What Drives Innovation by Foreign Multinationals?*

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We use 30 years of US patent data to study the role of subsidiaries of foreign multinationals in innovation in 30 countries and 33 industries. Variance decomposition reveals that country borders matter much more than industry affiliation as correlates of multinationals' innovative output abroad, suggesting that multinational behavior in innovation is constrained much more by differences in national institutions and policies than by technological constraints inherent in different industries. We find relatively small increase in the role of foreign multinationals subsidiaries in innovation over the past three decades, which is interesting given the large increase in overall economic activity overseas for multinationals over the same time period. A regression analysis suggests that multinational subsidiaries might be better than domestic firms at overcoming a country's limitations in specialized human capital, availability of finance and protection of intellectual property rights. We also find that the country of origin of multinationals matters a lot in determining their innovative behavior overseas.

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INTRODUCTION

What role do foreign multinationals play in transferring knowledge to their host countries? This question is an important part of the debate on welfare effects of foreign direct investment, which has assumed particular significance in the wake of recent backlash against globalization. Understanding how multinationals contribute to the technological and innovative fabric of their host countries is a critical part of understanding their overall welfare impact. Presence of local subsidiaries of foreign multinationals can lead to knowledge spillovers from these multinationals to the domestic firms in a country, since inter-firm spillovers and learning are often geographically localized (Lundvall ed., 1992; Jaffe, Trajtenberg and Henderson, 1993; Almeida, 1996; Jaffe and Trajtenberg, 1999; Frost, 2001). However, just the presence of any multinational activity in a country is not enough to ensure significant knowledge spillovers (Aitken and Harrison, 1999). The potential for spillovers is maximized if the foreign multinationals can be convinced to locate their knowledge-intensive innovative activities in a host country (Porter, 1990, 1998). Understanding the extent and drivers of such innovative activities carried out by subsidiaries of foreign multinationals therefore assumes central importance in the overall question of welfare effects.

Motivated by the above discussion, this paper has three goals: The first is to document the extent of innovation carried out by subsidiaries of foreign multinationals around the world. The second is to study how this role varies across countries (e.g. because of differences in national institutions and policies), industries (e.g., because of different technological characteristics) and time periods (e.g., because of increase in cross-border flows of products and factor inputs in recent decades). This also helps us address the broader issue of primacy of technological primitives (as embodied in industry affiliation) versus country-specific institutional factors as drivers of decision-making by multinational firms. The third is to study the underlying drivers that can help us understand why some countries and industries exhibit a greater role of foreign multinationals in innovation.

We measure innovation using successful patent application with the US Patent Office from the last 30 years, filed by inventors from 30 different countries in 33 different industries. We compare the country of residence of the inventing person with the home base for the assignee organization in deciding whether a given patent should be classified as belonging to a domestic player or a foreign multinational subsidiary. We use this to calculate the *fraction* of patents arising from subsidiaries of foreign multinationals. The advantage of this measure is that, unlike a measure based on *levels* of patents, this ratio is more comparable across different countries, industries and time periods. This helps us carry out a comprehensive study of the role of multinational subsidiaries in innovation.

In order to identify differences in the role of multinational subsidiaries, we use the variance decomposition methodology that is well established in the strategy literature in the context of studying structure of profitability (e.g. Schmalensee, 1985; Rumelt, 1991; McGahan and Porter, 1997, 2002; Furman, 2000; Khanna and Rivkin, 2001a). We find that, for an industry, country and time period picked up at random, the average fraction of patents coming from subsidiaries of foreign multinationals is about 15%. Further, although industry effects are important (explaining about 5.5% of the variance in a model that allows serial correlation), they seem far less important than country effects (which explain about 14% of the variation). This is consistent with a spate of recent studies that emphasize the continued importance of national boundaries and local context on economic outcomes (Porter 1990, 1998; Lundvall ed., 1992; Nelson ed., 1993; Helliwell, 1998; Khanna and Rivkin, 2001a; Khanna, Kogan and Palepu, 2001).

Our finding that national boundaries continue to matter a lot is inconsistent with the popular rhetoric about increasing "globalization" (Ohmae, 1990; Greider, 1998; Cairncross, 2001). The average increase in the fraction of multinational activity in innovation has been only around 3% in the past three decades, with little evidence of convergence across countries. In fact, the average fraction fell from about 14.5% in the 1970s to 13.6% in the 1980s before rising to 17.6% in the 1990s. This evidence on at least one measure of globalization of know-how production sits uneasily with larger changes, over comparable periods, in the globalization of product and factor markets (Maddison, 1995). It appears that the willingness of multinational corporations to move their innovative activities abroad has been much less than the extent to which they have increased their participation in other economic activities in recent decades.

While the variance decomposition analysis is useful for studying which of the effects – country or industry – matters most, it still leaves open the question as to what fundamental explanatory variables lead to the observed cross-country and cross-industry differences. In order to explore this question, we carry out a regression analysis that studies how the relative role of subsidiaries of foreign multinationals varies with fundamental country characteristics (openness, size, human capital, intellectual property rights protection, rule of law and availability of capital) and industry characteristics (capital intensity and need for external capital). We find that subsidiaries of foreign multinationals tend account for a higher fraction of innovative activities in countries that have less developed labor and capital markets, and in industries that are more dependent on external capital. We interpret this as evidence that multinational subsidiaries might play a role in overcoming a country's domestic constraints in availability of capital and skilled labor. We find interesting differences between multinational subsidiaries whose home firm is located in the US versus those whose home base is located in another country. While the US multinationals seem to play a stronger role in overcoming financing constraints, the non-US multinationals seem to play a stronger role in overcoming human capital constraints in their host countries. Also, unlike non-US multinationals, US multinationals account for a higher fraction of activity in countries with weak intellectual property rights, indicating that they are better at protecting their intellectual assets.

This paper is organized as follows. In the next section, we relate our paper to existing research on the activities of multinationals in carrying out innovation overseas. We then explain our data in more detail, and provide summary statistics on the role of multinational subsidiaries in different countries, industries and time periods. This is followed by a section of methodology. The two sections that follow thereafter present results from our variance decomposition analysis and regression analysis respectively. Finally, we discuss the strengths and weaknesses of the paper as a whole, suggest directions for future research, and conclude.

MULTINATIONAL SUBSIDIARIES AND INNOVATION

There is a growing consensus in strategy literature that the multinational firm can be seen as a global network where not just the headquarters but also the foreign subsidiaries have an important role to play. In particular, the subsidiaries are no longer seen just as a means of producing and selling goods designed at the headquarters, but as actively engaging in two-way knowledge and resource transfer to and from the other parts of the company (Bartlett and Ghoshal, 1989; Porter, 1990, 1998; Hedlund, 1994; Gupta and Govindrajan, 2000). Being a part of such a global network, a subsidiary of a multinational firm faces different incentives and constraints than do domestic firms operating in the same country and industry. Thus it might be able to compensate for institutional deficiencies and resource constraints that firms face in different countries. For example, Foley (2001) provides evidence that subsidiaries of US multinationals overcome the lack of local availability of high-quality human capital or adequate financing by drawing on the resources of the parent company. The extent to which multinational subsidiaries exhibit a behavior different from that of the local firms therefore depends on differences in the institutions and resource constraints in different countries as well as differences in technological characteristics of different industries (Ghoshal and Nohria, 1989; Jarillo and Martinez, 1990). Thus we can expect a variance in the extent of any economic activity carried out by foreign multinational subsidiaries in different countries and industries, the extent of innovation being one such activity. In particular, the extent of innovation arising from subsidiaries of foreign multinationals might differ across countries depending on the quality of domestic human capital, availability of finance and extent of intellectual property rights protection. Similarly, it might differ across industries depending on technological factors like ease of appropriability, need for external financing, importance of local knowledge, economies of scale and complexity of technology.

The idea that multinational enterprises arise as an optimal organizational form for application of scarce intangible knowledge assets in multiple countries has been around for a long time (Hymer, 1959; Vernon, 1966; Caves 1971, 1974; Teece 1977, 1986). The reason why the knowledge transfer of production technology is internalized within the same firm is postulated to be the transaction costs associated with market contracts in knowledge assets. In these models, however, overseas foreign subsidiaries are not active in innovation and only engage in local production and sales of products that have already been developed at the headquarters. Recent general equilibrium models in the trade literature, like Helpman's (1984) vertical model and its subsequent incarnations in the "knowledge-capital" models proposed by Markusen et al (1996) and Markusen (1997), formalize this intuition. However, even in these models, there is typically little role for overseas R&D since the firm's R&D activities are again assumed to be performed at its home base.

The theoretical assumption that no R&D takes place overseas is not consistent with the facts. Surveys of multinationals even in the 1970s and early 1980s revealed that large multinational firms were already locating more than 10% of their R&D activities overseas at that time (Mansfield, Teece and Romeo, 1979; Mansfield, 1984). Industrial economists usually saw this decision to locate R&D abroad as a trade-off between the coordination economies from locating the R&D function at the headquarters and the availability of local information from locating R&D in target markets (Hirschey and Caves, 1981; Caves, 1996). Recent in-depth field-based and survey-based research by scholars of innovation (Pearce, 1989, 1999; Håkanson and Nobel, 1993; Florida, 1997; Nobel and Birkinshaw, 1998; Kuemmerle, 1999) confirms that multinationals do indeed locate a large part of their R&D overseas. However, this stream of literature finds that the reason for locating R&D abroad is not always adaptation of products to local conditions but often learning the latest technologies by locating in places that are on the cutting edge of innovation.

While the studies mentioned above are very helpful in understanding the motivation for overseas R&D that MNEs might have, they are usually constrained in the coverage of the data in terms of number of countries, industries and firms. One way to complement this field research is to use the richness of patent data in systematically analyzing cross-country and cross-industry differences in innovative activity by multinationals. We draw upon patent data from the past 30 years for 33 different industries and 30 major patenting countries, giving more confidence in the generality of the results than the typical small-sample studies on role of multinational subsidiaries in innovation. Since patent data makes large-scale comparisons possible, it has been used before in cross-country regression studies of drivers of innovation (Stern, Porter and Furman, 2000; Lerner, 2001). However these papers focus on comparing the total innovative output in different countries and not on the role of multinationals. Papers that do make use of patent data to specifically study the role of multinationals (Patel and Pavitt, 1991; Dunning, 1992; Cantwell and Andersen, 1996), on the other hand, tend to be rely more on informal description of aggregate summary statistics rather than on rigorous statistical analysis of the underlying factors driving cross-country and cross-industry variation in the role of multinational subsidiaries. Our paper fills this gap through an econometric analysis based on a comprehensive dataset formed by combining a database on all patenting activity registered with the US Patent Office with a dataset that matches foreign subsidiaries of multinational firms (which are often listed under separate names in the patent database) with their corporate parents.

