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# Examining US Productivity: Knowledge Flows from Industry and Country Sources

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## Abstract

This paper examines Total Factor Productivity (TFP) and knowledge flows, using international patent data. The result is a measure of technology that isolates sources of innovation and their contributions to domestic TFP. Within-industry innovation enhances domestic productivity, and domestic between-industry innovations are productivity enhancing. However, foreign-sourced between-industry innovation has a negative effect on domestic productivity. This highlights the dual aspect of patents as a measure of innovation. However, when controlling for domestic market structure, foreign-owned firm employment, or imports, foreign-sourced knowledge flows have potentially positive effects on domestic TFP. Overall results are sensitive to sectors and country of origin.

JEL Classification: F19, O3, O4

Key words: productivity, patents, innovation, and knowledge flows.

## Introduction

For economists, technical change is recognized as the primary reason for increases in productivity.<sup>1</sup> Where this change comes from is a closely related issue. Given the unpredictability of idea generation and

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how new knowledge affects productivity, determining and measuring the sources of innovation is an important area for investigation.

The main contribution of this paper is to isolate the relative contribution of various sources of knowledge to Total Factor Productivity (TFP) in an industrial sector. This is accomplished by utilizing international patent data in a novel way. As a measure of innovation, patents have considerable economic value. The number of patents applied for each year in the US Patent and Trademark Office (USTPO) from 1970 to 1995 has increased almost 30 fold.<sup>2</sup> Given an estimated average value of a patent in the 1980's of \$500,000 and the 65000+ patents applied for in 1980 (Griliches 1989), the total values are substantial.

Previous analyses relating TFP and inventive activity have been performed using relatively aggregated R&D data by time and industrial sector. A newly constructed international patent data set is now available across 170 countries over 20 years, utilizing an algorithm that allows for direct mapping of patenting activity to industrial sectors. These data allow for a highly disaggregated analysis of knowledge flows and their paths within and between industries and countries. In addition, patents as a proxy for innovative activity differ conceptually from R&D expenditures. Patents are viewed as outputs from innovation. In contrast, R&D investments are made earlier in the process before any results may be known, and as such, are more accurately considered an input into the innovation process. Finally, taking out a patent is an explicit strategic decision, a decision based upon R&D already performed. The outcome is an innovation that is deemed economically valuable. A patent is thus a measure that captures both positive and negative (competition inhibiting) effects.

The main findings are that Domestic Same and Other (within and between) industry technology knowledge flows are positively related to US TFP growth. For example, innovations originating in the domestic transportation and computer sectors increase productivity in the transportation sector. Further,

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<sup>1</sup> In his seminal work, Robert Solow observed that an increase in capital and labor alone could not explain the increase in production in the first half of the 20th century (Solow 1957). Rather, shifts in, not movements along, the production function are the most likely explanation.

innovations originating in the foreign transportation sector also increase domestic productivity in that sector. However, contrary to much of the current literature, Foreign Other industry knowledge flows are found to be negative and statistically significant. By interacting Foreign Other industry with measures of market power, employment at foreign-owned domestic firms, and with import ratios, this result becomes clearer. Less foreign patenting activity along with greater competition in a given industry, higher employment at foreign-owned firms, and higher import ratios result in positive Foreign Other source knowledge flows. Higher rates of patenting by foreign firms in the US, however, suggest strategic patenting to block competition, resulting in a negative effect on US productivity. This dual nature of patents becomes clearer when disaggregated by country.

Further, when innovations originating in the Information Technology sector (IT) are separated out from other possible sources, a dominating effect, in terms of idea generation and TFP, is clearly indicated. Knowledge flows from the domestic IT sector affecting other manufacturing sectors in terms of TFP, are large and statistically significant. However, the opposite is true of ideas originating in the foreign IT sector. Foreign IT sector knowledge flows to the US have a negative effect on US TFP, suggesting that increased foreign productivity due to improvements in the IT sector occur at the expense of US TFP.

The remainder of the paper will proceed as follows: Section 2 discusses the link between TFP, innovation, and technology knowledge flows using patents as a measure in this process. Section 3 lays out the theoretical model to be used as the basis for the empirical section. The data used in the analysis are given in section 4. Section 5 presents the main empirical results and section 6, the conclusion.

## Section 2: Knowledge Flows, Their Measurement, and the Role of Patents

The fundamental question of how productivity growth and endogenous technical change are related has been studied extensively. In this literature several aspects stand out. Models using Research

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<sup>2</sup> From 530 patents applied for in the USTPO in 1970 to 149248 in 1995. Source: USTPO.

and Development (R&D),<sup>3</sup> patents,<sup>4</sup> international trade,<sup>5</sup> and Foreign Direct Investment (FDI),<sup>6</sup> along with human capital accumulation,<sup>7</sup> have been posited and empirically tested. The research indicates that technical change has a fundamental effect on the production function. The level and direction of this effect, however, remains an open question (Aitken and Harrison 1999).

### Research and Development

Empirically, R&D is measured in a variety of ways, including total expenditures, number of scientists and technical personnel, and the percentage of intermediate goods from other firms used in production. Because of its broad definition, R&D is a standard measure of inventive activities.

Since expenditures on R&D, whether capital or labor, take place at the beginning of the inventive process, they are considered inputs to the technical function. This has both advantages and disadvantages. The advantage is R&D expenditures have the potential for capturing both explicit and implicit improvements in productivity due to innovation. The disadvantage is the obverse: namely, that R&D may have difficulty measuring specific effects.

### Patents

As a measure of inventive activity, patents are included under the heading of R&D but differ in important aspects. Unlike R&D expenditures, patents, given the timing, are modeled as outputs. Other qualities that make patents useful include the sheer volume of data.<sup>8</sup> In addition, with the signing of the

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<sup>3</sup> Coe and Helpman [1994], Griffith, Redding and Van Reenen [2000], Keller [2001a], Keller [2004]

<sup>4</sup> Eaton and Kortum [1996], Eaton and Kortum [1999], Hu and Jaffe [2001]

<sup>5</sup> Fink and Braga [1999], Keller [2004]

<sup>6</sup> Keller [2002], Aitken and Harrison [1999]

<sup>7</sup> Griffith, Redding and Van Reenen [2000], Romer [1990]

<sup>8</sup> Griliches [1989], Griliches [1990], Lerner [2002], Sokoloff [1988]

Trade-Related Intellectual Property Rights (TRIPS) agreement,<sup>9</sup> patents and the broader construct of intellectual property (IP) are receiving increasing attention.

### International Trade

International trade and, in particular, trade in intermediate goods is seen as a route through which technology has propagated.<sup>10</sup> As the level of technology increases in intermediate goods, the quality of final goods also improves. An increase in the quality of these intermediate goods could require an improvement in the manufacturing process and updated worker skills.

### Foreign Direct Investment

Although often a leading indicator of technology transfers across countries (Nadiri 1993), FDI includes elements of both R&D and trade. Direct investment in a foreign country includes investment in R&D. OECD countries in particular may derive up to 20 percent of R&D activities from foreign-owned firms. Firms may base R&D divisions in foreign countries to take advantage of access to local technology and consumer preferences, thereby increasing local sales. In addition, investment in foreign production plants includes imported intermediate goods in the production process. However, FDI in domestic production, depending upon firm ownership, can have negative competition effects (Aitken and Harrison 1999).

