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The Maturation of Global Corporate R & D: Theory and Evidence

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THE MATURATION OF GLOBAL CORPORATE R&D: THEORY AND EVIDENCE

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ABSTRACT

This industry-level study examines the impact of foreign country factors like market size, technological strength, and science and engineering (S&E) capability on the conduct of U.S. overseas R&D during the 1991-2002 period. We find that while overseas markets primarily predict the entry of U.S. R&D, the S&E knowledge base of nations critically determines the level and sophistication of U.S. foreign subsidiaries' innovative activity. We also find important inter-industry differences: U.S. electrical, electronics, computers, and communication industries are strongly drawn towards overseas S&E capability; industries including machinery, automobiles, and transport equipment are primarily attracted by the technological strength of foreign nations; U.S. R&D in chemicals mostly follows overseas markets.

Keywords: Globalization, Research and Development, Location

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1.0 Introduction

Around the world innovation is now recognized as a prime source of national competitive advantage. Many nations have focused policy initiatives on strengthening their innovative capacities and success is becoming apparent. As a result, the answer to the question: "who will own the technologies of the future?" is becoming less obvious, and the globalization of U.S.-owned innovative activity is a subject of some anxiety. To judge by media reports, U.S. firms are performing an increasing portion of their innovation activities in foreign "independent R&D centers" (see for example, *New York Times* 2004; *Wall Street Journal* 2004). In that these laboratories are not necessarily tied to the geography of product demand, our classic understanding of forces driving global R&D needs updating. Vernon's "product life cycle" hypothesis (1966) that American R&D overseas develops around its foreign markets may well account for a diminishing share of the "globalization of U.S. R&D" story.

"Globalization" of innovation variously refers to innovation by overseas subsidiaries, or the sourcing of R&D through alliances and joint ventures with foreign companies or universities, or the exploitation of foreign technologies through patents and licenses (Archibugi & Michie 1997). In this paper we seek to investigate factors that determine the initiation and growth of innovative activity by foreign subsidiaries of U.S.-owned large firms. Specifically, we look for the influence of a host country's scientific and technological capability on the conduct of U.S. multinational R&D in that country. Inter-industry differences in the explanatory power of these factors are also investigated. To put our empirical contribution into perspective, we do not here treat the nature of the product, firm, or markets as explanations for the overseas conduct of U.S. R&D. Such approaches were originally pursued by Vernon (1966, 1979), Horst (1972), Mansfield et al (1979), and have been developed more recently by others (Caves 1996 presents a review).

Our panel data comprise annual industry-level patenting and R&D expenditure records (the outcome variables of our study) of the majority-owned affiliates of U.S. multinational

corporations ("MNC" for short) in 45 foreign nations where they have a significant presence. The principal feature of our analysis is the attempt to move away from the comparative cost doctrine and market-based theories, and instead concentrate on technological strength and S&E capability of foreign nations as explanations of U.S. innovative activity in their locales. Further, we distinguish the effect of our explanatory variables on (a) the probability of U.S. subsidiary innovation activities, and (b) the intensity of innovation by the subsidiaries on their shores. Set in a period of intense corporate dynamism and change (1991-2002), our study also addresses inter-industry differences among foreign markets, industrial strength, and S&E capabilities as predictors of U.S. innovation abroad.

In investigating a topic as complex and important as the innovation location decision of industries, we have encountered a large volume of pertinent theoretical and empirical literature. The next section presents a brief survey of the antecedents of our effort. We bring together publicly available data from the United States Patents and Trademarks Office (USPTO), the Bureau of Economic Analysis (BEA) and the National Science Foundation (NSF) for our empirical analysis. A following section explains this and the operationalization of our constructs into variables and hypotheses. Description of the statistical models employed and results obtained are dealt with in the fourth section. A fifth and final section discusses implications of our research for innovation and public policy.

2.0 Literature Review

Here, we offer an account of the changing role of foreign subsidiaries in the innovation activities of multinational corporations. Our review is selective, with an effort to capture broad trends in the globalization of technology as mapped by representative literature over the last five decades.