DATA

In this section, we describe how we have used US patent data for studying innovation by subsidiaries of foreign multinationals. As discussed below, the biggest challenge was how to identify whether a patent assignee is a subsidiary of a foreign multinational or a domestic player. We then provide summary statistics from our dataset to document how the role of foreign multinational subsidiaries in innovation varies across countries, industries and time periods.

Data on innovation

We use successful patent applications as an indicator of innovation. There are, of course, several challenges with using patent data to measure innovation. Patents are not necessarily the primary way that firms appropriate returns to their innovations. Firms also use several other mechanisms such as secrecy, complementary sales and service capabilities and quicker lead times. In fact, surveys that have come to be known as the Yale survey (Levin, Klevorick, Nelson and Winter, 1987) and the Carnegie Mellon Survey (Cohen, Nelson and Walsh, 2000) suggest that these alternate mechanisms might often be more important than patents. Further, even when firms do patent, it is often not for direct profits from an innovation but instead for either blocking the development of a substitute or as a threat to force rivals into negotiations. However, when used in large samples, patent counts are still a useful measure of innovation and hence widely used in research (Griliches, 1990).[1]

One should be careful in comparing raw patent counts across different countries, industries and time periods since the use of patents, the cost of patenting, the ability to patent and the average value of accepted patents differs in different settings (Scherer, 1983; Griliches, 1990; Lerner and Kortum, 1998). Therefore, this paper emphasizes not the aggregate *level* of patenting but only the *fraction* of patenting done by local subsidiaries of foreign firms as a part of the total patenting *within* the same country,

[1] A specific example should help visualize why study of patent data can be a useful exercise: Consider US patent number 5,098,694 for "A natural deodorant composition containing glyceryl laurate, sorbic or benzoic acid and citric acid," a deodorant invented by Procter & Gamble in Germany. The patent description says, "Triclosan, which is a phenolic ether, has been widely used in deodorant compositions because of its excellent antibacterial properties. However, Triclosan exhibits certain undesirable properties and is particularly unpopular in Germany and other European countries because it is believed to contain traces of dioxines and furanes, which are very environmentally undesirable and questionably safe for human use. There is thus a need for a deodorant composition which effectively inhibits body odor but without causing skin irritation or other undesirable effects." As is clear from this statement, the need for this new product came out of needs of the European market, something that might have been much harder to spot by employees in P&G's labs in the US. However, P&G's prior experience in designing the deodorant for the US market helped them come up with a new one for the European market.

industry and time period. We feel that this measure is much less subject to various possible biases and hence much more comparable across different industries, countries and time periods.[2]

Patent counts from different patent offices are not comparable to each other because of different patent breadths, patenting costs, approval requirements and enforcement rules for patenting in different countries. Therefore, it is common practice to use data from a single patent granting country like US (Patel and Pavitt, 1991; Jaffe and Trajtenberg, 1999) or UK (Lerner, 2001) to standardize the unit of innovation, making cross-country comparisons possible. Following this well-established convention, we also use patent data from the US patent office to compare innovation across all countries. Our dataset, which includes successful applications registered with the US Patent Office (USPTO) during 1970-1999, was obtained by combining data obtained directly from USPTO with an enhanced dataset by Hall, Jaffe and Trajtenberg (2001).[3] Since the US is the largest and technologically most advanced market in the world, any sufficiently big invention being patented anywhere with a global market in mind is very likely to be patented in the US as well. Admittedly, using US patent data is likely to bias one towards measuring innovations that are large enough to justify the patenting cost and more global in application. This might, on an average, bias our data towards finding a bigger role for multinationals. However, our hope is that the bias is not so systematic across firms, industries and countries as to completely overshadow the fundamental drivers of innovation. Therefore, we hope that our analysis would provide useful insights to complement the small-scale field and survey studies done to explore innovation in small samples of firms in specific industries in specific countries.

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[2] An alternative for large-scale studies is to use aggregate R&D data, but that has its own problems. For example, accounting practices in reporting R&D differ across countries and even across firms of different sizes. There is often also a disagreement on how to adjust for different price levels in comparing R&D expenses in different countries. Good R&D data is not available for countries other than the most developed ones, particular when one tries to separate the role of domestic players and subsidiaries of foreign multinationals. Finally, even if we believe that R&D numbers are accurate and comparable, they might not be a good measure of the *output* of the innovation process.

[3] We thank Adam Jaffe for making their data available to us.

As is common practice in use of patent data, we take the country listed in the address of the first inventor for a patent to be the country where innovation takes place. In order to determine whether a given patent is to be considered as originating from a domestic organization or from the local subsidiary of a foreign multinational, we check whether the "home country" of the assignee organization is the same as the country of the first inventor.[4] A large fraction of the patents is unassigned, which is effectively the same as them still being assigned to the original inventor (Hall, Jaffe and Trajtenberg, 2001). We therefore classify all these individual patents to be in the "domestic player" category. To the extent that these might include a few patents resulting from innovatory work done in the foreign subsidiary of a multinational but still assigned to the inventor, there could be a bias. However, according to US Patent Office, the fraction of such patents is likely to be small given that it is in the interest of firms to protect their property rights.[5]

We take the application year and not grant year for the patent to be the year in which the innovation actually took place since, unlike the grant date, the application date is more contemporaneous with the timing of the R&D investments made (Pakes and Griliches, 1984). We divide the entire period of thirty years into six consecutive five-year periods based on the application year (1970-74, 1975-79, ..., 1995-99). Since patent counts are a noisy measure of innovation and also since there is a variable lag between the actual innovation and application date, aggregating over five years helps reduce the erratic year-to-year variation in the data. Use of application date still faces a data truncation problem. In particular, there are innovations that would have taken place near the end of our sample period but are not in the sample yet since those applications would only be granted in the time following when the patent data were published. Therefore, the patent counts towards the end of the period are downward biased, which manifests in our data as the 1995-99 numbers being much lower than 1990-94 numbers. A simple way around would be that one could simply drop all observations in the last period (i.e. 1995-

[4] Note that this means that the innovations made by a multinational in its "home country" are counted towards "innovations arising from domestic players" in that particular country, and the innovations made by a multinational in countries other than its "home country" are counted towards "innovations arising from subsidiaries of foreign players" in each of those respective countries. We go into the details of determining the "home country" of an organization in the next subsection.

[5] Private e-mail correspondence with US Patent Office.

99) since the lag between the application date and the grant date rarely exceeds five years (Hall, Jaffe and Trajtenberg, 2001). However, this might be unnecessary since there is no reason to expect a systematic bias in the time lags for patents from different firms. Even though the number of patents for 1995-99 would be lower than what they will finally be, there is therefore no reason to believe that the ratio between the two is systematically biased. For this reason, we continue to include data from 1995-99 in our reported analysis, though the results do not change substantially even if we simply drop these observations instead.

Another challenge in using patent data is that patents are very heterogeneous in value (Pakes, 1986). This makes patent counts a noisy measure of total output from innovation. One effective way for improving a measure based on simple patent counts has been found to be weighting the simple patent counts with forward citations received by the respective patents (Trajtenberg, 1990; Lanjouw and Schankerman, 1999). Therefore, as a robustness check, we repeated our analysis with forward citation-weighted patent counts. Although this paper reports only the results from simple patent counts because of space constraints, the qualitative results obtained using the alternative measure were identical.

Data on multinationals

As already mentioned, a crucial step in building the dataset was identifying whether an assignee firm had its home base in the country of patenting or was part of a foreign firm. There is no included information that can tell if a given assignee is indeed a part of a company with headquarters in the same country as the inventor, or is a subsidiary of a foreign multinational. For example, a patent originating from an IBM's researcher based in its German subsidiary might be listed under the assignee code for either the corporate entity "IBM" or the subsidiary entity "IBM Germany" (or some other more cryptic name from which it is not obvious directly if the assignee is a subsidiary of IBM). Cleaning up the patent data in order to identify each firm's "home country" was, however, a non-trivial task since the patent database has about 150,000 assignees. We undertook the following extensive data cleaning exercise.

First, we used Compustat-based CUSIP numbers (from year 1989) included in the database by Hall, Jaffe and Trajtenberg (2001) to make sure that the subsidiaries of major US companies and the few non-US companies that do have CUSIP numbers are correctly matched to their respective corporate parents identified using the same CUSIP number. The number of consistencies found at this stage was small, leading us to have good confidence in the data, at least for the multinationals with CUSIP numbers. Next, we used Stopford's (1992) directory of 428 largest multinationals to manually associate all their major subsidiaries correctly with the corporate parent in the patent database.[6] This was a very time-consuming task since some of the multinationals have a very large number of subsidiaries. We did find a significant number of inconsistencies in this stage of clean-up, particularly for multinationals that did not have US as their home base.[7] Finally, for the remaining assignees, we defined the "home country" simply as the country in which that assignee number showed maximum patenting. This would obviously lead to errors in cases where a multinational is included neither in Stopford's directory nor in the CUSIP list, and patents by its foreign subsidiary are listed under a different assignee number from that of their parent. However, this issue should not affect our results too much since the fraction of such patents should be relatively small. Another concern with the clean-up process might be that our classification of assignees into multinational subsidiaries versus domestic players is static, based only on 1989 CUSIP codes and 1992 classification by Stopford. However, we feel that the qualitative insights would not change even if a more dynamic based on several years of such snapshots were adopted, though time constraints made such an exercise infeasible.

Another potential criticism of our research design is that the pool of firms classified as "foreign multinationals" differs across countries since the same firm,

[6] We defined the subsidiary as being a company in which the multinational has a majority stake. While one can argue that even a "high enough" minority stake can give a multinational enough control over a foreign company, we wanted to avoid the situation in which a company could not be identified with a unique parent. For cases where two multinationals had exactly 50-50 stake in a company, we broke the tie by assuming it was a part of the multinational whose name appeared first in the joint venture.

