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PATENT CITATIONS AND INTERNATIONAL KNOWLEDGE FLOW: THE CASES OF KOREA AND TAIWAN

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ABSTRACT

This paper examines patterns of knowledge diffusion from US and Japan to Korea and Taiwan using patent citations as an indicator of knowledge flow. We estimate a knowledge diffusion model using a data set of all patents granted in the U.S. to inventors residing in these four countries. Explicitly modeling the roles of technology proximity and knowledge decay and knowledge diffusion over time, we have found that knowledge diffusion from US and Japan to Korea and Taiwan exhibits quite different patterns. It is much more likely for Korean patents to cite Japanese patents than US patents, whereas Taiwanese inventors tend to learn evenly from both US and Japanese inventors. The frequency of a Korean patent citing a Japanese patent is almost twice that of the frequency of a Taiwanese patent citing a Japanese patent. We also find that a patent is much more likely to cite a patent from its own technological field than from another field.

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I. Introduction

Korea and Taiwan are two of the newly industrializing economies that have achieved tremendous technological progress and economic growth. Both have graduated from imitation to innovation within a single generation, by building their indigenous technological capabilities and moving up the technology ladder. Technology diffusion from U.S., Japan, and other OECD economies has played an important part in the two economies' transition from labor-intensive manufacturing to technology- and human-capital-intensive manufacturing. The mechanisms of this diffusion process are not well understood. Partly, it takes the form of technology transfer embodied in imported goods or brought about through foreign direct investment by multinational firms. But technology diffusion can also occur via "knowledge spillovers," whereby developing world researchers and inventors benefit from their knowledge of research programs and research outcomes in more advanced economies. In this paper, we investigate the pattern of knowledge spillovers from U.S. and Japan to Korea and Taiwan, using patents citation data as a proxy for knowledge flows.

There is a growing literature on international technology diffusion. Most of these studies focus on technology diffusion embodied in traded goods. Coe and Helpman (1995) examined R&D spillovers among OECD countries. They constructed a foreign R&D stock using the import shares of a country's trading partners and found a strong link between domestic total factor productivity and foreign R&D stock, which they interpreted as evidence of international R&D spillover. Wolfgang Keller (2001) explores the extent to which R&D in one G-7 country spills over to productivity growth in other G-7 countries. He finds that geographical proximity is important, and that much of the variation in the magnitude of bilateral spillovers can be explained by patterns of trade, investment and language. Coe, Helpman, and Haffmaister (1997) examined north-south R&D spillover. They found that total factor productivity in developing countries is significantly boosted by the R&D stock of industrial countries, which they computed as the import-share-weighted sum of the R&D expenditures of a developing country's trading partners in the north. They interpreted this as evidence of north-south R&D spillover.

Jaffe and Trajtenberg (1999) examined patterns of patent citation among the U.S., U.K., France, Germany and Japan, as an indicator of international flows of knowledge. They found significant evidence of geographic localization that fades slowly as knowledge diffuses over time. They also found interesting country differences, with Japan being highly localized, but more focused on recent developments, and spillovers from the U.S. to the U.K. being the most intense bilateral flow, suggesting a possible role for language and/or cultural connections.

We use patent citations as an indicator of knowledge flow from technologically advanced to developing economies. We extract from the NBER Patent Citations Data File (Hall, Jaffe and Trajtenberg, 2001) all patents taken out in the U.S. by Korea, Taiwan, Japan and the U.S. from 1963 to 1999[1]. We explore first the simple statistics of these data regarding the rate and technological composition of invention in Korea and Taiwan over time. Both of these countries have seen a dramatic acceleration in their patenting over time, with Taiwan in particular now among the lower end of "first world" countries in terms of patents per capita.

We then present simple statistics regarding the frequency with which each of these cite patents originating in the U.S. and in Japan. We use these data to try to answer two questions. First, how does north-south knowledge diffusion differ among the country pairs in our sample? Second, what underlying factors contribute to the patterns of diffusion that we observe? We start with simple comparisons of overall citation rates, and then proceed to examine these rates after controlling for a number of factors likely to affect observed citation rates over time.

Given the non-rival and non-excludable nature of knowledge use, we assume that there is an international stock of knowledge, upon which every economy can draw to facilitate its own technological innovation. The OECD economies create most of this stock, whereas the developing economies are able to tap into this stock constrained by the availability of the channels of knowledge diffusion and their abilities to absorb and adapt new knowledge. An implication of situating our study in this context is that we should observe similar patterns of knowledge flow from the north to two similar economies in the south. Any disparity in knowledge diffusion should be accounted for by economy specific characteristics in the south.

The rest of the paper is organized as follows: Section 2 describes the data used in this paper. We present some stylized patterns of knowledge diffusion using patent citation as a proxy. Institutional background for technological change in Korea and Taiwan is presented in Section 3. We discuss several stylized patterns of patent citation between U.S., Japan, Korea, and Taiwan in Section 4. Section 5 describes the knowledge diffusion model. We discuss how the empirical results from estimating the diffusion model can account for the stylized patterns we observe in Section 6. Section 7 concludes.

II. The Data

The data set used in this study consists of all utility patents granted by the U.S. Patent and Trademark Office (U.S.PTO) to inventors residing in Korea, Japan, Taiwan, and the U.S. from 1977 to 1999. The data are from the NBER Patent Citations Database (Hall, Jaffe and Trajtenberg, 2001)[2] The data elements that we utilize are:

- The country of residence of the primary inventor
- The dates of application and grant for the patent
- The U.S.PTO Patent Classification
- The identity of previous patents contained in the citations or "references made" in each patent.

When a patent is granted by the U.S.PTO, it is assigned to one of over 400 Patent Classes according to its technological area. We use these "3-digit" patent classes for some of our analyses. For other purposes, it is desirable to have a more aggregated technological classification. The U.S.PTO classification system does not have a hierarchical structure, so there is no way within the U.S.PTO system to aggregate patent classes. Adam Jaffe and Manuel Trajtenberg have grouped the patent classes into six major technological categories: Chemical; Computers and Communications; Drugs and Medical; Electrical and Electronic; Mechanical; and All Other.

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[1] In utilizing patents taken out in the U.S., we focus on inventions for products intended (at least in part) for world trade, and for process inventions whose outputs are exported (at least in part). For the remainder of the paper, we use the shorthand "patents" to refer to "patents granted in the U.S."

[2] The patent database begins in 1963, but the citations information does not begin until 1975, and the number of patents from inventors in Korea and Taiwan are very small before the mid-1970s. For these reasons, our analysis focuses on 1977-1999.

Patent citations serve an important legal function, since they delimit the scope of the property rights awarded by the patent. Thus, if patent B cites patent A, it implies that patent A represents a piece of previously existing knowledge upon which patent B builds, and over which B cannot have a claim. The applicant has a legal duty to disclose any knowledge of the "prior art," but the decision regarding which patents to cite ultimately rests with the patent examiner, who is supposed to be an expert in the area and hence to be able to identify relevant prior art that the applicant misses or conceals. We assume that the frequency with which a given country's inventors cite the patents of another country is a proxy for the intensity of knowledge flow from the cited country to the citing country. For further discussion of the limitations of using citations data for this purpose, see Jaffe and Trajtenberg (1999) and Hall, Jaffe and Trajtenberg (2001). Jaffe, Trajtenberg and Fogarty (2000) present survey evidence regarding the extent to which citations reflect actual knowledge flows between inventors. They find that citations are a noisy indicator of knowledge flow, in the sense that knowledge flow is much more likely to have occurred where a citation is made, but many citations also occur in the absence of any knowledge flow.

[Insert Table 1 here]

Table 1 presents statistics of patent counts and citation counts of U.S., Japan, Korea, and Taiwan. Table 1 shows the aggregate number of patents, the distribution of patents over these six categories, and the average number of citations each received for the 6 technological categories in each of the 4 countries. In columns (1) to (4), we report these statistics for 1985 and 1998. The sample averages of the statistics are reported in the last two columns. The year 1985 was chosen because this was the year when Korea and Taiwan began to have a balanced portfolio of patents.

The first thing to note about Table 1 is that although the absolute numbers of patents are still only fractions of those of the U.S. and Japan, Korea and Taiwan are catching up very rapidly. In 1985, for example, Taiwan was granted 174 patents, or 0.4 percent of the U.S. total and 1.4 percent of the Japanese total. Thirteen years later, Taiwanese inventors claimed 3100 patents, a seventeen-fold increase and equivalent to 4 percent and 10 percent of the U.S. and Japanese totals respectively. During the same period, Korea managed to increase its patent count from 41 to 3259, an almost eighty fold increase.

Secondly, Table 1 suggests that even with the much larger number of patents they are now receiving, the patent portfolios of Taiwan and Korea are specialized in terms of technological field. The U.S. and Japan innovate in many technological areas, due to their size and comprehensive technological capabilities. On the other hand, the distributions of Korean and Taiwanese patents are more concentrated in certain areas and have changed considerably over the years. In 1998, 35 percent of Korean patents and 34 percent of Taiwanese patents belong to the electrical and electronic category. The same fraction is 15 percent and 21 percent for the U.S. and Japan respectively. Indeed the two categories of electrical and electronic and computers and communications together account for 63 percent of all Korean patents granted in the U.S. in 1998[3]

As a more systematic measure of the concentration of patenting in these countries across technological fields, we calculate the Herfindahl index of patent concentration across the approximately 400 three-digit patent classes, for each of the four economies. As shown by Hall, Jaffe and Trajtenberg (2001), the HHI measure is biased upward when the number of patents on which it is based is small. Essentially, if there is a modest "true" probability of a random patent being in one of many classes, the true concentration may be low; if very few patents are actually observed they can only be in a few classes and the measured concentration will be high. Assuming the unobserved distribution across classes is multinomial, and the observed draws from that distribution are independent, Hall, Jaffe and Trajtenberg show that an unbiased measure of the true concentration is given by:

$$\hat{H} = \frac{N \cdot HHI - 1}{N - 1}$$

where $\hat{H}$ is the bias-adjusted Herfindahl measure, N is the number of patents, and HHI is the traditional Herfindahl, calculated as the sum of squared shares across patent classes.

