.0889)
94	0.559	0.552
	(0.0827)	(0.0889)
95	0.609	0.396
	(0.0827)	(0.0908)
96	0.571	0.0720
	(0.0841)	(0.0958)
97	0.463	-0.193
	(0.0849)	(0.0988)
_cons	-0.515	-1.32
	(0.115)	(0.109)

Figure 7



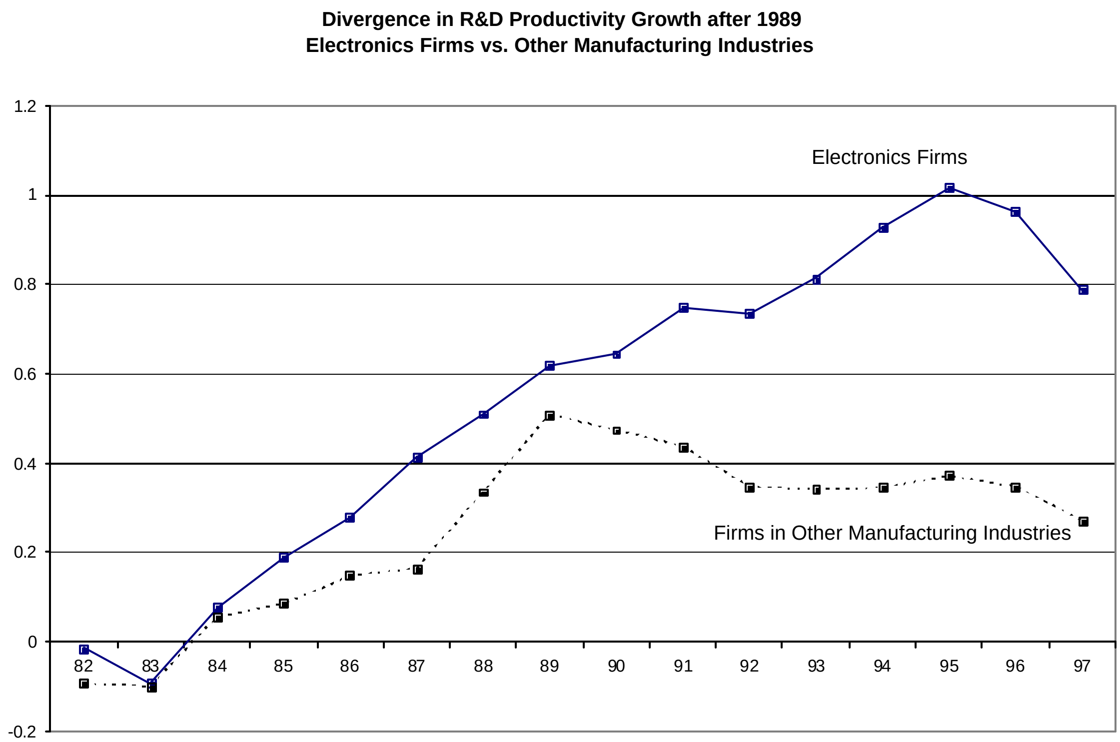
Source: Year dummy coefficients from Table 1, with associated 95% confidence bounds

Figure 8



Source: Year dummy coefficients from Table 1, with associated 95% confidence bounds