### Other Measures of Technology Knowledge Flows

Other important influences on international technology knowledge flows and TFP include such variables as geographic distance and language (Keller 2002). Common borders facilitate trade and the transfers of physical and human capital. How open in terms of trade and the movement of workers a

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<sup>9</sup> Fink, Carston, Braga [1999], McCalman [1999], McCalman [2001]

<sup>10</sup> Keller [2004], Fink, Carston and Braga [1999]

given border is can be a mitigating factor for the level of innovation flows. A common language would also facilitate any type of cross-border flows, including technology.

### Patents as a Measure of Innovation

Patents, as a measure of inventive activity, have a number of advantages. First, extensive historical data on patents and intellectual property rights law exist across a wide range of countries. Second, each patent contains detailed information concerning design and usually some measure of provenance (Griliches 1990). Third, inherent in patents are a number of interesting properties that distinguish them from other measures of inventive activity. In particular, by deciding to patent, the inventor indicates a belief in the economic value of the idea. Also, as noted above, R&D expenditures are considered an input while patents are considered an output of the innovation process. This makes the decision by an individual or firm of where and when to patent an idea explicitly strategic in nature. Use of patent statistics in economic research reveals three approaches: one uses the number of patents applied for or granted to a firm, industry, or country as a general indicator of inventive activity (Eaton and Kortum 1999). A second utilizes the citation data included in each patent.<sup>11</sup> The citations listed on a patent trace technology upon which the current patent is based and are put there either by the inventor or patent office examiners. And finally, patents can be attributed to either industry of manufacture (source of innovation) or to sector of use (innovation destination). Until recently, this last approach was of limited utility given the time needed to perform individual patent to industry assignments. Its primary disadvantage is the fact that not all inventions are patented or even patentable, and the value of those that are patented is highly variable (Griliches 1990). In addition, patent and other intellectual property rights laws vary across countries and time (Dutfield 2002).

### Section 3: The Model

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<sup>11</sup> Hu and Jaffe [2001], Jaffe and Trajtenberg [1998]

Domestic TFP in a particular industry can be related to same industry domestic innovation, other industry domestic innovation, same industry foreign-derived innovation, and other industry foreign-derived innovation with the following Cobb-Douglas specification:

$$(1) \quad F = A(S^s)^{\beta_1}(S^o)^{\beta_2}(S^{s,f})^{\beta_3}(S^{o,f})^{\beta_4}(X)^\gamma$$

where  $F$  represents domestic factor productivity in a particular industry,  $S^s, S^o$  represent innovation knowledge flows from patenting activities within an industry and from outside that industry. Further,  $S^{s,f}, S^{o,f}$  represent the equivalent industry innovation knowledge flows from foreign sources.  $X$  represents other factors that could facilitate or hinder knowledge flows above and beyond source, such as market structure, foreign-owned firm penetration or import levels. Taking the log of (1) and adding subscripts and error term the result is:

$$(2) \quad \log f_{it} = \log a_{it} + \beta_1 \log s_{it}^s + \beta_2 \log s_{it}^o + \beta_3 \log s_{it}^f + \beta_4 \log s_{it}^{f,o} + \gamma \log x_{it} + \varepsilon_{it}$$

where  $i$  and  $t$  are industry and time subscripts respectively. If technology from sources other than own industry, both foreign and domestic, do not affect TFP in the receiving industry,  $i$ , then  $\beta_2, \beta_3$  and  $\beta_4$  will all be equal to 0.

#### Section 4: Data Description

The OECD Technology Concordance (OTC) concordance program allows inventive activity, proxied by patents, to be mapped onto industrial sectors using the International Patent Classification, rev. 7 (IPC) and the U.N. International Standard Industrial Classification, rev. 3 (ISIC) (Johnson 2002). The OTC is essentially an extension of the Yale Technology Concordance (YTC) but goes one step further in mapping IPCs directly to the ISIC system. Until the YTC, any analyses using patents either used raw patent counts from countries or firms or hand-constructed data sets assigning individual patents to industrial sectors. Raw patent counts missed possible industrial uses inherent in a patent design. Hand-

constructed data sets were labor intensive and subject to idiosyncratic sample selection bias limiting the generalizability of any results.

Between 1972 and 1995, the Canadian Intellectual Patent Office assigned an IPC, an SIC number for Industry of Manufacture (IOM), and an SIC number for Sector of Use (SOU) to 300,000 patents. The assignments were made by patent examiners who were experts in their respective fields, increasing the accuracy of patent designations. Utilizing this database, researchers at Yale constructed a concordance program that determined the probability that a given patent mapped onto a given IOM-SOU pair. This allowed for a continuous mapping rather than forcing a one to one mapping of IOM-SOU pairs. For example, IPC categories E01D (Bridges) and E01H (Street cleaning, Cleaning of permanent ways; Cleaning beaches) could have the following mapping:

IPC	IOM	SOU	Mapping Probability
E01D	1	1	.20
	2	1	.30
	2	2	.50
E01H	2	4	.05
	3	4	.55
	4	5	.20
	3	5	.10
	5	1	.10

A single patent could then map onto a number of IOM-SOU pairs even though one mapping dominated. Since the number of patents in a single IPC category might run into the hundreds for a given country/year, a continuous mapping more accurately reflects disaggregated technology flows. Taking advantage of the statistical power inherent in a probability matrix constructed from 300,000 data points results in a highly diffuse mapping of a given patent data set to industrial sectors. The OTC takes this mapping one step further, translating patent IPCs to the International Standard Industrial Classification (ISIC rev.3), thus making international comparisons possible.

To confirm the reliability of the OTC, a random sample of 400 patents from the US Patent and Trademark Office (USPTO) and 1,500 patents from the European Patent Office (EPO) were selected for

hand examination and assignment. Since a hand-assignment is the only alternative to the OTC method, such a comparison would reveal any major flaws in methodology. Using both chi-square and Spearman rank/Kendall tau statistics, correlations ranging from .84 to .96 were calculated, most being greater than .93 confirming the statistical accuracy of using the OTC. Further, since the mappings create a 66 by 126 matrix (66 IOM classifications – manufacturing sectors only by 126 manufacturing and service sectors) from an IPC to IOM-SOU probability table of roughly 70,000 entries, the results are highly disaggregate.

This mapping algorithm is an essential characteristic of the OTC in that it captures the random nature of the inventive process in terms of where an idea originates and where it might be used. The serendipitous nature of discovery and subsequent practical application is precisely the aspect of innovation that makes it at once fundamental to increased productivity and difficult to track. History is replete with stories of inventions in one area of science and their transforming effects in other, seemingly completely unrelated areas. Other measures of innovation may employ weighting factors to simulate knowledge flows, possibly missing or at least dampening the explanatory power of this random process.

The main source of patent data is the U.S. Patent and Trademark Office (USPTO). Table 1 displays some summary statistics on overall level of patent activity from 1980 to 2000 for the USPTO.<sup>12</sup> There are several observations to make about these data. First and foremost, as a percentage of all countries represented in the USPTO, the US, Japan, and Germany generate over 80 percent of the patent applications across the time period considered. When Great Britain, France, Canada, Italy and Sweden are included, the percentage rises to 90 percent and above. Since patents taken out abroad represent the leading edge of technology in the origin country and with the US being, on average, the leading source of technical innovation in the world, the USPTO is a reasonable approximation for global patenting activity. Of the three major innovator countries, the US is far and away the leading source of patents, even when accounting for home country advantage (Eaton and Kortum 1999). Furthermore, although the US,

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<sup>12</sup> The drop in patent applications after 1990 was a function of the number of patent examiners (Griliches 1989).