[3] For Korea and especially Taiwan, unlike the U.S. and Japan, the "other" category captures an extremely large fraction of patents. In Table 1, we report the two largest sectors within the other category. For Korea these are receptacles and apparel and textile. In the Taiwanese case, the "miscellaneous" group accounts for

As N grows large, $\hat{H}$ converges to the traditional measure, but for small N the adjustment can be quite large. For example, if there are 8 patents spread evenly across 4 classes, the HHI is .25, but $\hat{H}$ is about .14. If there were only 4 patents spread across 4 classes, the HHI would still be .25, but $\hat{H}$ is actually zero.

Figure 1 presents the bias-adjusted Herfindahl across patent classes over time for each country.[4] It shows the technological concentration of Taiwan as similar to that of Japan up until the mid-1990s, after which there is evidence of a significant upward trend. This is at least partly associated with the increasing focus on electronics patents that is visible in Table 1. The technological concentration of Korea varies much more from year to year, but appears to be rising over time. In the 1980s, it was comparable to that of Japan, but by the mid-1990s was about twice as high. As discussed below in connection with Figure 3, rising technological concentration in the 1990s in Korea was accompanied by a similar rise in concentration across patent assignees. Large Chaebols associated with Samsung, Hyundai and Goldstar made major investments in penetrating specific high-tech industries, and this seems to be reflected in the concentration of patenting in these entities and the sectors they targeted.

[Insert Figure 1 here]

The trends in overall technological concentration for Korea and Taiwan mask to some extent significant shifts that have occurred with respect to *which* areas are most important. The share of electrical and electronic patents in total Korean patents increased from 5 percent in 1985 to 35 percent in 1998, whereas the share of All Other patents declined from 41 percent to 11 percent during the same period. The fraction of electrical and electronic patents increased from 13 percent to 34 percent for Taiwan, with the decline again occurring in the All Other category. Besides the size difference between the northern and the southern economies, and the fact that Korea and Taiwan have been fast developing, we suspect the uneven patent portfolios of Korea and Taiwan may also have to do with the industry policy of the two economies, which is characterized by targeting,

as much as 20% of the patents Taiwan received in 1985 and 10% in 1998. The second largest group in the other category for Taiwan is furniture and house fixtures.

[4] The unadjusted HHI is much higher for Korea, and to a lesser extent Japan, in the early years when their patent totals were relatively low.

or preferential policies to promote certain industries (Amsden, 1989; Dollar and Sokoloff, 1994).

Lastly, we compare the technological significance of the four economies' patents using the average number of citations a patent receives as an indicator of the patent's quality. Given the strong evidence of the geographical localization of patent citation (Jaffe, Trajtenberg, and Henderson, 1993), the average cites we report in Table 1 are based on citations made by U.S. patents only. In looking at citations from the U.S. to patents of Japan, Korea and Taiwan, the phenomenon of geographical localization is held constant, permitting comparisons of citation rates for these 3 recipient countries. The overall average cites suggest that Japanese patents are technologically more significant than Korean and Taiwanese patents. However, this overall average comparison may conceal the probable increasing significance of the latter. Although the average of 3.54 cites a 1985 Korean patent receives is largely driven by patents in the other categories, Korean and Taiwanese patents receive at least as many citations as Japanese patents in mechanical and electrical and electronic categories respectively in 1985. At the end of the data period, no patents have received very many citations because very little time has passed in which to observe them, but limited information suggests rough parity between Korea and Japan, and Taiwanese patents are actually more highly cited in all categories than those of Japan.

III. Korea and Taiwan: from imitators to innovators

We will not elaborate on the economic success that Korea and Taiwan have achieved in the second half of the twentieth century. It has been documented and debated extensively elsewhere (World Bank, 1993; Krugman, 1994). Our focus is the role of knowledge diffusion from the U.S. and Japan in the technological progress that Korea and Taiwan have obtained. With a successful export-oriented development strategy and an interventionist government, both Korea and Taiwan have worked hard to move up the international technology ladder. In this process many Korean and Taiwanese companies have graduated from imitators of western technology to genuine innovators (Kim, 1997). The electronic industry, where for example, Korea's Samsung and Taiwan's Acer are already world players, is often cited to attest to the success story.

[Insert Figure 2 here]

We plot the number of patents per 100,000 people for U.S., Japan, Korea, Taiwan, and Israel from 1977 to 1999 in Figure 2 to provide some further comparison. The performance of Korea and Taiwan has been very impressive. Korea started from a low base – 0.02 in 1977, but managed to increase it to 7.57 in 1999. The number of patents for every 100,000 Taiwanese increased from 0.31 to 16.78 from 1977 to 1999. During the same period, Israel, another newly industrializing economy with a cutting-edge high-tech sector (Trajtenberg, 2001), increased the number of patents for every 100,000 Israelis from 2.57 to 12.94. In 1994 Taiwan surpassed Israel for the first time on this measure of innovation output. Impressive as their performance has been, Korea and Taiwan are still minor players in the world innovation scene, at least in terms of the number of patents. Figure 2 indicates that the dominance of U.S. and Japan shows no sign of shrinking. Nonetheless, Korea and Taiwan have come a long way in catching up with other world innovators.

[Insert Table 2 here]

Another indication of the innovativeness of Korea and Taiwan is their effort to venture into new technological areas. Between 1996 and 1999, the U.S.PTO created a number of new patent classes in response to increasing patent applications in relatively new technological areas. We compare the patenting behavior of the U.S., Japan, Korea, and Taiwan in these new patent classes in the Appendix. At first blush, the list of new classes does seem to represent "cutting edge" technologies, including a number of classes related to data processing and computers. Manuel Trajtenberg has suggested, but never implemented, testing the proximity of a country to the world technology frontier by examining the fraction of patents that are in newly created classes. Applying this test to Korea and Taiwan produces startling results, which are shown in Appendix Table A.2. In 1999, approximately 19% of patents granted to both Korea and Taiwan were in classes new since 1996, compared to 15% for Japan and only 12% for the U.S. The significance of this comparison is greatly mitigated, however, by more detailed examination of the classes involved. Many of these patents are in a single class, Semiconductor Device Manufacturing Process (84 percent of "new-class" patents for Taiwan and 43% for Korea). The heavy patenting by Korea and Taiwan in this category is not surprising given the success of their semiconductor industry. While this is an important "high-tech" industry, it is not clear that it is particularly indicative of truly cutting-edge technology.

Korea and Taiwan's success is due to both their expanding indigenous technological capability and their relentless effort to acquire technology from the west. The two are complementary to each other and reinforce each other, as an economy's ability to absorb new technology or knowledge depends on its indigenous R&D capability (Cohen and Levinthal, 1989). New knowledge absorbed in turn broadens and deepens an economy's technological base, leading to opportunities of further indigenous innovation. Table 2 compares R&D intensity as measured by the ratio of R&D expenditure to GDP for U.S., Japan, Korea, and Taiwan. In about two decades, R&D expenditure increased from 0.6 percent of GDP to 2.9 percent and 2.1 percent in Korea and Taiwan respectively. In fact the 1998 R&D-GDP ratio of Korea exceeded those of Germany (2.3%), France (2.2%), and Great Britain (1.83%), and was similar to those of the U.S. and Japan.

Technology diffusion and knowledge spillover from developed economies, particularly Japan and the U.S., has played an important role in the success of Korea and Taiwan. Hobday (1995) identified several mechanisms through which Korea and Taiwan have acquired foreign technology. These include foreign direct investment (FDI), joint ventures, licensing, original equipment manufacture (OEM), and capital goods import. Korea and Taiwan have much in common in their relationship with Japan and the U.S.. Both were colonized in the first half of the twentieth century by Japan. Both received substantial aid from the U.S. after the Second World War. Both have made U.S. their major export market. However, there are major differences between these economies as well.

[Insert Figure 3 here]

In venturing to new industries and technologies, Korea has relied on big business groups, or the Chaebols, which bear much resemblance to their Japanese antecedent, the *Zaibastu*. Taiwan has seen a large number of small and medium enterprises playing an active role. In Figure 3 we plot the Herfindahl index of patent concentration across patent assignees for the four economies.[5] Korea's high concentration of patent assignees certainly reflects the role of big business groups in the country's economic life. In fact the degree of concentration increased steadily from the late 1980s to early 1990s and has been rising again since 1997. The degree of concentration of inventors in Taiwan is lower than that in Korea, but it has also been rising and is still much higher than the concentration in the U.S. and Japan. The U.S., having the most liberal and dynamic innovation system in the world, not surprisingly has the most diversified population of inventors.

[Insert Table 3 here]

The two often-cited channels of technology transfer and diffusion, FDI and capital goods import, have also played different roles in the two economies. As Hobday observed, Korea has shown a greater reliance on Japan for capital goods import than Taiwan. This is no historical accident. The Korean government undertook a restrictive policy towards FDI after the 1970s, which led to a limited role of FDI in Korea's economic development. Instead, "Korea promoted technology transfer in the early years through the procurement of turnkey plants and capital goods" (Kim, 1997, p.42). In Table 3 We present statistics on FDI and capital goods import for Korea and FDI for Taiwan. Japan clearly dominates the U.S. in Korea's capital goods import, consistently accounting for between 40 to 50 percent of Korea's enormous capital goods import. In a study of intra-industry trade between Japan and Korea in the machinery industry, Tahara-Domoto and Kohama (1989) reported that, "at the beginning of the 1980s, Korean government worried about the heavy dependency of the machinery parts imported from Japan. In spite of the increasing trend of local content ratio, more than 90% of the parts imported from foreign countries for various electronics products was from Japan."

