The generation, diffusion, absorption, and application of new technology, knowledge, or ideas are crucial drivers of development. The authors examine the exceptionally fast growth in domestic innovation efforts in Korea, Taiwan (China), Singapore, and China, drawing on information about R&D as well as patent and patent citations data. They also use the World Bank Investment Climate Surveys to investigate sources of technological innovation in the other middle- and low-income East Asian economies. They then evaluate the role of three main channels for knowledge flows to East Asia—international trade, acquisition of disembodied knowledge, and foreign direct investment. Results from estimating an international knowledge diffusion model using patent citations data show that, while East Asian innovations continue to draw heavily on knowledge flows from the US and Japan, citations to the same or to other East Asian economies are quickly rising, indicating the emergence of national and regional knowledge stocks as a foundation for innovation. JEL codes: F2, L2, O3

Knowledge creation and diffusion is at the heart of economic growth and development. Romer (1993), for example, stresses the importance of overcoming ‘idea gaps’ relative to ‘object gaps’ in the process of development, that is of overcoming barriers to the creation and absorption of productive ideas versus gaps in the availability of objects such as factories or raw materials.¹ No other part of the developing world has seen more dynamism and success in knowledge diffusion and creation over the last three decades than in the more advanced emerging market economies of East Asia. We aim to document the patterns and trends of knowledge diffusion and creation in these dynamic East Asian economies, to relate them to the economic forces that have led to greater economic integration in the region, and to place them in a comparative global context. To sharpen the comparative perspective, we contrast, whenever possible, statistical findings on East Asia with those on other parts of the world. We do not attempt to link
innovation outcomes to specific public policies in East Asian economies, although
we are hopeful that the analysis may be suggestive of fruitful hypotheses for
future research in this regard.

A working definition of innovation is needed before we embark on our analysis.
The economic and technological heterogeneity of East Asia necessitates a defi-
nition of innovation that encompasses the introduction of new or improved goods,
services, production processes, and marketing methods, as well as better modes of
business organization in general. In particular, a key component of innovation in
East Asia is what can be broadly termed ‘knowledge diffusion’. This involves
absorbing and adapting existing knowledge and applying it in a productive and
commercially viable way. It includes knowledge flow that crosses national borders
as well as diffusion of technology within those borders. We are agnostic about
whether such flows represent an externality, a knowledge spillover, or that all the
private rents have been appropriated.\textsuperscript{2}

East Asia as a region has outspent every other region on R&D (as a proportion
of GDP) over the last decade. Within the region, disparities in spending have
widened, though. Newly Industrialized Economies (NIEs) such as Korea,
Singapore, and Taiwan (China) now devote 2 percent or more of GDP to R&D,
comparable to the level in developed countries. China has seen a rapid intensifica-
tion of R&D spending that has brought it close to its official target of 1.5 percent
of GDP. On the other hand middle-income economies such as Indonesia, the
Philippines, and Thailand spend a miniscule 0.1–0.2 percent of GDP on R&D.
Patenting per capita in the NIEs has grown at a pace four times that in the devel-
oped world and is now approaching average developed-country levels; on the
other hand, patenting in most middle- and low-income economies of the region
remains negligible.

Notwithstanding the difficulty of establishing causal relations, a distinctive and
common feature of those East Asian economies that have made significant progress
in technological innovation is their exceptionally high engagement in international
trade. The robust econometric evidence on capital goods imported as a conduit of
technology diffusion has also been corroborated from surveys of Southeast Asian
firms who report new machinery as the primary source of innovation. While the
econometric evidence is mixed, a rich body of case study literature argues that East
Asian firms may have derived significant technological benefits from exports under
long-term contract manufacturing agreements with foreign multinational corpor-
ations, as part of the latter’s global production networks.

Recent decades have also seen deepening East Asian economic integration,
reflected in increasing flows of goods, services, and investment between the
region’s economies, largely driven by growing vertical specialization within the
region. This, and the increasing pre-eminence of the R&D capability of East Asia’s
NIEs, raises the possibility of increasing technology diffusion within the region.
Using patent citations made by the U.S. Patent and Trademark Office (USPTO) as a measure of knowledge flow, we find that, while East Asia continues to draw heavily on knowledge flows from the US and Japan, citations to other “compatriot” patents from the same East Asian economy or to other East Asian economies are quickly rising, indicating the emergence of East Asian national and regional knowledge stocks which are now providing an indigenous or regional foundation for innovation and cross-border knowledge flows.

A key insight of the technological innovation literature that effective knowledge diffusion is dependent on the absorptive capacity of the firms at the receiving end finds support in our patent citation analysis. While Japan and the United States remain key sources of knowledge diffusion for Korea, Taiwan (China), and Singapore, economies such as China and Malaysia, who have weaker indigenous R&D capability, cite Korean and Taiwan (China) patents more intensively, controlling for existing stocks of patented knowledge.

Our analysis is subject to two caveats. First, while we characterize the geographical focus of the study as East Asian, we are mainly dealing with the more advanced and middle-income economies of East Asia. Second, it is beyond the scope of this paper to establish causal linkage from public policy to the patterns of knowledge creation and diffusion that we document, although we do observe correlations between the two in our analysis of the East Asian experience.

The rest of the paper is organized as follows. We provide, in a comparative context, an overview of technological innovation in East Asia using R&D and patent statistics and evidence drawn from the World Bank’s Investment Climate Surveys (World Bank, 2006a). We then survey the theories and empirics on channels of international knowledge diffusion and summarize East Asia’s experience with these channels. We use patent citations to investigate the intensity of knowledge diffusion both from Japan and the United States to East Asia, and within East Asia. We conclude by briefly drawing implications for policies and institutions that may help foster domestic innovation as well as absorption of knowledge from abroad.

**Technological Innovation in East Asia: An Overview**

East Asia has made rapid progress in technical change over the past decade. But the progress has been uneven. While Korea, Taiwan (China) and, to a lesser extent, Singapore are closing in on the world technology frontier in areas they excel at, and while China is going through a rapid process of R&D intensification, the rest of East Asia, particularly Southeast Asia, remains far behind, both in absorbing existing technologies and in creating new ones. We will use
conventional measures, including patents and R&D, to provide an overview of the current status of technological innovation in East Asia.