Germany, and Japan make up the bulk of patenting activity in both patent offices, the other countries, from the perspective of number of patents applied for, exhibit quite a bit of innovative activity.

Tables 2a and 2b display the absolute number of patents and percentage for Germany in 1990 originating from a particular industry, by industry of manufacture (IOM) – Sector of Use (SOU) pairs. Given the number and technological breadth of patents applied for at the USPTO in 1990, Germany provides a good example of preliminary output from the OTC. IOM and SOU have been aggregated into thirteen manufacturing categories based upon the ISIC (rev 3.) specification.

The first thing to note in Table 2a is that two categories, Chemicals and Drugs (ISIC 24) and Non-Electrical Machinery, Office and Computing Equipment, and Professional Goods (ISIC 29,30,33) make up the bulk of innovation, in terms of both source (IOM) and destination (SOU) of technical knowledge flows. This is in line with other research using R&D expenditure data (e.g. Keller 2004). Further, a good portion of innovation for each of the SOUs comes from either Chemicals and Drugs (ISIC 24) or Non-Electrical Machinery, Office and Computing Equipment, and Professional Goods (ISIC 29,30,33). Also notable, of the 7769 patents applied for by German inventors in the USPTO in 1990, 5241 (67 percent) of those that came from manufacturing ended up in manufacturing. Finally, there is quite a bit of variation in terms of the ISIC manufacturing categories, where patents originate, and their ‘technology spillover’ destination.

Table 2b rearranges information from Table 2a to indicate the percentage of innovation coming from a particular IOM that flows into a particular SOU. This highlights the relative importance of all manufacturing categories to a given manufacturing SOU. Here, the variation across ISIC categories becomes clearer. In particular, of the approximately 159 patents originating in all manufacturing categories that ended up in Food, Beverages, and Tobacco (ISIC 15-16), 17.1 percent originated in that industry itself. However, the bulk of innovation affecting the Food, Beverages and Tobacco industry originated in Non-Electrical Machinery and Office and Computing Equipment (ISIC 29-30, 33). Similarly, while 12.7 percent of innovations that flowed into Paper, Paper Products, and Printing (ISIC 21-22) originated from within the industry, most innovation originated in Non-Electrical Machinery,

Office and Computing Equipment, and Professional Goods (ISIC 29,30,33). The above illustrates how some industries are net generators of innovation and some net users, with significant variation in between. In particular, while Chemicals and Drugs (ISIC 24) and Non-Electrical Machinery, Office and Computing Equipment (ISIC 29-30,33) are the destination for the bulk of innovation from their respective categories, they are a major source of innovation for most of the other manufacturing categories as well.

In Table 3a, US productivity in manufacturing sectors is cross-referenced with USPTO patent data. Variations in average TFP growth across industries range from -.3 percent decline in the Paper industry for the period 1975-1996, to 0.3 percent annual growth in the Basic Metals industry, to 4.6 percent growth in the Machinery, Instruments, and Computer industry. It is interesting to note that, from a patenting standpoint, the Paper industry exhibits a relatively high 3 percent annual growth rate in both flow and stock variables. The Transportation industry also shows evidence of a disconnect between average TFP growth (-0.2 percent) and either domestic or foreign annual patent stock growth (4.6 percent and 5.3 percent growth, respectively).

Table 3b indicates that, over time, the number of patents utilized by a given industry as a share of all patents has remained relatively constant. For the last 20 years, Chemicals and Drugs and Machinery, Instruments, and Computer Equipment make up over 50 percent of patenting activity. Transportation (ISIC 34-35), averaged over 22 years, makes up the next largest share of patents. However, Electrical Machinery and Communication (ISIC 31-32) has grown steadily as a share of overall patenting activity. Given the growth of communication technology since 1975, a rise in the importance of communication in the generation of new technology is to be expected. This provides a good robustness check on the OTC concordance. When considering Table 3a, here also the Electrical Machinery and Communication category displays both the highest annual TFP growth and patent growth, regardless of the measure (i.e., stock vs. flow and foreign vs. domestic).

Tables 4a and 4b provide correlations between patent flows and measures of R&D, production, and trade. Table 4a correlates patent flow from the countries in the data set with other indicators of technology and R&D activity from 1987 - 2000. The results shown are for contemporaneous

expenditures and number of personnel, with patent flows by industry group.<sup>13</sup> Total expenditures on R&D, from business and government combined, are highly correlated with patent flows from the three main patent generating countries, the US, Japan, and Germany. This pattern holds in general for the other indicators in the table. A notable exception is Sweden in terms of funding from government sources and the number of business enterprise university graduates. Given the relatively large expenditures the Swedish government devotes to education as a percentage of GDP, this is not surprising (Kletzer and Koch 2004). In addition, the time period of the table encompasses the 1990's when Japan's economy was stagnant. Nevertheless, given its strong position in the world economy, its comparatively high correlations make sense. If the data for the R&D indicators had included 1975 – 1986, a period of steady economic growth, the correlations for Japan may have been even higher.

As a gauge of innovation, the high correlation of patent flows with other measures of innovation confirms that patents, as processed by the OTC, is indeed a useful tool. Moreover, these correlations are not so high that patents do not add something new to the empirical study of international technology knowledge flows. Also, the variation between country measures, such as current vs. capital expenditures and government vs. business sources of funding, strongly suggests the capability of patent data to address a variety of academic and policy questions.

In Table 4b, Same and Other Sector categories indicate the source sectors of innovation. Same Sector looks at within sector technology flows. Other Sector considers between sector technology flows. An example would be innovations originating in the IT sector but used in the Transportation sector. With respect to Total Output and Value Added, except for Germany, it is interesting to note that Other Sector correlations are higher than Same Sector. This could indicate that, for a given country, inter-industry technology “spillovers” are even more important than those within an industry. However, given the preponderance of patents taken out in the IT and Chemicals and Drugs sectors relative to the rest of the

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<sup>13</sup> Lags of up to three years of the technology and R&D indicators were also calculated with similar results.

economy, this result could be driven mostly by those sectors. Although the timing and level may be in some dispute, the IT sector certainly has economy-wide productivity effects.

Another interesting observation is that Value Added correlations are higher than Total Output for almost all countries, using both Same and Other Sector measures. This result makes sense. A priori, it would be expected that innovation and quality should be more highly correlated than innovation and output. Given the overall positive correlations between patent flows and Total Output and Value Added, these results highlight the benefits from technology knowledge flows.

Turning to the Imports and Exports measures, overall Export correlations are generally higher than Import correlations, although all are positive and significant. These results underscore the dual nature of technology knowledge flows. On the one hand, trade and innovation knowledge flows are positively related. On the other hand, higher export correlations highlight the strategic, competitive aspect of patents. Taking a patent out in a foreign country, by definition, legally blocks foreign firms from utilizing that technology without a licensing agreement. The result could be to boost exports to and/or limit production in that country. Considering the strategic nature of patents, domestic TFP then could be either positively or negatively affected by foreign-based patenting activity.

Finally, the tariff data results from the United Nations Conference on Trade and Development (UNCTAD), although incomplete, nevertheless have the expected sign. Higher tariffs inhibit both trade and technology flows. Given the legal aspects of tariffs and patents and the myriad of tariff laws in different countries, the low correlation levels are not surprising (Dutfield 2002).