Figure 9

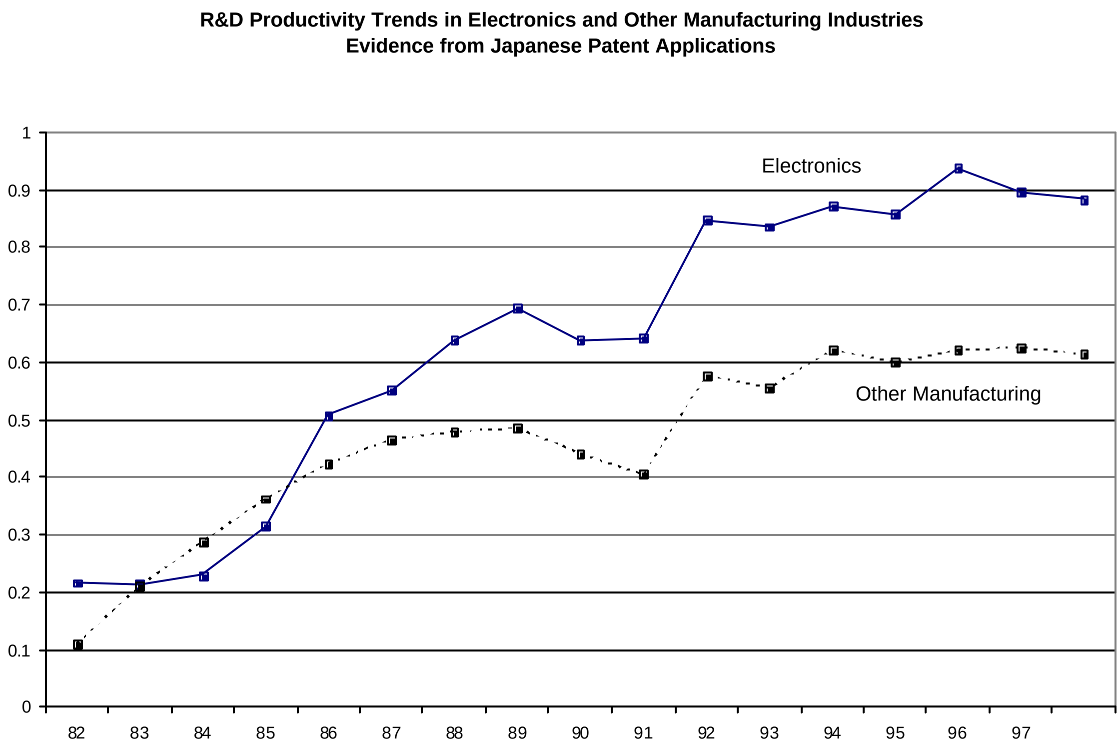


Source: Author's regression results

Table 2 Japanese R&D Productivity Trends
Fixed effects negative binomial regression models
using Japanese patent application data

Variable	Patent counts	Patent counts (electronics)	Patent counts (other manufacturing)
new_lrnd	0.119	0.0470	0.186
	(0.0147)	(0.0236)	(0.0212)
82	0.140	0.216	0.109
	(0.0677)	(0.137)	(0.0748)
83	0.201	0.214	0.210
	(0.0615)	(0.124)	(0.0682)
84	0.264	0.230	0.288
	(0.0605)	(0.122)	(0.0669)
85	0.349	0.316	0.362
	0.0597	(0.121)	(0.0659)
86	0.455	0.508	0.424
	(0.0584)	(0.117)	(0.0648)
87	0.501	0.552	0.466
	(0.0581)	(0.116)	(0.0646)
88	0.533	0.638	0.479
	(0.0573)	(0.112)	(0.0644)
89	0.557	0.694	0.486
	(0.0573)	(0.112)	(0.0645)
90	0.511	0.638	0.441
	(0.0579)	(0.113)	(0.0651)
91	0.489	0.642	0.404
	(0.0583)	(0.114)	(0.0659)
92	0.675	0.847	0.576
	(0.0571)	(0.112)	(0.0645)
93	0.651	0.836	0.555
	(0.0577)	(0.113)	(0.0648)
94	0.698	0.871	0.622
	(0.0573)	(0.113)	(0.0641)
95	0.679	0.858	0.600
	(0.0578)	(0.114)	(0.0645)
96	0.720	0.937	0.621
	(0.0587)	(0.116)	(0.0655)
97	0.706	0.895	0.625
	(0.0587)	(0.118)	(0.0652)
_cons	0.763	0.671	0.734
	(0.0771)	(0.130)	(0.104)

Figure 10



Source: Table 10 year dummy coefficients.