**R&D in East Asia**

Total world spending on R&D amounted to $830 billion in purchasing power parity (PPP) terms in 2002 (table 1), of which some 78 percent was performed by developed countries, much higher than their 59 percent share in world GDP (in PPP terms). However, the developed country proportion has fallen over the last decade, as developing or emerging economies raised their share from 13 percent in 1992 to 22 percent in 2002. East Asia has been at the heart of the rise in developing country R&D, contributing almost three-quarters of the increase and quintupling over the decade (in nominal terms) to reach $112 billion in 2002 or 13.5 percent of the world total. R&D intensity in East Asia—the ratio of R&D spending to GDP—rose from 0.7 percent in 1992 to 1.2 percent in 2002.

**Table 1. Research and Development Expenditures**

<table>
<thead>
<tr>
<th>Region</th>
<th>R&amp;D spending 2002</th>
<th>R&amp;D (% GDP*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US$ bill (PPP)</td>
<td>% of world</td>
</tr>
<tr>
<td>East Asia</td>
<td>111.7</td>
<td>13.5</td>
</tr>
<tr>
<td>NIEs</td>
<td>36.4</td>
<td>4.4</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Korea</td>
<td>20.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Singapore</td>
<td>2.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Taiwan, China</td>
<td>12.2</td>
<td>1.5</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>3.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Philippines</td>
<td>0.4</td>
<td>0.0</td>
</tr>
<tr>
<td>Thailand</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>China</td>
<td>72.0</td>
<td>8.7</td>
</tr>
<tr>
<td>World</td>
<td>829.9</td>
<td>100.0</td>
</tr>
<tr>
<td>Developed</td>
<td>645.8</td>
<td>77.8</td>
</tr>
<tr>
<td>Japan</td>
<td>106.4</td>
<td>12.8</td>
</tr>
<tr>
<td>USA</td>
<td>275.1</td>
<td>33.1</td>
</tr>
<tr>
<td>Developing</td>
<td>184.1</td>
<td>22.1</td>
</tr>
<tr>
<td>Latin America</td>
<td>21.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Emerg. Europe</td>
<td>30.3</td>
<td>3.7</td>
</tr>
</tbody>
</table>

* Regional data are sum of R&D divided by sum of PPP GDP. a2001; b1995; c1994.  
East Asian economies differ widely in R&D performance. Korea, Singapore, and Taiwan (China) now devote 2.2–2.5 percent of GDP to R&D spending, comparable to levels in the United States and the upper end of the scale among developed economies. On the other hand R&D spending in economies such as Indonesia, the Philippines, and Thailand is only 0.1–0.2 percent of GDP, among the lowest of all economies for which we have data. In-between these two extremes is China, where R&D spending has risen at 20 percent a year over the last decade to reach 1.4 percent of GDP by 2004, or $109 billion in PPP terms. R&D spending in Malaysia also accelerated after the mid-1990s, reaching 0.7 percent of GDP by 2002.

Figure 1 shows a scatter plot of panel data for R&D intensity and the logarithm of per capita GDP for a sample of developed and developing economies between the mid-1970s and the early to mid-2000s. A fitted regression line—obtained by regressing R&D to GDP ratio on the logarithm of per capita GDP and the square of it—is plotted, as well as the time paths of a small sample of countries. R&D intensity not only increases with per capita GDP but does so at an accelerating pace. Among the East Asian economies for which we have data, China, Korea, and Singapore have demonstrated an R&D intensification—the acceleration of R&D expenditure in relation to GDP—trajectory that is much steeper than that elsewhere in the world. On the other hand R&D intensity in Indonesia, the Philippines, and Thailand has been decelerating, both before and after the

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**Figure 1.** R&D Intensity and Per Capita GDP, mid 1970s to mid 2000s
financial crisis of the late 1990s. The three countries have also been investing less in R&D than their level of economic development would predict.

Patenting in East Asia

The limitations of patents as an indicator are well known: not all inventions are patentable and not all patentable inventions are patented. Of the inventions that are patented, the vast majority do not find their way into commercial utilization, so the distribution of the economic and technological significance of patents is highly skewed. Nevertheless an empirical regularity that arises from the literature on patents and R&D is the high correlation between the two. The relatively standard process that all patent applications have to go through makes the counts of patents granted by national patent offices to inventors of different nationalities a useful tool for the enormously difficult task of cross-country comparison of technological innovation. For this study we use patents granted by the USPTO. While this might induce bias if the propensity to seek U.S. patents varies across countries, the United States has been the most important export market for East

Table 2. USPTO Patents Granted, annual averages

<table>
<thead>
<tr>
<th>Number of patents</th>
<th>Patents per 100,000 people</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1990–04</td>
</tr>
<tr>
<td>East Asia (9)</td>
<td>2,239</td>
</tr>
<tr>
<td>NIEs</td>
<td>2,159</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>184</td>
</tr>
<tr>
<td>Korea</td>
<td>633</td>
</tr>
<tr>
<td>Singapore</td>
<td>36</td>
</tr>
<tr>
<td>Taiwan (China)</td>
<td>1,307</td>
</tr>
<tr>
<td>Southeast Asia</td>
<td>31</td>
</tr>
<tr>
<td>Indonesia</td>
<td>6</td>
</tr>
<tr>
<td>Malaysia</td>
<td>13</td>
</tr>
<tr>
<td>Philippines</td>
<td>6</td>
</tr>
<tr>
<td>Thailand</td>
<td>6</td>
</tr>
<tr>
<td>China</td>
<td>48</td>
</tr>
<tr>
<td>World</td>
<td>107,361</td>
</tr>
<tr>
<td>Developed (21)</td>
<td>104,170</td>
</tr>
<tr>
<td>Japan</td>
<td>22,647</td>
</tr>
<tr>
<td>USA</td>
<td>59,024</td>
</tr>
<tr>
<td>Developing</td>
<td></td>
</tr>
<tr>
<td>Latin Amer. (11)</td>
<td>173</td>
</tr>
<tr>
<td>Emerg. Europe (9)</td>
<td>205</td>
</tr>
</tbody>
</table>

Asia. It also has the most open and dynamic innovation system in the world. The USPTO patent and patent citations data have been well developed and have been subject to rigorous analysis. Therefore we believe USPTO patents are the best available patent statistics for us to assess the current status of technological innovation across East Asia in relation to the rest of the world.