The Taiwanese government's more liberal policy towards FDI led to a larger role of FDI in Taiwan than in Korea. U.S. and Japan account for the majority of foreign direct investment in Korea and in Taiwan. In the early 70s, as Table 3 shows, 71 percent of Korea's FDI was from Japan and only 15 percent was from U.S.. In Taiwan, on the other

[5] Again, these numbers have been corrected for the bias due to low patent counts in the early years. The patent "assignee" is the legal entity to which the property right is assigned. To the extent that members of the Chaebol accept patent assignments as distinct entities, our measure of concentration arguably understates the true concentration by treating these affiliated but distinct entities as separate.

hand, 38 percent was from U.S. and 21 percent was from Japan. This pattern remained in the late 70's and early 80's. Since then Japan has become the largest investor in both economies. Taiwan's connection to the U.S. semiconductor industry through Taiwanese engineers working in the U.S. played an important role in the development of the electronics industry in Taiwan (Mathews, 1995, and Saxenian, 2000). According to Mathews and Cho (2000, p.158), Taiwan's strategy of developing the semiconductor industry was largely the brainchild of a group of Taiwanese engineers working in the U.S. semiconductor industry. And the whole industry started off with the licensing of an IC fabrication technology from the U.S. semiconductor firm, RCA in 1976.

In sum, Korea and Taiwan are graduating from imitation to genuine technological innovation and are fast catching up with advanced economies. However, the technological gap remains. U.S. and Japan have maintained a close economic association with Korea and Taiwan through investment and trade. To the extent that FDI and trade are potential facilitators of knowledge diffusion, the economic connections between U.S./Japan and Korea/Taiwan are likely to have an impact on the patterns of knowledge diffusion.

IV. Patent Citation, Technology Proximity, And Knowledge Diffusion

The validity of using patent citations as an indicator of knowledge spillover has been extensively discussed elsewhere (Jaffe, Trajtenberg, and Henderson, 1993 and Jaffe, Trajtenberg and Fogarty, 2000). We do not intend to discuss this issue at length here. Patent citation is a coarse and noisy measure of knowledge spillover, but it does contain much useful information that provides insight on how knowledge may diffuse across geographical and technological regions as well as over time.

[Insert Figure 4 here]

Figure 4 presents a rough picture of how patent citation has evolved for Korea and Taiwan. We observe the following stylized facts. First, U.S. and Japan appear to be the major source of international knowledge flow to Korea and Taiwan. The share of citations made by Korean and Taiwanese patents to their U.S. and Japanese counterparts consistently account for over 70 percent of all citations they make. Second, both Korean and Taiwanese inventors have made more citations to U.S. patents than Japanese patents. Third, there seems to be a trend for the shares of citations to U.S. and Japanese patents to converge, particularly for Korea from the mid 1980s' to 1997. Fourth, Figure 4 also seems to suggest that Korea makes a larger fraction of citations to Japanese patents than Taiwan, whereas Taiwanese inventors cite relatively more U.S. patents.

Stylized fact One suggests that U.S. and Japan are the major sources of knowledge spillover for Korea and Taiwan. Indeed this is part of the reason we choose to focus on U.S. and Japan as the origins of external knowledge that Korea and Taiwan draws upon. It is also consistent with the close economic association between Korea and Taiwan with the U.S. and Japan, which we discussed in the previous section. It is tempting to interpret stylized facts two to four as indicating different patterns of knowledge diffusion from U.S. and Japan to Korea and Taiwan. As we will see, interesting as they are, some of these stylized facts may be artifacts that result from the fact that the raw share of total citations fails to account for certain factors that can potentially distort the picture.

A. Citation frequency and knowledge spillover

One problem with the share of citations measure is that it does not account for the change in the absolute number of the potentially citable patents in the source economy. The number of patents (taken out in the U.S.) by U.S. inventors is larger than the number taken out by Japanese inventors, although the Japanese total has been rising much more rapidly. This makes it more likely, all else equal, for *any patent* to cite U.S. patents than to cite Japanese patents, with this difference declining over time. To the extent that the relative patenting rates of the two countries reflected their relative rates of knowledge creation, the tendency for more citation to the country that produces more patents could be an accurate reflection of the relative contribution of the U.S. and Japan to knowledge spillovers. It is likely, however, that the "propensity to patent in the U.S." is different for the two countries, and has been changing over time. To the extent this is the case, both the greater rates of citation of U.S. patents relative to Japan, and the decline in that difference over time, are likely to be artifacts of differential patent propensities, rather than reflections of differences in spillover flow. For this reason, we develop measures of citation intensity that control for differences in the rate of patenting by the source country.

To remove the effects of the patenting rate of the source country, we interpret the intensity of knowledge spillover as the likelihood that any given inventor in a recipient country will cite any given invention created in a potential source country. This intensity measure does not necessarily capture the overall magnitude of knowledge flow; it is better interpreted as the strength of the communication pathway from the cited country to the citing country. To estimate the likelihood or frequency of citation from Korea and Taiwan to the U.S. and Japan, we adopt a slight modification of the citation frequency measure defined in Jaffe and Trajtenberg (1999):

$$CF_{i-j,t} = \frac{NC_{i-j,t}}{NP_{i,t} NP^{D}_{j,t}} \ , \qquad (1)$$

where $CF_{i\text{-}j,\,t}$ denotes the frequency of country i's patents that are granted in year t citing all potentially citable patents taken out by country j up to t. The numerator of the right hand side of (1), $NC_{i\text{-}j,\,t}$, represents the total number of citations made by i's patents granted in year t to j's patents. The denominator is the product of the number of i's patents in year t ($NP_{i,\,t}$) and the number of *potentially citable* patents in country j as of year t. The number of citations and the number of citing patents are given in the data. It is not immediately clear how the number of potentially citable patents should be constructed. This is the number of patents in the cited country j, which can be cited by an inventor in country i as of year t. Since the knowledge embodies in patents becomes obsolete, the total stock of patents of country j up to year t would not be a proxy for this variable. Instead of trying to construct some kind of measure of an effective pool of patents of the cited country, we propose the following *relative* citation frequency measure:

$$RCF_{k-i-j,t} = \left(\frac{NC_{k-j,t}}{NC_{i-j,t}}\right)\left(\frac{NP_{i,t}}{NP_{k,t}}\right) \qquad (2)$$

where $RCF_{k\text{-}i\text{-}j,t}$ is the ratio of the frequency of country *k* citing country *j* to that of *i* citing *j* in year t. Equation (2) says that for example, the relative frequency of Korean (k) and Japanese (i) inventors citing a U.S. (j) patent is equal to the ratio of the number of citations Koreans make to U.S. patents in year t over the number of Korean patents in year t, multiplied by the inverse of this same ratio for Japan. By looking at the Korean citation frequency to the U.S. *relative* to that of Japan, we remove effects due to the number of U.S. patents available to be cited.

[Insert Figure 5 here]

The relative citation frequency measure in equation (2) is particularly helpful in assessing the fourth stylized fact we identified above, i.e., is it more likely for Korean (Taiwanese) inventors to cite Japanese (U.S.) patents than Taiwanese (Korean) inventors? In Figure 5 we plot four series: Korean citations to the U.S. relative to Japanese citations to the U.S. (RCF_{KUJ}), Taiwanese citations to the U.S. relative to Japanese citations to the U.S. (RCF_{TUJ}), Korean citations to Japan relative to U.S. citations to Japan (RCF_{KJU}), and Taiwanese citations to Japan relative to U.S. citations to Japan (RCF_{TJU}). These ratios are were fairly volatile early in the period, probably due to the relatively small number of citing patents in Korea and Taiwan, but they settle into a reasonably stable pattern in the mid-1980s. For both Korea and Taiwan, the rate of citation to the U.S. is similar to that of Japan, i.e., the relative citation frequency is approximately unity, with perhaps some weak evidence of a higher rate for Taiwan in the 1990s. In contrast, citations from these countries to Japan are at different rates than citations to Japan from the U.S. Korea cites Japan at close to twice the rate that the U.S. does, while Taiwan cites Japan at a rate approximately one-half to two-thirds the U.S. rate.

B. Technology proximity and knowledge spillover

One factor that may account for the observed patterns of citation from U.S. and Japan to Korea and Taiwan is the degree of closeness or similarity between countries in technological space. In other words, if both Japan and Korea do disproportionately more R&D and therefore patent more intensively in electronics than Taiwan and U.S., then we would expect Korean inventors to cite Japanese patents more often than Koreans cite U.S. patents, and more often than Taiwanese patents cite Japanese patents. The technology space is a multi-dimensional space, with each dimension defined by a unique technological area. We use the patent technological class information to construct a measure of the closeness between two countries in the technology space.

The U.S.PTO assigns each granted patent into one of the 400 plus three-digit patent technological classes. Each class represents a unique technological area. The distribution of a country's patents can be thought of as a 400-element vector, with each element being the number of patents assigned to a specific patent technology class. These 400 patent classes span the technology space. We can then compute the closeness between two countries in the technological space as the distance between the two vectors of patent distribution. Following Jaffe (1986) and Jaffe and Trajtenberg (1999), we use the following variable to measure the technological proximity of two countries in a given year:

$$TP_{i,j,t} = \sum_{n=1}^{400} f_{n,i,t} f_{n,j,t} \tag{3}$$

where technology proximity between countries i and j in year t, $Tprox_{i,j,t}$, is the sum of the product of $f_{n,i,t}$, the share of country i's patents in year t allocated to patent class n, and $f_{n,i,t}$, the counterpart for country j. The greater the extent to which the two patent distribution vectors overlap, the bigger the technology proximity between the two countries. When the two vectors are orthogonal, Tprox will be zero. It will be at its maximum when the two vectors are identical.

[Insert Figure 6 here]

In Figure 6, we plot the technology proximities Korea-U.S., Korea-Japan, Taiwan-U.S. and Taiwan-Japan. The most striking contrast is between the Korea-Japan technology proximity and the Taiwan-Japan technology proximity. Korea is much closer to Japan in the technology class distribution of patents than Taiwan is to Japan. This difference increased from the mid 1980s to 1996, and has since shrunk slightly as Taiwan and Japan moved slightly closer to each other. On the other hand, although Korea resembles the U.S. more than Taiwan does, the difference is not large and has been stable. Comparing Figures 5 and 6 we can see that the technology proximity differences vis-à-vis Japan seem quite consistent with the observation that the citation frequency from Korea to Japan is higher than that of Taiwan to Japan. The small and stable difference between the Korea-U.S. and Taiwan-U.S. technology proximities also corresponds to the difference between Taiwanese and Korean citation rates to the U.S. (relative to the Japanese rates) in Figure 5.