## Section 5: Empirical Analysis

The empirical analysis section begins with a brief discussion of the patent variables used in the main analysis. Next is the main OLS analysis of domestic and foreign technology knowledge flows from all countries to the US. Domestic and Foreign Same and Other Sector knowledge flows are examined along with interactions with market structure, foreign firm penetration, and import ratio variables. Following this, an analysis of country subsets investigates how knowledge flows are affected by

geography and language. Finally, given that the patent data allows specific industry tracking of innovation flows, Information Technology (IT) sector effects are considered separately.

### Data Characteristics

The main empirical results are presented in Tables 5 and 6. Both tables include industry and time fixed effects, which account for any country specific or business cycle effects. Although an examination of the patent data across domestic and foreign sources and industries reveals no major outliers, industrial categories Computers and Office Equipment and Communications Equipment show increased patenting activity in the last few years of the sample (1995 and 1996). These categories also make up a large portion of the total patents taken out for any given year in manufacturing. Since these categories are one of the main sources of outside innovation to other industrial categories, these values are left in the dataset. A White general test for heteroskedasticity performed on the variables in the main analysis indicates no heteroscedasticity. For the main OLS specification, residual vs. predictor variable plots indicate no clear departure from linearity except for the last two years in the sample (1995, 1996) for the Communications Equipment industry. However, even when these years are included, the overall regression results merely indicate a stronger coefficient for the Foreign Other Sector variable while signs of coefficients do not change. Kernel density plots indicate minor skewness on the part of all variables. Again, when the data are restricted to the 1975 to 1994 time period, the results change very little.

### Main Analysis

The main empirical result is presented in Table 5. All patent variables are stock variables, calculated using the perpetual inventory method at a 10 percent rate of depreciation. The dependent variable, log of US TFP in sector  $i$ , is derived from the NBER TFP data set, which includes a number of

TFP measures.<sup>14</sup> All analyses use the Value Shipped measure of TFP. Based upon previous literature, the coefficients associated with domestic innovation should all be positive. Column (5.1) includes only domestic patents originating and utilized in a given industry (e.g., innovation coming from the transportation sector that is used by the transportation sector). In line with previous research, the coefficient is positive and significant. Similarly, when innovation from other domestic industries is added to the column (5.2), both Same Sector and Other Sector innovation affects on TFP are positive and significant. Same Sector influence is somewhat larger than Other Sector, which makes intuitive sense. Innovation originating in a given industry should have the greatest effect on that industry's productivity. Adding foreign patenting activity to the specification, however, yields less clear-cut results. When Foreign Same industry effects are included in the model, both domestic effects remain positive, but Foreign Same industry enters negatively into the regression. And on addition of the final variable to the specification, Foreign Other Sector, Same Domestic and Foreign Sector are positive and significant, but Foreign Other Sector enters strongly negative and significant. The result is in contrast to much of the research on diffusion of technology (Keller 2002). This last specification, as evidenced by the higher adjusted  $R^2$  and lower Akaike Information Criterion (AIC), indicates the importance of Foreign Other Sector innovation knowledge flows to US TFP, although not in the direction expected. The first three positive coefficients indicate positive innovation flows within domestic and foreign industries and between domestic industries. However, unlike other measures of technology, patents may be picking up the effects of competition at the firm or industry level, effects not found by other measures of R&D. In particular, depending upon sector and the level of domestically owned producers in that sector, any positive knowledge flow effects of domestic patenting activity by foreign firms could be overwhelmed by the competition effects (Aitken and Harrison 1999). Given the dual nature of patents as both a measure of innovation and a strategic business decision, this result should not be surprising. To further explore the

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<sup>14</sup> These include Value Shipped, Materials Cost, Investment and Energy weighted measures of TFP. Analyses using all these outcomes were performed with results that are broadly similar.

negative Foreign Other sector knowledge flow coefficient, market structure, foreign firm penetration, and import ratios were added to the model.

### Industry Concentration Ratio

The results in Table 5 indicate that, contrary to most findings concerning knowledge flows, Foreign Other Sector flows have a negative effect on US TFP growth. A possible cause for this may have to do with the level of competition in a given domestic sector. A central rationale for limiting monopoly power is the dampening effect it has on innovation and growth. Furthermore, the maturity of the industry and the level of firm entry and exit are indicators of receptivity to, and source of, innovation in productivity (Klepper 1997).<sup>15</sup> Table 6 displays an analysis examining whether market power can help explain the negative result from Foreign Other Sector flows. Column (6.1) repeats the basic model specification. Column (6.2) adds into the basic model the Concentration Ratio (CR20) for the top twenty firms in a given industry.<sup>16</sup> As expected, the main effect of the CR variable is negative, indicating a growth inhibiting effect on US TFP. However, the interaction of Foreign Other Sector flows with CR is positive and significant at the one percent level. To understand what this means, Table 7a displays a static analysis of this interaction. Specifically, average values for all the coefficients in the model without the interaction term are used to calculate the predicted value of TFP Growth. For the Foreign Other Sector knowledge flows and CR coefficients, lower quartile, average, and upper quartile values are used. When both Foreign Other Sector flows and CR are high, holding other model coefficients constant, the effect on US TFP growth is both strong and negative. However, a lower CR (i.e., greater competition), in conjunction with fewer patents from Foreign Other Sector, indicates an equally strong positive effect on US TFP growth. In an industry exhibiting greater competition, some foreign patent activity originating

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<sup>15</sup> The younger the industry, the more open it is to fundamental innovation. As an industry matures, product improvements from innovation are more of the incremental variety.

outside that industry can contribute to growth. However, more foreign patents are evidence of the innovation blocking aspect of patents (McCombs 2000). A patent confers upon the recipient the exclusive right both to use and prevent others from using an invention for a specified time period. This does not prevent learning from published patents. But a higher level of patenting activity could indicate the scope for utilizing an idea is constrained by the breadth of patent coverage. Greater coverage in a given area of innovation would limit, in the short run, the ability of a firm to generate new ideas.

### Foreign-Owned Firm Employment

A similar dynamic can be observed when considering the level of employment in foreign-owned firms as a fraction of total employment in the US.<sup>17</sup> The prior on how employment in foreign owned firms influences US TFP could go either way. A higher or lower ratio could result in either greater or lesser positive or negative influence on US TFP growth depending upon worker type: office personnel, production line workers, retail sales-related workers, or technical and R&D-oriented employees. The data being used do not include such details. Therefore, the following results only suggest possible explanations. However, the main effect of the Employment Ratio variable in Table 6 column (6.4) indicates a positive influence on US TFP. When interacted with Foreign Other Sector patenting activity, the interaction is highly significant. Table 7b indicates a higher level of Foreign Other Sector patenting activity has a negative effect on US TFP growth, regardless of Employment Ratio. As with the result in Table 7a, this could be a function of the breadth of patent coverage in a given area of innovation. Similarly, at a lower level of foreign patenting activity, the effect on US TFP growth is positive, especially so at higher levels of foreign-owned firm employment. No information, such as worker type, is given other than absolute numbers of workers. However, it is reasonable to conjecture that a higher

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<sup>16</sup> Data source: Census of Manufactures report for 1992 and 1997 compiled by the US Department of Commerce.

Concentration ratio is defined as the value of shipments in an industry accounted for by the top firms.

<sup>17</sup> Data source: U.S. Department of Commerce collected from 1987 to 1992.

employment ratio corresponds to a better chance for a broad range of work to be performed. This, in turn, would mean a larger number of workers in idea-generating employment, i.e., R&D, and thus a greater possibility for positive innovation knowledge flows to the domestic economy.