**USPTO Patents Granted to East Asia**

The number of USPTO patents granted to East Asian economies averaged some 12,108 per year in 2000–04, more than five times the number a decade earlier, in 1990–94. Over the same period the number of patents registered by selected Latin American countries increased from 173 to 368. Table 2 also shows patent counts scaled by population. In the early 1990s the number of patents per 100,000 people in East Asia was 0.14, which is 2–3 times the levels in Latin America and in Emerging Europe. By 2000–04, East Asian patents per capita had risen to 0.72, some 6–9 times the levels in the other two regions. The vast majority of these patents are generated by the NIEs, Taiwan (China) and Korea in particular, which by 2004 had become the 4th and 5th biggest recipients of USPTO patents in the world, after the United States, Japan, and Germany.

US patenting by East Asian economies varies enormously across the region. Taiwan (China) now generates some 30 patents per 100,000 people, about as many as Japan and the United States, the best performers among the developed economies. Korea, Hong Kong, and Singapore generate around 8–10 patents per capita per year, similar to the performance of the developed OECD countries in the mid-1980s, although only about half the average OECD level today. Further down the scale, Malaysia generates 0.2–0.3 patents per capita, similar to Korea in the mid-1980s. Finally, countries such as China, Indonesia, the Philippines, and Thailand bring up the rear with patents per capita in the 0.01–0.07 range, although patenting in China is rising very rapidly from a low base.

**In which Technologies Is East Asia Innovating?**

Is patenting in East Asia broadly diversified or concentrated in particular sectors? The USPTO classifies patents into one of around 480 technology classes. Figure 2 shows adjusted Herfindahl indexes of concentration across these technology classes for several major Pacific Rim economies. An index level of 1 represents concentration in just one technology, while (in this case) an index of around 0.002 would mean equal distribution across all classes. Japan and the United States have the most diversified patent portfolios, whose composition has also been quite stable over time. Of the four East Asian economies, Singapore has the most technologically concentrated patent portfolio. Taiwan (China) had been
patenting more evenly across technology areas than Korea did before 1999, but the trend has been reversed since. China’s USPTO patents have been relatively diversified. In recent years the change in the degree of concentration of Chinese patents seems to track those of Taiwan (China) and Singapore.

Jaffe and Trajtenberg (1999) distill the lengthy list of USPTO patent classes into six broad groups: chemicals; computers and communications; drugs and medical; electrical and electronic; mechanical; all other. We use these highly aggregated groups to obtain a more concrete understanding of the technological composition of the East Asian economies’ USPTO patents. A major area of concentration in East Asia is electrical and electronics. The median share of patenting in this technology area for the seven East Asian economies in 2002–04 is 38 percent, ranging from a low of 25 percent in Hong Kong to 45–50 percent in Taiwan (China) and Singapore. The second most important area of concentration is computers and communications, with a median East Asian share of 15 percent, ranging from a low of 12 percent for China and Malaysia to 25–30 percent for Korea and Singapore. The share of East Asian patenting in these two areas has generally risen since the early 1990s.

Figure 2. East Asian Technological Concentration, Selected Economies, 1990–2004
The high shares of East Asian patenting in these sectors may just reflect the high technological opportunity and propensity to patent in these sectors worldwide. To put these concentration measures in a global perspective, we construct a Revealed Comparative Advantage (RCA) measure. This is computed as the share of a technology group in a given economy’s total patents as a ratio of the same share for the world as a whole. A ratio above 1 suggests that an economy patents disproportionately in the technology group relative to the world average. Drawing a parallel with the corresponding concept in international trade empirics, we consider this economy as having a comparative advantage in that particular area of technology. The RCA measures for five East Asian economies, Japan and the United States are plotted in figure 3. The RCA ratio for electrical and electronics is well above unity for all five East Asian economies. For Singapore it is over two, suggesting that the country has twice as large a share of patents in this technology area as an average country. The electrical and electronics RCA for the United States, on the other hand, is below unity. That East Asia has been patenting disproportionately in electrical and electronics accords with the general perception of the region’s strength in this area. Notable cases of excellence include Korea in DRAM technology and LCD manufacture and Taiwan (China) in the wafer foundry industry, and in testing and packaging services. By comparison most East Asian economies show a distinct revealed comparative disadvantage in the drugs

\[\text{Figure 3. Patenting Revealed Comparative Advantage, Selected Economies and Technologies, 2000–2004}\]
and medical sector, with only China achieving parity with the world average. In computers and communications, Korea and Singapore patent more than the world average, alongside Japan and the United States.

How Good is East Asian Patenting?

Although the volume of patenting in economies such as Korea and Taiwan (China) equals or exceeds that in most developed economies, is the same also true of the quality of their innovations? The technological or economic value of patents can vary enormously. In fact the distribution of patent values is highly skewed. A survey of the realized economic value of patents in Germany and the United States, for example, found that the top 10 percent of patents accounted for over 80 percent of economic value (Scherer and Harhoff 2000). Thus a simple count of patents may not provide an adequate summary of the quality of the underlying innovations.

A particularly useful feature of patents is that they contain citations to the previous patents and scientific literature, which define the “prior art” to which the patent is making an original contribution. Trajtenberg, Henderson, and Jaffe (1997) suggest measuring the quality of patents with indexes of patent

Figure 4. Patent Generality, Selected Economies and Technologies, 2000–2004

![Patent Generality Index 2000-04](image)
“generality” and “originality” based on patent citations. A patent is said to have greater generality and impact if it is cited by patents from a wider range of technology classes. It is also said to be more basic or original if it cites patents from a wider range of patent technology classes.

Since the absolute magnitude of the indexes is hard to interpret, we plot, in figures 4 and 5 respectively, the originality and generality measures of Korean, Japanese, and Taiwan (China) patents from four technology groups relative to the corresponding measures of U.S. patents in the same technology group. U.S. patents have higher generality and originality indexes across all technology fields than those of Korea, Japan, and Taiwan (China).11 Japanese patents generally achieve quality ratings that are 80 to 90 percent or more of U.S. quality ratings. Korea, in particular, is close to Japan in most technology areas, even matching or exceeding it in some. Taiwan (China) tends to achieve somewhat lower generality and originality scores, but still scores 70 to 80 percent of U.S. levels.

**Investment Climate Surveys**

Our analysis using R&D and patents statistics is somewhat skewed toward the higher-income and newly industrialized economies in East Asia. What is arguably...
more important in low- and middle-income economies, which are far from the world technology frontier, is absorptive capacity and channels to effect technology transfer from developed countries. Therefore R&D and patent statistics will not capture the main technological innovation activities in these economies. The challenge is the scarcity of meaningful measures of these diffusion related activities. The World Bank Investment Climate Surveys collected information on technological innovation activities in firms around the world. The survey data provide a window to examine the nature and sources of innovation in this less developed part of East Asia.

