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INTERNATIONAL KNOWLEDGE FLOWS: EVIDENCE FROM AN INVENTOR-FIRM MATCHED DATA SET

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ABSTRACT

We describe the construction of a panel data set from the U.S. patent data that contains measures of inventors' life-cycle R&D productivity--patents and patent citations. We match the data set to information on the U.S. pharmaceutical and semiconductor firms for whom they work. In this paper we use these data to examine the role of research personnel as a pathway for the diffusion of ideas from foreign countries to U.S. innovators. In particular, we find in recent years an increase in the extent that U.S. innovating firms collaborate with or employ researchers with foreign experience. This increase appears to work primarily through an increase in U.S. firms' employment of foreign-residing researchers; the fraction of research-active U.S. residents with foreign research experience appears to be falling, suggesting that U.S. pharmaceutical and semiconductor firms are increasingly locating operations in foreign countries to employ such researchers, as opposed to such researchers immigrating to the U.S. to work. In addition, we investigate which U.S. firms conducting R&D build upon innovations originating abroad. We find that employing or collaborating with researchers who have research experience abroad seems to facilitate the use of output of non-U.S. R&D. We also find that in the semiconductor industry smaller and older firms, and in the pharmaceutical industry, younger firms are more likely to access foreign R&D output.

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1. Introduction

Understanding the nature of knowledge spillovers is an important area of research because of its implications for economic growth and science and technology policy. The importance of knowledge spillovers has been well recognized in the literature (for example, Griliches, 1992). Knowledge spillovers can take place in a number of ways: through various methods of communication (scholarly publications, the material published in universities' patent applications and the like) or through person-to-person contacts in informal settings.[1] Knowledge spillovers may also occur through employing or collaborating with researchers.

Studies in both the economics and sociology of innovation literatures argue that new technologies are frequently difficult to transmit to the uninitiated via spoken or written communication (see Polyani, 1958, for an early discussion of the 'tacitness' of knowledge). Often the most efficient means of transmission across organizational boundaries for tacit knowledge is via person-to-person contact involving a transfer or exchange of personnel. Recent findings that technological diffusion appears to be geographically limited (e.g., Jaffe, 1989; Jaffe, Trajtenberg, and Henderson, 1993; Audretsch and Feldman, 1996; Zucker, Darby, and Brewer, 1998; and Mowery and Ziedonis, 2001) are often interpreted as evidence of the tacitness of knowledge. Feldman (1994) suggests that tacit knowledge transmission can only take place through intense communication and is facilitated by close location.

More direct evidence exists that person-to-person interaction is important for the diffusion of technology. Cohen, Nelson, and Walsh (2002) surveyed R&D managers on the means by which they gather and assimilate new technologies. They find that firms access

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[1] See Cohen, Nelson and Walsh (2002) on the various means by which innovating firms access know-how developed externally. See Agrawal, Cockburn, and McHale (2003) for evidence of the importance of social networks in promoting diffusion. Von Hippel (1988) documents how direct informal contacts between researchers affect knowledge spillovers.

externally-located technology partly through the hiring of and collaboration with researchers from the outside. Moreover, they find that hiring/collaboration with outside scientists is complementary to other means of accessing externally produced knowledge, such as through informal communications with outsiders and more formal (such as consulting) relationships with outsiders. Almeida and Kogut (1999) find that scientific references that firms cite in their patent applications reflect the employment histories of their inventors, suggesting that ideas in the semiconductor industry are spread by the movement of key engineers among firms, especially within a geographical area.[2] Zucker, Darby, and Armstrong (2001) find evidence of a pay-off to firms that seek interactions with outside researchers. They find a positive impact on patent productivity for biotech firms that collaborate with university researchers on research and scholarly publications.

We have constructed a scientist-based data set that will allow us to study the role of research personnel as a pathway for the diffusion of ideas, among other aspects of innovation. This paper details the construction of these data and then describes their use in an analysis of the influence of foreign R&D on U.S. innovating firms. This paper is part of a larger project examining empirically issues related to the labor market for scientists.

The first half of the paper describes the construction of these data. The inventors behind the patented invention, as well as their home addresses, are listed on each U.S. patent, as are the firms to which the patent is assigned and the assignees' nationalities of incorporation. The firm to which the patent is assigned is in most cases the employer of the persons named in the

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[2] See also the (indirect) evidence of a link between scientific mobility and technological diffusion in Kim and Marschke (2005) and Moen (2005). Kim and Marschke find that firms are more likely to patent in environments where scientists are more likely to switch employers, suggesting that workers do transmit technological know-how when they move from one employer to another. Technical knowledge acquired by the scientist that can be transmitted to future employers is a form of general human capital. Thus, like general human capital, scientists should pay to acquire technological knowledge that they can exploit possibly with multiple employers with lower wages. Moen finds some evidence of this: he shows that technical workers in R&D intensive firms in Norway accept lower wages early in their career in exchange for higher wages later.

inventor field. We match names in the inventor fields of patents to construct a panel data set of inventors that contains the patents in each year of the inventors' careers. The resulting data set allows us to track scientists geographically over the course of their career. These data afford us a window on the migration of technological human capital across national borders, one possible mechanism by which technology diffuses internationally. Patent applications disclose any knowledge they have of previous relevant inventions. Through its citations to previous patents each patent documents the "prior art" upon which the new innovation builds, and because we know each cited patent's assignee type, we know in which sector and country the prior art originated. These citations provide an additional window on the pathways of knowledge. In the final stage of constructing our patent-inventor data set we merge in citations made by the patent for each patent to which the inventor is named.

One use to which we wish to put our data is in understanding the factors that influence the innovating firm's accessing of recent innovations developed externally. A focus of this part of the analysis is the pharmaceutical and semiconductor industries, two industries that are especially prolific generators of innovations and patents. Thus the last stage of data construction involves carefully matching the inventor data to data on publicly traded firms in these two industries.

After detailing our data construction efforts, we put our data to use investigating the international transmission of technology through scientific labor markets. For each patent assigned to a U.S. firm, we can determine the country of the inventor's residence at the time of patent application, and whether they had ever been named as an inventor on a patent while residing abroad. Inventing in a foreign country can be regarded as evidence of an inventor's exposure to research abroad. We also investigate which U.S. firms in our two industries cite foreign-assigned patents as prior art and thus build upon innovations originating abroad.

Our main findings are the following. We find that there has been an increase in recent years of U.S. innovating firms employing or collaborating with researchers with foreign experience. This increase appears to work primarily through an increase in U.S. firms' employment of foreign-residing researchers; the fraction of research-active U.S. residents with foreign research experience appears to be falling, suggesting that U.S. pharmaceutical and semiconductor firms are going to foreign countries to employ such researchers as opposed to such researchers immigrating to the U.S. to work for U.S. firms. In addition we investigate the firm-level determinants of accessing non-U.S. technological know-how. We find, for example, that employing or collaborating with researchers with research experience abroad seems to facilitate this access. Also, in the semiconductor industry, smaller and older firms and in the pharmaceutical industry, younger firms are more likely to make use of the output of non-U.S. R&D.

The paper is organized as follows. Sections 2 and 3 describe the sources for the data construction and the construction itself. Section 4 details some descriptive statistics of the data set. Section 5 describes our analysis on the influence of foreign R&D on U.S. innovation. Section 6 concludes.

2. Data Sources

The data set we have created contains measures—patents and patent citations—of the R&D productivity of individual researchers between 1975 and 1998 and includes information on their advanced degrees in the natural sciences and engineering fields. These data also contain, for patents assigned to publicly traded firms in the U.S. pharmaceutical (Primary SIC code 2834) or semiconductor industry (Primary SIC code 3674), information (e.g., firm size and R&D expenditures) on the patents' assignees. Budgetary and time constraints limited the number of industries that we could include in our analysis. The pharmaceutical and semiconductor industries were selected because they are especially prolific generators of innovations[3] and their products are relatively homogeneous[4] compared to those of other industries.