2.1 Foreign R&D as customization and modification

Foreign R&D of multinational companies was first understood as supporting foreign markets. This pattern is apparent in Vernon's (1966) product life cycle hypothesis which argued

that MNCs' foreign laboratories mainly concentrate their work in the development end of the R&D spectrum, with a mandate to customize products and processes for local tastes and requirements. In contrast, sophisticated research and major product innovations stayed home, inseparably bound to headquarters by requirements for swift and frequent communication between researchers, sales and customers. [2]

According to Vernon's initial formulation, the need for close communication and cooperation between producers, consumers, suppliers and competitors is critical in the early stages of a product's lifecycle, due to uncertainty regarding the dimensions of the market (Vernon 1966, p. 195). As products matured, they would be more price sensitive, subject to greater competitive pressures and would be manufactured more cheaply abroad. Such products were mostly standardized, and the need for any significant R&D to follow manufacturing was not considered. In a second paper, Vernon recognized that routine aspects of development could be spun off to distant locations to reduce development costs and appease local governments (Vernon 1979, pp. 262-3). Today we might interpret Vernon's analysis of the product development stages in international location decisions as supporting the theme that early stage innovation is best served by locating close to headquarters and home-country markets.

Much of traditional economic analysis aligns with Vernon's hypothesis. Caves (1996) for example, notes that effective R&D requires a continuous interchange of information with manufacturing and marketing to ensure that research is directed at significant economic problems and solutions are market-worthy. Because R&D plays a strategic role, research operations should also be in close contact with top corporate management. Requirements for frequent

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[2] Most of the surveyed studies here model R&D location as a matter of the firm's choice between home- and foreign country location factors. In contrast, our model addresses determinants of U.S. industry's innovation activities in alternate foreign locations. Yet many of the results from studies reviewed here are pertinent to our exercise.

communication and interchange along with scale economies of the R&D function call for the centralization of R&D activities at company headquarters. Hence, despite the "centrifugal pull of manufacturing facilities dispersed to serve far-flung markets,…the agglomerative tendencies for research to remain at corporate headquarters remains strong" (p 164).

Empirical studies of patenting and surveys of MNCs during the 1980s also found that sophisticated research tends to stay at home in a globalizing world, and that what does go abroad is mostly development. Patel and Pavitt (1991) investigated the patenting activities of 686 of the world's largest manufacturing firms and report that a rather miniscule percentage (3.2%) of the technology activities of U.S.-based firms were conducted overseas (1981-1986). Hence, in comparison to manufacturing, technological innovation represented an anomalous case of "non-globalization" (Patel & Pavitt 1991). Mansfield et al (1979) surveyed 55 large U.S. firms (for the 1960-1974 period) to report that foreign R&D comprised about a tenth of their overall R&D expenditures. Further, the authors' note (p. 188): "[A]bout three-fourths of these firms' overseas R and D expenditures are aimed at product or process improvements and modifications, not at entirely new processes or products. This percentage is much higher than for all domestic R and D" (p. 193). This finding supports the idea that "overseas laboratories are closely geared to the special design needs of foreign markets (and the firm's overseas plants). . ."

2.2 Foreign R&D includes listening posts

Empirical studies during the late 1980s and early 90s reported an increase in the share of R&D and patents attributable to overseas subsidiaries of U.S. firms. Dunning (1992) found an increase in the share of patents assigned to U.S. firms abroad from 4.2% (during 1969-1972) to 7.4% (during 1983-1986). A later study by Pavitt and Patel (1998) found that about 8% of patents assigned to 128 of America's largest firms (during 1992-1996) were assigned to their foreign subsidiaries.

Paralleling the apparent increase, was the observation that customizing products for local markets does not completely account for foreign R&D. Mansfield et al (1979) reported evidence

for basic research (albeit limited) overseas. Dunning (1994) explained that MNC R&D overseas can encompass the following activities:

(i)   Product, material or process adaptations or improvements.