Thus, at a descriptive level, we observe a pattern of significant citation of Japanese and U.S. inventions by Korean and Taiwanese patents, with differences that appear to have some connection to patterns of technological proximity. We now move on to econometric estimation of a model of the citation process that incorporates the effects of technological proximity, and allows more explicitly for the gradual diffusion and obsolescence of knowledge over time.

V. A Model for Knowledge Diffusion

We have examined citation frequency at the country level. The basic unit of analysis is for example, the frequency with which Korean patents granted in 1990 cite all U.S. patents. This formulation subsumes within the overall average frequency of citations the time path over which knowledge transfer occurs. On the one hand, knowledge becomes obsolete and therefore is less likely to be cited as time elapses. On the other hand, due to language, geographical, trade, and other barriers, the accessibility to new knowledge grows with time. The two effects are offsetting each other. To account for these factors, we move the unit of our analysis to a more specific level and specify the following citation frequency equation as in Jaffe and Trajtenberg (1999):

$$CF_{iT,jtg} = (1+\gamma Tprox_{iT,jtg})\alpha(i,j,g,T)e^{(-\beta_{1ij}(T-t))}[1-e^{(-\beta_2(T-t))}]+\varepsilon_{iT,jtg} \quad (4)$$

where $CF_{iT,jtg}$ is the frequency of country *i*'s patents in year *T* citing country *j*'s patents in technology area *g* in year *t*. *Tprox* is the technology proximity index measuring the technological closeness of the citing country *i*'s patents in year *T* and the cited country *j*'s patents in year *t* in one of the six technology subclasses, *g*.[6] The rate at which a piece of knowledge embodied in a patent becomes obsolete is measured by β_1, which is allowed to vary across country pairs. β_2 measures the rate of diffusion, i.e., all else equal, how fast a piece of knowledge travels across geographical and technological areas. The various indices take on the following values: *i* = Korea, Taiwan, U.S., Japan; *j* = U.S., Japan; *T* =1977, …, 1999; *t* =1963,…, 1998; g =1,…,6. For citing countries, we include U.S. and Japan for comparison with earlier studies, although our main interest focuses on the citing behavior of Korea and Taiwan.

In addition to the above three basic parameters, we also exam how the citation frequency differs across technological and geographical areas, and time by including a number of shift parameters, which are collectively denoted by $\alpha(i,j)$:

[6] Jaffe and Trajtenberg (1999) derive Eq. (4) from an underlying model in which a single patent cites other patents with a probability that is increased by γ if the patents are in the same class.

$$\alpha(i,j,g,T) = \alpha_{ij}\alpha_g\alpha_T \quad (5)$$

where all α's enter in multiplicative form[7]. For example, for α_{ij}, there are eight parameters for the eight country pair combinations: U.S.-U.S., U.S.-JP, JP-U.S., JP-JP, KR-U.S., KR-JP, TW-U.S., and TW-Japan. When equation (4) is estimated, one of the parameters, say $\alpha_{U.S.\text{-}U.S.}$, is set to one as the reference case. If $\alpha_{KR\text{-}U.S.}$ is estimated to be 0.5, it means a Korean patent is only half as likely to cite a U.S. patent as a U.S. patent is to cite a U.S. patent. We also allow the rate of decay, β_1, to differ across country pairs by including β_{ij}, which is similar to α_{ij} by construction.

As we mentioned before, the relative citation frequency patterns we observed in Figure 5 are cumulative in the sense that the citation frequency has been aggregated over all the lags between t and T, to use the notation in equation (4). The parameters α_{ij} and β_{ij} help us to decompose this aggregate difference into two components: on average how much more likely it is for say Korea to cite U.S. relative to U.S. citing U.S. and how much faster (slower) Korea cites U.S. than U.S. citing U.S.. α_{ij} and β_{ij} have offsetting effects on the cumulative citation frequency: higher α means a higher probability of citation across all lags, while higher β_1 means the rate of citation decays more quickly, which (holding other parameters constant) reduces the cumulative total made by any given lag.

VI. Results

The model in equation (4) is estimated with weighted nonlinear least square (NLS). As long as the error term ε is not correlated with any of the regressors in (4), the NLS estimation should yield consistent estimates. We weight each of the observations to account for potential heteroskedasticity with the reciprocal of $\sqrt{NP_{jtg}NP_{iT}}$, where NP_{jtg} is the number of potentially citable patents and NP_{iT} is the number of potential citing patents in the cell defined by *j, t, g, i*, and *T*.

[Insert Table 4 here]

Results from estimating various variations of the model are presented in Table 4. Column (3) represents the "full" model as presented in Eq. (4). Column (1) constrains

[7] There are six α_g's, one for each technological are, and 23 α_T's, one for each T.

the obsolescence effects to be the same for all country pairs. Column (2) suppresses the technological proximity effect. Column (4) explores whether, given the rapid changes in apparent citing behavior visible in Figures 4 and 5, there are measurable differences in citation rates from Korea and Japan after 1990, controlling for other effects.

All parameters estimated are highly statistically significant, far above conventional confidence levels. The adjusted R^2 of the model, ranging from 0.46 for the bare bone version to 0.80 for the full model, suggests that the model fits the data reasonably well. The technology proximity parameter is very significant, both economically and statistically. The coefficient from the full model indicates that, all else equal, citations to patents in the same patent class as the citing patent are over 500 times as likely as citations to patents in other classes. This is even bigger than the corresponding estimate of 99 that Jaffe and Trajtenberg (1999) estimated. It is unclear why we get this larger technological proximity effect. One possibility is that we are using more recent data (citations made through 99 versus through 94). The recent surge in patenting has been generally observed to have led to overburdened patent examiners; it is possible that this has led to citation searches that are less complete, and hence less likely to require citations to more technologically distant inventions.[8]

The α parameter for each country pair captures the overall average rate of citation, relative to citations by U.S. patents to U.S. patents, which is normalized to unity. Consistent with the previously noted finding of geographic localization, all of these are less than unity, except for Japan-Japan, which indicates extreme localization of Japanese citations, consistent with previous findings. The effects of greatest interest for this group of parameters are the estimates for Korea-U.S., Korea-Japan, Taiwan-U.S., and Taiwan-Japan. The striking result is that Korea cites Japan at a rate 86% of the base U.S.-U.S. rate, while all of the other estimates are in the 50%-60% range. What this says is that, on average, Korea is almost as close to Japan as the U.S. is to itself. This is higher than any other cross-border rate found previously; it suggests, for example, that Korea is closer to Japan in this sense than the U.K. is to the U.S. (estimated at .72 in Jaffe and Trajtenberg, 1999). In contrast, the rates for Korea citing the U.S. and for Taiwan citing both Japan

[8] Hall, Jaffe and Trajtenberg (2001) show that the absolute number of citations made over this period has been falling, also suggesting less thorough patent searches.

and the U.S. are slightly lower than most of the pairwise estimates for G-5 countries found by Jaffe and Trajtenberg. Overall, then, Taiwan draws on Japan and the U.S., and Korea draws on the U.S. at rates consistent with their being slightly more remote in terms of knowledge flows than G-5 countries are from each other.

While these α coefficients shift the rate of citation at all lags, the β_1 parameters capture the speed with which citations decay. The estimated base value for β_1 (again corresponding to citations from the U.S. to the U.S. is about .2, implying a modal lag of about 5 years, i.e., on average, the peak of the citation frequency occurs about 5 years after a patent is granted. This value is similar to that found by Jaffe and Trajtenberg. The estimates for each country pair indicate the decay rate relative to this base, with an estimated value greater than unity implying faster decay. Interestingly, all of the Korea and Taiwan estimates are greater than one, implying a focus on more recent inventions, compared to citations made by U.S. inventors. This is particularly true for Korea, whose values of 1.30 (for citations to the U.S.) and 1.48 (for citations to Japan) exceed the estimate for Japan citing the U.S. and approach the estimate of 1.55 for Japan citing itself. Thus these countries (particularly Korea) appear to behave in a manner similar to Japan, focusing more narrowly on recently developed technology to an extent significantly greater than is the case in the other G-5 countries. This is particularly interesting, given that it might have been supposed that Korea and Taiwan are "catching up," potentially adapting and building on older technology than would be of interest to more technologically advanced economies. The age of their citations is not consistent with that view of innovation in countries like Korea and Taiwan.

Comparison of columns (2) and (3) shows that there is some degree of interaction between the technological proximity effects and the estimated citation parameters. In particular, the estimated α for Korea citing Japan is increased significantly if the technological proximity effect is suppressed (1.34 in column (2) as compared to .86 in column (3)). In effect, part of the high rate of citation can be attributed to the close technological proximity of the two countries, visible in Figure 6. Once this effect is controlled for, the "pure" citation frequency is not estimated to be as high. Other contrasts between columns (2) and (3) are not as easy to relate to the contrasts in Figure 6. This could be because there is variation in the proximities between countries at the lower level of aggregation used in the estimation, and also because all of the pairwise effects are changing simultaneously between columns (2) and (3), including those in the reference case of U.S.-U.S.

Comparison of columns (1) and (3) illustrates how overall citation rates are affected by both the multiplicative α effects and the obsolescence effect captured by β_1. When β_1 is allowed to vary, Japan-Japan and Korea-Japan evidence high rates of obsolescence, which reduce the predicted number of citations at later lags. If this variation in obsolescence rates is suppressed as in column (1), the model attempts to fit the lower citation rates at high lags by reducing the *overall* citation intensity parameterized by α. Thus, the α effects for Japan-Japan, Korea-Japan and Korea-U.S. are reduced in column (1). Allowing both the α and β_1 parameters to vary in column (3) allows the model to fit both the higher overall citation intensity and higher obsolescence of these pairs.

Finally, Column (4) was motivated by differences in citation patterns from Korea and Taiwan in the latter part of the time period that appear in Figures 1,3,4 and 5. We allowed both the α and β_1 parameters to differ in value for citations made before and after 1990. As can be seen, however, there are no large differences in these parameters. This means that the changes visible in the Figures were not associated with changes in the underlying citation rate, after controlling for other factors such as technological proximity.