[7] If we had not done this stage of clean-up, the fraction of innovations attributable to multinational subsidiaries in a country would have been less by between 0% to 5% than the values reported in Table 1 for most countries.

according to our definition, is a “domestic firm” in its home country but a “foreign multinational” in all other countries. As a robustness check, we therefore repeated the analysis with only multinationals that had US as the home base. Additionally, we did not include US in the list of inventor countries we consider. This made sure that exactly the same set of firms was being classified as “foreign multinationals” in all the countries included in our analysis.

Country-level summary statistics

Table 1 summarizes the number of patent applications originating from inventors in 30 countries with successful patent applications with the US patent office between 1970 and 1999. Since patent data is a noisy measure of innovation, we only include countries that show a significant amount of patenting (i.e., more than 100 patents for the period 1990-94) in order for the analysis to be meaningful. Also, we exclude US from our list of inventor countries because of lack of comparability to other countries given a “home bias” that would arise from using data from US Patent Office to compare different countries. Additionally, we exclude observations from communist and ex-communist countries (USSR, Hungary and China) since we don’t think these numbers are comparable to data from other countries. This leaves us with a list of 30 countries. One should be extremely careful in making direct comparisons of levels across time because small differences in patenting can reflect factors other than simply innovation, such as different constraints on the time of the US Patent Office officials, changing cost of patent applications and changing minimum threshold of innovativeness for an innovation to be patentable (Griliches, 1990; Lerner and Kortum, 1998). Similarly, one should be careful in making cross-country comparisons of the levels of patents since the firms from different countries could differ in the propensity to patent. Despite these caveats, some patterns in the data are striking. For example, it appears that Taiwan and Korea have made tremendous jumps in their innovative capabilities over the past few years and are now among the world leaders in innovation, an observation that seems consistent with what researchers have found using other methods (Hobday, 1995). Similarly, there seems little doubt in the observation that, over the past few decades, Japan has been able to grow its innovative capabilities far more than European nations like Germany or France.

More relevant for our discussion here, Table 1 also gives the fraction of the cases in which the patent assignee was a local subsidiary of a foreign player. We will use this number to compare the relative role played by multinational subsidiaries in different countries and time periods. The summary statistics seem to indicate that there is considerable cross-country variation in the fraction of patents attributable to multinationals as well as how it changes over time. For example, for the past thirty years, the percent of successful patents applied by local multinational subsidiaries has remained less than 3% for Japan, between 9% and 14% for Germany, between 17% and 33% for United Kingdom, and between 31% and 45% for Belgium. As interesting examples in cross-country variation from the emerging economies, it appears that the recent surge in innovation in Taiwan and Korea has almost exclusively been the result of innovation by domestic entities[8], while multinationals have played a relatively more important role in countries like Ireland, Hong Kong and Singapore that have actively encouraged foreign direct investment. It appears that differences in national institutions and policies are behind differences in the role that foreign multinational subsidiaries play in different countries. A more general conclusion one might draw is that countries are quite different in the institutions that shape structure of innovation, a finding consistent with work on national systems of innovation (Lundvall ed., 1992; Nelson ed., 1993).

Industry-level summary statistics

An important issue is carrying out industry-level analysis is defining the industry boundaries. If the sectors of analysis are too broadly defined, they may conceal differences between industries. On the other hand, if we use fine a classification, it reduces the data available per industry, making the measures more noisy and harder to interpret. In resolving this inherent conflict, we started with 3-digit SIC codes, but aggregated some of these up (especially the ones that were not clearly delineated in the patent data and those with very little patenting activity) to give a total of 33 sectors as

[8] Even though Taiwan and Korea have both relied on domestic players for innovation, the exact nature of these players has been quite different between these countries. While the policymakers in the former has

listed in table 2. This seemed like a reasonable trade-off between the richness of sector-level data and the number of patents per sector. Also, this gave a number of industries (33) comparable to the number of included countries (30) so that there is a fair comparison between the relative importance of countries versus industries in the variance decomposition we carry out in a later section. In cases where a patent was reported in the USPTO database as belonging to more than one of the industries as classified by us, we avoided double counting by "splitting" the patent between different industries.

We present, in table 2, the average across countries of the fraction of patents attributable to subsidiaries of foreign multinationals in each of the 33 industries. Once more, one should exercise caution in comparing the raw numbers on patents across industries. First, those numbers are obviously a function of exactly how we classify the data into industries in the first place. Second, there are significant inter-industry differences in the propensity to patent (Scherer, 1983) because of different technological opportunity and different conditions for appropriability of returns from innovation (Cockburn and Griliches, 1988; Levin, Klevorick, Nelson and Winter, 1987; Klevorick, Levin, Nelson and Winter, 1995). However, analogous to our argument for the case of cross-country comparisons, we can still make cross-industry and cross-period comparisons by calculating the average *fraction* of patents held by subsidiaries of foreign multinationals. This fraction is also included in the summary data reported in table 2.

A cursory glance at table 2 reveals that the fraction of multinationals seems to vary significantly across industries, though it has remained relatively more stable over time within each individual industry. For example, some active industries for the fraction of patenting by subsidiaries of foreign multinationals are "Soaps, detergents, cleaners, perfumes, cosmetics and toiletries" (with the multinational share average over 30% for the 30 years) and "Computers and Office" (with the multinational share average being over 25% for the 30 years). On the other hand, industries where this ratio seems particularly low are industries such as "Ship and boat building" and "Railroad

focuses on encouraging small entrepreneurial firms, the latter has focuses on large business groups. However, we do not pursue the differences in different domestic players in this paper.

equipment" (with the share being less than 10%). In a later section, we will return to formalizing these differences.

METHODOLOGY FOR VARIANCE DECOMPOSITION

Our central goal in this paper is to study the variation in the relative role of multinationals in innovation in different countries, industries and time periods. The dependent variable we choose for measuring the relative extent of multinational activity is the *fraction* of patents by subsidiaries of foreign multinationals as a part of the total number of patents arising within the same single country, industry and time period. If we had used the level of patenting activity as the dependent variable, it would be faced with the challenge that the propensity to apply for a US patent varies across countries, industries and time periods. Additionally, the results would have been affected by scale effects, i.e., country size as well as industry definitions would have driven the results. Using the fraction defined above avoids these problems and makes the dependent variable more comparable across countries, industries and time periods.

To start with, we study how the variance in the relative importance of multinationals for innovation can be explained by cross-country differences versus cross-industry differences versus cross-period differences. If the world of today is so "globalized" that the effects of national boundaries get dwarfed by technological differences across industries, we should expect the role of foreign multinationals in innovation to differ much more across industries than across countries. If, on the other hand, national institutions and policies still matter much more than technological differences, we should expect the role of foreign multinationals in innovation to differ much more across countries than across industries. We derive the methodology on variance decomposition from the strategy literature on the structure of profitability among firms.

Because of computational limitations of computers, early papers (e.g. Schmalensee, 1985; Rumelt, 1991; McGahan and Porter, 1997) in the variance decomposition literature relied on components-of-variance techniques and/or nested ANOVA techniques. However, both of these techniques have some statistical shortcomings that can now be overcome by using the increasing computing power of computers to run an OLS-based simultaneous ANOVA (McGahan and Porter, 2002; Furman, 2000; Khanna and Rivkin, 2001a). In particular, the nested ANOVA technique ignores covariance among different types of effects while the components-of-variance technique assumes independent realization of different covariances. An OLS-based simultaneous ANOVA, in contrast, allows for a full set of covariance effects without assuming any independence of these effects. Therefore, that is the technique of choice for us. Additionally, OLS has the advantage that it helps us directly infer not only the incremental contribution of each type of effect but also the actual coefficient on each of these fixed effects. This, from our point of view, makes it easier to make cross-country and cross-industry comparisons, which we will return to in the section following the reported results from our variance decomposition.

We start with the following reduced form model of the process that determines the fraction of patents arising from subsidiaries of foreign multinationals in a given industry, country and year:

(1) $y_{i,c,t} = \mu + \gamma_t + \alpha_i + \beta_c + \varepsilon_{i,c,t}$

The dependent variable $y_{i,c,t}$ is the fraction of patents arising from multinational subsidiaries in industry i, country c and time period t. On the right hand side, μ represents the overall mean of this fraction, γ_t is the average deviation (from the overall mean) for year t, α_i represents the average deviation for industry i and β_c is the average deviation for country c. $\varepsilon_{i,c,t}$ captures the remaining idiosyncratic variation for the current observation. We model the first-order serial correlation in the residuals as

(2) $\varepsilon_{i,c,t} = \rho\, \varepsilon_{i,c,t-1} + \omega_{i,c,t}$

where the error term $\omega_{i,c,t}$ is assumed to be independently drawn for each observation. This forms the basis of the standard Cochrane-Orcutt technique to correct for serial correlation. The first step is to get a consistent estimate for ρ. To do this, we use the residuals from equation (1) to come up with estimates for $\varepsilon_{i,c,t}$ and $\varepsilon_{i,c,t-1}$. These are then used to obtain an estimate for ρ using the regression implied by equation (2). Finally, this value of ρ forms the basis of estimating the other unknown parameters by using ordinary least squares (OLS) analysis based on the following equation (which is obtained by subtracting from (1) its own lagged equation scaled by ρ)[9]:

(3) $(y_{i,c,t} - \rho\, y_{i,c,t-1}) = (1-\rho)\mu + \gamma_t - \rho\gamma_{t-1} + (1-\rho)\alpha_i + (1-\rho)\beta_c + \omega_{i,c,t}$

The above discussion suggests two different ways to proceed with the estimation. The first method is to simply ignore the serial correlation issue and estimate all unknown parameters directly through OLS using equation (1). The second method is to explicitly model the serial correlation as an AR-1 process and estimate equation (3) using the estimates ρ. We report results from both methods in order to show the robustness of our results.