(ii)   Basic materials or product research – on immobile subjects such as tea plantations, oil refineries, bauxite mines or agricultural productivity

(iii)   Rationalized research, i.e. all research on a particular topic conducted in one location

(iv)   To acquire or gain an insight into foreign innovating activities, i.e. learning and building firm research capability (p. 75-76).

Type i represented classic overseas R&D supporting overseas markets. Type ii was an elaboration, more sophisticated applied research forced to locate abroad due to the immobility of natural resources or the subject of research. Type iii introduced the possibility of high end innovation outside the home country, and according to Dunning, such research was restricted to the triad: U.S., Europe and Japan. Type iv might be termed "listening post" R&D. This recognized the high level R&D capability abroad and the need for firms to learn from it. The rationale was that technical knowledge will be picked up abroad and transferred back to the home base. Type i was the most prevalent, while types ii and iv were the fastest growing (Dunning 1994). This framework advanced understanding of overseas R&D by expanding discussion from local market adaptation to listening post functions in recognition of high levels of technological capability in Europe and Japan.

The most sophisticated innovative role afforded to foreign subsidiaries in this line of thinking recognized that firms had adopted a global approach not only to applying their knowledge in foreign operations, but to enhancing their home innovation capabilities (during the late 1990s). Where multinational firms seek a foreign R&D presence to support their overseas manufacturing facilities or to adapt standard products to local demand conditions, the arrangement has been called "home-base exploiting" R&D (Kuemmerle 1997). Here information flows from the central firm's R&D capacity at home to the foreign subsidiary. In a second type,

"home-base augmenting" R&D, the foreign facility is established to tap the knowledge of foreign competitors and universities. In this case, knowledge is absorbed from the local community; new knowledge is created and transferred to the company's central R&D. Instead of building on their existing technological capabilities and seeking to extend these to foreign circumstances, firms aim to use local knowledge bases to develop new capabilities at home (Kuemmerle 1997). This representation recognizes a more sophisticated level of knowledge located abroad than ever before, yet the home remains dominant in that both home-base exploiting and home-base augmenting R&D are defined relative to and indeed serve the needs of the home base.

2.3 Foreign R&D emerging as a source of innovation

In both the adaptation/modification and the listening post models, overseas R&D sites were auxiliary outposts, subservient to home R&D laboratories. Although we might detect hints of equality in overseas R&D labs, for example in Dunning's level iii, the models' emphasis lay elsewhere. These models are no longer adequate as MNCs are now able to seek innovation abroad and not just from Europe or Japan but also from Asian countries. The Economist Intelligence Unit (EIU 2004) surveyed 104 senior corporate executives who reported that MNCs now seek to establish and manage "global research networks" of geographically dispersed units that contribute more or less equally to the company's research enterprise. Recent studies suggest the possibility of a truly networked corporation in which responsibility for innovation is globally dispersed and an important role in the innovative process is played by the subsidiaries in accessing, sharing, and creating new knowledge (Almeida & Phene 2004).

3.0 Hypotheses, Variables and Data

We propose that the emerging recognition of advanced innovative capability in MNC foreign laboratories requires a fresh examination of the determinants of foreign R&D. It seems implausible that the location decisions for more sophisticated foreign R&D functions are driven

by the market-based factors classically associated with foreign R&D location. We therefore seek

to explore the emergence and growth of simple and more sophisticated foreign R&D function.

3.1 Dependent variables

Since we seek to explain the innovative activity of U.S. overseas subsidiaries, R&D

expenditures and patents of American industries abroad are the outcome variables in our study.

Our treatment of these variables is somewhat non-standard. The relation between the R&D input

variable and the patent output variable has been widely studied, and the two are known to

correlate (Schmookler 1967, and Hall, Grilliches & Hausman 1986 are seminal works). U.S.

firms that spend more on R&D tend to produce more patents than other U.S firms in their

industry. Nevertheless, in this study we focus on the difference between these two measures.