[Insert Figures 7 and 8 here]

Using the estimated coefficients in column (3) of Table 4, we calculated simulated citation distributions. These simulated frequencies are driven by the estimated the α and β_1 parameters, as well as the technological proximities between countries. In Figure 7 the estimated frequencies of Japanese, Korean, and Taiwanese patents citing U.S. patents are plotted, as a function of time elapsed after initial patent grant. The rising and then falling citation probability is the combination of the diffusion and obsolescence effects estimated in the model. The combination of similar α and higher β_1 for Korea is visible in that the simulated citation frequency is initially higher and than lower for Korea as compared to Taiwan. Overall, the pattern of citation of these 3 countries to the U.S. is similar, showing again the surprising extent to which Korea and Taiwan behave like Japan with respect to citation of U.S. patents.

The much more intensive knowledge flow from Japan to Korea than to Taiwan is dramatically displayed in Figure 8, where the estimated frequencies of Korean, Taiwanese, and U.S. patents citing Japanese patents are plotted. Not only do Korean patens cite Japanese patents much more intensively than do Taiwanese patents, but the Korean citations also occur faster than Taiwanese ones. A year after a Japanese patent is granted, the likelihood that a Korean patent cites it is over two times larger than the likelihood that it is cited by a Taiwanese patent. The peak frequency of the Korean citations is more than two times as large as that of the Taiwanese citations. The modal lag for the Korean citation frequency distribution is 4 years, whereas the Taiwanese modal lag is 6 years.

VII. Conclusions

Korea and Taiwan are graduating from imitation to innovation. The number of patents granted in the U.S. to these two economies has been growing rapidly. On per capita patent count terms, Korea and Taiwan are catching up with the lower-tier developed economies. Anecdotal evidence suggests that knowledge diffusion from the advanced economies, particularly U.S. and Japan, played an important role in this catching up process. We used patent citation as an indicator of knowledge diffusion to investigate the pattern and intensity of knowledge flow from U.S. and Japan to Korea and Taiwan. With a knowledge diffusion model that explicitly takes into account the role of technology proximity and knowledge decay and knowledge diffusion over time, we analyzed several stylized patterns that are derived from simple citation statistics.

We found interesting differences between the citation practices of Korea and Taiwan. Korea is much closer to Japan than it is to the U.S., whereas Taiwan draws on both Japan and the U.S. with similar frequency. Further, the frequency of citation of Taiwan to the U.S. and Japan (after controlling for other effects) is similar to the frequency of citation of Korea to the U.S., making the high frequency of citation of Korea to Japan the "outlier" among these four country pairs. This high citation dependence of Korea on Japan is partly due to their technological proximity, but even after controlling for that effect, it is very high, higher than has been found among any of the G-5 countries.

These patterns of knowledge flow seem to be consistent with the anecdotal evidence various authors have provided that Japan and the U.S. have played an important role in the economic development of Korea and Taiwan through investment and trade. Korea maintains a very close link to Japan economically and technologically. Our data show that Japan is a more important source of foreign direct investment and capital goods for Korea than the U.S. The fact that there is a higher incidence for Taiwan to cite U.S. patents than Japanese patents is also consistent with the argument that foreign direct investment from the U.S. and linkage of Taiwanese firms to U.S. firms through returning students and Taiwanese expatriates working in the U.S. play an important role in Taiwan's technological progress, particularly in the electronics industry. Therefore, our study points to the potential linkage between international knowledge flow and foreign direct investment and trade in capital goods.

The other strong finding is that Korea and, to a lesser extent, Taiwan exhibit rapid obsolescence, implying focus on relatively recent inventions and neglect of older technology in their citation patterns. This is somewhat surprising given their presumed distance from the world technology frontier. In this behavior they resemble Japan, indeed they are more like Japan in this respect than are other G-5 countries. This apparent focus on "rapid" adaptation of recent technology would be a fruitful area for future research.

Our analysis of patent citation data has yielded several interesting patterns of knowledge diffusion from U.S. and Japan to Korea and Taiwan. Although knowledge has the property of being non-rival and non-exclusive, it follows different paths in diffusing across countries. Many authors have proposed various channels through which knowledge diffusion may be facilitated, such as foreign direct investment, international trade, scholarly exchange, exchange of personnel, so on and so forth. Therefore, an interesting research avenue we would like to pursue is whether and to what extent these channels may facilitate knowledge diffusion from world innovators to developing countries. This line of research is likely to generate interesting policy implications, particularly for developing countries.

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Appendix—New Patent Classes

Table A.1 List of patent classes created, 1996-99	
Class number	Description
349	Liquid Crystal Cells, Elements and Systems
386	Television Signal Processing for Dynamic Recording or Reproducing
396	Photography
399	Electrophotography
438	Semiconductor Device Manufacturing: Process
442	Web or Sheet Containing Structurally Defined Element or Component (428/221)
463	Amusement Devices: Games
508	Solid Anti-Friction Devices, Materials Therefor, Lubricant or Separate Compositions for Moving Solid Surfaces, and Miscellaneous Mineral Oil Compositions
510	Cleaning Compositions for Solid Surfaces, Auxiliary Compositions Therefor, or Processes of Preparing the Compositions
516	Colloid Systems and Wetting Agents; Subcombinations Thereof; Processes Of
700	Data Processing: Generic Control Systems or Specific Applications
701	Data Processing: Vehicles, Navigation, and Relative Location
702	Data Processing: Measuring, Calibrating, or Testing
704	Data Processing: Speech Signal Processing, Linguistics, Language Translation, and Audio Compression/Decompression
705	Data Processing: Financial, Business Practice, Management, or Cost/Price Determination
706	Data Processing: Artificial Intelligence
707	Data Processing: Database and File Management, Data Structures, or Document Processing
708	Electrical Computers: Arithmetic Processing and Calculating
709	Electrical Computers and Digital Processing Systems: Multiple Computer or Process Coordinating
710	Electrical Computers and Digital Data Processing Systems: Input/Output
711	Electrical Computers and Digital Processing Systems: Memory
712	Electrical Computers and Digital Processing Systems: Processing Architectures and Instruction Processing (e.g., Processors)
713	Electrical Computers and Digital Processing Systems: Support
714	Error Detection/Correction and Fault Detection/Recovery

Table A.2 Fraction of Country Patents in the New Classes

A. Fraction of total patents in all new patent classes

	1996	**1997**	**1998**	**1999**
U.S.	8.3%	8.9%	11.3%	11.7%
Japan	15%	14.2%	15.2%	14.8%
Korea	16.1%	17.9%	17.2%	19.2%
Taiwan	13.1%	14.7%	16.1%	19.4%

B. Fraction in Class 438: Semiconductor Device Manufacturing: Process

	1996	**1997**	**1998**	**1999**
U.S.	0.9%	1.2%	1.2%	1.8%
Japan	1.9%	2.1%	1.8%	2.6%
Korea	7.1%	9.3%	7.4%	8.2%
Taiwan	11%	12.2%	12.2%	16.2%

Table 1
Basic Patent Statistics

	1985		1998		Overall average	
	Patents	Cites	Patents	Cites	Patents	Cites
(1) US: All Classes	39556	5.7	80291	0.4	47252	4.0
Chemical	21%	5.4	14%	0.2	9591	3.7
Computers & Communications	8%	9.1	20%	0.8	4190	5.8
Drugs & Medical	7%	10.3	15%	0.3	3286	6.4
Electrical & Electronic	17%	5.5	15%	0.3	7785	3.7
Mechanical	22%	4.2	15%	0.3	10624	3.2
Other	26%	5.2	20%	0.3	11776	3.8
(2) Japan: All Classes	12746	3.1	30840	0.1	10843	2.1
Chemical	20%	3.3	15%	0.1	2142	2.2
Computers & Communications	13%	4.5	26%	0.2	1811	2.7
Drugs & Medical	4%	3.7	5%	0.1	493	2.6
Electrical & Electronic	20%	3.4	23%	0.2	2339	2.1
Mechanical	28%	2.2	21%	0.1	2731	1.6
Other	14%	3.1	10%	0.1	1327	2.1
(3) Korea: All Classes	41	3.5	3259	0.2	342	0.9
Chemical	17%	2.1	11%	0.1	55	0.5
Computers & Communications	10%	2.3	28%	0.2	162	1.0
Drugs & Medical	5%	1.5	2%	0.2	15	1.3
Electrical & Electronic	5%	2.5	35%	0.2	190	1.0
Mechanical	22%	2.7	14%	0.1	61	0.7
Other	41%	5.2	11%	0.1	47	1.1
Receptacles	12%		0.50%			
Apparel & Textile	10%		2%			
(4) Taiwan: All Classes	174	3.0	3100	0.2	679	1.5
Chemical	7%	2.7	8%	0.1	52	1.1
Computers & Communications	3%	3.3	10%	0.3	51	1.9
Drugs & Medical	2%	2.5	2%	0.1	21	1.9
Electrical & Electronic	13%	3.4	34%	0.3	173	1.4
Mechanical	22%	1.7	19%	0.2	156	1.4
Other	52%	3.4	27%	0.2	239	1.6
Furniture, House Fixtures	11%		6%			
Miscellaneous	20%		10%			

Table 2. Research and development intensity in US, Japan, Korea, and Taiwan

	R&D as a share of GDP (%)					
	1978	1982	1988	1990	1995	1998
US	2.2	2.5	2.7	2.7	2.6	2.8
Japan	1.8	2.2	2.7	3	2.7	3
Korea	0.6	1	1.9	1.9	2.7	2.9
Taiwan	0.6	0.9	1.3	1.7	1.8	2.1

Source: OECD Basic Science and Technology Statistics, 1999; US NSF website (www.nsf.gov); National Statistical Office of Korea website (www.nso.go.kr); and National Science Council of Taiwan website (www.nsc.gov.tw).

Table 3. FDI and capital goods import in Korea and Taiwan
(million US dollars)

	1972-1976	1977-1981	1982-1986	1987-1994
Korea				
FDI				
Japan	71%	42%	50%	34%
US	15%	33%	33%	28%
Total	879.4	720.6	1,767.70	8891.2
Capital goods import				
Japan	50%	51%	41%	43%
US	22%	22%	24%	28%
Total	8,841	27,978	50,978	188,104[a]
Taiwan				
FDI				
Japan	21%	27%	33%	33%
US	38%	48%	34%	23%
Total	598.7[b]	1013.1	2580.9	11929

Source: The Korean data are from Kim (1997: 40-41). The Taiwanese FDI data are from Ministry of Economic Affairs (1996).