RESULTS FROM VARIANCE DECOMPOSITION

The results of our variance decomposition analysis are reported in Figure 1 in a format that is now standard in strategy literature. This baseline case ignores effects of serial correlation, and reports the R^2 values for OLS models based on equation 1. We start with the null model, and successively report the effect on R^2 and adjusted- R^2 as we add dummy variables to capture the fixed effects of industry, country and time period in all possible orders. Each line is accompanied by a fraction that represents the probability with which the restriction of equivalence between the two models it joins is rejected. The fact that we have ">.99" next to every single line in this figure means that no two models are statistically equivalent, i.e. the F-test of statistical insignificance of each of the three types of effects (time period, country or industry) can always be rejected. However, the economic significance (as indicated by the incremental change in R^2) varies for the three effects. In particularly, it is quite clear that the variation caused by the country effects is much higher than that by the industry effects, which in turn is much higher than that by the period effects. This highlights that national boundaries and institutions continue to be

[9] We additionally divided both sides by 1-ρ so that we did not need to rescale the constant term of 1 included among the regressors, and also directly got correct estimates for the overall mean μ, R^2 and

extremely important in determining the role that subsidiaries of foreign multinationals play in different countries. Although cross-industry differences are also important, they are much less so than cross-country differences.

Figure 1 to be included about here

Figure 2 is analogous to figure 1 except that it uses equation 3 instead of equation 1 as a basis for estimation, hence incorporating the effect of serial correlation. The Durbin-Watson statistic of 0.92 indicated that serial correlation was indeed present with a high probability, and the coefficient of correlation ρ estimated from equation 2 using residuals from the full model was found to be 0.31. This estimated value of ρ was used in equation 3 not just for the full model but also for all other models in order to ensure comparability of the R^2 and adjusted R^2 from the different models. The central result from figure 2 is once more that country effects are most important, followed by industry effects, finally followed by time period effects. Thus our findings from the previous analysis are robust to the presence of serial correlation.

Figure 2 to be included about here

The dependent variable used so far is the fraction of patents originating from subsidiaries of *any foreign multinational*. For robustness, we repeat our analysis using as dependent variable the fraction of patents in an industry-country-year combination originating from subsidiaries of *only the foreign multinationals with US as home base*.[10] While the average value of our original index was 0.153 (i.e. the expected number of patents from subsidiaries of all foreign multinationals was about 15.3% from an industry, country and period chosen at random), the average value of the new dependent variable is 0.085% (i.e. the expected number of patents from subsidiaries of US multinationals is about 8.5% from an industry, country and period chosen at random). Figure 3 is

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adjusted R^2 directly from our statistical package.

[10] We do not attempt to further break down the non-US multinational data into data for individual home countries since the number of patents coming from subsidiaries of multinationals from any individual

analogous to figure 2 except that the new dependent variable is now used for doing the analysis of variance instead. The Durbin-Watson statistic of 0.848 indicated that serial correlation was again present with a high probability, and the coefficient of correlation ρ estimated from equation 2 using residuals from the full model was found to be 0.3001. Since the dependent variable is different, the R^2 values from figures 2 and 3 cannot be directly compared. However, the qualitative result remains exactly the same as before - country effects are most important, followed by industry effects, finally followed by time period effects. Thus our main findings from the previous discussion are again found to be robust to using the new dependent variable.

Figure 3 to be included about here

FIXED EFFECT COEFFICIENTS

We now we use the fixed effect coefficients obtained from equation (3) above to document the differences in relative role of multinational subsidiaries in innovation across countries, industries and time. We also offered some informal thoughts on what could be driving the cross-country, cross-industry and cross-period differences, leaving formal regression analysis based on potential explanatory variables for the next section.

Cross-Country Differences

Table 3 reports the estimated coefficients for country fixed effects from equation (3), while controlling for industry effects and period effects. The median country, Mexico, is normalized to have a zero coefficient, and countries are listed in decreasing importance of the role of multinational subsidiaries. At one extreme are countries like Luxembourg, Belgium, Singapore, India and Ireland, with coefficients that indicate that fraction of foreign multinational activity in R&D there exceeds that in the median country by 15% or more. At the other extreme are countries like Japan, South Korea and Taiwan, where this fraction is more than 10% below the median.

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country (other than the US) is quite small, making such a potential analysis subject to a high degree of

What explains these differences? It would appear that the national institutions and government policies have a significant impact at the outcome in terms of role of multinationals in innovation. Luxembourg and Belgium are probably at the top of the list since, being extremely open yet small economies in the heart of Europe, they have seen multinationals play a disproportionately higher role than in other places. Likewise, both Ireland and Singapore have actively encouraged multinationals to set up local facilities there, often even at the expense of domestic firms (Porter 1990, 1998), causing them to be near the top of the list. At the other extreme, some of the East Asian economies like Japan, South Korea and Taiwan have actively sought policies to build domestic innovative capabilities rather than rely on multinationals (Nelson, 1993; Hobday, 1995), the result of which is reflected in terms of their being at the bottom of the list for fraction of innovative activity arising from multinationals.

Cross-Industry Differences

Table 4 reports estimates of the fixed effect coefficients for industries in the complete model, i.e., controlling for industry and time period effects. The effect for the median industry, "Miscellaneous chemical products", is normalized to zero. A positive coefficient indicates an industry with a relatively high multinational activity and a negative coefficient indicates an industry with a relatively low multinational activity. The industries are reported in the decreasing order of multinational activity. The deviations from median seem to be somewhat less extreme for the case of the industries than for the countries discussed above, which should not come as a surprise given that country effects accounted for a much higher fraction of the R^2 than the industry effects in the variance decomposition analysis in the last section.

What is it about these industries that makes them be near the bottom or top of the list? Just glancing at the list, one can propose several hypotheses. For example, "Soaps, detergents, cleaners, perfumes, cosmetics and toiletries", at 18.5% above the median, is the most active industry for multinational subsidiaries probably because multinationals in this industry are highly dependent on understanding the needs and preferences of the

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noise and hence uninteresting.

local customers, and hence very likely to locate R&D overseas. Other reasons that might explain why some of the other industries are near the top of the list are that multinationals are locating R&D centers close to the global centers of excellence for these industries (Porter, 1990, 1998) or that the economies of scale from keeping the R&D centralized at the headquarters are low than the potential gains from learning more about customer needs that differ in different places (Hirschey and Caves, 1981). At the other extreme are industries like "Ship and boat building and repairing" (9.6% below median) and "Railroad equipment" (6.6% below median). Consistent with suggestions by Caves (1996), these appear to be industries where scale economies might play a more important role than local customization, thus reducing multinational activity overseas.

Cross-Period Differences

Table 4 reports the estimated coefficients for the time period fixed effects from equation (3), while controlling for industry effects and country effects. Since our model uses first differencing to eliminate biases from serial correlation, coefficient for 1970-74 is not included. The next period, 1975-79, is normalized to have a zero coefficient. The coefficients from 1980-84 and 1985-89 are not statistically significant, indicating that there is no evidence of much change in the relative role of multinational subsidiaries for innovation between the late 1970s and 1980s. Relative multinational activity does seem to have gone up significantly during the 1990s, by 2.8% during 1990-94 and an additional 2.3% during 1995-99. Part of this is, however, to only make up for the slight dip in the innovative role of multinationals in early 1980s relative to early 1970s that we saw using summary statistics earlier but does not show up in the analysis here because the 1970-74 data had to be dropped to correct for serial correlation. Thus, on the whole, increase in relative innovative activity by foreign multinational subsidiaries over the past 25 years seems rather modest.

REGRESSION ANALYSIS

In this section, we turn to formal regression analysis on a set of underlying explanatory variables to give further insights on these differences. We used the Prais-Winston enhancement of the standard Cochrane-Orcutt method to handle AR1 serial correlation, since it is more appropriate for samples covering relatively small number of time periods.[11] Additionally, we were conservative in reporting standard errors: We used a modification of the Huber-White robust standard errors that allows for heteroskedasticity of error terms as well as an arbitrary correlation structure across cross-sectional terms for each country.

Because of the large number of countries included, comparable measures were hard to find. The measures that we do use are somewhat simplistic and likely to be noisy. However, they are still useful at generating insights that should be further tested using other research methods. The set of explanatory variables we used and the effects we expected to find for each of these variables is as follows:

1. *Degree of openness*: This measures the degree of openness of a country to foreign direct investment, and is defined as the ratio of FDI flow to GDP. The FDI flow and GDP data were taken from various issues of *UN Statistical Yearbook.* We expected multinationals to have a greater role in innovation in economies where the importance of FDI in the economy is higher. Thus *we expected the sign on the estimated coefficient for openness to be positive.*
2. *Size of the economy*: We expected multinational subsidiaries to play a much larger role for smaller countries where the domestic players are typically weaker and less global in reach, and hence less likely to have a large share of patenting in the US compared with the multinational subsidiaries there. Thus *we expected the sign on the estimated coefficient for the size of the economy to be negative.* The size of the economy for each country was measured as the GDP expressed in constant 1995 US dollars using data obtained from *UN Statistical Yearbook.*
3. *Specialized human capital*: Increases in skilled human capital can be expected to lead to more innovation by both domestic and foreign players in a country. However, since a subsidiary of a foreign multinational is likely to be less

[11] The Prais-Winsten method also uses first differencing just like the Cochrane-Orcutt technique discussed to come up with equation (3). The distinct feature of the Prais-Winsten method is that, instead of simply throwing away observations from the first period after doing the first differencing for all other periods, it transforms the first period equation by multiplying all terms by $\sqrt{1-\rho^2}$. This is just a special case of the

dependent on the local labor market because it has easier access to foreign human capital, we expected it to be affected less by the human capital improvements than a domestic firm would be. Thus *we expected the sign on the estimated coefficient for specialized human capital to be negative.* We construct a measure of specialized human capital as the fraction of population with tertiary education in science and engineering. To get this measure, we multiplied the fraction of population with tertiary education from the Barro-Lee (2000) database with the fraction of tertiary-level students that engage in science and engineering from World Bank's *World Development Indicators* data.

4. *Intellectual Property Rights (IPR) Protection*: The extent of a country's intellectual property right protection should increase innovation in that country. We expected this increase in innovation to lead to an increase in the extent of patenting from inventors of that country in the US. However, since multinationals are often a response to market failures in the market for intellectual property and hence as rely less on the IPR protection granted through market contracts, increase in IPR should affect the domestic firms more than multinational subsidiaries. Thus *we expected the sign on the estimated coefficient for IPR protection to be negative.* We use an IPR index, composed by Ginarte and Park (1997)[12], which captures both the existence and enforcement of intellectual property rights laws for a country in any given time period.
5. *Rule of law*: A poorer law and order situation is likely to discourage innovation by both domestic and foreign players, though it is likely that the domestic players find a way around the local problems (e.g. through political connections or bribing the right people) while the foreign players simply stay out. *Thus we expected the sign on the estimated coefficient for rule of law to be positive.* We use a measure of the law and order tradition in the country produced by the country risk-rating agency International Credit Risk, as reported in La Porta et al (1998).
6. *Capital availability:* Since multinationals usually have better access to capital from international capital markets, we expected the relative share of multinationals to

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Feasible Generalized Least Squares (FGLS) technique, and is more efficient than Cochrane-Orcutt technique since the latter just "wastes" data from the first period.