We are interested in the changing composition of foreign R&D expenditure. Mansfield et

al. (1979) established through a survey that R&D expenditure in subsidiaries is heavily weighted

towards development compared to the research emphasis of domestic corporate R&D. Here we

probe growth in non-development activity as a component of foreign subsidiary R&D. Absent a

survey, movement in R&D expenditure data will not reveal increased sophistication in the

composition of R&D. However, we argue that within the context of foreign subsidiary R&D,

U.S. patenting signals the presence of more sophisticated inventive activity. Note that Mansfield

et al. concluded using R&D expenditure data that U.S. foreign R&D was more substantial than

Pavitt found using patent data, and that this is consistent with our argument that USPTO patenting

indicates a sophisticated component of foreign R&D and is therefore more limited in extent than

R&D as a whole. For a firm to incur the cost of a U.S. patent for an invention originating in a

foreign subsidiary implies that the invention is both new to the world and likely to be used in the

U.S. market. Product modifications tailored to local foreign markets are unlikely to justify the

expense of protection in the U.S. market bestowed by a U.S. patent. Patents require a distinct

element of novelty, which means that "listening post" or learning activities are unlikely to

produce them. Our contention then is that in the context of foreign subsidiary R&D, U.S.

patenting represents a more innovative component of an activity that is fully encompassed by R&D expenditure.

We also distinguish between the initiation of foreign R&D and its growth. That is, we model the probability of there being non-zero R&D expenditure (or patenting), as well as modeling the amount of R&D expenditure (or patenting), conditional on the measure being non-zero. The first decision to locate an operation in a country is made under conditions of greater risk and uncertainty than subsequent decisions to expand the operation. Vernon (1979) noted the "self-reinforcing" nature of foreign operations, that after the first decision to go abroad, subsequent decisions became easier and quicker as companies "felt at ease over a wider portion of the earth's surface." We hypothesize that the decision to initiate R&D in a country is likely to be related to the need to modify products for a market, and that the decision to develop a worldwide network of more or less equal R&D labs comes later and is made against a background of established foreign R&D operations and is therefore associated with growth, not initiation of R&D. Therefore the factors associated with the probability of activity abroad may well differ from the factors associated with magnitude, and we explore this in our modeling.

3.2 Independent variables and hypotheses

Our first independent variable is overseas sales. That the R&D of multinational enterprises follows overseas sales has been established, enabling us to expect a positive relationship between the size of overseas markets and U.S. subsidiary R&D activity that will manifest in the R&D-sales relationship.

Our second independent variable is national output of scientific and engineering articles. We use S&E articles as an indicator of productive, world class scientific talent in a nation's public sector. Papers indicate the tacit knowledge and skills possessed by their authors (Hicks 1995), and so we argue that a nation's scientific publication oeuvre provides an indicator of its scientific and technical human capital. Unlike money spent on universities or number of PhD graduates, number of papers is a selective measure in which unproductive people and resources

are invisible. In a sense, the measure reflects the success of education, research support, institutional development and other policies to enhance the research base of a national system of innovation. The measure also has the virtue of imposing an international quality standard. When multinational firms search for expertise, one might assume that only world class expertise is of interest. The papers were counted in Thomson's *Science Citation Index*, which has frequently been faulted for under-representing non-Anglo Saxon research. Thus for most countries in the world, a count of their papers in this database represents their most internationally competitive science and technology, with international competitiveness defined by peer reviewers often located in the U.S.

We hypothesize that public sector S&T capability attracts multinational global R&D activity of the more sophisticated sort. We do not argue that global R&D is initially attracted by S&T capability; rather we expect that market factors predominate in the early stages of globalizing R&D. However, we do expect that once an R&D base has been established, growth of innovative global R&D (indicated by patenting rather than R&D spending) requires indigenous world class scientific talent. We cite in support of our hypothesis the EIU survey, which concluded that "expertise is the top attraction for globalised research" (EIU, 2004, p. 2). Our S&E paper variable measures the amount of world class scientific expertise in a country.