The data for this study come from six sources: (1) Patent Bibliographic data (Patents BIB) released by the U.S. Patent and Trademark Office (U.S.PTO), which contains bibliographic information on all U.S. utility patents issued from 1969 to 2002; (2) the ProQuest Digital Dissertation Abstracts database, which contains information on the date, field, and type of degree for those who earned degrees in all natural science and engineering fields between 1945-2003; (3) the Compact D/SEC database from 1989 to 1997, which contains firm information taken primarily from 10-K reports filed with the Securities and Exchange Commission; (4) the Standard & Poor's Annual Guide to Stocks-Directory of Obsolete Securities, which includes a history of firm name changes, and merger and acquisition; (5) the Thomas Register, Mergent, and Corptech data which report a firm's founding year, and finally (6) the NBER Patent-Citations data collected by Hall, Jaffe and Trajtenberg (2001), which contain all citations made by patents granted in 1975-1999. These data sources are described in detail below and variables used in our study from each data source are in Table 1.

2.1. Patent Bibliographic data (Patents BIB)

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[3] Based on NBER-Case Western University data of U.S. patents from 1963 to 1999, 15.3% of industry patents were granted to the firms in the pharmaceutical industry and 14.8% were granted to those in the semiconductor industry.

[4] In a cross-sectional analysis involving multiple industries, differing technologies and patent propensities make interpretation of results difficult. By limiting analysis to the patents and their inventors in a specific industry, we resolve heterogeneity in the propensity to patent across industries, thus making comparisons of patents and citations more meaningful.

Patents BIB is one of the Cassis Series of optical disc products released by the U.S.PTO. Patents BIB contains bibliographic information for U.S. utility patents issued since January 1969. The information includes patent ID number, dates of the patent's application and granting, patent assignee, and geographic information on all inventors involved. The original optical disc we use covers patents issued between 1969 and 2002, and contains over 3 million U.S. patents granted. We use only the patents granted after January 1975 because detailed geographic information for all inventors is available in Patents BIB only for patents granted after that date. Most foreign innovating firms, especially those in Western Europe and in Japan apply for patents in the U.S. in addition to their home countries so that U.S. patent data reflect nearly the universe of patented innovations. The number of patents during this period is 2,493,610 (U.S. Patent No. 3,858,241 through 6,351,850), which together list 5,105,754 inventors (an average of 2.05 inventors listed per patent).

2.2. ProQuest Digital Dissertation Abstracts

This database contains information on the author and the title of dissertation, degree conferring institution, date of degree, academic field, and type of degree (MA, MS, MBA, LLM, Ph.D., or Ph.D. equivalent) for those who earned degrees between 1945 and 2003 from over 1,000 North American graduate schools and European universities. Before matching to Patent BIB information of inventors, we took total 1,068,551 dissertation abstracts in all the natural science and engineering fields among over 2 million doctoral dissertations and Masters theses in all fields of the ProQuest database.

2.3. Compact D/SEC

The Compact D/SEC contains about 12,000 firms that have at least $5 million in assets and at least 500 shareholders of one class of stock of U.S. companies traded on the American Stock Exchange, the NASDAQ, the New York Stock Exchange, or the Over-the-Counter equities market. The data set provides financial and other information obtained from Annual Reports, 10-K and 20-F filings, and Proxy Statements for those companies. Most of the companies included are American. Company records include directory information, primary and secondary SIC codes, brief business descriptions, names of subsidiaries, names of top executives, ownership data, financial data, and excerpts from annual reports and other SEC reports.

2.4. Standard & Poor's Annual Guide to Stocks (S&P)

The firm-level information from the Compact D/SEC data cannot be directly matched to assignees in the Patents BIB data because parent firms patent sometimes under their own names and other times under the names of their subsidiaries. Mergers and acquisitions at both the parent firm and subsidiary levels and name changes further complicate linking the patent to firm-level data. To track the ownership of firms over the entire period of our study, we use the information in the Standard & Poor's Annual Guide to Stocks. The S&P data provide histories of firm ownership changes due to mergers and acquisitions, bankruptcy, dissolution, and name changes, updated through December 2002.

2.5. NBER Patent-Citations

Patent applicants are legally obligated to disclose any knowledge they have of previous relevant inventions. Citations are of two kinds: to science (or prior science publications) and to technology (or previous patents). The patent examiner may add to the application relevant citations omitted by the applicant. Thus, through the patent citations each patent documents the "prior art" upon which the new innovation builds. Through the citations we can trace knowledge flow, measure the "closeness" of technological innovations, and measure an innovation's impact.

The data collected by Hall, Jaffe and Trajtenberg (2001) contain all citations made and received by patents granted between 1975 and 1999. Their data contain a total of 16,522,438 citation records; the mean number of citations received by a patent is 5.07, ranging from a minimum of 1 and a maximum of 779, respectively. The number of patents granted to the firms identified in the pharmaceutical and semiconductor industries between 1975 and 1999 is 244,158. The mean citations received by a patent in these two industries is 8.13, ranging from a minimum of 1 and a maximum of 631.

3. Data Set Construction Process

This section discusses key issues that arise in assembling our data set from these six sources. The assembly requires three steps. First, we create an inventor identifier in Patents BIB because of the non-uniqueness of inventors' names. The primary challenge in this step is identifying who is who among inventors with same or similar names. The authors in the Dissertation Abstract data are then matched with inventors in the Patents BIB data. Second, we identify each firm's ownership structure of subsidiaries and their name changes over the data period to construct firm-level data, using the Compact D/SEC and the S&P data. In the final step, we combine the inventor data and the firm data and then add the patent citation data where each citing patent that was granted between 1975 and 1999 is matched to all patents cited by the patent.

3.1. Identifying the same inventor among ‘same/similar’ names

Over 5.1 million inventor names are contained in the U.S. patent data from January 1975 through February 2002. Each inventor name record includes the last name, first name, middle name and suffix (Jr., Sr., etc.) of the inventor, as well as his/her street address, city, state, zip code (often missing), and country of residence at the time of the granting of the patent.

Identifying the same inventor in different records with same or similar names (for example, John Maynard Keynes, John M. Keynes, John Keynes and John Keyens) is not an easy task. Our matching method uses as much information in the patent data as possible to increase the number of names matches without losing matching accuracy. Our name-matching methodology is similar to that in Trajtenberg (2004).

To start, we treat each entry that appears in the inventor name field of every patent in the Patents BIB data as a unique inventor. Given N number of names in this name pool, we pair each name with all other names, which generates N(N-1)/2 number of unique pairs. The 5.1 million names in the Patents BIB data (2.05 inventors per patent) thus produce 13 trillion unique pairs. For each pair, we consider the two names as belonging to the same inventor if the SOUNDEX codes of their last names and their full first names are the same, and at least one of the following three conditions is met: (1) the full addresses for the pair of names are the same; (2) one name from the pair is an inventor of a patent that is cited by another patent whose inventors include the other name from the pair; or (3) the two names from the pair share the same co-inventor. These three criteria in our name matching method are similar to the “Strong” criteria of Trajtenberg (2004).

SOUNDEX is a coded index for last names based on the way a last name sounds in English rather than the way it is spelled. Last names that sound the same, but are spelled differently, like SMITH and SMYTH, have the same SOUNDEX code. We use the SOUNDEX coding method to expand the list of similar last names to overcome the potential for misspellings and inconsistent foreign name translations to English; misspellings are common in the U.S.PTO data as are names of non-Western European origin (see Appendix A for the detailed SOUNDEX coding method).