[12] We would like to thank Walter Park for making an updated version of their data available to us.

decrease as capital availability increases since domestic capital constraints that affect local firms probably affect multinationals to a lesser extent. Thus *we expected the sign on the estimated coefficient for capital availability to be negative.* In order to construct an index of how easily capital is available in a country, we use two measures derived from data reported in Rajan and Zingales (1998): (i) the quality of accounting standards, and (ii) the ratio of domestic credit to private sector to the country's GDP. We prefer to use a index based on domestic credit rather than stock market capitalization since, as explained in detail by Rajan and Zingales (1998), stock market capitalization is a much poorer measure of the amount of funding actually obtained by issuers. Quality of accounting standards, on the other hand, can help capture the potential of raising money in capital markets since higher quality of accounting standards is known to increase investment by reducing information asymmetry in the capital markets.

7. *Dependence on external capital*: This is an industry-level measure that captures how much capital an industry needs. If we believe that, because of better access to global financial markets, multinationals can raise capital abroad more easily than local firms, we might expect them to be relatively less constrained than the local players as the need for capital increases. This might suggest that multinational subsidiaries might have a higher degree of activity in industries that require more capital. *Thus we expect the sign on the estimated coefficient for dependence on external capital to be negative.* We use two measures derived from Rajan and Zingales (1998) to capture this effect: (i) capital requirements in an industry (measured as the average ratio of capital expenditures to net property plant and equipment for the industry in the US during 1980-1990), and (ii) external financing requirements of the industry (defined as the part of the capital requirements met through raising capital externally rather than internal cash flows). While the latter measure is conceptually better as it directly gets to the need for external financing, we also report results from the first since the second can be criticized for being more dependent on the exact economics of the US, and hence less generalizable to other countries.

The correlations and summary statistics for variables are reported in table 6, and regression results are reported in table 7. In columns (1) through (4), we focus on explaining cross-country variation and continue to use dummy variables to control for industry and period fixed effects as before. As column (1) in the table shows, the relative role of multinationals is greater in more open countries and in smaller countries, as per our hypotheses above. Column (2) shows that increase in human capital decreases the relative role of multinationals, again as hypothesized. We expected a similar result to hold for intellectual property rights (IPR) protection. However, though the sign is negative as predicted in all specifications, the result is not statistically significant. This might, however, be simply a result of the IPR measure being extremely noisy, particularly because countries often have very different levels of IPR protection for different industries while the Ginarte-Park index assigns the same value to all contemporaneous observations from a country. Likewise, rule of law does not seem to have a statistically significant impact in any specification, though the sign is always positive as predicted. While noisiness of the measure could again be an explanation, an alternate explanation for the absence of statistically significant effect could also be that poor IPR protection and rule of law reduces innovation by both domestic firms and subsidiaries of foreign multinationals, so the ratio does not change significantly.

Next, we turn to testing the effect of availability of external finance in a country. Columns (3) and (4) measure the availability of finance using accounting standards and credit availability respectively. While the sign is negative as hypothesized for both cases, the effect is not statistically significant for either case. This continues to be true for other specifications as well. In each of columns (5) through (7), we include a measure for the financing needs in the industry. As predicted, the relative role of multinationals increases as the financing requirements increase, whether measured by the capital intensity or directly by the observed financing needs for the US during the 1980s.

We repeat the analysis separately for multinationals with US as a home base and multinationals with any country other than the US has a home base. The results are reported in table 8. We find some striking differences between the two. First, for multinational subsidiaries whose home base is the US, we find that their relative role does not diminish in the size of the host country's economy (as measured by its GDP) in any statistically significant way. Second, the relative role of subsidiaries of US multinationals does not change significantly with human capital (though the sign as negative as predicted) while that of non-US multinationals does decrease significantly with the level of human capital in the host country. Thus, only the subsidiaries of US multinationals seem to depend on the host country's human capital in a way similar to how the local firms do (so the *fraction* does not change for US multinationals but changes for non-US multinationals). Third, the relative role of US multinationals decreases sharply with increases in IPR protection in the host country while that of non-US multinationals does not seem to change significantly with IPR protection in the host country. Thus, only the subsidiaries of non-US multinationals seem to depend on the host country's IPR protection in a way that the local firms there do (so the *ratio* does not change for non-US multinationals). Fourth, the relative role of US multinationals does not change with rule of law in the host country while that of non-US multinationals seems to increases significantly with the level of rule of law. Finally, our hypothesis for the role of need for external and availability of financing seem to hold only for US multinationals. The wide differences between US and non-US multinationals are really intriguing and should be an interesting area for more in-depth research.

CONCLUSION

There is no consensus on whether, on the whole, multinational subsidiaries are beneficial for their host countries or not. On the one hand, researchers argue, the extent of innovative activities that foreign multinationals undertake in a country can have significant welfare benefits for the country because of knowledge spillovers to other firms. On the one hand, large multinational corporations are sometimes seen as exploiters who do not contribute much to the local economy of their host country. In particular, the argument goes, they only seek new product markets and cheaper factor markets abroad but do not want to locate their highest-value innovative activities overseas, leading to minimal extent of knowledge spillovers from their foreign subsidiaries to the local economy. Understanding under what conditions does one or the other view hold true and what drives the innovative activities of foreign multinationals therefore becomes an important research question.

In this paper, we use 30 years of US patent data to study the role of subsidiaries of foreign multinationals in innovation in 30 countries and 33 industries. We find that the average amount of patenting activity attributable to multinational subsidiaries operating in any country in our sample in any industry has been around 15% during the past 30 years. Thus, it seems that, on an average, foreign multinationals do play an important role in innovation. However, there is huge variance in this role. We find that country borders matter much more than industry affiliation in determining the innovative role of foreign subsidiaries. Also, characteristics of the host country as well as the country of origin of multinationals seem to matter in determining a multinational's behavior. The finding of this paper gives further emphasis to the need for moving beyond study of only inter-industry differences in economic outcomes and trying to understand what drives inter-country differences in the way economic activity is organized. Many other researchers have also highlighted the importance of national institutions and policies as a prime driver of how economic activity gets organized (Lundvall 1992; Nelson, 1993; Khanna and Rivkin, 2001b; Khanna, Kogan and Palepu, 2001).

We find relatively small increase in the role of foreign multinationals subsidiaries in innovation over the past three decades, which is interesting given the large increase in overall economic activity overseas for multinationals over the same time period. It appears that, despite the hype about globalization, the underlying cross-country differences that drive economic outcomes tend to be pretty persistent. A regression analysis suggests that multinational subsidiaries might be better than domestic firms at overcoming a country's limitations in specialized human capital, availability of finance and protection of intellectual property rights. This supports the conjecture that multinational firms could play an important role when markets do not function well by possibly filling in the institutional voids (Foley, 2001).

The generality and comprehensiveness of our study comes at the cost of having to use both independent and dependent variables that are somewhat simplistic. Patent counts are far from being a perfect measure of innovation, but we were constrained by lack of availability of any other measures of innovation that could make a study of this scale feasible. The classification of patents into those by domestic firms versus multinational subsidiaries itself is subject to errors because of possible omissions during the data clean-up process as well as the static classification based on only the year 1992. Because of these challenges, we see our work not as a substitute for detailed field studies based of small samples of firms, industries and countries but rather as a complement that helps generalize finding of such studies and set agenda for future research.

Analyzing the extent and drivers of multinational innovation is an important step in addressing whether what drives how much multinationals can potentially contribute to the host countries through knowledge spillovers. However, in future research, we want to carry out a more direct micro-level analysis of knowledge spillovers and its drivers across different countries and industries by looking at patent citations as a measure of knowledge spillovers (Jaffe, Trajtenberg and Fogarty, 2000). While there has been some promising work in this area in studying specific countries and industries (Almeida, 1996; Jaffe and Trajtenberg, 1999; Frost, 2001), much more needs to be done in measuring the extent of spillovers between multinational and domestic players across a large number of countries and industries to get at the question of welfare effects of multinationals more directly.

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Table 1: Total number of successful patent applications per country