Our third independent variable is the number of USPTO patents invented in the country and not assigned to US companies which we use to measure the technological strength of a nation. The patent variables, national and U.S. multinational, are categorized the same way, so a specific match between company and national technical strengths is obtained. Like the paper variable, the national patent variable indicates innovation that meets a certain internationally benchmarked minimum threshold of inventiveness and significance. Because "listening post" R&D must have something worthwhile to listen to, we expect a positive relationship between a foreign country's technological strength and the extent of U.S. R&D carried out therein.

Like the paper variable, the national patent variable reflects the amount of world class technical expertise in a country. However, in this case the experts are employed by other firms, perhaps competitors. Competition from technologically strong local firms can under certain circumstances deter subsidiary innovation activities.[3] Therefore, the effect of national patenting is not entirely clear. However, the presence in our models of both the national patent and paper variables will have the advantage of distinguishing between the effects of public sector, general, scientific expertise and private sector, targeted, technical expertise.

3.3 Data

Since we intend to explain the R&D location decisions of American industry, only majority-owned foreign affiliates or subsidiaries in which the combined ownership of all U.S. parents exceeds 50 percent are included in our analysis. Our sample was constructed from three publicly available data sources. First, industry-level statistics on the international activity of U.S. multinational companies are produced annually by the Bureau of Economic Analysis (BEA). This includes industry-level information on the sales of majority-owned subsidiaries in various foreign countries and their R&D expenditures. Since the BEA industry classifications were not consistent across panels, we recoded the numbers to comply with one of eight broad industry classifications. Accordingly we have annual local sales and R&D data for American firms for the following industries between 1991 and 2002: chemicals; electrical, electronics, computers, and telecommunications; food; industrial equipment and machinery; oil, minerals and natural gas; primary and fabricated metals; automobile, air, and transport equipment. An eighth "others" category accounts for leftovers.

Second, patents assigned to all overseas inventors were collected from the United States Patents and Trademarks Office (USPTO). From this population of patents originating abroad, we identified patents assigned to U.S. corporations including majority-owned subsidiaries. The

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[3] Especially where the country environment does not support rigorous enforcement of IP rights

residual is the number of foreign-owned patents which indicates the technological strength of countries. It is possible that the residual includes USPTO patents assigned to subsidiaries of other foreign country firms. If this were the case, what we label the "technology strength" of foreign nations could be driven by non-US multinationals. For example, China's measure of technological strength in any industry could be influenced by the USPTO patents of European or Japanese –owned Chinese subsidiaries. To confirm that this is not the case, we examined the national origins of the top-20 patentees in 10 different countries (including China). The exercise revealed that the weight of non-US, non-local patents for any given country is negligible. To account for the fact that a patent can have inventors from multiple countries, we calculated fractional counts for non-U.S. owned patents such that if a patent has two Japanese inventors and one U.K. inventor, two-thirds of the patent is assigned to Japan, and the remaining third to the U.K. We then matched and merged the two variables (patents assigned to majority owned U.S. subsidiaries, and patents assigned to foreign countries) with the BEA variables by country, technology class, and year (for the years 1991 and 2002) after establishing a concordance between the IPC technology class of patents and eight broad industry sectors.

Finally, data on science and engineering publications of various countries were drawn from the National Science Foundation's annual *Science and Engineering Indicators.* This information is available from the year 1988 through 2001 and is based on Thomson's *Science Citation Index* which covers all scientific fields for primarily English language journals that are well cited. Like our patents, the article counts are based on fractional assignments such that an article with two authors from different countries is counted as one-half of an article for each country. The patent and S&E article variables differ, as exemplified by the subject coverage of the articles. In 2001, only 14.5% of Western European and 8.1% of Asian S&E articles were from engineering and technology fields. The rest were from scientific fields including physics,

chemistry, biology, clinical, and biomedical fields.[4] Note that these classifications could not be matched to industry sectors and so our publishing variable does not vary by sector.