Table 3 Manfield's Survey Evidence on the Allocation of Japanese and U.S. R&D Expenditure

Percent of R&D expenditures devoted to:	U.S.	Japan
Basic research	8	10
Products (rather than processes)	68	36
Entirely new products/processes	47	32

Source: Mansfield (1988)

Table 4 Goto and Nagata's (1995) Evidence on the Allocation of Japanese and U.S. R&D Expenditure

Variable	US	Japan
Percent of R&D budget devoted to process innovation	30.1	14.7
Percent of R&D budget devoted to product innovation	65.9	80.9
Effectiveness of patents for protecting product innovation	40.6	39.7
Fraction of process innovations patented	36.5	29.7
Fraction of product innovations patented	55.1	60.2

Source: Goto and Nagata, 1995

Table 5 Aggregate Evidence on the Allocation of Japanese and U.S. R&D Expenditure from the Management and Coordination Agency

Country	Basic research	Applied research	Development
Japan (1998)	13.9	24.6	61.4
US (1999)	16.3	22.9	60.9

Source: *Gijutsu Yoran*, 2000

Table 6 Measuring Spillovers *to* Japanese Firms
Negative Binomial Regressions
Dependent Variable: Citations Obs=1,857

	Fixed Effects(1)	*Fixed Effects(2)*	*Fixed Effects(3)*	*Fixed Effects*	*Fixed Effects(1)*	*Fixed Effects(3)*
log R&D	-.020 (.014)	.029 (.021)	-.017 (.014)	-.020 (.014)	-.017 (.014)	-.017 (.014)
log U.S. patents	.846 (.016)	.510 (.024)	.840 (.016)	.847 (.016)	.840 (.016)	.840 (.016)
Proximity	.574 (.084)	1.02 (.119)	.543 (.085)	.579 (.085)	.543 (.085)	.543 (.085)
U.S. FDI	**.005** **(.002)**	**.034** **(.025)**	**.017** **(.004)**		**.0035** **(.002)**	**.015** **(.004)**
U.S. alliances				**.004** **(.002)**	**.0032** **(.002)**	**.0016** **(.002)**
Time Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Log Likelihood	-6440.5	-6895.2	-6433.7	-6440.5	-6433.4	-6433.4

(1) Indicates FDI measured as cumulative counts of all U.S. subsidiaries.
(2) Indicates FDI measured as cumulative counts of acquired U.S. subsidiaries.
(3) Indicates FDI measured as cumulative counts of U.S. R&D/product development facilities.
Source: Branstetter, 2001

Table 7 Do Increased Knowledge Flows Raise Innovative Productivity?
Negative Binomial Regressions
Dependent Variable: Citation-adjusted patent output

	Fixed Effects(1)	***Random Effects(2)***
log R&D	.031 (.021)	.023 (.027)
log real sales	.011 (.034)	.101 (.036)
log U.S. patents	.956 (.016)	.822 (.021)
log citations to U.S. patents	**.0001** **(.00002)**	
Dummy for citation greater than median		**.899** **(.096)**
Time Dummies	Yes	Yes
Log Likelihood	-6119.5	-7884.8

TECHNICAL APPENDIX

Sketch Derivation of Negative Binomial Regression Models

Here, I summarize the results of the derivation of count data estimators by Hausman, Hall, and Griliches (1984). The notation below borrows extensively from the presentation of these basic results found in Montalvo and Yafeh (1994).

The Poisson estimator posits a relationship between the dependent and independent variables such that

$$pr(n_{it}) = f(n_{it}) = \frac{e^{-l_{it}} \, l^{nit}{}_{it}}{n_{it}!}$$

where $l_{it} = e^{X_{it}b}$ (11)

Econometric estimation is possible by estimating the log likelihood function using standard maximum likelihood techniques. The negative binomial estimator generalizes the Poisson by allowing an additional source of variance. I allow the Poisson parameter lambda to be randomly distributed according to a gamma distribution. Thus defining lambda as before

$$l_{it} = e^{X_{it}b} + e_i \qquad (12)$$

Using the relationship between the marginal and conditional distributions, I can write

$$\Pr[N_{it} = n_{it}] = \int \Pr[N_{it} = n_{it} | l_{it}] f(l_{it}) d l_{it} \qquad (13)$$