### Import Ratio

Imports to the US and the knowledge embodied in those imports affect US productivity. To examine how this impacts Foreign Other Sector knowledge flows, the ratio of imports to domestic production in a given sector was added to the model.<sup>18</sup> The results are reported in the last two columns of Table 6. The main effect, in column (6.6), indicates that increased imports mitigate the negative effect of Foreign, Other Sector knowledge flows on US productivity. If imports of intermediate goods to the US incorporate foreign technology, then part of the strategic blocking aspect of patents is circumvented. Greater imports denote greater US productivity-enhancing knowledge flows. Table 7c indicates the same dynamic as Table 7b. Namely, fewer Foreign Other Sector patents have a positive effect on US productivity. Further, fewer Foreign Other Sector patents combined with a higher import ratio show the greatest positive impact on US productivity.

### Country Subsets

The results in Table 5 consider only overall foreign effects, combining innovation flows across all foreign sources, and do not address questions about specific industrial sectors. An analysis that considers subsets of countries provides a more refined picture of the positive technology knowledge flow vs. competition question. The results displayed in Table 8 consider country subsets from several perspectives. Japan and Germany, as the most prolific patent generators after the US, are considered in the first column. The results are similar to those in Table 5, column (5.4) where all countries are included. However, when Japan and Germany are considered separately, different patterns emerge.

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<sup>18</sup> Data source: NBER Trade Database of U.S. Imports, 1972-1994, compiled by Robert Feenstra.

Contrary to the combined country results, Germany's Same Sector coefficient is negative and significant indicating a strong innovation inhibiting effect on Same Sector US TFP. Given that Germany has a large chemicals and drugs sector, trade competition in this sector may be driving the results. Contrast this outcome with the last column in Table 8 that looks at Japan's effect on US TFP. Here the result is similar to the combined country results, i.e., that Japan's Same Sector coefficient is positive and significant while the Other Sector knowledge flow coefficient is negative. This could be an indication of a greater ability of Japanese industries to adopt ideas generated from innovation outside a particular industry. Japanese consumers are known for the speed with which they embrace products with new features. In addition, innovations which do not catch on are quickly dropped. This ability to utilize innovations quickly would increase the competition effect implied in the negative knowledge flow coefficient.

Pacific Rim countries (i.e., Japan and Canada) is another country subset considered. The results are similar to those where Japan and Germany are considered separately in the last two columns. This should not be surprising given that Japan is dominant in the Pacific and Germany is the patent leader in Europe. However, when Canada is considered separately, the results indicate more direct, Same Sector competition but positive knowledge flows from Canadian Other Sector sources of innovation.

A common language for technical specifications in patent descriptions could facilitate both the ability to utilize and block innovation. Thus, only English-speaking countries, Canada and the U.K., are considered in a further country subset. Similar to Canada alone, the Foreign Other Sector coefficient is positive and significant, while Foreign Same Sector knowledge flows remain negative and significant. Given the positive coefficient for Foreign Other Sector innovations, this result could be highlighting the importance of ease of communication in utilizing innovation from outside a given industry. Technical specifications in a given language are more easily understood by a native speaker and would facilitate innovation knowledge flows. Given patent datasets (originally in German or Chinese), an interesting test would be to repeat the analysis with Germany, Austria, and Switzerland in Europe or Singapore, China, and Taiwan in Asia to see if a similar positive Other Sector effect results.

### Industry Specific Knowledge Flows

Thus far, international innovation knowledge flows have been examined across *all* manufacturing sectors. However, the output of the OTC allows one to separate the influence of a particular industry on any other industry within the ISIC (rev. 3). Here, Information Technology (IT) stands out, both in terms of economic importance and number of patents. This industry has had a profound effect on the US economy. However, it has heretofore been difficult to isolate and measure this effect. The disaggregated structure of the OTC output makes it possible to separate out and examine the effect innovations originating in the computer or other industries, have on all other industries.

### Information Technology (IT) Sector

Table 9 separates out the Other Sector coefficient into Other Sector (without IT) and IT Sector.<sup>19</sup> The IT Sector variable includes all patents originating in the IT Sector that are used in other sectors. The table displays an analysis of this effect by country subsets. When only domestic variables are considered in the first column, the IT Sector is positive and statistically significant, indicating considerable positive flows. This is a clear indication of the pervasive influence of the IT industry. However, unlike previous analyses, the Domestic Other Sector coefficient is negative. This may be an indication of how much more dynamic the IT sector has been relative to other sectors in its effect on the economy.

When foreign variables are added to the model in column (9.2), an interesting pattern emerges. Domestic flow effects increase, including the domestic IT coefficient, and remain statistically significant. Unlike Table 5, however, both Foreign Same and Other Sector coefficients are no longer statistically significant although both are positive. Now, the innovation inhibiting effect of Foreign IT, indicated by the negative coefficient, overshadows any positive knowledge flows from that sector to the domestic economy. Increases in foreign productivity, along with the strategic aspect of patenting in the domestic economy, have a major impact on domestic TFP.

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<sup>19</sup> When the IT Sector and Same Sector are the same, IT Sector is set to 0 to avoid double counting.

The last two columns of Table 9 consider the next two largest sources of foreign patent activity separately. The results for Japan, column (9.3) and Germany, column (9.4) differ somewhat from those for Japan and Germany in Table 8. In Table 9 the IT Sector coefficient for both countries is negative and significant. Since innovation flowing from the IT sector to other parts of an economy is viewed as critical to continued growth and the ability for a country to successfully take part in the world economy, this result makes intuitive sense. Competition to innovate in IT and quickly make use of those innovations in the manufacturing sector is of continued interest to economists and policymakers alike.

#### Section 6: Concluding Discussion

The recently developed OECD Technology Concordance (OTC), has great potential for further empirical work. Previous research has utilized other measures of technology, including R&D expenditures and Foreign Direct Investment (FDI). These enter earlier in the innovation process before clearly useable innovations have been identified and are perhaps better suited for measuring average long-term potential benefits rather than short or medium term effects. Further, given the imprecise nature of expenditures on general R&D, even when classified by sector, it is unclear where the resulting innovations will be used other than the originating industry. Input-output tables or import share weighting mechanisms go some way toward remedying the problem but may not capture the strategic aspects of firm production decisions.

Patent data processed by the OTC, incorporating both the random aspect of inventions and identifying the path of innovations, allow a clearer picture to emerge of where an innovation originated. And more importantly for this study, which industries will take advantage of that innovation can be identified. The very characteristics of patent applications taken out in one country by domestic and foreign inventors obviate much of the need for adjustments and inferences required for measures such as R&D expenditures. Further, patents highlight not only the positive effects of technology flows in terms of productivity but also reveal the strategic choice a firm makes implied in the decision to apply for a

patent at home and abroad. This strategic side of patenting suggests competition effects, in that patents are explicitly useful for boosting foreign productivity or inhibiting foreign and domestic competition.

When considering domestically originating technological innovations alone, the results of this study are consistent with existing literature. Namely, a given industry's productivity is positively affected by innovations originating both in that industry and elsewhere in the domestic economy. However, contrary to recent research, this study finds foreign technology effects which decrease domestic productivity growth, as exhibited by negative coefficients.

Further, when foreign patent variables are interacted with measures of market power, domestic employment in foreign-owned firms, and with imports, a more nuanced picture emerges. As long as the level of patenting by foreign countries in a given industry is not too high, knowledge flows have a positive influence on domestic productivity. High levels of patenting, though, make the use of patented ideas more difficult and provide evidence of competition-inhibiting behavior by firms within an industry.