Table 3 shows that the single most important source of knowledge for firms in these East Asian economies was technology embodied in new machinery or equipment. In Indonesia and Malaysia, close to half of the technological innovation took the form of new machinery. The next two most cited sources of innovation—those developed in cooperation with client firms and the hiring of key personnel—were cited by 12–13 percent of firms, while innovations developed or adapted within the firm were cited by 11–12 percent. One should be cautioned against interpreting these different sources as exclusive to each other. Development within the firm locally, for example, may well be related to adopting new capital equipment. The Investment Climate Survey data obviously reaffirm the importance of embodied technology transfer in the form of new machinery for low- to middle-income countries.

Channels of Technology Diffusion: The Literature and the East Asian Experience

With developed countries performing 80 percent of world R&D, for a country that is far from the world technology frontier, absorbing and adapting existing,
advanced technology for its own use is often a more effective way of closing the technology gap than relying on the country’s indigenous R&D. However, the extent and quality of knowledge absorption from abroad is dependent on the absorptive or learning capacity of the domestic economy, and conducting R&D can be an effective way of acquiring that capacity (Cohen and Levinthal 1989). Empirical evidence, albeit largely based on developed country data, indicates a large magnitude of the benefits of international knowledge flows. This is especially relevant for most East Asian economies—including low- and middle-income countries—because of their generally exceptionally high levels of engagement in world trade and direct investment flows.

**Technology Transfer through Imports**

Capital goods become a conduit of international technology diffusion when they are imported by countries where the technology embodied in the capital equipment is new and more advanced. Coe and Helpman (1995) identify international R&D spillover through imports by relating a country’s total factor productivity to its own R&D stock and a weighted sum of its trade partners’ R&D stock, with the weights being the shares of the country’s imports from its trade partners. They find that about one-quarter of the total benefits of R&D investment in a G7 country accrues to its developed-country trade partners from 1971–90. Coe, Helpman, and Hoffmeister (1997) refine and extend this approach to studying R&D spillover from developed to developing countries over the same period of time. They find that a 1 percent increase in the R&D stock of industrialized countries raises output in developing countries by 0.06 percent, half of which is contributed by the United States. A cross-country comparison shows that most East Asian economies have exceptionally high levels of imports (including capital goods imports) for economies at their level of per capita income.

**Learning through Exports?**

Developing country firms can acquire new technology and learning capabilities by exporting to the developed country market and engaging with customers in that market. A large literature of case studies has developed which affirms the beneficial effect of exporting on technical progress in East Asia, particularly for firms in the electronics industry. As developed country firms outsource manufacturing activities to developing countries, to take advantage of the latter’s low labor cost, a result of trade liberalization measures, these firms often provide their developing country subcontractors with technology, capital equipment, and training so that the latter can produce to the specifications demanded by customers in the developed country markets. Some 70–80 percent of Korea’s electronics
exports were under this type of contract manufacturing by 1990, while over 40 percent of Taiwan (China)’s computer hardware exports were of this form at around the same time. Over the past 15 years China has seen such contract manufacturing become central to the enormous expansion of its manufactured exports.

In contrast to the compelling tone of the case study literature, econometric evidence on the learning effect of exports is rather inconclusive when the non-random choices that firms make regarding exports is taken into consideration. Clerides, Lach, and Tybout (1998) find little evidence for learning benefits from exports using plant-level data from Colombia, Mexico, and Morocco. However, Kraay (2006) and Aw, Chen, and Roberts (1997) find evidence that past export experience helps explain current productivity for Chinese and Taiwan (China) firms.14

Reconciling the gap between the case studies literature and the econometric literature, Pack (2006) observes that export data do not typically distinguish exports under long term contract manufacturing relationships, which are more likely to involve technology transfer from other types of exports; so it is perhaps not surprising that econometric studies based on generic export data arrive at only mixed results regarding export learning effects.15

Technology Licensing and Disembodied Knowledge Flows

Firms can also purchase disembodied external knowledge through acquisition of patents, non-patented inventions, licenses, disclosures of know-how, trademarks, designs, patterns, and other consultancy and technological services. Royalty payments abroad provide a rough measure of this form of technology transfer. Figure 6 indicates that royalty payments abroad by East Asian economies are also generally much higher relative to other economies at similar income levels. Firms may also derive disembodied knowledge flows through technological spillovers, benefiting from open source information such as scientific, technical, and industry journals; informal contacts and communications through networks of researchers and specialists; trade and industry associations; and trade fairs.

Foreign Direct Investment

The literature on foreign direct investment (FDI) as a channel of technology diffusion makes a distinction between horizontal and vertical diffusion. The former occurs between competing firms in the same industry, whereas the latter represents knowledge spillovers between firms from different industries that are vertically linked.
Gorg and Greenaway (2004) review 40 studies on horizontal productivity spillovers in manufacturing industries worldwide and conclude that only eight find unambiguous evidence of positive horizontal spillovers, mostly for developed economies. Some authors (for example Aitken and Harrison 1999; Konings 2001) have attributed the lack of evidence for technology spillover from FDI to the competitive pressure FDI has imposed on the domestic market, which may dominate any technology spillover that may have occurred. Other authors (Kokko, Tansini, and Zejan 1996; Glass and Saggi 2002; Borensztein, De Gregorio, and Lee 1998; Lipsey 2000) argue that technology spillover is dependent on the absorptive capacity of the local firms: the smaller the gap between foreign and domestic firms, the greater the spillover.

Several studies have reported affirmative evidence on vertical technology spillover from FDI. Javorcik (2004), for example, finds that a one standard deviation increase in foreign presence in the purchasing sector of the economy in Lithuania is associated with a 15 percent rise in output of local firms in supplying sectors.

Keller (2002) examines the impact of international trade, FDI, and disembodied knowledge flows (for example through direct communication) as channels of knowledge flow. He finds that all three channels are significant, but that imports are the most important, explaining about two-thirds of the estimated

Figure 6. Royalty Payments and Per Capita GDP, 2003

![Graph showing the relationship between Royalty Payments (% of GDP) and Per Capita GDP (PPP).](image-url)
impacts, while FDI and disembodied flows explain about one-sixth each on average.\textsuperscript{19}

Historically East Asian economies have embraced FDI with different levels of enthusiasm. Korea and, to a lesser extent, Taiwan (China) have tended to restrict FDI while emphasizing licensing of foreign technology and upgrading of domestic technological capabilities, including through domestic R&D and strengthening of technical education and labor force skills. Singapore’s economic development has largely been driven by FDI. In-between these two extremes are China, which has drawn large FDI inflows, and middle-income Southeast Asian economies such as Malaysia, Thailand, Indonesia, and the Philippines (since the 1980s).