We also consider a pair of names as a match if two have the same full last and first names, and at least one of the following two conditions is met: (1) the two have the same zip code; or (2) they have the same full middle name. These two criteria correspond to the “Medium” criteria of Trajtenberg (2004). As an additional step beyond the aforementioned pair-wise comparisons, we treat a pair of inventors as mismatched if the middle name initials of the pair are different.

Table 2 illustrates our name-matching procedure. Inventors 001 and 002 in Table 2 have the same last and first names, and share the same co-inventor. Thus, the two records in this pair are treated as the same inventor. Inventors 002 and 003 do not have the same full middle name but share the same zip code, and thus the two inventors are treated as the same inventor. Although inventors 002 and 005 share the same zip code, the middle name initials are different. Therefore, the pair is not considered a match (they would not be considered a match by our algorithm even if their street addresses were identical, possibly a case of a parent and a child).

Imposing transitivity

Transitivity is imposed in the following sense: If name A is matched to name B and name B is matched to name C, name A is then matched to name C. We iterate this process until all possible transitivity matches are completed. After the transitivity procedure, we assign the same inventor ID number for all the names matched. For instance, inventors 001 and 003 are not linked in the initial round of name matching, but they are matched through transitivity because inventors 001 and 002 are matched and inventors 002 and 003 are matched.

Imposing transitivity, however, poses a possibility of name mismatch. Suppose, for example, Adam E. Smith and Adam Smith are matched in one pair, and Adam J. Smith and the same Adam Smith are matched in another pair. According to our transitivity procedure, Adam E. Smith and Adam J. Smith are identified as a match although their middle name initials are different. The number of matches through transitivity suffering from this problem appears to be trivial, however: we find 126 cases where two inventors are matched although their middle names were different out of 2.3 million uniquely identified inventors. Upon further investigation of these cases, we found the mismatches are of three kinds. In the first kind, some middle names in the Patents BIB data are incorrectly coded. For instance, our transitivity procedure matched the names 'Laszlo Andra Szporny' and 'Laszlo Eszter Szporny' which appear to belong to the same inventor according to other information. We found that this particular inventor does not have a middle name, and the middle names attributed to him were in fact the first names of the next co-inventors listed on his patents. In the second kind of mismatch, an inventor with two middle names is coded in the Patents BIB data with one middle name in some cases and with the other middle name in other cases. In the third kind, a mismatch occurs when two inventors with the same last and first name but different middle names appear in the same patent. We corrected by hand instances of the first two kinds of mismatch, but dropped from our data the observations displaying the third kind of mismatch.

Trajtenberg (2004) assigns scores for each matching criterion and considers a pair matched only if its total score from all matching criteria exceeds a threshold. Because the choice of weights and the score threshold for a match is largely arbitrary, we do not use this scoring method in our data construction. Our method also differs in that we do not use as a matching criterion whether two inventors share the same assignee because name matching based on this criterion might bias our measure of mobility among inventors. Instead we apply the rule that two inventors are not treated as a match if their middle name initials differ. From our experience with the patent data, imposing this rule is effective because the SOUNDEX coding system sometimes so loosely specifies names that apparently different last names are considered a match.

In the end, because of these differences, the number of distinct inventors identified with our procedure is a little higher than the number of distinct inventors reported in Trajtenberg (2004). We identified 2.3 million unique inventors (45%) out of 5.1 million names in the entire patent data while Trajtenberg (2004) found 1.6 million distinctive inventors (37%) out of 4.3 million names. Note that our patent database is larger because it includes additional years, 2000-2002.

Adding in Dissertation Abstracts information

We next match names in the Dissertation Abstract data to the inventors in the patent data. Each inventor identified through the above-described procedure may have a list of names matched to him or her (for example, John Maynard Keynes, John M. Keynes, John Keynes) due to names linked to each other by employing our matching criteria. Since the Dissertation Abstract data contain for each individual a full name in a string instead of separate last, first and middle name fields, we convert all the names under each inventor ID number in the patent data to strings to search for them within the Dissertation Abstract data.[6] When an inventor holds multiple degrees, we assign the highest degree to the inventor. On rare occasions when multiple names from the Dissertation Abstract data are matched to one ID number in the patent data, we randomly pick one name. Out of 2.3 million unique inventors in our patent data, 5.3 percent (122,168) are identified as holders of advanced degrees.

3.2. Identifying the ownership structure and combining patent-inventor data with firm data

Because parent firms patent sometimes under their own names and at other times under the names of their subsidiaries, combining the Patents BIB data with firm-level data in the Compact D/SEC data is not straightforward. Mergers and acquisitions at both the parent firm and subsidiary levels, common in these two industries during the 1990s, and name changes complicate linking the patent to firm-level data. (The U.S.PTO does not maintain a unique identifier for each patenting assignee at the parent firm level nor does it track assignee name changes.) Thus, to use the firm-level information available in the Compact D/SEC data, the names of parent firms and their subsidiaries and the ownership of firms must be tracked over the entire period of the study.[7]

To start, we identify mergers and acquisitions, and name changes of firms in the two industries, pharmaceutical preparation (primary SIC code 2834) and semiconductor and related devices (3674), over the period between 1989 and 1997, using the Standard & Poor's data. We also identify the ownership structure of subsidiaries of firms using subsidiaries information

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[6] In addition, we impose conditions on the time frame of the inventor's patenting history as follows: the inventor's last patent is no later than forty years following the dissertation date, and the first patent is no more than twenty years before the dissertation date.

[7] NBER-CWRU researchers created a database of parent firms and their subsidiaries for all the names among U.S.PTO patent assignees. However, they only linked subsidiaries based on the corporate ownership structure as it existed in 1989.

available from the Compact D/SEC from 1989 to 1997.[8] We can then relate each assignee in the patent data to a firm in the Compact D/SEC data, which enables us to match each patent to a firm in the Compact D/SEC data. We then combine firms' founding years, obtained from Thomas Register, Mergent, and Corptech, with the other firm-level information.

As the final step, we add information on all citations from the NBER Patent-Citations data collected by Hall, Jaffe and Trajtenberg (2001) where each citing patent that was granted between 1975 and 1999 is matched to all patents cited by the patent.

4. Descriptive statistics

Figure 1 provides a distribution of U.S. patents granted by year of application. The annual number of patents granted dips sharply after 1997. This dip reflects a lag between the application and granting dates. About 70 to 80 percent of all patent applications ultimately granted are granted within the first three years of the application and 97 percent of all patent applications are granted within the first four years of the application date (Hall, Griliches, and Hausman, 1986). Between January 1975 and February 2002, 45.5% were granted to the U.S. assignees and 37.4% were granted to foreign assignees (see Table 3). In Figure 2, we report the number of patents granted to firms in each of our two industries. Note that in both industries the number of patents granted annually rose over the period we study: the annual number of patents granted between 1989 and 1998 rose from about one thousand patents annually, but by a factor of two in the pharmaceutical industry and nearly seven in the semiconductor industry.

Table 4 shows that the number of inventors named as an inventor to at least one patent assigned to a firm in one of our two industries is 59,292 out of the 2,299,579 unique inventors in

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[8] The subsidiary list reported in the Compact D/SEC is not always complete. For example, some subsidiaries appear intermittently and some firms report subsidiaries every other year. Hence, we have treated a subsidiary as one for the firm throughout the period 1989-1997, if it is reported once as a subsidiary of the firm.

our data (25,609 inventors in the pharmaceutical and 33,683 in the semiconductor industry). The percentage of master’s or higher-degree holders in natural science and engineering is relatively higher in these two industries. Among the 2,299,579 unique inventors in our data, 5.3% hold masters or higher degrees (3% of inventors hold a Ph.D. or equivalent). Among the inventors in the pharmaceutical and semiconductor industries, 13.3% and 11.7%, respectively, hold an advanced degree.