Note:

[a] The Korean capital goods import is for the period, “1987-1993”.

[b] The Taiwanese FDI data is for the period 1971-1975 (Chou, 1988).

Table 4. Diffusion Function Estimation

	(1)	(2)	(3)	(4)
Tprox	577.76* (34.97)		576.30* (31.70)	580.05* (32.01)
$\alpha_{JP\text{-}US}$	0.40* (0.004)	0.46* (0.01)	0.48* (0.01)	0.48* (0.01)
$\alpha_{KR\text{-}US}$ *(pre-1990)*	0.39* (0.01)	0.49* (0.03)	0.57* (0.02)	0.56* (0.04)
$\alpha_{KR\text{-}US}$ *(post-1990)*				0.57* (0.02)
$\alpha_{TW\text{-}US}$ *(pre-1990)*	0.42* (0.01)	0.37* (0.02)	0.52* (0.02)	0.51* (0.03)
$\alpha_{TW\text{-}US}$ *(post-1990)*				0.52* -0.02
$\alpha_{US\text{-}JP}$	0.47* (0.004)	0.44* (0.01)	0.43* (0.01)	0.43* (0.01)
$\alpha_{JP\text{-}JP}$	0.88* (0.01)	2.56* (0.03)	1.64* (0.02)	1.64* (0.02)
$\alpha_{KR\text{-}JP}$ *(pre-1990)*	0.49* (0.01)	1.34* (0.05)	0.86* (0.02)	0.93* (0.05)
$\alpha_{KR\text{-}JP}$ *(post-1990)*				0.86* (0.02)
$\alpha_{TW\text{-}JP}$ *(pre-1990)*	0.38* (0.01)	0.35* (0.03)	0.48* (0.03)	0.53* (0.05)
$\alpha_{TW\text{-}JP}$ *(post-1990)*				0.47* (0.03)
$\beta_{1,JP\text{-}US}$		1.09* (0.01)	1.13* (0.01)	1.13* (0.01)
$\beta_{1,KR\text{-}US}$		1.21* (0.04)	1.30* (0.03)	1.30* (0.03)
$\beta_{1,TW\text{-}US}$		1.08* (0.04)	1.16* (0.03)	1.16* (0.03)
$\beta_{1,US\text{-}JP}$		0.93* (0.01)	0.93* (0.01)	0.93* (0.01)
$\beta_{1,JP\text{-}JP}$		1.55* (0.01)	1.55* (0.01)	1.55* (0.01)
$\beta_{1,KR\text{-}JP}$		1.45* (0.03)	1.48* (0.03)	1.48* (0.03)
$\beta_{1,TW\text{-}JP}$		1.15* (0.06)	1.18* (0.05)	1.18* (0.05)
β_1	0.23* (0.001)	0.20* (0.001)	0.20* (0.001)	0.20* (0.001)
β_2	1.19E-6* (5.70E-08)	3.39E-6* (7.60E-08)	9.83E-7* (4.30E-08)	9.78E-7* (4.30E-08)
No. of obs.	27600	27600	27600	27600
Adjusted R^2	0.77	0.74	0.80	0.80

Figure 1
Herfindahl Index of Patent Concentration Across Patent Classes
(Bias-adjusted)

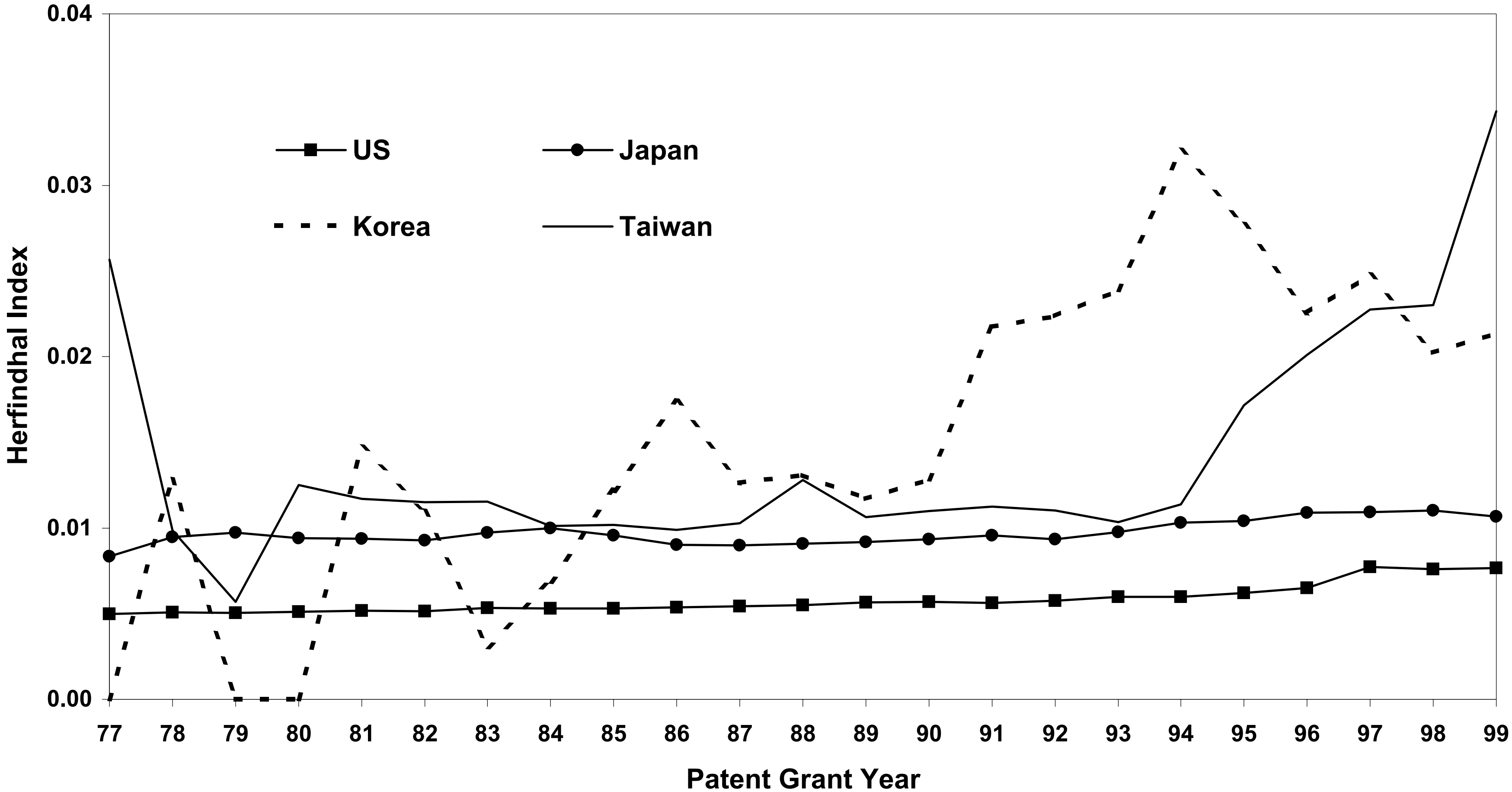

Figure 2
Patents per Capita

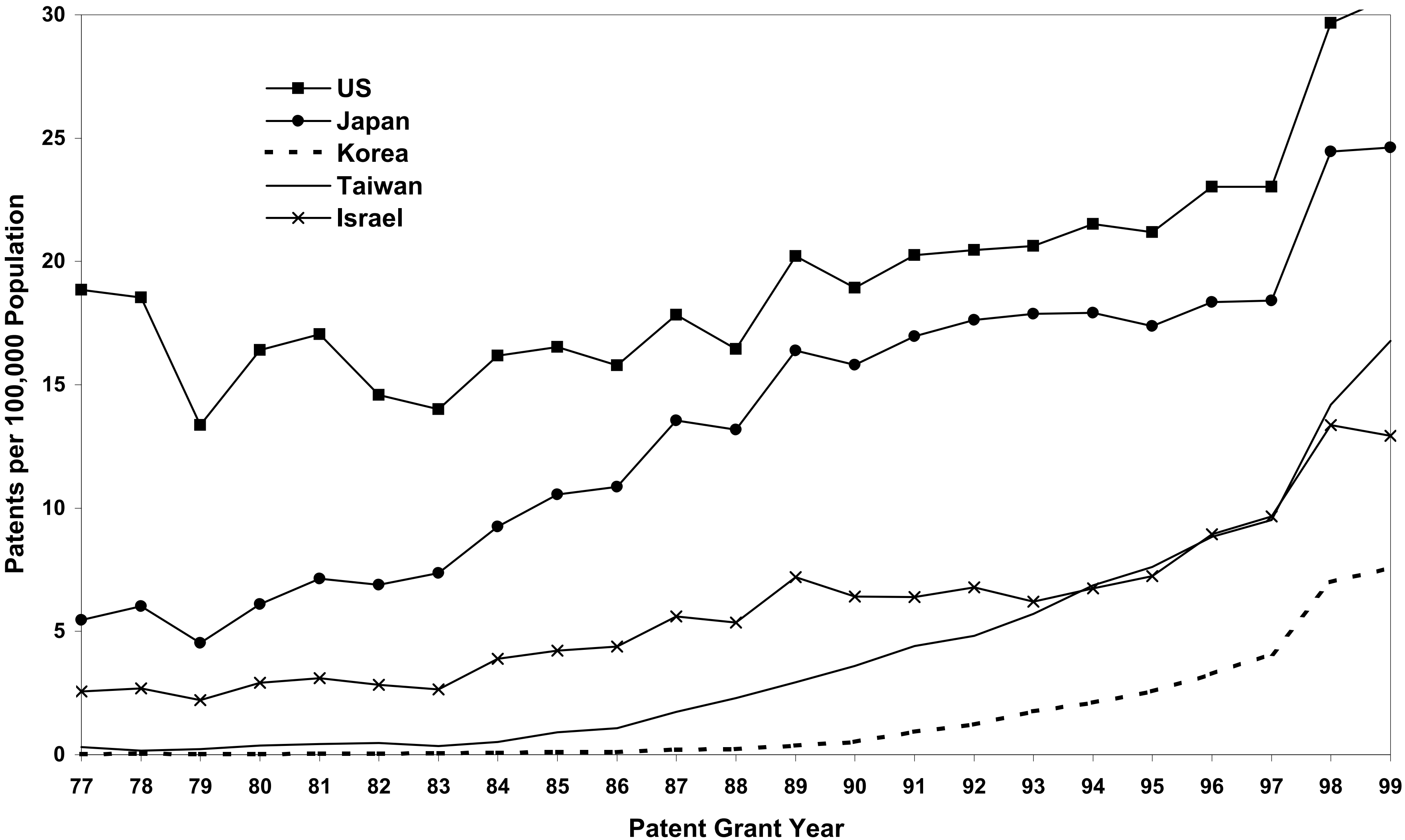

Figure 3
Herfindahl Index of Patent Concentration Across Assignees
(Bias-adjusted)