The disaggregated nature of the OTC output, the time span considered, and the different countries in the study allow for further investigation of adverse competition effects. The language spoken in the source country, the level of trade and industry source-all may affect the ease with which technical knowledge flows to the receiving country. Industries differ in rates of knowledge diffusion, regardless of source. In addition, certain industries create more inter-industry knowledge flows than do others with the IT sector as perhaps the best example.

A consideration of subsets of countries using specific characteristics yields diverse results. Canada's contemporaneous Same Sector coefficient is negative and highly significant, reflecting the common border with the US and the amount of trade. Canadian industry competes strongly and directly with the US, and thus the strategic aspect of patents might be expected to dominate any positive knowledge flows. The common language country subset of Canada and the UK exhibits a different pattern. As with Canada alone, Foreign Same Sector is negative and significant, but here the Foreign Other Sector coefficient is positive and significant. This suggests that when countries share a common language but are not in direct competition, significant positive knowledge flows result. With Japan alone,

Foreign Same Sector is positive and statistically significant. However, Foreign Other Sector is negative and significant. This suggests that the industrial structure of a country is important in how innovation diffuses from that country. .

The organization of the patent data allows the effects of specific industries to be studied. The IT sector is a major contributor to world patenting activity, exhibiting considerable influence on productivity. Domestic IT knowledge flows are positive and statistically significant and may overshadow innovation originating from other industries. Foreign IT effects indicate a strong competition effect. Foreign productivity is increased at the expense of domestic productivity.

In conclusion, with the use of newly developed patent data, the analysis suggests that international knowledge flows do not always benefit domestic productivity, a result contrary to some current research findings. In addition, patents measure other aspects of technology diffusion that illuminate positive flow effects along with competition (negative) effects. The OTC data are relatively new, and this study represents a first step at empirical research exploiting these international patent data at the industry level. In considering first the G7, where one would expect to find the best evidence for positive knowledge flow effects on productivity, countries such as Brazil, Indonesia, Malaysia, China, and India were excluded from the analysis. However, the latter countries are major consumers of foreign technology and, increasingly, originators of their own innovations. Moreover, the disaggregation of the OTC output and the direct linkage between source and destination industries for a set of inventions increases the possibilities for further research. In short, empirical research, focusing on the impact of technological innovation, has a new tool at its disposal.

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Table 1  
 Number of Patent Applications to US Patent & Trademark Office  
 for 1980, 1990 and 2000 G-7 Countries and Sweden

Source: US Patent & Trademark Office (USPTO)

Country	1980		1990		2000	
	Number of Patents	% <sup>a</sup>	Number of Patents	% <sup>a</sup>	Number of Patents	% <sup>a</sup>
US	38991	59%	53979	54%	48575	52%
Japan	9595	14%	22216	22%	18999	20%
Germany	6383	10%	7769	8%	7414	8%
Great Britain	2481	4%	2786	3%	2305	2%
France	2339	4%	3173	3%	2499	3%
Canada	1192	2%	2060	2%	2176	2%
Italy	883	1%	1333	1%	1198	1%
Sweden	762	1%	698	1%	921	1%
Total	62626		94014		84087	

a: Total percentage of patents taken out in 1980, 1990 and 2000 by the G-7 Countries and Sweden were 94%, 95% and 90% respectively. Total number of patents applied for in USPTO in those year were 66462, 99258 and 92951 respectively

Table 2a

IOM/ SOU	Number of German Patents Applied for in USPTO, 1990													IOM total
	15-16	17-19	20, 36	21-22	24	23	25	26	27	28	29-30 +33	31-32	34-35	
15-16	<b>27.3</b>	0.1	0.0	0.1	0.5	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.0	28
17-19	0.5	<b>40.7</b>	1.8	0.9	0.4	0.1	0.7	0.2	0.0	0.1	3.0	0.8	2.1	51
20+36	2.0	15.7	<b>70.4</b>	4.0	17.7	0.4	1.8	1.1	3.0	3.9	62.2	6.5	15.8	204
21-22	11.6	0.7	1.8	<b>33.3</b>	1.1	0.1	0.6	0.3	0.0	0.5	2.2	0.3	0.1	52
24	18.1	33.0	15.9	32.9	<b>931.5</b>	26.5	122.0	8.9	5.9	31.2	31.8	15.9	12.0	1286
23	0.0	0.0	0.0	0.1	0.5	<b>4.6</b>	0.1	0.2	0.3	0.3	1.5	0.0	2.4	10
25	16.3	5.9	10.8	4.6	17.4	0.6	<b>113.8</b>	1.8	0.6	4.2	14.6	4.9	20.4	216
26	0.6	0.3	1.0	0.4	1.9	0.3	0.3	<b>39.6</b>	3.3	1.8	6.6	1.7	3.4	61
27	0.0	0.0	0.4	0.1	0.8	0.1	0.2	0.1	<b>15.6</b>	4.2	4.6	0.6	2.5	29
28	5.2	2.5	16.2	1.1	4.6	0.8	6.5	1.9	4.4	<b>64.9</b>	31.5	1.4	13.9	155
29-30 ,33	77.7	97.8	39.7	183.8	119.9	24.3	102.9	42.4	80.4	71.1	<b>1334.5</b>	48.3	116.3	2339
31-32	0.0	0.6	0.4	0.2	0.2	0.0	0.1	0.0	0.1	0.1	100.5	<b>176.2</b>	3.5	282
34-35	0.0	0.0	0.2	0.0	0.2	0.0	0.1	0.2	0.1	0.1	4.5	0.1	<b>520.8</b>	526
														5241

Table 2b

IOM/ SOU	German Patents Applied for in USPTO, 1990, Individual element as a percentage of row												
	15-16	17-19	20, 36	21-22	24	23	25	26	27	28	29-30 +33	31-32	34-35
15-16	<b>17.1</b>	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17-19	0.3	<b>20.6</b>	1.1	0.4	0.0	0.1	0.2	0.2	0.0	0.0	0.2	0.3	0.3
20+36	1.2	8.0	<b>44.4</b>	1.5	1.6	0.6	0.5	1.2	2.6	2.1	3.9	2.5	2.2
21-22	7.3	0.3	1.1	<b>12.7</b>	0.1	0.2	0.2	0.3	0.0	0.3	0.1	0.1	0.0
24	11.4	16.7	10.0	12.6	<b>84.9</b>	45.9	34.9	9.2	5.2	17.1	2.0	6.2	1.7
23	0.0	0.0	0.0	0.0	0.0	<b>8.0</b>	0.0	0.2	0.3	0.2	0.1	0.0	0.3
25	10.3	3.0	6.8	1.8	1.6	1.0	<b>32.6</b>	1.8	0.6	2.3	0.9	1.9	2.9
26	0.4	0.1	0.6	0.1	0.2	0.5	0.1	<b>41.0</b>	2.9	1.0	0.4	0.6	0.5
27	0.0	0.0	0.3	0.0	0.1	0.2	0.1	0.1	<b>13.8</b>	2.3	0.3	0.3	0.3
28	3.3	1.3	10.2	0.4	0.4	1.4	1.9	2.0	3.8	<b>35.6</b>	2.0	0.5	1.9
29-30 ,33	48.8	49.6	25.0	70.3	10.9	42.1	29.5	43.8	70.8	39.0	<b>83.5</b>	18.8	16.3
31-32	0.0	0.3	0.3	0.1	0.0	0.0	0.0	0.0	0.1	0.1	6.3	<b>68.6</b>	0.5
34-35	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.1	0.1	0.3	0.0	<b>73.0</b>