Country	1970-74	1975-79	1980-84	1985-89	1990-94	1995-99
Japan	25,912 (2.8%)	35,627 (1.8%)	54,126 (1.4%)	88,200 (1.8%)	115,685 (1.7%)	85,511 (2.3%)
Germany	26,722 (9.3%)	29,521 (8.8%)	30,308 (9.9%)	36,848 (10.7%)	35,756 (12.4%)	26,263 (13.9%)
France	10,431 (9.8%)	10,883 (8.4%)	10,859 (8.9%)	13,547 (11.2%)	15,041 (13.8%)	10,434 (16.1%)
Taiwan	40 (2.5%)	274 (2.2%)	559 (3.0%)	2,402 (1.4%)	6,793 (1.9%)	9,911 (1.9%)
United Kingdom	13,649 (17.7%)	12,948 (17.9%)	11,320 (21.5%)	13,158 (24.6%)	12,588 (28.4%)	9,504 (33.3%)
South Korea	35 (17.1%)	53 (13.2%)	151 (1.3%)	914 (1.5%)	4,838 (1.1%)	8,848 (0.6%)
Canada	5,783 (20.5%)	5,949 (18.3%)	5,778 (16.1%)	8,293 (14.9%)	10,790 (15.9%)	8,756 (17.5%)
Italy	3,472 (10.5%)	3,946 (8.2%)	4,044 (9.3%)	5,691 (9.6%)	6,268 (11.6%)	4,436 (14.1%)
Switzerland	6,274 (9.6%)	6,625 (7.7%)	5,708 (9.8%)	6,279 (11.9%)	5,860 (15.5%)	3,740 (21.3%)
Sweden	3,911 (4.8%)	4,222 (4.1%)	3,661 (6.3%)	3,781 (7.6%)	3,898 (13.2%)	3,459 (10.8%)
Netherlands	3,070 (10.2%)	3,401 (11.9%)	3,461 (11.6%)	4,398 (12.0%)	4,419 (16.9%)	3,228 (19.1%)
Belgium	1,326 (38.2%)	1,272 (31.1%)	1,150 (37.7%)	1,524 (40.9%)	1,921 (42.4%)	1,915 (45.0%)
Israel	381 (13.9%)	566 (7.1%)	788 (9.1%)	1,315 (9.0%)	2,014 (17.3%)	1,912 (17.8%)
Australia	1,035 (23.3%)	1,402 (12.0%)	1,474 (11.1%)	2,099 (10.5%)	2,348 (11.5%)	1,827 (14.9%)
Finland	420 (5.0%)	615 (5.2%)	819 (1.7%)	1,265 (2.2%)	1,862 (3.8%)	1,695 (5.9%)
Austria	1,221 (19.7%)	1,417 (14.6%)	1,363 (14.4%)	1,733 (16.4%)	1,769 (18.8%)	1,273 (23.2%)
Denmark	736 (7.9%)	767 (6.6%)	748 (6.6%)	884 (8.7%)	1,130 (8.8%)	1,183 (11.7%)
Spain	374 (10.2%)	406 (4.4%)	338 (8.9%)	597 (9.0%)	791 (16.2%)	643 (24.3%)
Norway	411 (8.8%)	495 (7.7%)	389 (11.6%)	555 (8.1%)	654 (8.3%)	568 (12.1%)
Hong Kong	54 (16.7%)	108 (16.7%)	111 (18.0%)	217 (21.2%)	358 (15.1%)	404 (16.3%)
Singapore	15 (26.7%)	14 (35.7%)	24 (25.0%)	62 (32.3%)	261 (55.6%)	359 (37.9%)
South Africa	337 (4.5%)	437 (8.5%)	399 (8.8%)	527 (8.0%)	563 (7.5%)	313 (12.5%)
New Zealand	119 (9.2%)	208 (9.6%)	219 (3.2%)	259 (8.5%)	238 (11.3%)	294 (15.3%)
India	75 (53.3%)	51 (47.1%)	55 (43.6%)	89 (48.3%)	160 (36.3%)	237 (22.8%)
Ireland	89 (28.1%)	85 (18.8%)	129 (27.1%)	244 (30.3%)	309 (45.3%)	229 (43.7%)
Brazil	83 (24.1%)	119 (12.6%)	117 (24.8%)	188 (14.4%)	305 (15.4%)	221 (16.3%)
Mexico	233 (19.7%)	221 (10.0%)	177 (5.1%)	189 (12.2%)	212 (8.0%)	178 (20.8%)
Argentina	114 (7.9%)	117 (9.4%)	83 (16.9%)	80 (3.8%)	151 (7.3%)	117 (9.4%)
Venezuela	20 (10.0%)	36 (5.6%)	58 (8.6%)	101 (4.0%)	144 (6.9%)	92 (5.4%)
Luxembourg	58 (17.2%)	101 (25.7%)	136 (28.7%)	116 (27.6%)	128 (32.8%)	65 (53.8%)

Percentages in parentheses indicate fraction of patents attributable to foreign players
Countries sorted in decreasing order of their patent applications in 1995-99

Table 2: Total patenting by industry

Industry	1970-74	1980-84	1985-89	1990-94	1995-99
Food, related products & beverages	687 (14.3%)	824 (18.4%)	1,203 (13.2%)	1,170 (18.7%)	845 (21.9%)
Textiles, apparel, leather and footwear	818 (20.4%)	1,046 (14.3%)	1,328 (17.8%)	1,361 (21.6%)	1,033 (21.2%)
Basic industrial chemicals (org & inorg)	12,385 (28.1%)	9,797 (17.1%)	11,743 (14.4%)	13,309 (21.7%)	9,474 (23.5%)
Plastic materials and synthetic resins	1,945 (32.8%)	2,085 (22.8%)	3,341 (28.3%)	3,920 (29.6%)	2,524 (24.2%)
Agricultural chemicals	1,055 (29.2%)	3,037 (20.4%)	4,110 (22.1%)	4,643 (18.8%)	3,570 (23.8%)
Soaps, cleaners, cosmetics & toiletries	507 (52.8%)	761 (28.5%)	1,084 (30.5%)	1,197 (33.3%)	1,316 (38.0%)
Paints, varnishes, lacquers & enamels	736 (15.5%)	808 (25.0%)	1,082 (23.3%)	1,398 (20.7%)	950 (30.3%)
Miscellaneous chemical products	977 (21.9%)	1,357 (14.2%)	1,741 (15.0%)	1,956 (14.9%)	1,571 (17.9%)
Drugs and medicine	1,755 (27.1%)	3,578 (18.9%)	4,910 (20.3%)	6,773 (18.5%)	5,893 (21.4%)
Petroleum, natural gas & related products	348 (17.5%)	661 (7.2%)	725 (6.7%)	707 (16.0%)	494 (28.9%)
Rubber and plastic products	4,053 (18.8%)	5,516 (15.2%)	8,055 (19.0%)	9,205 (18.1%)	6,448 (20.4%)
Stone, class, glass & non-metal minerals	1,860 (13.4%)	2,538 (8.7%)	3,703 (14.4%)	4,047 (12.7%)	2,920 (15.5%)
Ferrous and non-ferrous metals	1,579 (14.1%)	1,914 (17.2%)	2,356 (11.5%)	2,606 (9.4%)	1,620 (19.4%)
Fabricated metal products	6,870 (9.5%)	8,372 (8.6%)	11,699 (8.4%)	11,932 (8.7%)	8,781 (11.5%)
Engines and turbines	1,224 (5.4%)	1,912 (6.2%)	2,195 (11.0%)	2,284 (15.5%)	1,736 (16.9%)
Farm & garden machinery and equipment	1,049 (7.3%)	1,262 (9.4%)	1,519 (10.1%)	1,524 (7.9%)	1,077 (11.8%)
Metal working machinery and equipment	3,614 (8.2%)	3,887 (14.0%)	4,846 (9.3%)	4,919 (9.3%)	3,302 (12.6%)
Computers and office	2,594 (24.6%)	5,555 (21.3%)	9,766 (18.8%)	15,376 (34.2%)	13,639 (34.3%)
Industry machinery, excl. metal working	7,517 (14.8%)	8,042 (14.2%)	9,717 (13.2%)	10,655 (11.3%)	7,466 (13.0%)
Other non-electric machinery & equipment	11,544 (12.1%)	13,143 (9.5%)	17,381 (8.6%)	18,260 (11.7%)	12,883 (13.7%)
Electric industrial machinery & equipment	5,616 (14.9%)	6,870 (18.3%)	9,407 (14.1%)	10,955 (21.3%)	8,876 (23.1%)
Electric household appliances	914 (9.4%)	1,261 (18.5%)	1,669 (15.3%)	1,403 (10.6%)	1,144 (14.5%)
Electric misc apparatus and supplies	1,697 (12.8%)	2,187 (11.8%)	3,162 (12.3%)	4,294 (20.5%)	3,244 (17.7%)
Electronics, radio, tv & communication	10,352 (25.6%)	17,360 (18.8%)	29,027 (21.7%)	46,042 (29.9%)	41,709 (28.2%)
Motor vehicles & motor vehicle equipment	2,877 (6.2%)	4,558 (7.5%)	6,390 (8.8%)	6,310 (12.8%)	4,859 (19.6%)
Guided missiles and space vehicles	73 (10.7%)	53 (0.9%)	92 (11.9%)	82 (1.4%)	49 (5.0%)
Ship and boat building and repairing	405 (3.9%)	355 (2.1%)	514 (10.3%)	483 (6.1%)	320 (2.7%)
Railroad equipment	415 (4.6%)	302 (8.9%)	377 (2.6%)	356 (10.0%)	234 (8.5%)
Motorcycles, bicycles, and parts	203 (11.9%)	374 (9.0%)	467 (7.2%)	498 (14.2%)	392 (9.2%)
Misc transport equipment and ordinance	1,001 (4.9%)	1,113 (4.3%)	1,533 (3.9%)	1,430 (13.9%)	915 (7.4%)
Aircraft and parts	1,325 (6.8%)	1,948 (7.4%)	2,520 (13.7%)	2,618 (20.9%)	2,096 (14.7%)
Professional and scientific equipment	11,921 (15.1%)	18,144 (11.5%)	26,408 (10.9%)	32,031 (14.4%)	25,347 (15.5%)
Other manufactured products	6,489 (7.0%)	7,927 (7.3%)	11,490 (7.8%)	13,510 (10.3%)	10,884 (13.0%)

Percentages in parentheses indicate average fraction of patents attributable to foreign players for each given industry

Table 3: Countries in decreasing order of fixed effect coefficients

Country	coef	std err	t value	p > |t|
Luxembourg	0.267	0.032	8.26	0.000
Belgium	0.261	0.028	9.47	0.000
Singapore	0.226	0.035	6.39	0.000
India	0.176	0.031	5.63	0.000
Ireland	0.145	0.030	4.92	0.000
Brazil	0.094	0.028	3.31	0.001
United Kingdom	0.091	0.027	3.33	0.001
Canada	0.061	0.027	2.24	0.025
Netherlands	0.057	0.027	2.07	0.039
Austria	0.056	0.028	2.03	0.042
Hong Kong	0.049	0.032	1.56	0.118
Spain	0.024	0.028	0.86	0.389
Australia	0.014	0.027	0.53	0.597
Switzerland	0.007	0.027	0.26	0.798
Mexico	0.000			
South Africa	-0.006	0.028	-0.23	0.815
France	-0.012	0.027	-0.42	0.672
Germany	-0.018	0.027	-0.67	0.503
Italy	-0.020	0.027	-0.75	0.456
Venezuela	-0.021	0.033	-0.64	0.525
New Zealand	-0.021	0.029	-0.73	0.465
Norway	-0.030	0.028	-1.07	0.285
Sweden	-0.037	0.027	-1.36	0.173
Denmark	-0.054	0.028	-1.94	0.052
Israel	-0.055	0.028	-2.00	0.045
Argentina	-0.057	0.030	-1.89	0.058
Finland	-0.089	0.028	-3.18	0.002
Taiwan	-0.102	0.029	-3.56	0.000
South Korea	-0.114	0.029	-3.97	0.000
Japan	-0.116	0.027	-4.26	0.000