\textit{Deepening East Asian Economic Integration}

East Asia has seen a deepening of intraregional economic integration over the past decades. According to a recent study by the Asian Development Bank (ADB 2008), the share of intraregional trade in total trade for integrating Asia—basically East Asia plus India—has steadily increased from a fifth in the early 1950s, to about a third in the 1990s, to over a half today. The report goes on to observe that “Asia now trades more with itself than either the EU or North America did at the outset of their integration efforts.” But unlike the EU and North America, where intraregional trade is driven by final goods trade, in East Asia it has been driven by intermediate goods due to vertical specialization (IMF 2007). The increasing flows of goods, services, and investment between East Asian countries has generated potential opportunities for more intensive knowledge flow within East Asia.

\textit{Knowledge Flows to, from, and within East Asia: Patent Citations}

The large empirical literature on international knowledge diffusion largely adduces evidence of knowledge flows by investigating correlations between activities that are expected to facilitate knowledge flows—for example, foreign trade, FDI, or technology licenses—and economic productivity. This section looks at evidence from patent citations, which provide a unique and more direct window onto flows of knowledge between inventors, firms, and economies.\textsuperscript{20}

\textit{Patent Citations and Knowledge Diffusion}

We use citations made by USPTO patents to other USPTO patents to trace knowledge flow within and beyond East Asia. An applicant for a USPTO patent
has a legal duty to disclose any knowledge of prior art related to his or her invention in the form of citations to a previously granted USPTO patent among other forms of publications of existing inventions, including patents granted in other jurisdictions and scientific journal articles. Patent citations therefore play an important legal function in delimiting property rights. On the other hand, 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. All this makes patent citations perhaps less arbitrary than, say, academic journal citations, but it does also open the door to the possibility that citations may have been inserted by the patent examiner, which therefore do not necessarily track knowledge flow. In addition the citations data we use only include those made to USPTO granted patents, thus citations made to patents granted by other patent offices are not considered. To the extent that the propensity to cite non-U.S. granted patents varies across the East Asian countries that we investigate, our knowledge flow measures may be biased. However, we are not aware of any study that validates this concern.

A number of studies have directly or indirectly confirmed the usefulness of patent citations as an indicator of knowledge diffusion, despite their noise content. Trajtenberg (1990), for example, finds a robust correlation between citation-weighted patent counts and consumer surplus from the invention and diffusion of computer tomography. In a direct attempt to address the noisiness of patent citations as an indicator of knowledge flow, Jaffe, Trajtenberg, and Fogarty (2000) report results from a survey of inventors who have cited other inventors in their patent applications. 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; however, many citations also occur in the absence of any knowledge flow.21

Figure 7 shows the share of various foreign economies in patent citations made by seven East Asian economies (as a group).22 The United States remains by far the largest source of citations for East Asian innovators, providing close to 60 percent, this proportion having risen slightly between 1992–94 and 2002–04. Japan is the second largest source, contributing close to 20 percent. (Korea is an interesting exception to this general pattern: its reliance on US citations is substantially lower than other East Asian economies—around 45 percent—while its reliance on Japan is higher, around 33 percent). The share of other G5 economies, defined here as comprising Canada, France, Germany, Italy, and the United Kingdom, is lower, less than 10 percent, having fallen over the last decade. Perhaps most interesting, the share of citations made by East Asian economies to other East Asian economies, while still low, is rising fast, picking up from 1.7 percent of citations in
1992–94 to 5.9 percent in 2002–04. Most of these intra-East Asian patent citations are to those held by Korea and Taiwan (China), the two largest innovators in the region. Figure 7 also indicates that the share of citations by inventors in an East Asian economy to patents granted to other inventors in the same economy (referred to as “compatriot citations”) is also rising, reaching 3.3 percent on average in 2002–04.

Figure 8 provides a closer look at the rise of intraregional and compatriot knowledge flows for individual East Asian economies. The share of citations to other East Asian economies, typically to Korean and Taiwan (China) patents, is highest—around 7–8 percent—in China, Hong Kong, Malaysia, and Singapore. The share of compatriot patent citations is highest in Korea—around 6 percent—and Taiwan (China), where it is already over 10 percent.

Such raw citation shares provide useful information on the gross flows of knowledge between economies but say little about the intensity of knowledge relationships. It is not surprising that East Asian economies should have large shares of citations to U.S. patents, simply because the United States is by far the largest generator of patents worldwide, and thus of potential citations. Even Japan, which produces almost as many patents per capita as the United States, still has over 40 percent of its citations to the latter. Researchers have therefore developed a citation frequency measure of how intensively patents in one country
cite patents from another, after controlling for the size of the potential pool of citations between the two: 23

\[ CF_{A,B} = \frac{C_{A,B}}{N_A N_B} \]

where \( CF_{A,B} \) is the number of citations made by country A’s patents to those of country B, \( C_{A,B} \), divided by the product of the potential number of citing patents in country A (\( N_A \)) and potential number of citable patents in country B (\( N_B \)).

Figure 9 shows patent citation frequencies between the United States, Japan, Korea, and Taiwan (China) in the electrical and electronics technology field. There are several striking features. Each of these four economies cites compatriot patents from the same economy much more intensively than patents in the rest of the world. Thus, after controlling for the fact that the potential pool of citable electrical and electronics patents in Korea is much smaller than the potential pool in the United States, Korean patents cite other Korean patents almost five times as intensively as they do U.S. patents. This finding is consistent with earlier findings that there is a significant degree of \textit{geographical localization} in knowledge spillovers. Jaffe, Trajtenberg, and Henderson (1993) find that the frequency of citations from a patent in one American state to other patents from the same
state is higher than from other states, while Jaffe and Trajtenberg (1999) confirm that citation frequencies within OECD economies are much higher than those from one OECD economy to another.

A major reason for geographical localization of knowledge spillovers is the tacitness of knowledge. Complex scientific and technical knowledge often cannot be easily codified and can only be fully communicated if accompanied by face-to-face interaction. Tacitness and geographical localization help explain the economic usefulness of cities and industrial clusters, which facilitate face-to-face interactions and knowledge spillovers. At the national level these findings provide more evidence for the value of domestic R&D and innovation efforts, since they suggest that it is easier for local residents to absorb the knowledge spillovers from local innovations than it is from foreign ones. Jaffe, Trajtenberg, and Henderson (1993) also find that localization within U.S. states fades away over time, while Audretsch and Feldman (1996) find that geographical clustering is greatest in industries with high R&D intensity and high employment of skilled labor, as well as in industries at an early stage of their life cycle, when more of the knowledge about that industry is still in the heads of skilled workers and less of it has been codified in manuals and protocols.