15-16 Food, beverages, and tobacco

17-19 Textiles, apparel, and leather

20+36 Wood products and furniture

21-22 Paper, paper products and printing

24 Chemicals and drugs

23 Petroleum refineries and products

25 Rubber and plastic products

26 Non-metallic products

27 Basic metal industries

28 Metal products

29-30 Non-electrical machinery, office and

+33 computing equip.  
Electrical machines and communication

31-32 equipment

34-35 Transportation equipment

Table 3a  
Average Annual TFP Growth for US  
(Time period: 1975 - 1996)

Industry	ISIC (rev 3)	Annual TFP Growth (%)			Annual USPTO Patent Flow Growth (%)		Annual USPTO Patent Stock Growth (%)	
		Avg	Min.	Max	Dom.	For.	Dom.	For.
Food	15-16	0.1	-2.7	2.3	1.8	3.4	2.6	4.3
Textiles	17-19	1.0	-0.8	4.4	2.0	2.4	1.9	3.4
Wood	20+36	0.4	-2.0	4.3	2.8	4.3	3.1	4.8
Paper	21-22	-0.3	-5.2	2.8	3.1	5.7	3.0	5.7
Chemicals & Drugs	24	0.1	-3.7	5.9	1.1	2.3	1.9	2.9
Petroleum	23	0.5	-5.4	5.0	-1.0	1.2	0.5	2.2
Rubber	25	1.0	-3.7	4.6	1.7	3.9	1.7	2.7
Non-met. Miner.	26	0.7	-3.8	6.3	1.2	3.8	1.8	3.2
Basic Metals	27	0.3	-6.3	3.7	0.2	1.6	1.3	2.1
Metal Products	28	0.0	-5.0	4.8	1.6	3.9	2.4	4.4
Machinery, Instr., Comp.	29-30+33	1.5	-2.9	8.0	4.5	6.6	3.6	5.8
Elec. Machinery, Comm.	31-32	4.6	-4.8	30.6	6.3	9.4	5.2	8.1
Transportation	34-35	-0.2	-6.0	5.4	2.0	4.6	2.7	5.3

Table 3b  
Share (%) of Total Patents

Industry	1975- 1996	1975- 1979	1980- 1984	1985- 1989	1990- 1994	1995- 1996	1995- 1980
Food	3.3	3.6	3.5	3.4	3.1	2.7	3.5
Textiles	2.6	3.1	2.9	2.7	2.4	2.2	3.0
Wood	4.2	4.5	4.1	4.3	4.2	3.9	4.3
Paper	4.0	3.7	3.9	4.1	4.2	4.0	3.7
Chemicals & Drugs	15.7	18.5	17.1	15.3	14.5	13.4	17.7
Petroleum	1.3	1.9	1.9	1.3	1.0	0.7	2.0
Rubber	5.3	5.6	5.5	5.5	5.2	4.6	5.4
Non-met. Miner.	1.7	1.9	1.9	1.9	1.6	1.4	2.0
Basic Metals	1.7	2.1	2.0	1.8	1.5	1.2	2.0
Metal Products	3.4	3.7	3.7	3.5	3.2	2.8	3.6
Machinery, Instr., Comp.	37.3	33.9	35.5	36.3	38.7	42.1	35.2
Elec. Machinery, Comm.	9.2	6.4	7.7	9.0	10.6	12.2	7.1
Transportation	10.2	11.0	10.4	10.8	9.8	8.9	10.5

Source NBER TFP dataset, USPTO Data processed by OECD Technology Concordance

**Table 4a**  
**Basic Science<sup>a</sup> Indicators by Patent Flows**  
**(Pairwise correlations)**

	US	Japan	Germany	UK	France	Canada	Italy	Sweden
Total Business Enterprise R&D Expenditures	0.782	0.957	0.686	0.662	0.570	0.367	0.488	0.641
Expenditure Funding Source: Business Enterprises	0.763	0.960	0.727	0.623	0.639	0.329	0.624	0.583
Expenditure Funding Source: Government	0.410	0.424	0.253	0.166	0.406	0.191	0.233	0.684
Total Personnel in Business Enterprise R&D	-	0.955	0.715	0.578	0.643	0.392	0.575	0.710
Business Enterprise University Graduates	-	-	0.589	-	-	0.374	0.559	0.718
Capital Expenditures	-	0.882	0.609	0.609	0.587	0.267	0.532	0.492
Current Expenditures	0.691	0.961	0.681	0.620	0.590	0.349	0.521	0.649

**Table 4b**  
**Trade and Production Indicators<sup>b</sup> by Patent Flows**  
**(Pairwise correlations)**

	US	Japan	Germany	UK	France	Canada	Italy	Sweden
Same Sector: Total Output <sup>c</sup>	0.527	0.646	0.538	0.421	0.306	0.120	0.395	0.332
Other Sector: Total Output	0.676	0.676	0.406	0.557	0.444	0.475	0.584	0.618
Same Sector: Value Added	0.664	0.684	0.619	0.506	0.395	0.196	0.545	0.488
Other Sector: Value Added	0.769	0.723	0.393	0.620	0.500	0.580	0.602	0.705
Same Sector: Tariffs, UNCTAD <sup>d</sup>	-0.091	-0.280	.	.	.	-0.262	.	.
Other Sector: Tariffs, UNCTAD <sup>e</sup>	-0.015	-0.287	.	.	.	-0.190	.	.
Same Sector: Imports	0.607	0.447	0.548	0.664	0.712	0.654	0.641	0.686
Other Sector: Imports	0.597	0.387	0.437	0.684	0.730	0.603	0.526	0.388
Same Sector: Exports	0.815	0.780	0.777	0.805	0.611	0.302	0.599	0.590
Other Sector: Exports	0.791	0.683	0.545	0.737	0.637	0.470	0.624	0.612

a: Source: USPTO and OECD Basic Science Indicators Database. Correlations are with Same industry patents only. All expenditures in 1995 US dollars. All results significant at < 1% level unless otherwise specified

b: Source: USPTO and World Bank Trade and Production Database. All expenditures in US dollars. All results significant at < 1% level unless otherwise specified

c: Canada significant at < 5% level

d: US not significant, Japan significant at 1% level, Canada significant at 10% level

e: US, Canada not significant, Japan significant at 1% level

Table 5

OLS Specification<sup>a</sup>: LHS: Log of US TFP index - Value Shipped weighted  
(Technology depreciation rate = 10%, Time Period: 1975 - 1996)

Patent Stocks	(T5.1)	(T5.2)	(T5.3)	(T5.4)
Same Sector, Domestic	0.464** (0.04)	0.330** (0.08)	0.573** (0.12)	0.370** (0.12)
Other Sector, Domestic		0.233* (0.11)	0.274* (0.11)	1.130** (0.17)
Same Sector, Foreign			-0.133** (0.05)	0.436** (0.10)
Other Sector, Foreign				-0.905** (0.14)
Constant	-3.866** (0.37)	-4.769** (0.56)	-6.122** (0.75)	-8.879** (0.82)
Adjusted R-squared	0.25	0.26	0.28	0.38
Observations	286	286	286	286
AIC	-4.28	-4.28	-4.30	-4.45

a: All specifications include Industrial Sector and Time fixed effect variables

Standard errors in parentheses

+ significant at 10%; \* significant at 5%; \*\* significant at 1%

Table 6  
Market Power, Foreign Firm Penetration and Import Ratio  
OLS Specification<sup>a</sup>