Inventors working in these pharmaceutical and semiconductor industries are named as inventors on more patents on average than inventors in other industries (see Table 4). An inventor in a pharmaceutical firm is named as an inventor on average on 2.80 patents over our sample period, whereas an inventor in the semiconductor industry appears on average on 2.60 patents. Inventors with advanced degrees are shown in Table 4 to have more patents than those without advanced degrees. While advanced-degree holders in the pharmaceutical industry are more productive in patent output, those in the semiconductor industry appear to be similar in patent productivity to advanced-degree holders in other industries.

We identified pharmaceutical and semiconductor firms in the Compact D/SEC data by their primary SIC. We identified 447 parent firms and 5,331 subsidiary firms in the pharmaceutical industry and 332 parent firms and 4,211 subsidiary firms in the semiconductor industry. Firm information period is from 1989 because we had access to only the Compact D/SEC data beginning in 1989. We then dropped all patent applications filed after 1997 because we found that starting with application year 1998 the patent time series tailed off due to the review lag at the U.S.PTO.

Some sample statistics from the firms in the two industries in our data—the number of selected firms and the number of employees, sales, and R&D expenditures—are reported in

Table 5. For the year 1997, for example, the data show 221 firms in the pharmaceutical and 151 firms in the semiconductor industry, with 177 firms and 135 firms, respectively, reporting positive R&D expenditures. Pharmaceutical industry firms are larger in terms of number of employees, sales volume, and R&D expenditures.

5. International Knowledge Flow

In this section, we test if the international migration of researchers facilitates knowledge transfers across borders. Understanding the consequences of the immigration of scientists and researchers to the U.S.—on not only for U.S. R&D productivity but for the wages and job prospects of native workers and for national security—has important implications for policy-making in the immigration, labor market, and education arenas. Understanding how knowledge spillovers across countries work is of interest because of the role spillovers may play in economic growth and because of its implications for science and technology policy. Knowledge spillovers from the U.S. and Europe may be an important factor for the impressive growth rates enjoyed in countries such as South Korea and Taiwan (Hu and Jaffe, 2003). As described in this paper’s introduction, work done with patent citations suggests that knowledge flows may be geographically localized (Jaffe, Trajtenberg, and Henderson, 1993). Some researchers have used patent citations to try to understand these international knowledge spillovers (Jaffe and Trajtenberg, 1998). We use the geographic mobility of scientists to track the transmission of foreign knowledge from other countries to the U.S. and to obtain a better estimate of the importance of international scientific labor markets as a mechanism of technological transmission than has been possible previously.

Table 6 shows the annual number of unique inventors named on U.S. domestic patents for the years 1985 through 1997. It also shows the percentage of inventors who (1) at the time of the patent application resided in a foreign country, (2) at the time of the patent application resided in the U.S. and had been previously listed as a foreign-residing inventor on a successful patent application, and (3) at the time of the patent application resided in the U.S. but had never been previously listed as a foreign residing inventor on a successful patent application. Because our data included patents granted in 1975 and later, we imposed a cut-off for the patents used to define whether an inventor has foreign-experience at the time of the patent's application. We chose to consider only those inventors who are currently foreign residents or had been foreign residents some time in the ten-year period prior to the date of the patent's application because ten years still leaves us a long period over which to conduct our analysis and because knowledge acquired in a foreign country far in the past may not be very valuable.

Table 6 shows a steady and swift increase in the number of unique inventors on U.S. domestic patents between 1985 and 1997, from 42,368 to 119,556, which translates to an average annual growth rate of 9 percent. Among those inventors with foreign experience, the percentage of inventors with current foreign addresses increased steadily during the period from 8.15 percent to 9.11 percent while the percentage of U.S.-residing inventors with foreign experience increased from 0.99 percent in 1985 to 1.30 percent in 1992, then dropping to 1.01 percent in 1997. Overall, the percentage of inventors with foreign experience increased (from 9.14 percent in 1985 to 10.13 percent in 1997).

Table 6 shows that the growth in the number of inventors in the pharmaceutical (13 percent annually) and semiconductor (31 percent annually) industries has been significantly faster than for all industries combined. In the pharmaceutical industry the share of inventors with foreign experience grew rapidly although the increase is mostly in the share of inventors with current foreign addresses and there is a decrease in the fraction of U.S.-residing inventors with past foreign experience. This finding is not surprising given the increasing rate at which U.S. pharmaceutical firms have been citing new laboratories abroad (Chacar and Lieberman, 2003) and findings that collaborations among academic scientists have become more dispersed, possibly due to improvements in telecommunications (Adams, Black, Clemmons, and Stephan, 2004). The semiconductor industry shows a similar pattern, but the changes are less pronounced than in pharmaceutical industry.

Figure 3A shows the average patent productivity of inventors in U.S. domestic patents by foreign-experience type for all patents. We first note that U.S.-residing inventors with past foreign experience have significantly higher patent-inventor ratio than other types of inventors. There are at least two reasons for this. First, inventors with higher productivity are more likely to migrate to the U.S. because of better compensation in the U.S. labor market or because of U.S. immigration policies. Alternatively, foreign experience somehow improves the productivity of researchers. Both the patent-inventor ratios for current foreign residents and for current U.S. residents without foreign experience show a similar level. Figure 3A also shows that the patent productivity for inventors with past foreign experience was steady at around 1.6 patents per inventor until 1993 and then it rose to 2 patents per inventor in 1997. On the other hand, the patent-inventor ratios for other types of inventors were stable or declined slightly over the period.

Figures 3B and 3C repeat the analysis of Figure 3A but for the pharmaceutical and semiconductor industries alone. These figures show the same gap between the productivity of U.S.-residing inventors with foreign experience and the U.S.-residing inventors without foreign experience and the foreign- residing inventors. These figures also show the productivity of U.S.-residing inventors with foreign experience increasing over the 1990s.

Where Figures 3A-C tracks the productivity of inventors by their patent output, Figures 4A-C tracks how the quality of inventors' output changes by inventor type. Figure 4A shows the citations received in the 5-year period after application filing per patent by inventor type for all industries over time. This figure covers only years of application up to 1992 because the NBER citation data contain citations made by patents granted in years up to 1999 and we take into account the 5-year period of citation and a 2-year gap between application and granting dates. Between 1985 and 1992, the citations per patent rose for all three classes of inventors. Throughout the 1985-1992 period, the average citations per patent produced was the highest for U.S. residents with foreign experience and lowest for foreign residing inventors. In 1992, the number of citations attracted by the average patent of a U.S. residing inventor with foreign-patenting experience, of a U.S.-residing inventor without foreign patenting experience, and of a foreign residing inventor, was about 6.5, 5, and 3.5 respectively. Thus, taken together, Figures 3A and 4A show that U.S.-residing inventors with foreign experience produce more patents on average and patents of higher quality than the other two classes of inventors. Figures 4B and 4C conduct the analysis separately for the pharmaceutical and semiconductor industries. The semiconductor industry shows the same ordering of inventor types, though the levels are higher for each type. The pharmaceutical industry however shows no clear distinction between the two classes of U.S.-residing inventors. Figure 4C does show that foreign-residing inventors produce the lowest quality patents, by the citation measure.

Is a patent more likely to cite foreign-assignee patents when its inventors have foreign experience? We are interested in learning if knowledge spillovers from foreign countries are facilitated by direct exposure to inventors with foreign experience. Table 8 presents the results of our estimation of the determinants of accessing foreign knowledge in two industries: pharmaceutical and semiconductor industry. The unit of observation of the regression is a patent applied for in year 1997. The dependent variable is the logit transformation of the fraction of citations to patents that are assigned to foreign assignees (CITE_FRGN). The key regressor in these regressions is a binary variable which takes 1 if at least one inventor on the patent is currently residing or formerly resided in one of the foreign countries where foreign assignees of cited patents are located (FRGN_EXP). Note that this regressor reflects not just whether an inventor has foreign experience but which country the inventor has experience from. We speculate that knowledge spillover is country-specific.