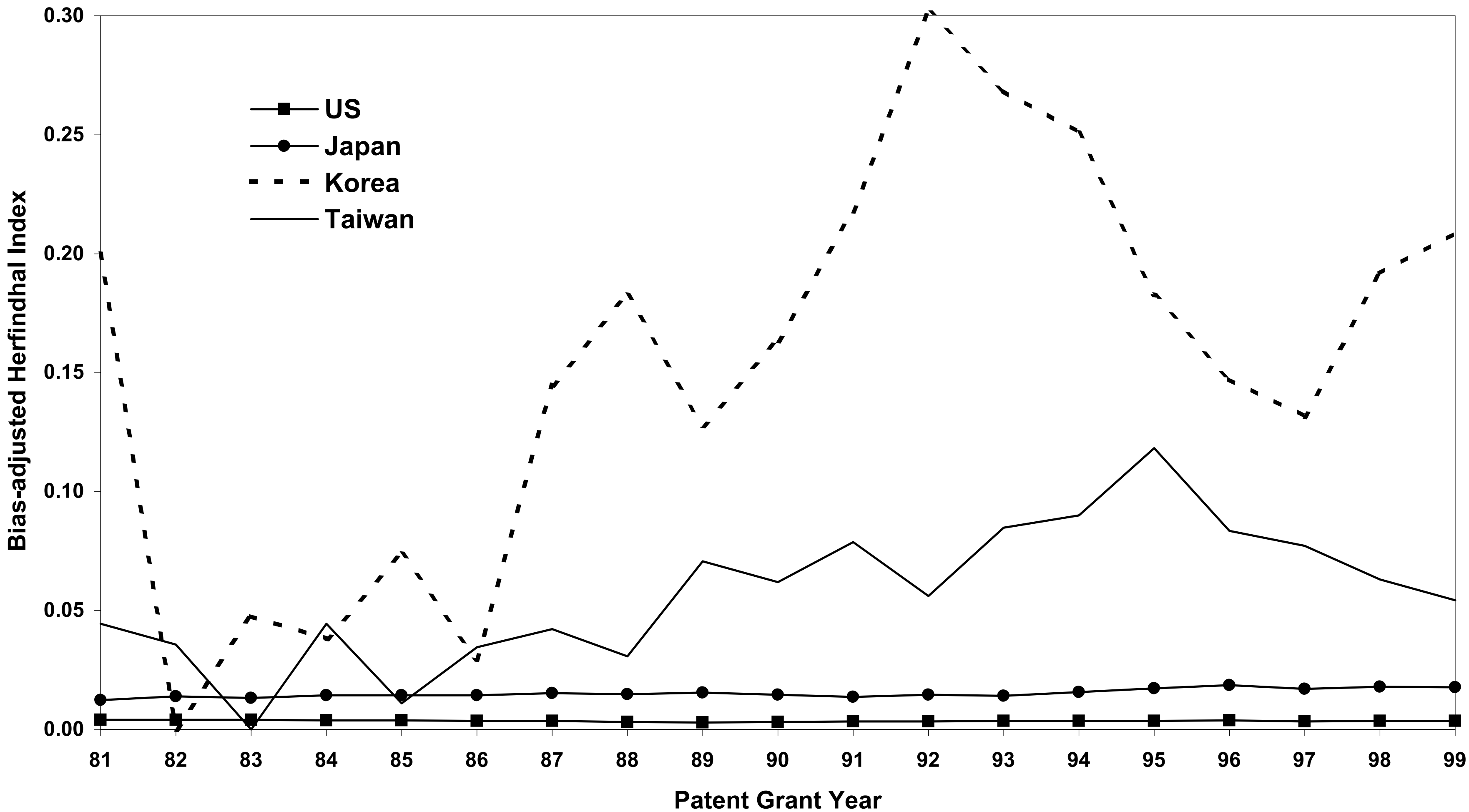

Figure 4
Japan and US Shares of Citations Made by Korea and Taiwan

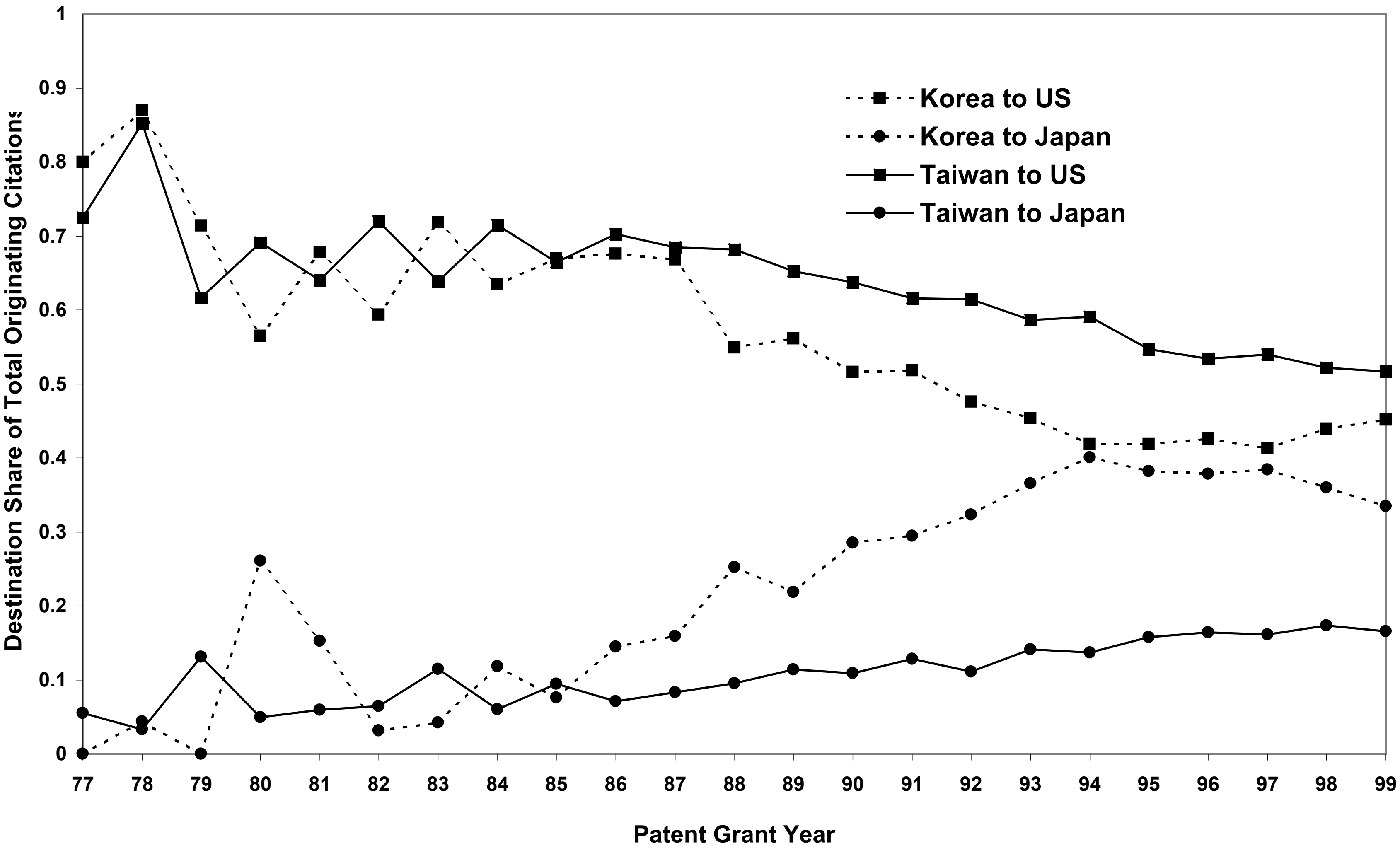

Figure 5
Relative Citation Frequency

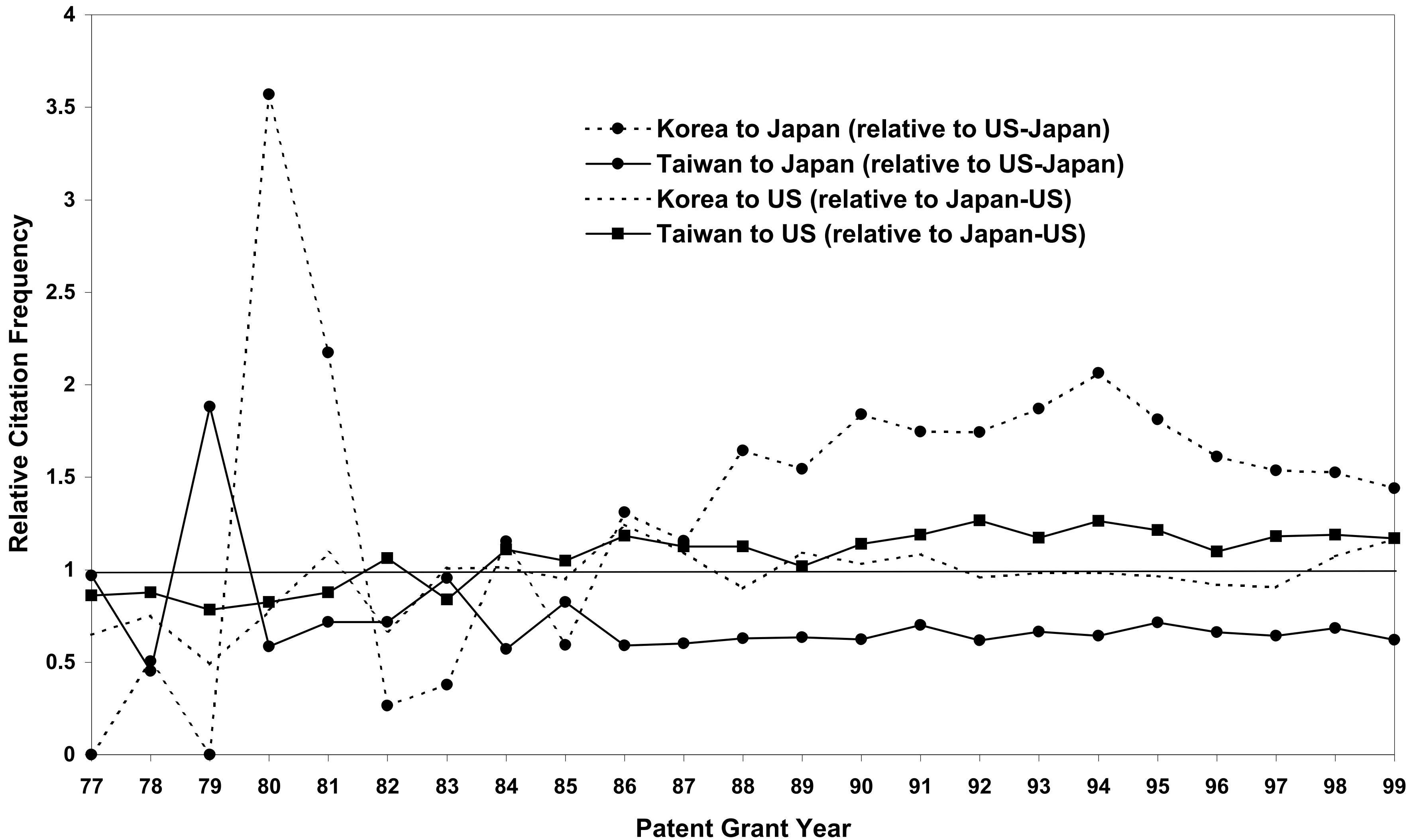