If the density function is assumed to follow a gamma distribution, then the Poisson model becomes a Negative Binomial model:

$$l_{it} = \Gamma(a_{it} j_{it}) \qquad (14)$$

where

$$a_{it} = e^{X_{it} b} \quad (15)$$

then

$$\Pr(n) = \int_0^\infty \frac{e^{-l_{it}} l_{it}}{n_{it}!} \frac{l_{it}^{-1}}{\Gamma(j_{it})} [\frac{j_{it} l_{it}}{a_{it}}]^{f_{it}} e^{f_{it} l_{it} \int a_{it}} d l_{it} \quad (16)$$

where

$$E(l_{it}) = a_{it} V(l_{it}) = \frac{a_{it}^{2}}{f_{it}} \quad (17)$$

Integrating by parts and using the fact that

$$\Gamma(a) = a\Gamma(a-1) = (a-1)! \quad (18)$$

yields the following distribution

$$\Pr(n_{it}) = \frac{\Gamma(n_{it} + f_{it})}{\Gamma(n_{it}+1)\Gamma(f_{it})} [\frac{f_{i}}{a_{it} + f_{it}}]^{f_{it}} [\frac{a_{it}}{f_{it} + a_{it}}]^{n_{it}} \quad (19)$$

with

$$E(n_{it}) = a_{it} \quad (20)$$

and

$$V(n_{it}) = a_{it} + a_{it}^{2} / f_{it} \quad (21)$$

This can also be estimated using maximum likelihood techniques. The log likelihood function becomes

$$L(b) = \sum_i \sum_t \log\Gamma(l_{it} + n_{it}) - \log\Gamma(l_{it}) - \log\Gamma(n_{it}+1) + l_{it} \log(d) - (l_{it} + n_{it}) \log(1+d)$$

(22)

with

$$V(n_{it}) = e^{X_{it} b} (1+d)/d \quad (23)$$

Thus, the coefficients are estimated using standard maximum likelihood techniques.

In the interests of space, I will not reproduce here the derivation of *fixed-effects* versions of the Poisson and Negative Binomial models. The reader is referred to Hausman, Hall, and Griliches (1984).

DATA APPENDIX

This data appendix briefly describes our data sources. A more detailed description of the data construction process is available from authors upon request.

Japanese Patent Data. Japanese patent data was obtained from PATOLIS, an on-line patent database maintained by the Japan Patent Information Organization (JAPIO). These data are counts of patent applications by firm and year.

U.S. Patent Data. The data on patents taken out in the United States by Japanese firms were taken from the NBER Patent Database, described in Hall, Jaffe, and Trajtenberg (2001). These data include counts of patent grants by firm and year, where the patents are dated by the year of application rather than the year of grant. We also include a firm-specific measure of patent output that is "quality-adjusted" by counting subsequent citations received by these patents, as described in the text.

R&D data. The overall R&D spending of individual Japanese firms are taken from several consecutive issues of the *Kaisha Shiki Ho*, published by Toyo Keizai, and the *Nikkei Kaisha Joho*, published by the Nihon Keizai Shimbunsha. All R&D expenditure data was deflated by the R&D price index constructed by the Japanese Science and Technology Agency and reported in *Gijutsu Yoran*.

Other firm variables. Data on firm sales and industry affiliation and are taken from various issues of the Japan Development Bank Corporate Finance Database. Data on the establishment of subsidiaries in the United States are taken from various issues of the publication *Kaigai Kigyou Shinshutsu Souran*, by Toyou Keizai. Data on R&D alliances with U.S. firms are taken from the SDC joint ventures database.

Sample Selection Issues. Firms were selected on the basis of availability of a sufficient quantity of R&D data and patent data in both Japan and the United States. We further required that there be no major jumps in such series as capital stock over the course of the 1980s, thereby screening out firms involved in major domestic mergers or acquisitions. This screening tends to over-sample R&D intensive firms relative to the population as a whole. A handful of large R&D performers are omitted due to data irregularities. A complete list of the firms in our sample and additional information on the sample are available from the authors upon request.