The regressions in Table 8 also include as right-hand side variables firm-level characteristics in the year 1997. A measure of the size of the research operation, proxied by the number of unique inventors named to patents awarded to the firm in 1997 (INVENTOR), is included to examine whether large-scale R&D enterprises are more likely to rely on foreign knowledge. We use the number of employees (EMPLOYEE) as an alternative measure of organizational size at the firm level. Included are the R&D-inventor ratio (R&D/INV) and the number of business lines in the firm (NSIC), measured by the number of secondary SIC's identified with the firm. We include the R&D-inventor ratio (R&D/INV) as a regressor because a highly capitalized firm may rely on more advanced technology and thus may be more open to foreign technology. We include NSIC as a regressor to estimate the impact of economies of scope in the firm's use of foreign knowledge. Our regressions also include two additional regressors: the median experience of all inventors in the firm (MEXP) and years elapsed since the founding year of the firm (FIRMAGE). The means and standard deviations of the independent and dependent variables, along with their definitions, are described in Table 7.[9]

Column 1 in Table 8 for each industry panel shows the estimated relationship between the fraction of a patent's citations to foreign-assigned patents and the existence of foreign-experienced inventors using OLS. Column 2 for each industry panel reports the estimates of the determinants of the citation to foreign patents.

One concern for our regression is that inventors are more likely to cite their own past patents than other inventors' patents, which may drive the estimated relationship between our dependent variable and the key regressor, FRGN_EXP. In column 3 for each industry panel we thus exclude patents which have the same inventors as those in their cited patents.

The results in Table 8 show that a patent by inventors with foreign experience in both industries is more likely to cite patents assigned to foreign firms from the same country where the inventors are residing or resided in the past: FRGN_EXP has a significantly positive effect in all models. This effect is still significant with the data without self-citing patents.

The results show a negative effect of the size of the R&D enterprise on the fraction of citations to foreign patents in the semiconductor industry. There is no significant effect of the size of the R&D enterprise in the pharmaceutical industry. On the other hand, the coefficient estimate on the firm size variable (EMPLOYEE) is insignificant in all models. The coefficient estimate on logR&D/INV is generally positive but insignificant in all regressions. The coefficient estimate on log NSIC is never significant by conventional criteria of significance. The coefficient estimate on log MEXP is negative and significant for both industries. This may partly reflect that it is more costly for older inventors to learn new technologies from abroad, or

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[9] Note that the means of the variables reported in table 7 are not the averages across firms because our regressions are at the patent level, not at the firm level. For instance, the mean value of INVENTOR and EMPLOYEE is greater than the firm mean in 1997 because larger firms tend to have more patents.

it may be due to a vintage or a composition effect (e.g., areas of technology that experienced innovators innovate in are somehow more "domestic"). The coefficient estimate on log FIRMAGE is significant for both industries but has different signs for the two industries. The effect is negative in pharmaceutical industry while it is positive in semiconductor industry. That is, we find that in the semiconductor industry older firms, and in the pharmaceutical industry, younger firms are more likely to make use of the output of non-U.S. R&D.

6. Conclusion

We describe the construction of a panel data set that links inventors to the U.S. pharmaceutical and semiconductor firms for whom they work. These data contain measures of inventors' R&D productivity—patents and patent citations—as well as information on the firms to which their patents are assigned. In this paper we use these data to examine the role of research personnel as a pathway for the diffusion of ideas from foreign to U.S. innovators. In particular, we find in recent years an increase in the extent that U.S. innovators employ or collaborate with researchers with foreign R&D experience. This increase appears to work primarily through an increase in U.S. firms' employment of foreign-residing researchers; the fraction of research-active U.S. residents with foreign research experience appears to be falling, suggesting that U.S. pharmaceutical and semiconductor firms are increasingly locating operations in foreign countries to employ such researchers, as opposed to such researchers immigrating to the U.S. to work. In addition we investigate the firm-level determinants of accessing non-U.S. technological know-how, as measured by the prevalence of citations to patents on innovations originating outside the U.S. We find that employing researchers who have research experience abroad seems to facilitate this access. We also find that in the semiconductor industry smaller and older firms, and in the pharmaceutical industry, younger firms are more likely to make use of the output of non-U.S. R&D.

We anticipate this data set will be useful in addressing other important questions. These data will allow us to investigate the consequences of the mobility of R&D personnel on firm R&D. What is the impact, for example, of the arrival of a researcher with a particular set of R&D experiences on the character and quantity R&D done by a firm? We will be able to address this question because we know each scientist's patenting history, both in terms of quantity but we also know the kinds of technologies underlying the innovations. This data set will allow us to directly observe the importance of inter-firm mobility for technological diffusion. From the perspective of the scientist, this data set will allow us to examine the determinants of inter-firm mobility. The panel nature of these data will allow us to investigate the productivity profiles of researchers working in industry over their careers. Because we observe all the inventors responsible for a patent we will be able to use this data set to investigate how firms organize the R&D enterprise, the extent of collaboration among scientists who are geographically dispersed, and the extent of interaction among scientists with different backgrounds.

Appendix A. The SOUNDEX Coding System

The SOUNDEX is a coded index for last names based on the way a last name sounds rather than the way it is spelled. Last names that sound the same, but are spelled differently, such as SMITH and SMYTH, have the same SOUNDEX code. We use the SOUNDEX coding method to expand the list of similar last names to overcome the potential for misspellings and inconsistent foreign name translations into English; misspellings are common in the U.S.PTO data, as are names of non-Western European origin.

A SOUNDEX code for a last name takes an upper case initial followed by 6-digit numeric codes. For example, the SOUNDEX code for Keynes is K520000. The rules for generating a SOUNDEX code are[10]:

1. Take the first letter of the last name and capitalize it.
2. Go through each of the following letters giving them numerical values from 1 to 6 if they are found in the Scoring Letter table (1 for B, F, P, V; 2 for C, G, J, K, Q, S, X, Z; 3 for D, T; 4 for L; 5 for M, N; 6 for R; 0 for Vowels, punctuation, H, W, Y).
3. Ignore any letter if it is not a scoring character. This means that all vowels as well as the letters h, y and w are ignored.
4. If the value of a scoring character is the same as the previous letter, ignore it. Thus, if two ‘t’s come together in the middle of a name they are treated as a single ‘t’ or a single ‘d’. If they are separated by another non-scoring character then the same score can follow in the final code. The name PETTIT is coded as P330000. The second ‘T’ is ignored but the third one is not, since a non-scoring ‘I’ intervenes.
5. Add the number onto the end of the SOUNDEX code if it is not to be ignored.
6. Keep working through the name until you have created a code of 6 characters maximum.
7. If you come to the end of the name before you reach 6 characters, pad out the end of the code with zeros.
8. You may choose to ignore a possessive prefix such as ‘Von’ or ‘Des’.

See "Using the Census SOUNDEX," General Information Leaflet 55 (Washington, DC: National Archives and Records Administration, 1995) for the detailed method.

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[10] The strings of ‘-, ., +, /, (,), %, ?, #, &, ", _’ in all name fields have been translated to blank space in advance and then last names are SOUNDEX coded.