Patent Stocks	(T6.1)	(T6.2)	(T6.3)	(T6.4)	(T6.5)	(T6.6)	(T6.7)
Same Sector, Domestic	0.370** (0.12)	0.385** (0.11)	0.503** (0.12)	0.380** (0.11)	0.317** (0.11)	0.319** (0.06)	0.330** (0.06)
Other Sector, Domestic	1.130** (0.17)	1.189** (0.17)	1.024** (0.17)	1.167** (0.17)	1.054** (0.16)	0.381** (0.09)	0.311** (0.09)
Same Sector, Foreign	0.436** (0.10)	0.433** (0.10)	0.434** (0.10)	0.376** (0.10)	0.496** (0.10)	0.254** (0.05)	0.293** (0.05)
Other Sector, Foreign	-0.905** (0.14)	-0.899** (0.14)	-2.418** (0.53)	-0.900** (0.14)	-1.082** (0.14)	-0.534** (0.07)	-0.601** (0.07)
Concentration Ratio, Top 20 Firms <sup>b</sup>		-0.613* (0.29)	-3.301** (0.95)				
Employment Ratio, Foreign owned firms <sup>c</sup>				0.904* (0.40)	-12.667** (3.75)		
Import Ratio <sup>d</sup>						1.029** (0.30)	-5.466** (1.86)
Interaction Term			0.356** (0.12)		1.588** (0.44)		0.744** (0.21)
Constant	-8.879** (0.82)	-6.980** (1.22)	4.919 (4.19)	-8.937** (0.81)	-6.815** (0.98)	-3.648** (0.51)	-2.881** (0.55)
Adjusted R-squared	0.38	0.38	0.40	0.39	0.41	0.38	0.41
Observations	286	286	286	286	286	260	260
AIC	-4.45	-4.46	-4.48	-4.46	-4.50	-6.02	-6.06

a: All specifications include Industrial Sector and Time fixed effect variables. Standard errors in parentheses

b: concentration ratio is the share of the value of shipments in an industry accounted for by the top 20 firms.

c: Employment Ratio, Foreign owned firms is the ratio of employment at foreign owned firms to total employment.

d: The Import Ratio is calculated as the ratio of Imports to Domestic Production.

+ significant at 10%; \* significant at 5%; \*\* significant at 1%

Table 7a

Market Structure: Concentration Ratio of the Top 20 Firms in the Domestic Industry<sup>a</sup>

		Greater Market Power →		
		Lower Concentration Ratio	Avg.	Higher Concentration Ratio
Foreign Other as Source of Patents	Fewer Patents	0.41	0.34	0.21
	Avg.	0.07	0.00	-0.13
	More Patents	-0.21	-0.28	-0.41

Table 7b

Foreign Penetration: Ratio of Employees in Foreign vs. Domestic owned firms as a percentage of all firms<sup>a</sup>

		Greater Foreign Penetration →		
		Lower Employment Ratio	Avg.	Higher Employment Ratio
Foreign Other as Source of Patents	Fewer Patents	0.30	0.35	0.38
	Avg.	-0.04	0.00	0.04
	More Patents	-0.33	-0.28	-0.25

Table 7c

Import Penetration: Imports/Domestic Production Ratio<sup>a</sup>

		Greater Import Share →		
		Lower Import Ratio	Avg.	Higher Import Ratio
Foreign Other as Source of Patents	Fewer Patents	0.16	0.19	0.20
	Avg.	-0.04	-0.01	0.00
	More Patents	-0.20	-0.18	-0.17

a: Cell contents are predicted value of Factor Productivity using average values for Domestic and Foreign Same and Other Industry Source of Patenting variables. For Foreign Different Sourced Fewer and More Patents rows, the bottom 25% and top 75% quartile values were used. Likewise for Higher and Lower Concentration Ratios, Lower and Higher Employment ratio values, and for Higher and Lower Import/Dom.Prod. Ratios, the bottom 25% and top 75% quartile values were used

Table 8  
Country Subsets - OLS Specification<sup>a</sup>

Patent Stocks	Primary Patent Sources <sup>b</sup>	Pacific Rim/ Europe <sup>c</sup>	English Speaking <sup>d</sup>	Canada	Germany	Japan
Same Sector, Domestic	0.448** (0.118)	0.274* (0.111)	0.278* (0.115)	0.613** (0.132)	0.353** (0.105)	0.387** (0.110)
Other Sector, Domestic	0.977** (0.185)	1.036** (0.152)	1.447** (0.203)	1.005** (0.167)	0.685** (0.160)	0.941** (0.162)
Same Sector, Foreign	0.831** (0.132)	0.995** (0.163)	-0.505** (0.131)	-0.279** (0.085)	-0.531** (0.137)	0.777** (0.157)
Other Sector, Foreign	-1.166** (0.147)	-1.004** (0.170)	0.225*** (0.200)	0.029*** (0.109)	-0.252* (0.161)	-0.816** (0.182)
Constant	-9.200** (0.844)	-5.982** (1.013)	-9.702** (0.812)	-9.826** (0.874)	-5.257** (0.919)	-6.813** (1.095)
Adj. R <sup>2</sup>	0.420	0.450	0.410	0.400	0.480	0.430
N	286	286	286	286	286	286

a: All specifications include Industrial Sector and Time fixed effect variables. Each column also controls for countries not in that specification.

b: Foreign Countries include: Japan, Germany

c: Foreign countries include: Japan and Canada, Remaining Fgn countries are essentially the european countries in the data (Germany, the UK, France, Italy, Sweden)

d: Foreign countries include: Canada, the UK

+ significant at 10%; \* significant at 5%; \*\* significant at 1%

Table 9  
Information Technology (IT)<sup>a</sup>: Dependent Variable: Log of US  
TFP index

(Time Period: 1975 - 1996)

Patent Stocks	(T9.1)	(T9.2)	(T9.3)	(T9.4)
Same Sector, Domestic	0.587** (0.082)	0.723** (0.153)	0.963** (0.161)	0.909** (0.189)
Other Sector, Domestic	-0.866** (0.131)	-0.966** (0.267)	-1.090** (0.274)	-0.713* (0.314)
IT, Domestic	0.807** (0.110)	1.104** (0.135)	0.877** (0.129)	0.487* (0.216)
Same Sector, Foreign		0.163 (0.114)		
Other Sector, Foreign		0.198 (0.197)		
IT, Foreign		-0.545** (0.136)		
Same Sector, Japan			0.474* (0.184)	
Other Sector, Japan			0.193 (0.153)	
IT, Japan			-0.646** (0.145)	
Same Sector, Germany				-0.717** (0.126)
Other Sector, Germany				0.746** (0.231)
IT, Germany				-0.267+ (0.140)
Constant	-4.730** (0.563)	-5.959** (0.861)	-5.054** (1.033)	-4.524** (0.916)
Adjusted R-squared	0.39	0.43	0.47	0.52
Observations	264	264	264	264
AIC	-4.46	-4.51	-4.57	-4.67

a: All specifications include Industrial Sector and Time fixed effects. Standard errors in parentheses. + significant at 10%; \* significant at 5%; \*\* significant at 1%. When the Same sector is the IT Sector, the values is set to 0 to avoid double counting.