Coefficient for median country (Mexico) normalized to 0

Table 4: Industries in decreasing order of fixed effect coefficients

Industry	coef	std err	t value	p > |t|
Soaps, detergents, cleaners, perfumes, cosmetics and toiletries	0.185	0.032	5.81	0.00
Computers and office	0.107	0.030	3.62	0.00
Paints, varnishes, lacquers, enamels, and allied products	0.095	0.031	3.05	0.00
Electronics, Radio, TV, Comm	0.092	0.029	3.18	0.00
Drugs and medicine	0.079	0.030	2.66	0.01
Agricultural chemicals	0.073	0.029	2.48	0.01
Textiles, Apparel, Leather and Footwear	0.072	0.030	2.41	0.02
Plastic materials and synthetic resins	0.066	0.031	2.11	0.04
Food, Other Related Products & Beverages	0.063	0.030	2.11	0.04
Basic Industrial chemicals (org & inorg)	0.034	0.029	1.16	0.25
Electric industrial machinery & equipment	0.031	0.029	1.08	0.28
Rubber and Plastic Products	0.023	0.029	0.79	0.43
Petroleum, Natural Gas & Related Products	0.016	0.032	0.51	0.61
Electric misc apparatus and supplies	0.010	0.030	0.35	0.72
Ferrous and Non-ferrous metals	0.006	0.030	0.20	0.84
Aircraft and parts	0.001	0.029	0.02	0.99
Miscellaneous chemical products	0.000			
Electric household appliances	-0.011	0.030	-0.37	0.71
Special industry machinery, except metal working	-0.011	0.029	-0.39	0.70
Engines and turbines	-0.015	0.029	-0.50	0.62
Motor vehicles and other motor vehicle equipment	-0.020	0.029	-0.70	0.48
Professional and scientific equipment	-0.025	0.029	-0.87	0.38
Motorcycles, bicycles, and parts	-0.035	0.032	-1.09	0.28
Farm and garden machinery and equipment	-0.037	0.029	-1.27	0.20
Stone, class, glass and non-metal minerals	-0.038	0.029	-1.32	0.19
Metal working machinery and equipment	-0.042	0.029	-1.45	0.15
Misc transport equipment and ordinance	-0.046	0.030	-1.51	0.13
Other non-electric machinery and equipment	-0.047	0.029	-1.65	0.10
Other manufactured products	-0.054	0.029	-1.88	0.06
Fabricated metal products	-0.059	0.029	-2.06	0.04
Railroad equipment	-0.066	0.033	-1.98	0.05
Guided missiles and space vehicles and parts	-0.070	0.044	-1.60	0.11
Ship and boat building and repairing	-0.096	0.031	-3.06	0.00

Coefficient for median industry ("Miscellaneous chemical products") normalized to 0

Table 5: Fixed effect coefficients for time periods

Period	coef	std err	t value	p > |t|
1970-74	-			
1975-79	0.000			
1980-84	0.005	0.008	0.65	0.516
1985-89	0.005	0.009	0.49	0.626
1990-94	0.028	0.010	2.88	0.004
1995-99	0.051	0.010	5.11	0.000

Coefficient for period 1970-74 not estimated because of first differencing
Coefficient for period 1975-79 normalized to 0

Table 6: Descriptive statistics and correlation among variables

		1	2	3	4	5	6	7	8	9	10
1	Fraction of patents by foreign multinational subsidiaries	1.00									
2	Openness to FDI	0.24	1.00								
3	GDP	-0.13	-0.19	1.00							
4	Human Capital	-0.08	0.17	-0.06	1.00						
5	IPR Protection	-0.10	0.12	0.26	0.30	1.00					
6	Rule of Law	0.02	0.23	0.13	0.19	0.46	1.00				
7	Accounting Standards	-0.02	0.28	0.02	0.36	0.30	0.41	1.00			
8	Credit Availability	-0.12	-0.08	0.48	0.13	0.51	0.22	-0.08	1.00		
9	Industry Capital Intensity	0.06	0.02	-0.01	0.00	0.00	0.01	0.00	0.00	1.00	
10	Industry Financing Need	0.07	0.02	-0.01	-0.01	-0.02	0.00	-0.01	-0.01	0.90	1.00
	Number of observations	5217	4884	5940	5610	5742	5742	5544	4554	5940	5940
	Mean	0.153	0.016	0.004	0.040	0.624	0.818	0.652	0.438	0.326	0.167
	Standard deviation	0.217	0.021	0.008	0.026	0.155	0.196	0.096	0.202	0.077	0.163

Table 7: Determinants of fraction of patenting activity arising from subsidiaries of foreign multinationals

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Openness to FDI	2.045***	2.047***	2.166***	2.005***	1.921***	1.920***	1.876**
	(0.616)	(0.590)	(0.683)	(0.695)	(0.603)	(0.602)	(0.721)
GDP	-1.994***	-2.042***	-1.811***	-2.069**	-2.156***	-2.154***	-2.157**
	(0.591)	(0.633)	(0.651)	(0.813)	(0.663)	(0.663)	(0.874)
Human Capital		-0.852***	-0.807***	-0.787***	-0.845***	-0.844***	-0.778***
		(0.273)	(0.281)	(0.269)	(0.277)	(0.277)	(0.273)
IPR Protection		-0.096	-0.090	-0.114	-0.091	-0.090	-0.104
		(0.062)	(0.062)	(0.071)	(0.065)	(0.065)	(0.074)
Rule of Law		0.047	0.052	0.057	0.048	0.048	0.055
		(0.040)	(0.044)	(0.042)	(0.043)	(0.043)	(0.045)
Accounting Standards			-0.040				
			(0.102)				
Credit Availability				-0.016			-0.020
				(0.051)			(0.054)
Industry Capital Intensity					0.164***		
					(0.062)		
Industry Financing Need						0.083***	0.077**
						(0.027)	(0.030)
Industry Fixed Effects?	Yes	Yes	Yes	Yes	No	No	No
Period Fixed Effects?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4364	4303	4147	3714	4303	4303	3714
R-squared	0.122	0.135	0.141	0.156	0.066	0.066	0.074

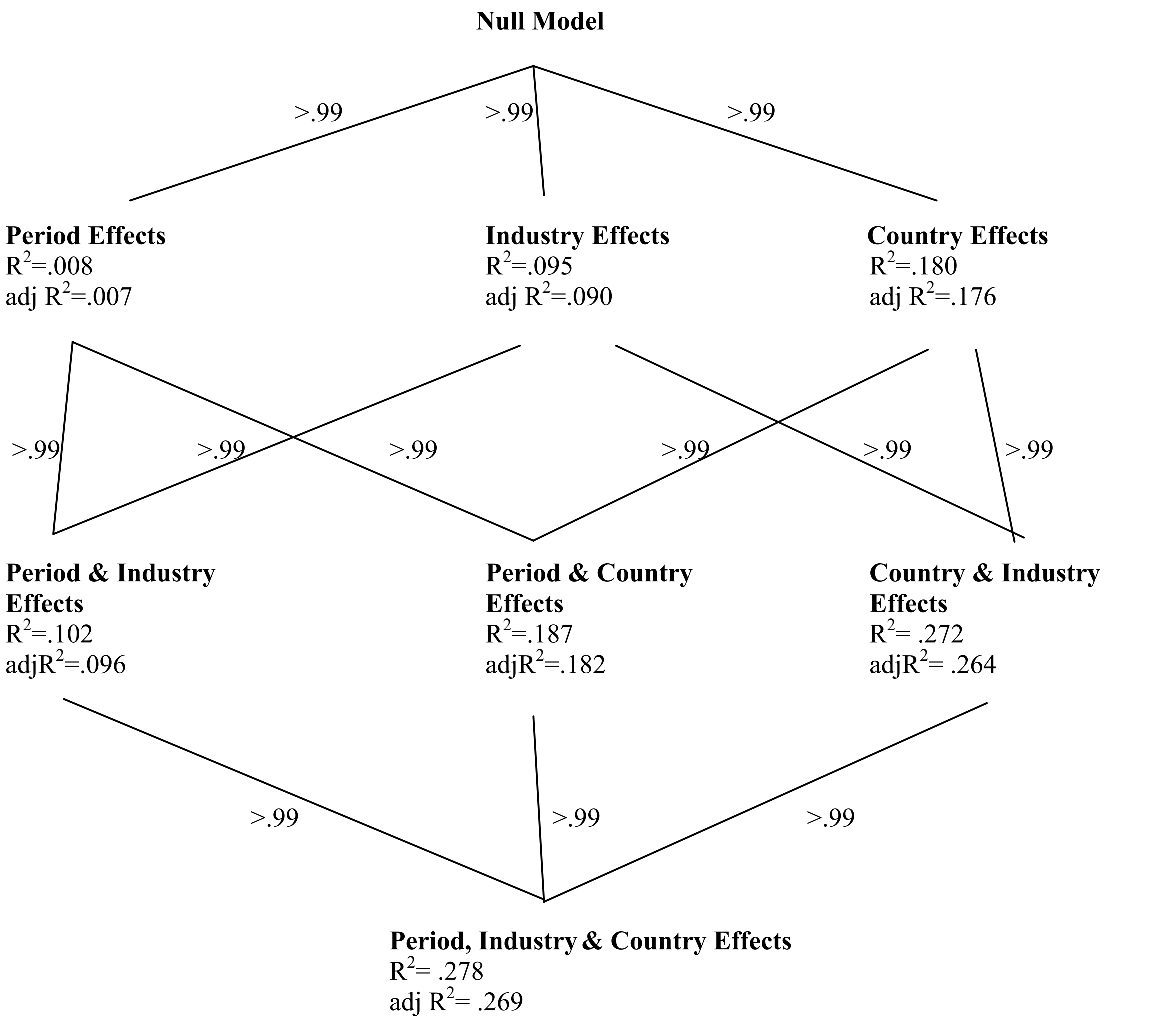
Dependent variable is fraction of patents in each country-industry-period combination from foreign multinational subsidiaries
Prais-Winsten regressions used to control for AR-1 serial correlation
Standard errors (in parentheses) are robust and allow for general cross-section within-country correlation in error terms
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 8: Analysis from table 7 broken up by multinationals with US vs. non-US home base