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Figure 1. Number of Patents Granted by Year of Application (1975-2001)

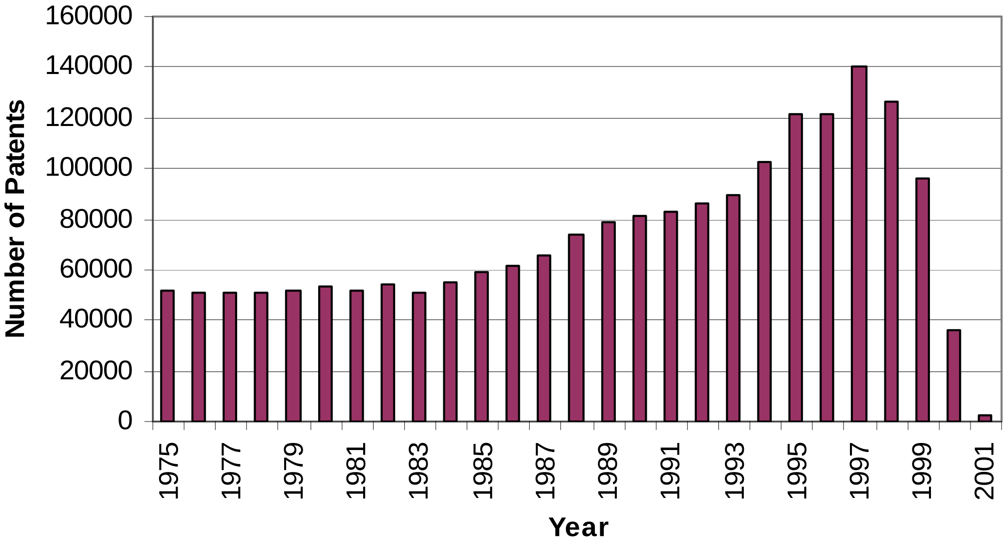


Figure 2. Number of Patents Granted by Year of Application in Two Industries

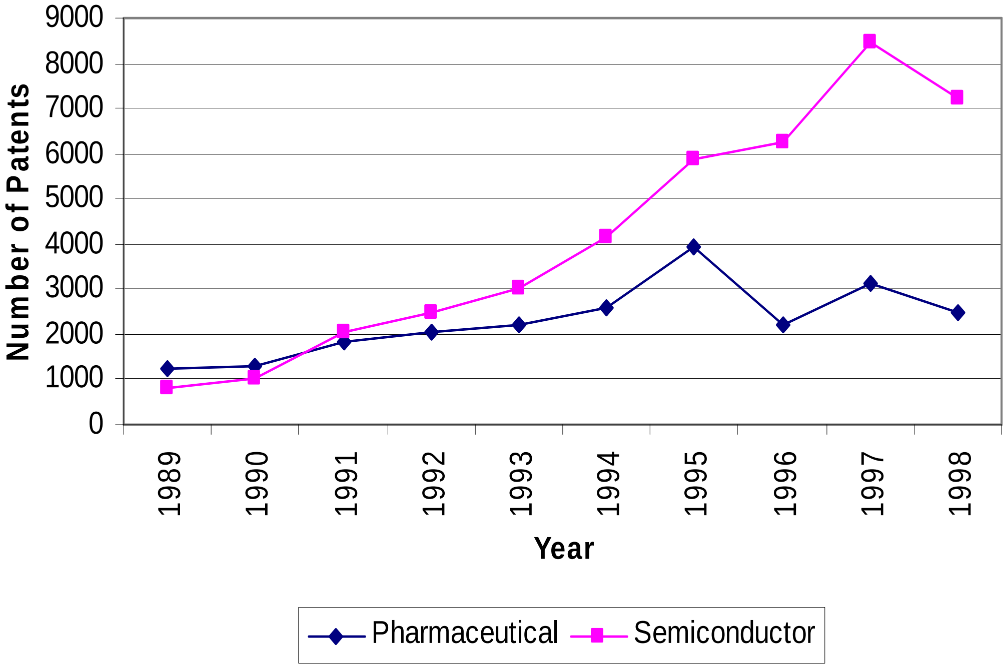
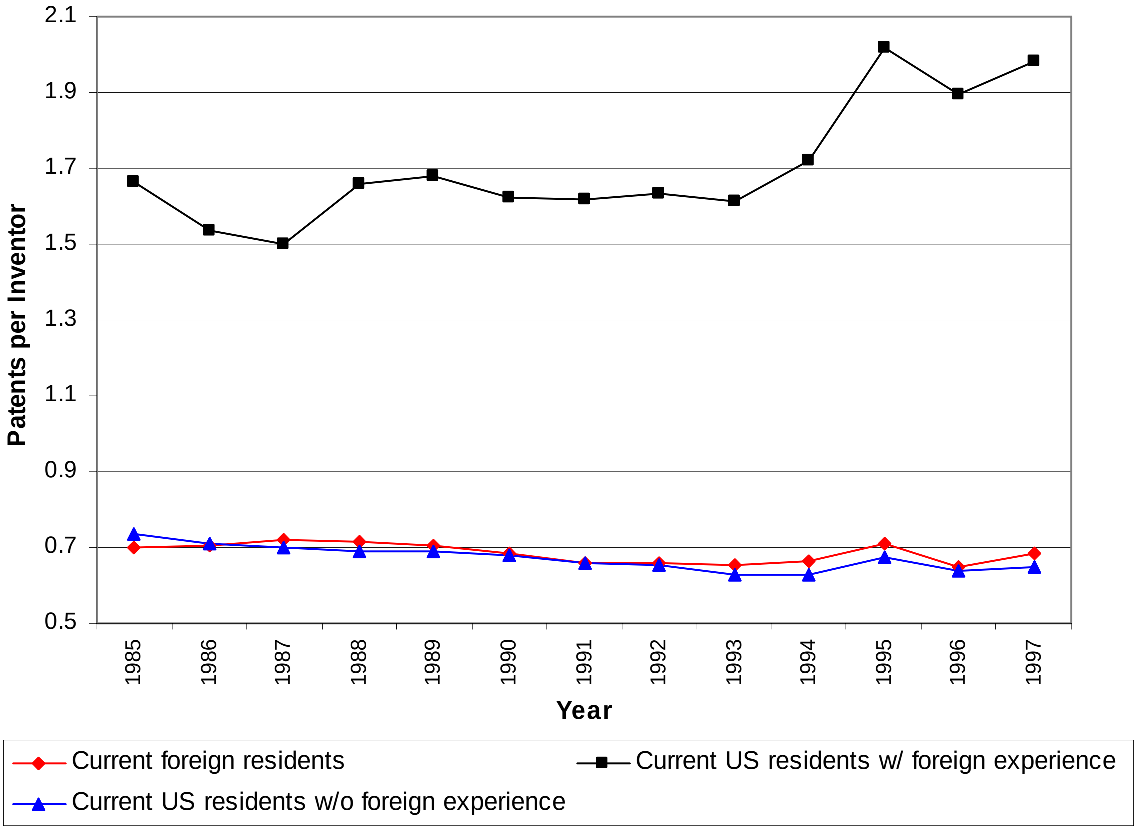
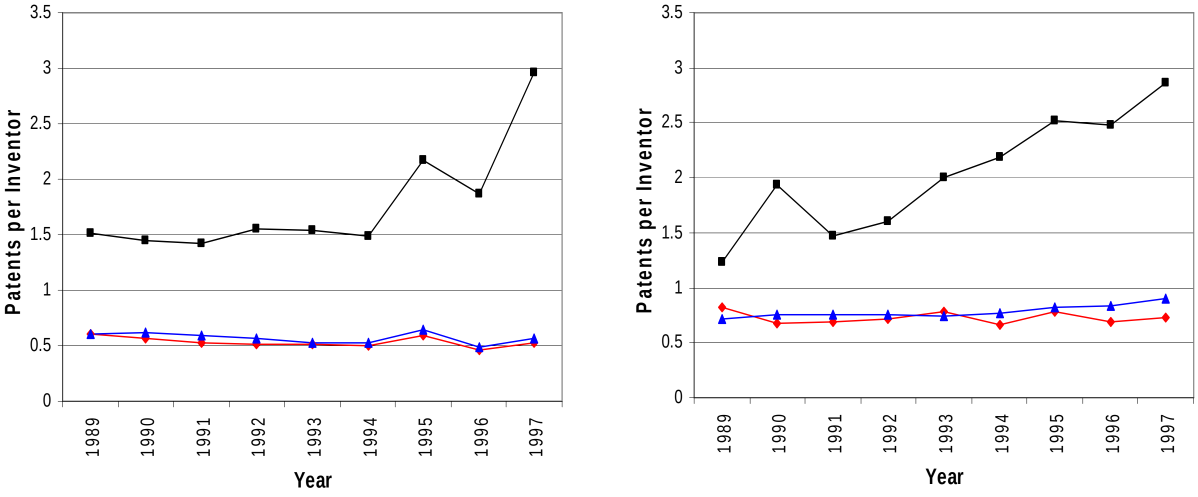