Figure 9 also provides evidence for the high intensity of intra-East Asian cross-border knowledge flows. The citation frequency from Korean to both Taiwan (China) and Japanese patents is more than twice as high as the citation frequency...
for U.S. patents. Reciprocating, Taiwan (China)’s citation frequency to Korea is also near three times its frequency with Japan and the US, while Japan’s frequency to Korea is almost as high as its citation frequency to U.S. patents. These trends again confirm the growing regional dimension in East Asian knowledge flows.

**Estimating the Knowledge Diffusion Model**

The preceding analysis of patent citations data, while revealing interesting patterns, is “partial” in the sense that it has not fully accounted for all the factors that may determine the intensity of knowledge flow as measured by citation frequency. In this section we investigate how the intensity of knowledge flow between two countries varies, controlling for the age structure of a country’s patent portfolio and how close the two countries are in technology space. A particular patent is more likely to be cited the longer it has been around, other things being equal, since the likelihood that the knowledge embodied in the patent has been observed and diffused would be higher. On the other hand, knowledge becomes obsolete over time and thus becomes less citable. To incorporate these two counteracting forces of knowledge diffusion and knowledge decay, we estimate a double exponential knowledge diffusion model, the details of which we describe in the appendix.

It is also more likely for two countries to cite each other if there is a greater overlap in the technology fields that the two countries’ inventors work in, everything else being equal. To measure how close two countries are in technology space, we construct a technology proximity measure for each pair of countries. When a patent is granted, the USPTO assigns it to one of over 400 technology classes on the basis of the technological nature of the invention. The technology proximity measure is essentially a correlation between two countries in the technology-class distributions of their patents.

Our primary interest in estimating the knowledge diffusion model lies with the country-pair fixed effects, that is, after the effects of knowledge decay and diffusion, and technology proximity, are controlled for, how much more intensive is the knowledge flow between one pair of countries than another? We report the country-pair estimates in table 4. The estimates are scaled by the effect of the United States citing itself for ease of interpretation. For example, if the country-pair estimate for country X citing country Y is 0.5, this would imply that X cites Y half as frequently as the United States cites itself.

Confirming our finding of intensive compatriot patent citations obtained using “raw” citation frequencies earlier, the diagonal elements of the upper half of table 4 are all bigger than the off diagonal elements. In the case of Korea, localization of knowledge flow is 16 percent higher than that in the United States. Both
Korea and Taiwan have become sources of knowledge diffusion. Japan cites Korea at 44 percent of the frequency at which the United States cites itself. This is quite close to the frequency at which Japan cites the United States. Taiwan (China) cites Korea more intensively than it cites the United States and Japan. Korea reciprocates by citing Taiwan (China) almost as intensively as it cites Japan, and more intensively than it cites the United States. Korean and Taiwan (China) patents appear to be more important as a source of knowledge for both China and Malaysia than those of the United States and Japan. An explanation is that, given the absorptive capacity of China and Malaysia, it is easier for them to build upon the technologies of Korea and Taiwan (China) than those of the United States and Japan. An explanation is that, given the absorptive capacity of China and Malaysia, it is easier for them to build upon the technologies of Korea and Taiwan (China) than those of the United States and Japan. Between the two city economies, Singapore shows an exceptionally high citation frequency to Taiwan (China), and also to Korea, which significantly exceeds or equals (also high) the citation frequencies to Japan and the United States. Thailand appears to be the anomaly by citing the United States and Japan more than it cites Korea and Taiwan (China).

### Concluding Remarks

We have analyzed the patterns of the generation and diffusion of ideas in East Asia. There seem to be four groups of economies sorted by their ability to generate and absorb new ideas. The first group consists of the NIEs that are at an advanced stage of transition from imitation to innovation. Most notably, Korea and Taiwan (China) have emerged as centers of technological innovation and sources of knowledge diffusion for the rest of the economies in the region, based

<table>
<thead>
<tr>
<th>Citing economies</th>
<th>USA</th>
<th>Japan</th>
<th>Korea</th>
<th>Taiwan (China)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>1.00</td>
<td>0.57</td>
<td>0.38</td>
<td>0.29</td>
</tr>
<tr>
<td>Japan</td>
<td>0.46</td>
<td>0.80</td>
<td>0.44</td>
<td>0.23</td>
</tr>
<tr>
<td>Korea</td>
<td>0.46</td>
<td>0.70</td>
<td>1.16</td>
<td>0.69</td>
</tr>
<tr>
<td>Taiwan (China)</td>
<td>0.26</td>
<td>0.25</td>
<td>0.71</td>
<td>0.83</td>
</tr>
<tr>
<td>China</td>
<td>0.36</td>
<td>0.31</td>
<td>0.44</td>
<td>0.41</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>0.45</td>
<td>0.41</td>
<td>0.42</td>
<td>0.40</td>
</tr>
<tr>
<td>Malaysia</td>
<td>0.44</td>
<td>0.32</td>
<td>0.53</td>
<td>0.57</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.95</td>
<td>0.60</td>
<td>0.93</td>
<td>1.63</td>
</tr>
<tr>
<td>Thailand</td>
<td>0.66</td>
<td>0.33</td>
<td>0.27</td>
<td>0.10</td>
</tr>
</tbody>
</table>


on conventional measures of innovation and patent citations analysis. The second group consists of China, which is fast moving up the technology ladder, with heavy investment in both indigenous innovation and absorptive capacity. The third group includes middle-income economies, including Thailand and Malaysia. They have had varying degrees of success with absorbing technology from developed countries, but have not shown clear signs of graduating from imitation to innovation. The fourth group consists of low-income economies in East Asia, which are at the beginning of the diffusion stage.

While East Asian economies have adopted different approaches to technological innovation, there are common lessons to be drawn. First of all, everyone starts with absorbing existing technologies from abroad. The economies’ successes with technical change is largely determined by their ability to avail themselves of channels of knowledge diffusion. These include capital goods import, exports to developed-country markets, hosting FDI, and movement of personnel who embody new and advanced technology. The relative significance of a particular channel may vary between countries, but the overall importance of these channels as catalyst of knowledge diffusion is universal.