Figure 6
Technological Proximities

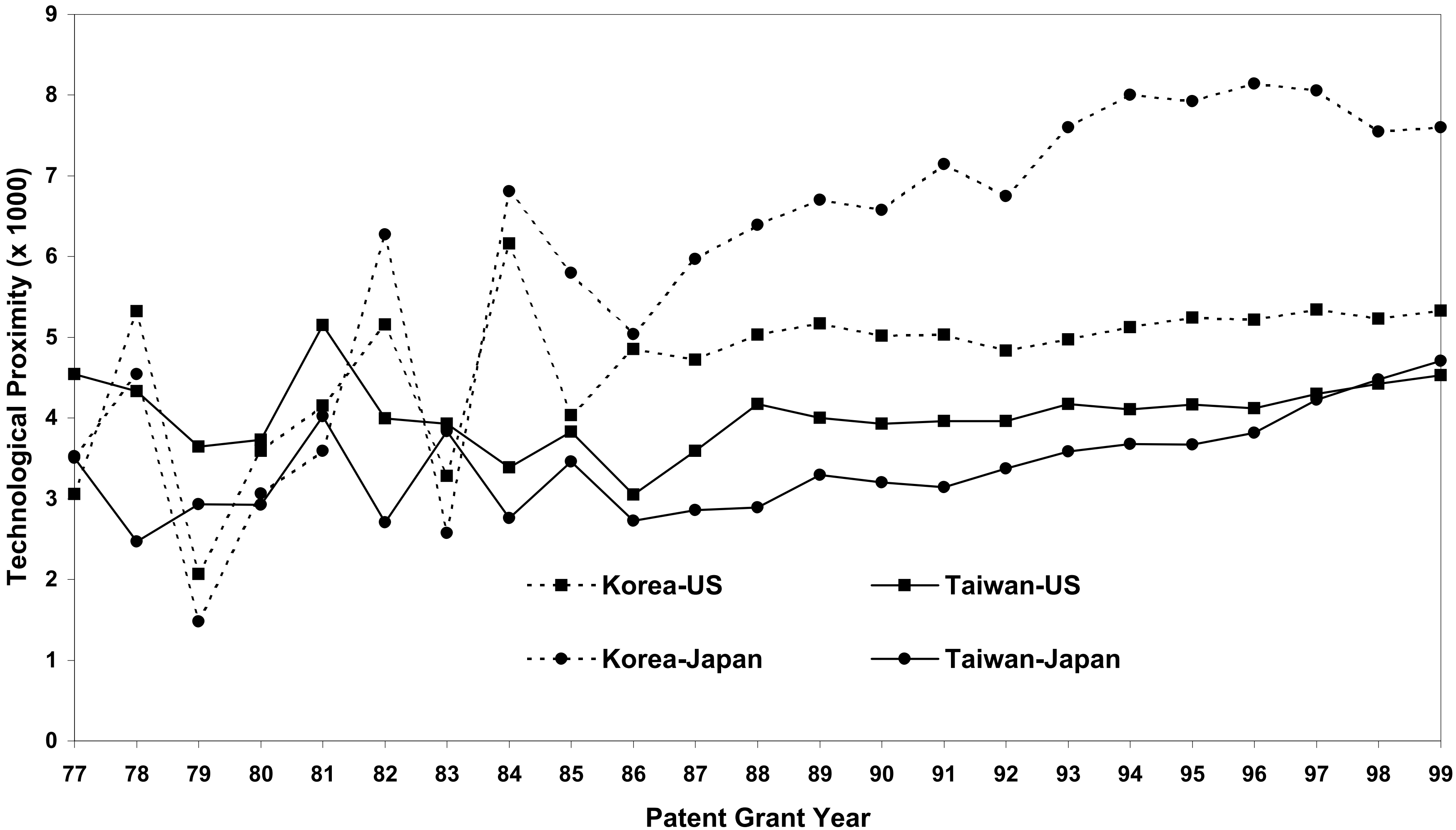

Figure 7
Simulated Frequency of Citation to US

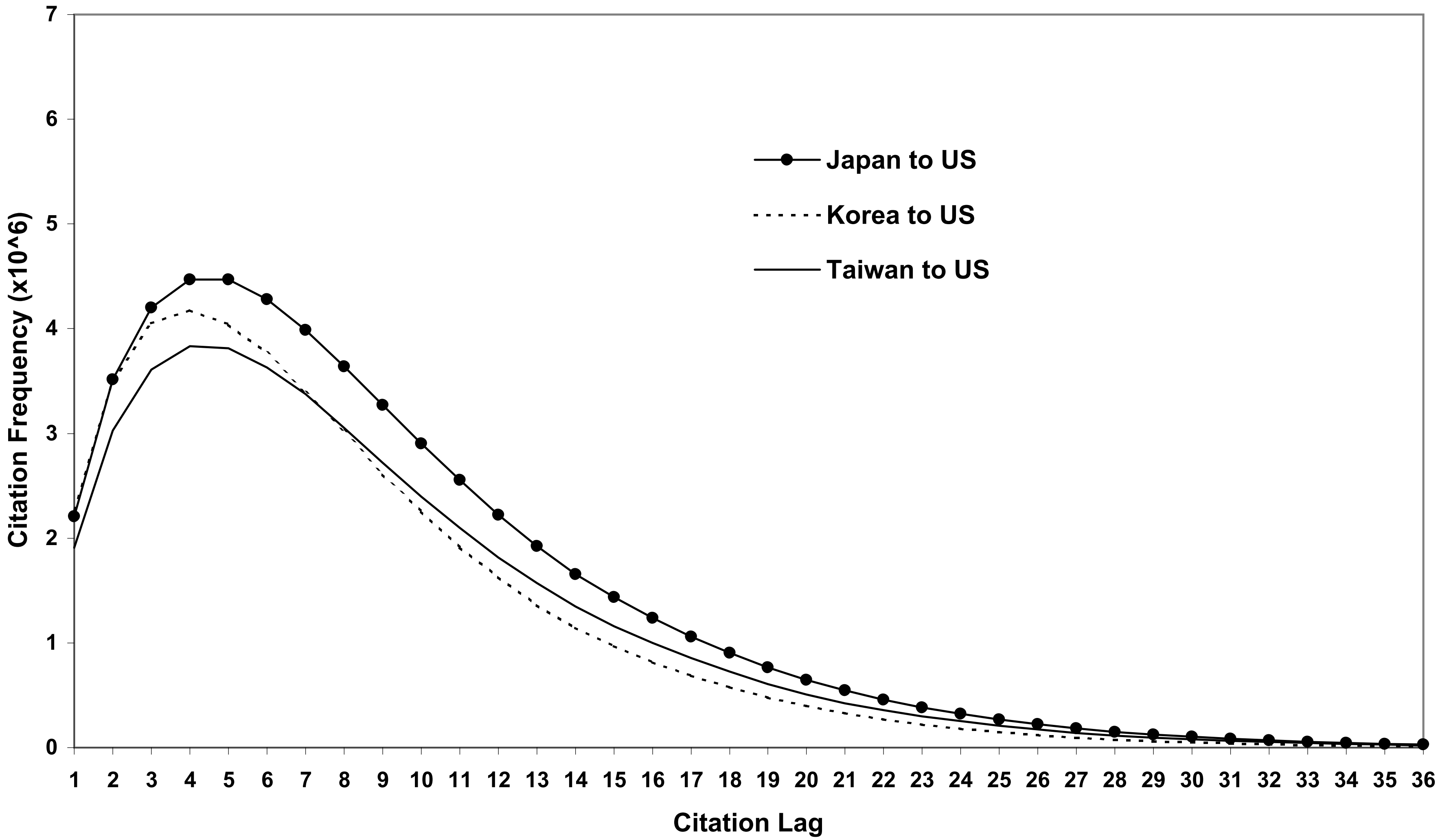

Figure 8
Simulated Frequency of Citation to Japan