Figure 3. Patent-Inventor Ratio by Foreign-Experience type

A. All Patents



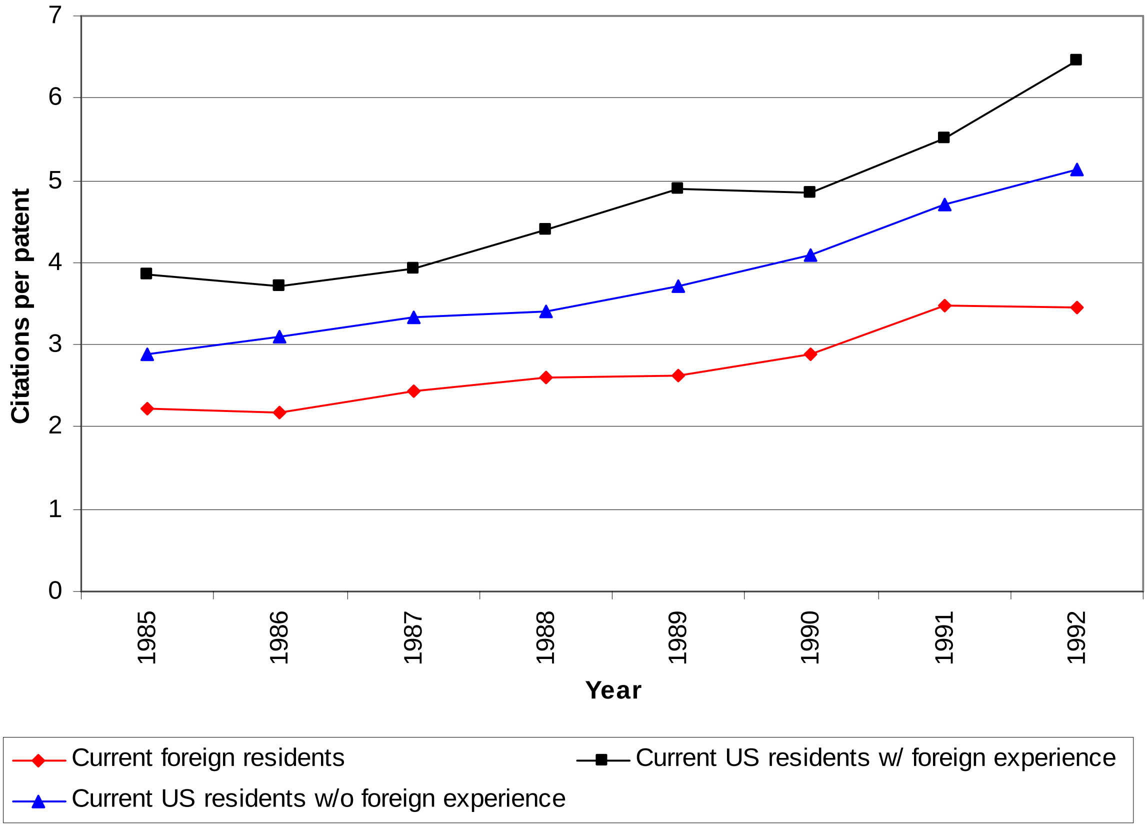


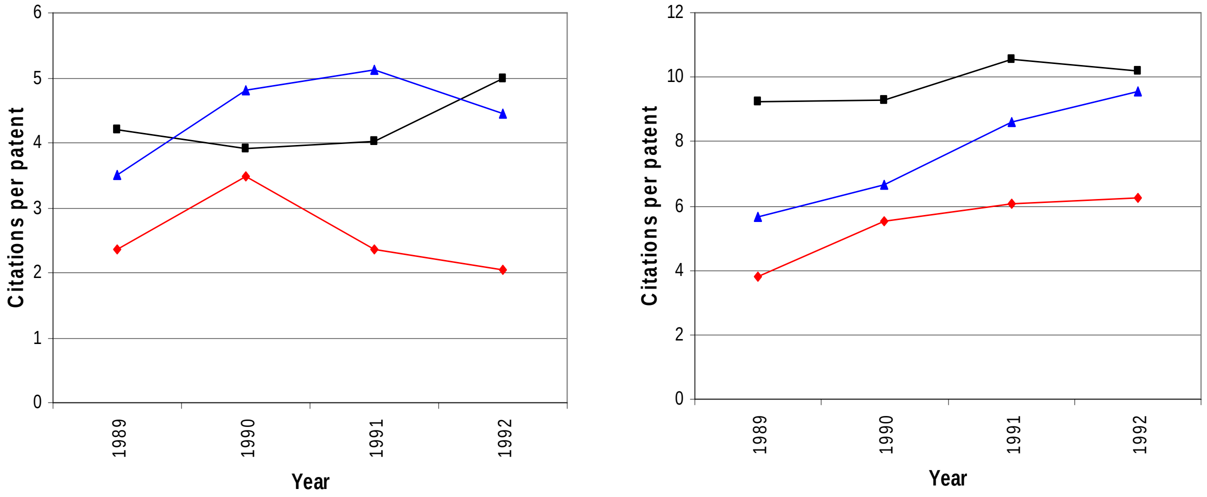
B. Pharmaceutical

C. Semiconductor

Figure 4. Citations per Patent by Foreign-Experience type

A. All Patents





B. Pharmaceutical

C. Semiconductor

Table 1. Variables from Each Data Source

Data Source	Variables
Patents BIB	Patent ID number, application year, inventors’ names, address, city, state, country, assignee ID and assignee name
ProQuest	Degree holders’ name, institution, degree type, degree year, and field
Compact D/SEC	Firm name, primary and other corresponding SIC codes, R&D expenditures, sales, number of employee, capital, and subsidiaries of the firms
S&P	Firm name and ownership changes due from merger and acquisition, and obsolete securities due to bankruptcy or dissolution
Thomas Register	Founding year of firm
Citation	Citing patent number and cited patent number

Table 2. Examples of Name Matching

Initial ID	Inventor name	Co-inventor	Middle name	ZIP	Final ID
001	Adam Smith	John Keynes		20012	001
002	Adam Smith	John Keynes	Emmanuel	14228	001
003	Adam Smith		E	14228	001
004	Adam Smith		Emmanuel	14214	001
005	Adam Smith	John Keynes	J	14228	005
006	Adam Smyth	John Keynes		14228	001

Table 3. Number of Patents by Assignee Type (January 1975 – February 2002)

Assignee	Description	# Observations	Percentage	
US	Assigned to U.S. organization and state/local governments	1,090,194	43.7	45.5
	Assigned to a U.S. resident (individual)	15,849	0.6	
	Assigned to a U.S. Federal Government organization	30,431	1.2	
Foreign	Assigned to a non-U.S., non-government organization	914,826	36.7	37.4
	Assigned to a non-U.S. resident (individual)	7,873	0.3	
	Assigned to a non-U.S. government organization (all levels)	8,613	0.4	
Others	Unassigned	412,621	16.6	17.1
	Missing observations	13,203	0.5	
Total		2,493,610		

Table 4. Patent Statistics for All Inventors and for Inventors with Advanced Degrees (January 1975 – February 2002)

	Total	Pharmaceutical	Semiconductor
Inventors (a)	2,299,579	25,609	33,683
No. of Patent per Inventor	2.22	2.80	2.60
Degree holders* (b)	122,168	3,399	3,941
No. of Patent per Inventor	3.07	3.70	2.95
(b/a)	5.3%	13.3%	11.7%

* Master's or higher.