Direct evidence in the form of robust causal relation has been hard to come by. However, there is an overwhelming amount of evidence based on correlations that is consistent with the hypotheses that international trade, FDI, and movement of people have accelerated intra- and inter-regional knowledge diffusion. Thus, policies that foster greater participation in trade and foreign investment, and which facilitate the easier movement of people involved in innovation—for example scientists, engineers, technical personnel, and business people more generally—are likely to accelerate knowledge diffusion.

Successful adoption of new technology may also depend on the technology gap. When the gap is too wide, the adopting economy may not have the absorptive capacity to learn and adopt the technology for its own use. The result that patents by China and Malaysia cite Korea and Taiwan (China) more intensively than they cite Japan and the United States corroborates this hypothesis.

The varying success East Asian economies have had with moving beyond pure imitation also indicates that exposing oneself to knowledge diffusion alone is not sufficient. The findings reported in this paper, explicitly and implicitly, lend support to the hypothesis that indigenous R&D is indispensable in the process of technological innovation in developing countries and that R&D and knowledge diffusion interact and reinforce each other. When a country is far from the world technology frontier, returns to absorptive activities are clearly higher than those to indigenous R&D. But as the country narrows the technology gap, R&D becomes productive both in strengthening the country’s ability to absorb more advanced existing technology and in innovating.
Policymakers in developing countries are ultimately interested in what institutions and public policies lead to greater knowledge diffusion and generation. Despite the challenge of establishing causality in empirical development research, we would certainly want to explore in a more direct way the roles of trade, FDI, and the movement of people in the diffusion of new technology and thus make the connection between the patterns of knowledge diffusion we have documented and the determinants of such patterns. From such work more practical policy recommendations are likely to follow.

Appendix: Estimating the Knowledge Diffusion Model

The double exponential knowledge diffusion model is specified as:

\[ CF_{iT,jtg} = (1 + TD_{iT,jtg}) \alpha(ij, T, t, g) \exp(1 - \beta_1(T - t))(1 - \exp(-\beta_2(T - t))) \]  \hspace{1cm} (A1)

where \( i \) and \( j \) denote citing and cited countries respectively; citing patents are granted in year \( T \) and cited patents in year \( t \); \( g \) is one of the six main technological fields. The left-hand side is the citation frequency of patents of country \( i \) granted in year \( T \) citing country \( j \)'s patents that are granted in year \( t \) in technological area \( g \), that is the empirical frequency of a patent from the group defined by \( iT \) citing a patent from the group with the characteristics of \( jtg \).

The probability that a patent is cited by another patent depends on, among other things, the likelihood that the cited patent comes to the knowledge of the inventor of the citing patent and the relevance of the knowledge embodied in the cited patent to the citing patent. The former increases with the lag between the grant dates of the citing and cited patents (\( T - t \)): the longer the cited patent has been around, the more likely it becomes known to the inventor of the citing patent, whereas the latter diminishes with the lag. As new knowledge emerges, as the wide adoption of the old knowledge reduces the economic rent accruable to the proprietary knowledge embodied in the cited patent, or both, the likelihood is reduced that the cited patent remains relevant and a prior art to a potential citing patent. The double exponential model in equation A1 captures these two processes with \( \beta_1 \) measuring the speed of obsolescence and \( \beta_2 \) the speed of diffusion.

The first term of the right-hand side of equation A1 contains the technology distance between the citing patents and the cited patents. The technology distance variable is defined as:

\[ TD_{iT,jtg} = V_{it}^\prime V_{jt,g} \]

where \( V_i \) is a 428-element vector of patent class shares of country \( i \)'s USPTO patents granted in year \( t \). TP is bounded between 0 and 1 and monotonically
increasing in the similarity between two economies’ patent portfolio, which we use to measure the technological proximity between the two economies. The closer the potentially citing patent is to the potentially cited patent in the technology space, the easier it is for the citing patent to capture knowledge spillover from the cited patent and therefore the likelihood of citation increases. Finally, $\alpha(ij, T, t, g)$ represents a number of fixed effects we are interested in estimating:

$$\alpha(ij, T, t, g) = \exp\left( \sum_i \sum_j \alpha_{ij}D_{ij} + \sum_T \alpha_T D_T + \sum_t \alpha_t D_t + \sum_g \alpha_g D_g \right).$$

For each set of fixed effects ($D$s), one reference case is left out in the estimation. The citing–cited country-pair specific effect is estimated with the $\alpha_{ij}$s. For example, with the United States citing itself as the reference group, $\alpha_{TWUS}$ would measure how much more intensively Taiwan (China) cites the United States relative to the United States citing itself. The citation frequency may also vary with the grant year of the citing patents; and this is captured by $\alpha_T$s. With both the effects of citing year and citation lag included, we are not able to estimate a full set of cited year effects of $\alpha_t$s. Instead we group the cited year $t$s into groups and estimate the group effects. Lastly, we also allow the average citation frequencies of the six main technology fields to differ.

Instead of estimating all the country-pair effects in our citation database, which would lead to an explosion of the number of parameters to be estimated and overtax the data’s identifying capability, we choose to be selective in the number of citing and cited countries to model. For cited countries, we include the United States, Japan, the G5, Korea, and Taiwan (China) in view of their dominance in patent numbers and as a source of citations. All seven East Asian economies and the United States and Japan are included as citing countries, the latter for comparison and benchmarking purposes.

The estimation results show that the model explains 99 percent of the variation in the citation frequency. Technology distance has a large impact on citation frequency: two patents being in the same technology class are 47 times more likely to cite each other than otherwise.

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**Notes**

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1. See also Romer (1990a, 1990b) and Aghion and Howitt (1992, 2006).

2. The OECD’s 2005 Oslo Manual defines innovation broadly as “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organisation or external relations.” Innovation activities are defined as “all scientific, technological, organisational, financial and commercial steps which actually, or are intended to, lead to the implementation of innovations” (OECD 2005).

3. UNESCO (2005, 2006). There is R&D data available for a number of economies through 2004 and 2005; but 2002 seems to be the most recent year for which there is comprehensive data for the world as a whole.