	US Multinationals		Non-US Multinationals	
	(1)	(2)	(3)	(4)
Openness to FDI	1.446***	1.231***	0.662**	0.745**
	(0.424)	(0.463)	(0.318)	(0.345)
GDP	-0.314	-0.013	-1.692***	-2.132***
	(0.401)	(0.509)	(0.410)	(0.617)
Human Capital	-0.121	-0.079	-0.742***	-0.734***
	(0.177)	(0.183)	(0.192)	(0.208)
IPR Protection	-0.140***	-0.123**	0.042	0.010
	(0.043)	(0.056)	(0.035)	(0.038)
Rule of Law	-0.012	-0.005	0.059**	0.060**
	(0.028)	(0.033)	(0.025)	(0.028)
Credit Availability		-0.058*		0.042
		(0.035)		(0.039)
Industry Financing Need		0.081***		-0.004
		(0.024)		(0.019)
Industry Fixed Effects?	Yes	No	Yes	No
Period Fixed Effects?	Yes	Yes	Yes	Yes
Observations	4303	3714	4303	3714
R-squared	0.088	0.049	0.075	0.042

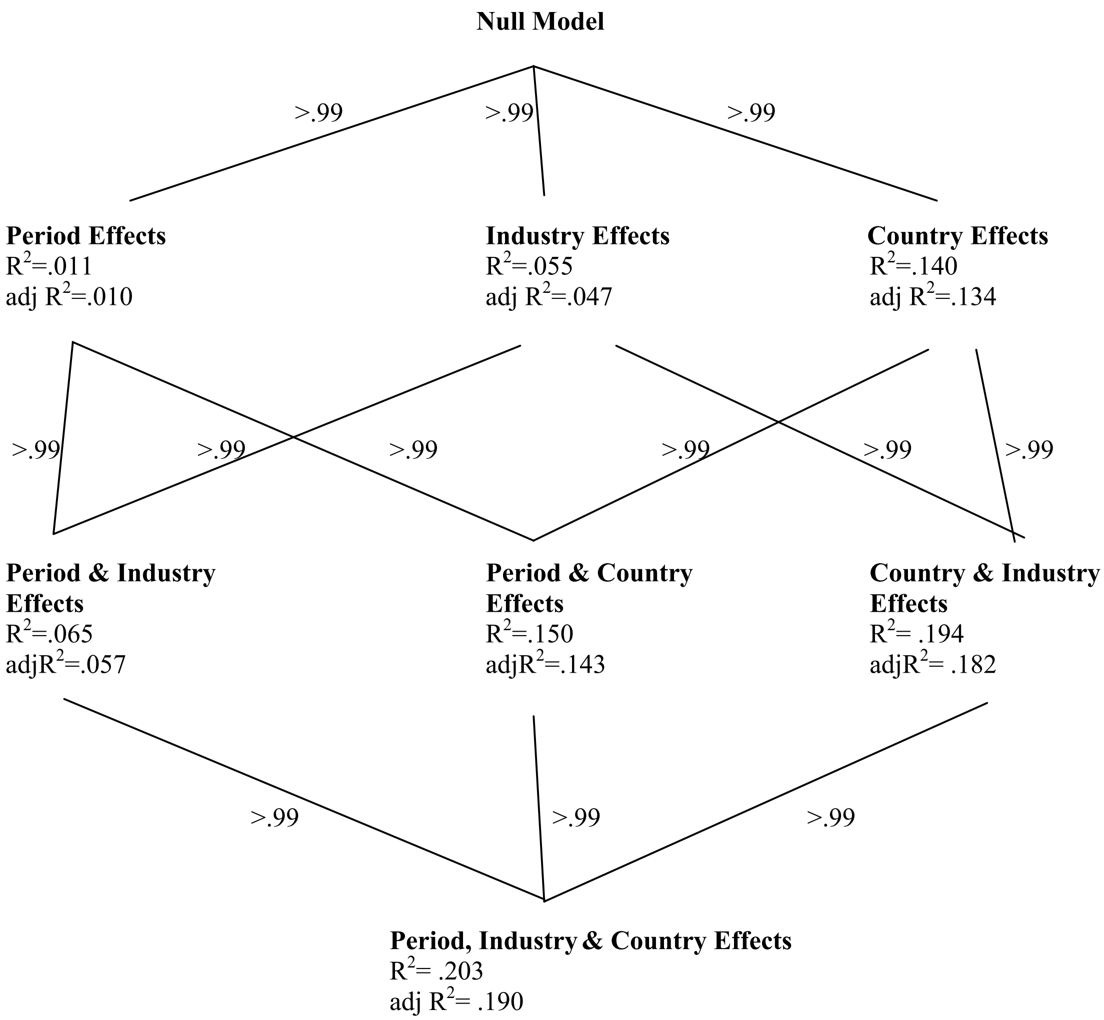
Dependent variable for cols (1) & (2) is fraction of patents from US multinational subsidiaries
Dependent variable for cols (3) & (4) is fraction of patents from non-US foreign multinational subsidiaries
Prais-Winsten regressions used to control for AR-1 serial correlation
Standard errors (in parentheses) are robust and allow for general cross-section within-country correlation in error terms
* significant at 10%; ** significant at 5%; *** significant at 1%

Figure 1: Analysis of variance (ignoring serial correlation)*



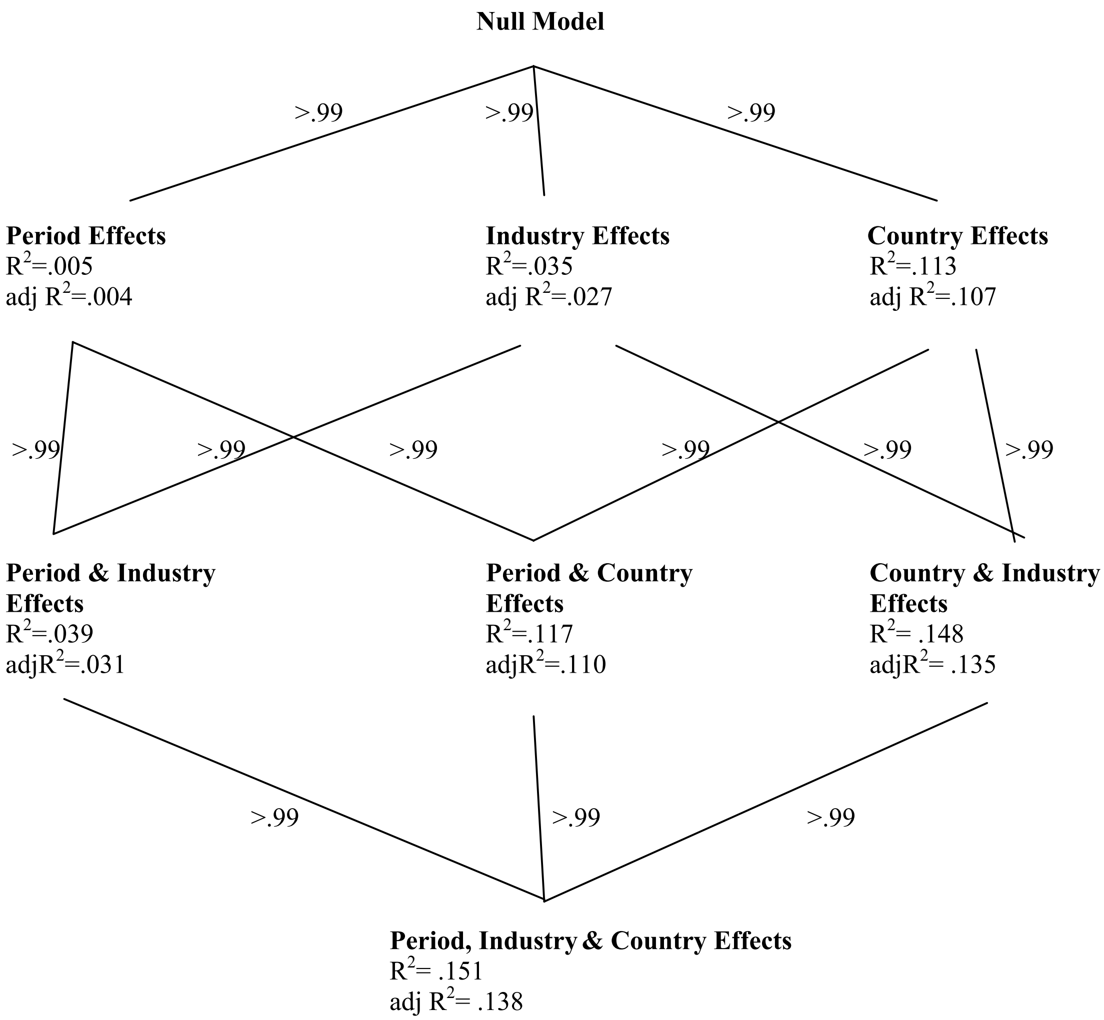
*Dependent variable is fraction of patents in an industry-country-year combination originating from subsidiaries of all foreign multinationals**.** The central finding is that the country effects exceed industry effects, which exceed period effects. This conclusion follows since the contribution to R^2 by adding country fixed effects always exceeds that by adding industry effects irrespective of the path one takes in the above graph in doing so. A similar argument holds for industry effects vs. time period effects. A probability of “>0.99” next to each line indicates that no two models are statistically identical.

Figure 2: Analysis of variance (allowing serial correlation)*



*Dependent variable is fraction of patents in an industry-country-year combination originating from subsidiaries of all foreign multinationals. The value of ρ estimated from the full model to be 0.3047 is used in all other models for comparability of R^2. The central finding is that the country effects exceed industry effects, which exceed period effects. This conclusion follows since the contribution to R^2 by adding country fixed effects always exceeds that by adding industry effects irrespective of the path one takes in the above graph in doing so. A similar argument holds for industry effects vs. time period effects. A probability of ">0.99" next to each line indicates that no two models are statistically identical.

Figure 3: Analysis of variance for measure based on US multinationals only*



***Dependent variable is fraction of patents in an industry-country-year combination originating from subsidiaries of US multinationals only. The value of ρ estimated from the full model to be 0.3001 is used in all other models for comparability of R2. The central finding is that the country effects exceed industry effects, which exceed period effects. This conclusion follows since the contribution to R2 by adding country fixed effects always exceeds that by adding industry effects irrespective of the path one takes in the above graph in doing so. A similar argument holds for industry effects vs. time period effects. A probability of ">0.99" next to each line indicates that no two models are statistically identical.