Table 5. Summary Statistics from Pharmaceutical and Semiconductor Industry Samples

(Units in sales and R&D: thousand dollars)

		No. of firms	No. of firms reporting			Mean			Standard Deviation		
	Year		employee	sales	R&D	employee	sales	R&D	employee	sales	R&D
Pharmaceutical Industry	1989	88	85	78	69	5903	895924	85151	13058	1940353	180615
	1990	88	85	81	64	5722	794134	78612	13726	2036458	188652
	1991	146	137	124	98	4741	884836	95712	12690	2187517	217398
	1992	151	145	123	109	4694	987210	101187	12374	2404976	237929
	1993	161	155	132	126	4297	1609557	105501	11764	7440985	250355
	1994	179	170	149	136	4668	1670350	104193	13395	7693383	255514
	1995	184	171	150	142	4460	1924112	124575	13263	7897844	323828
	1996	193	170	158	152	4114	1996128	126510	12652	8085530	355602
	1997	221	196	193	177	4078	2161856	194237	13980	9156677	797319
	1998	209	180	186	170	4391	2341263	210768	14307	10268340	830591

		No. of firms	No. of firms reporting			Mean			Standard Deviation		
	Year		employee	sales	R&D	employee	sales	R&D	employee	sales	R&D
Semiconductor Industry	1989	71	70	71	55	3108	275944	25530	10043	885337	64583
	1990	67	65	67	52	3273	309869	30203	10102	959953	82405
	1991	87	86	84	70	3492	410065	28720	13365	1521497	81478
	1992	93	92	91	79	3244	423890	28546	13226	1698277	94122
	1993	107	107	103	95	2919	477073	28395	13307	2044170	105515
	1994	114	112	108	100	2057	590914	33344	6922	2588848	119556
	1995	131	124	127	115	2050	720290	43822	7156	3103003	151508
	1996	136	123	131	122	3201	746105	62304	14466	3243984	215290
	1997	151	141	147	135	3277	1081964	87658	14750	4956544	336703
	1998	154	125	153	139	3328	1095652	102042	14013	5255021	392838

Table 6. Inventors with Foreign Experience in US Domestic Patents

Year	Number of Inventors			Percentage of Inventors by Foreign-Experience Type (%)								
				Current Foreign Residents			Current US Residents w/ Foreign Experience			Current US Residents w/o Foreign Experience		
	All	Pharma	Semi	All	Pharma	Semi	All	Pharma	Semi	All	Pharma	Semi
1985	42,368			8.15%			0.99%			90.86%		
1986	44,828			8.30			1.07			90.63		
1987	48,810			8.21			1.13			90.66		
1988	54,947			8.49			1.13			90.37		
1989	59,164	2,143	1,139	8.60	14.47	9.04	1.17	2.01	1.14	90.23	83.53	89.82
1990	63,812	2,259	1,362	8.02	17.35	7.78	1.22	1.51	1.25	90.76	81.14	90.97
1991	67,657	3,332	2,791	7.76	19.09	6.02	1.26	1.23	1.22	90.98	79.68	92.76
1992	73,640	3,876	3,370	7.86	20.38	7.15	1.30	1.21	1.13	90.85	78.41	91.72
1993	80,428	4,505	4,190	8.06	25.88	7.06	1.21	1.31	1.03	90.73	72.81	91.91
1994	90,910	5,320	5,739	8.44	26.86	14.76	1.20	0.98	0.94	90.36	72.16	84.30
1995	104,775	6,629	7,450	8.78	28.87	15.18	1.13	0.87	0.86	90.08	70.25	83.96
1996	104,829	4,894	7,916	9.19	31.55	13.26	1.07	0.90	0.78	89.75	67.55	85.95
1997	119,556	6,093	9,993	9.11	29.71	15.31	1.01	0.75	0.80	89.87	69.54	83.89

Note: Columns 2-4 show the number of unique inventors in all U.S. domestic patents, in pharmaceutical patents, and in semiconductor patents, respectively. In columns 8-10, we report the percent of inventors with current addresses in the U.S. who have at least one patent in the past 10 years while residing at a foreign address.

Table 7. Variable Definitions and Sample Statistics

	Definition	Mean (Standard Deviation)	
		Pharmaceutical	Semiconductor
CITE_FRGN	Fraction of citations to patents that are assigned to foreign assignees	0.5505 (0.3319)	0.4760 (0.2850)
FRGN_EXP	= 1 if at least one inventor is residing or has resided in the past in one of the foreign countries where foreign assignees of cited patents are located	0.0734 (0.2609)	0.0290 (0.1677)
INVENTOR	Number of all inventors in the patenting firm	326.0 (195.7)	923.5 (728.6)
EMPLOYEE	Number of employees in the patenting firm	35,979 (21,833)	41,538 (52,501)
R&D/INV	Real R&D expenditures in 1996 constant dollars divided by the number of inventors in the patenting firm (thousands of dollars per inventor)	31.67 (24.51)	12.04 (27.34)
NSIC	Number of secondary SIC's assigned to the patenting firm	3.791 (1.991)	3.154 (1.944)
MEXP	Median experience of all inventors in the patenting firm	5.292 (1.582)	3.832 (1.067)
FIRMAGE	Years elapsed since the founding year of the patenting firm	77.40 (51.51)	36.17 (23.40)

Table 8 Determinants of Citation to Foreign-Assigned Patents

Dependent variable = logit transform of CITE_FRGN

	Pharmaceutical			Semiconductor		
	(1)	(2)	(3)	(1)	(2)	(3)
FRGN_EXP	3.8950	3.3876	4.3832	5.8609	5.5730	6.4162
	4.95	3.92	3.87	4.18	3.66	3.75
Log INVENTOR		1.0813	1.1595		-1.1918	-1.1702
		1.10	1.19		-2.69	-2.64
Log EMPLOYEE		0.2124	0.1885		0.3871	0.3550
		0.38	0.34		1.24	1.14
Log R&D/INV		0.0557	0.0488		0.0658	0.0691
		0.66	0.59		1.14	1.18
Log NSIC		-0.2723	-0.4079		1.1469	1.1562
		-0.38	-0.57		1.57	1.56
Log MEXP		-6.5845	-6.4702		-6.8640	-6.8410
		-4.41	-4.40		-2.76	-2.66
Log FIRMAGE		-1.0956	-1.1361		2.3439	2.3771
		-1.96	-2.06		2.88	2.83
Observations	1430	1247	1215	4316	4186	4112
R^2	0.0189	0.1462	0.1539	0.0283	0.1280	0.1306

Note: Rows show the estimated coefficient and the t statistic for each regressor. The result for a constant term is suppressed. Column 3 shows the results from a regression that omits patents for which an inventor is listed as an inventor on a cited patent. The t statistic is based on the Huber-White sandwich estimator of variance.