4. It is worth noting that the absolute value of China’s R&D in PPP terms is particularly affected by the unusually large disparity between its PPP exchange rate (as calculated by the World Bank and other researchers) and its market exchange rate. Thus China’s R&D expenditures in 2004 at market exchange rates were, according to data from UNESCO (2006), $23.8 billion, or only 21 percent of the PPP figure. By comparison Korea’s R&D spending in 2003 was $22.8 billion in PPP terms and $16 billion at market exchange rates, or 70 percent of the PPP figure. In Malaysia R&D at market rates was 42 percent of R&D in PPP terms. Note, however, that while this issue is relevant for measuring absolute levels of R&D, it does not affect R&D intensity (the ratio of R&D to GDP), since both the numerator and denominator of that ratio use the same conversion rate. The recent 2007 revision of PPP exchange rate factors by the International Comparison Project should however lead to a downward revision in the PPP R&D figure for China in particular.

5. See Griliches (1992) for an early survey. Among recent studies, Bottazi and Peri (2005) examine the short and long run dynamics of knowledge production in OECD countries and find long run elasticities of patenting on R&D and the stock of foreign knowledge of around 0.8 and 0.6 respectively. Bosch, Lederman, and Maloney (2005) investigate the relationship between patenting and R&D worldwide, including developing economies. They find a significant relationship between patenting and R&D at the global level, although the estimated elasticity of patenting with respect to R&D for OECD economies (around 1) is substantially higher than among developing economies.

6. Issues and pitfalls in the use of patents as innovation indicators are discussed in Griliches (1992), Hall, Jaffe, and Trajtenberg (2001), Jaffe and Trajtenberg (2002) and Jaffe and Lerner (2004). Levin and others (1987) and Cohen, Nelson, and Walsh (2000) document the importance for U.S. firms of alternative methods of protecting proprietary knowledge such as secrecy, lead times, moving down the learning curve, and provision of sales and manufacturing services that complement the innovation.

7. This discussion draws on the NBER Patent Citation Database (http://www.nber.org/patents/, described in Hall, Jaffe, and Trajtenberg 2001), updated through 2002 by Bronwyn Hall (http://elsa.berkeley.edu/~bhhall/patents.html) and through 2004 by Albert Hu (Hu 2006). The use of U.S. patents may be justified by the fact that creators of commercially valuable inventions have a strong incentive to take out a patent in the United States, given its position as the largest market in the world. Close to 50 percent of patents granted by the USPTO in 2000–04 were to foreigners. Nevertheless, there is a large home bias in patenting (inventors are more likely to patent in their home jurisdiction than elsewhere), and inventors in different economies may also face different incentives to patent in the United States (for example depending on the level of exports to that country). These factors could introduce biases that need to be adjusted for. We concentrate on patents and patent citations for eight East Asian economies: China, Hong Kong, Korea, Malaysia, the Philippines, Singapore, Taiwan (China), and Thailand, together with two of their largest economic partners, the United States and Japan.
8. Hu and Jefferson (2005) suggest several reasons for the acceleration in Chinese patenting: (i) the acceleration in China’s R&D spending noted above; (ii) the strengthening of China’s Patent Law in 1992 and 2000; (iii) the vast influx of foreign direct investment to China, which has greatly increased the market value of intellectual property for both foreign and domestic firms; (iv) the rapid relative growth of “complex industries” like electronics and machinery, which involve many separately patentable subproducts and processes; (v) the acceleration of enterprise reform after the mid-1990s, which has greatly strengthened private property rights vis-à-vis state owned enterprises.

9. Bronwyn Hall suggested correcting for small sample bias when calculating Herfindahl indexes for patents-based concentration measures using the following formula: 
\[
\tilde{\eta} = \frac{(N-1)HHI - 1}{(N-1)},
\]
where \(HHI\) is the conventional Herfindahl index, 
\[
HHI = \sum_{i=1}^{J} \left( \frac{N_j}{N} \right)^2,
\]
where \(i\) indexes the number of patent classes and \(N\) the total number of patents.

10. The indexes are calculated as: 
\[
1 - \sum_{i=1}^{N} S_i^2
\]
where \(S_i\) is the share of patent citations made to patent class \(i\) for originality and the share of patent citations made by patents from class \(i\) to the patent concerned for generality. The second term of the formula is the Herfindahl index of concentration. The indexes are thus negatively correlated with the concentration of patent citations.

11. Some East Asian economies have few if any patents in some technology fields, resulting in few citations with which to compute generality or originality indexes. The discussion therefore focuses on Korea and Taiwan (China), economies with sufficient patenting activity for meaningful measurement.

12. Eaton and Kortum (1996), for example, estimate that foreign technology accounts for at least 80 percent of domestic productivity growth in most OECD countries, the only exceptions being the United States and Japan, the two world leaders. Bottazzi and Peri (2005) estimate that a 1 percent increase in U.S. R&D leads to a 0.35 percent rise in the number of USPTO patent applications from other OECD countries, with a lag of between 5 and 10 years.


15. Another possibility is that learning which is necessary for serving the export market takes place before firms actually start exporting (Hallward-Driemer, Iarossi, and Sokoloff 2002; Tybout 2006). Kim (1997) describes Samsung’s efforts to master production of microwave ovens in the 1970s in response to a prospective order from J.C. Penney, with improvements in productivity preceding actual export flows. Nabeshima (2004) observes that to be selected as an Original Equipment Manufacturer (OEM) supplier firms already need to possess production and technological capabilities that allows them to meet quality, cost, and delivery requirements.


17. See also Blalock and Gertler (2005) and Saggi (2002).

18. Keller (2002) proxies disembodied knowledge flows by bilateral language skills—the proportion of the population in the recipient country who speak the language of the spillover sender country. The study looks at knowledge flows at the industry level among countries at the world’s technology frontier—the G7 industrialized economies.

19. See also Xu and Wang (1999) and Schiff, Wang, and Olarreaga (2002)

20. The discussion draws on data from the NBER Patent Citations Database (Hall, Jaffe, and Trajtenberg 2001). See endnote 24 for further details.

21. Hall, Jaffe, and Trajtenberg (2001) delineate the conceptual, operational, and modeling issues that users of the data may come across.
22. All the citations that we analyze are “non-self” citations, which exclude citations made to a patentee’s own patents.

23. For further details see Jaffe and Trajtenberg (2002) and Hu (2006).

24. The model was first proposed and estimated in Caballero and Jaffe (1993) and again estimated in Jaffe and Trajtenberg (1999) and Hu and Jaffe (2003). The model makes two identification assumptions regarding the underlying structure of the knowledge diffusion process. One is proportionality, that is more highly cited patents are more highly cited at all lags. The second assumption is stationarity, which means that the citation lag distribution does not change over time. While these may be restrictive, they are needed to identify the model.

25. Full results are reported in Hu (2006) and are available upon request.

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