Our final data set contains observations from the years 1991 through 2002 for the 8 industry classes of 45 foreign countries on (a) the number of USPTO patents assigned to U.S. subsidiaries and invented in each country (b) R&D expenditures of U.S. subsidiaries in each country (c) local sales of the U.S. affiliates, and (d) patents assigned to foreign country firms. For each year through 2001 and country (but not industry) we have science and technology publication output. A country-industry observation for a given year constitutes a unique observation, of which we have 1817. This lower than expected number is because the BEA data does not provide information on each of the 8 industry sectors for all 45 countries and 12 years of study, plausibly due to the absence of significant industry activity for the missing observations.[5] This makes our dataset an "unbalanced panel."

TABLE 1 HERE

Table 1 lists country-level statistics for the five variables, aggregated over the period of our study as well as for the first and last years, from which a large increase in the overseas activity of U.S. firms is apparent.

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[4] For Asian countries the respective percentages are Physics (19.8), Chemistry (18.2), Biology(5.5), Clinical(22.2) and Biomedical research(11.9). For West European countries, the numbers are: Physics (12.7), Chemistry (11.5), Biology(6.6), Clinical(32) and Biomedical research(14).

[5] Data on all variables for Poland and Hungary for example, were available only for the years 2000 and 2001; U.S. industrial activity was observed in only a few of the 8 industry sectors in a majority of South American and African countries.

4.0 Model and Results

This section models the impact of foreign country markets, scientific capability, and industry innovation capabilities on (a) establishing U.S. corporate research where none existed, and (b) the extent of U.S. R&D activity, once established.[6] In the R&D expenditures of overseas subsidiaries and the number of patents assigned to them, we have two distinct measures of U.S. innovative activity abroad. The two variables indicate both the existence and magnitude of U.S. innovative activity overseas. 41% and 36% of our 1,817 country-industry-year observations have zero number of patents and R&D expenditures respectively.

4.1 Model specification

We hypothesize that the variables of our study are related per the following equation, where $E[y_{i,k,t}]$ is the conditional expected value of U.S.-owned foreign subsidiary R&D expenditures (or patents) y, for country i, in technology class k and year t. The expected value of the dependent variable takes on probabilistic values when establishment of activity is estimated and integer values when extent conditional on establishment is estimated.

$$E[y_{i,k,t}] = \beta_0 + \beta_1 x_{1i,k,t-1} + \beta_2 x_{2i,k,t-1} + \beta_3 x_{3i,t-1} + X'4\beta_4 + \sum_t \alpha_t x_5 + \sum_k \gamma_k x_{6k} \quad (1)$$

Here, x_1 is local sales and x_2 is the number of country i's own patents in technology class k for the year t-1 and x_3 is the number of science and technology articles. x_4 and x_5 express time and technology class dummies. By lagging regressors by a year, we also allow for some time for their

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[6] Strictly, a country-industry might report zero patents/R&D expenditures in time periods following years with non-zero, positive values for these variables. However, this being the case for a small portion of our observations, we use the term "initiation" to represent a nonzero probability of R&D/patents and "growth" to capture the magnitude of positive R&D/patents.

effect to bear fruit (patents).[7,8] $X'4$ expresses a vector of region-specific effects that do not vary with time or technology class. We used 5 regional (Europe, Japan, Rest of Asia, South America and Others) instead of 45 country dummies to minimize the number of regressors.[9] This controls for unobserved heterogeneity among regions and roughly simulates a "fixed effects" panel model, where region and technology-specific factors potentially correlated with the included regressors are accounted for as sources of identification by the various dummies.

Since R&D expenditures are integers and patents are whole number counts, we specify two different models to explain their determinants. The relationship between the explanatory variables in (1) and R&D expenditures of American overseas subsidiaries is estimated using a Tobit specification. The Tobit model has an advantage in that its coefficients can be easily disaggregated to determine the effect of a change in the explanatory variable on changes in the probability of having non-zero R&D as well as the size of R&D (McDonald and Moffit 1980).

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[7] This also conveniently allows us to utilize the maximum range of our dataset since information on one of the regressors (S&E articles) are available only through 2001, while patent data is updated to 2002. Our unreported estimations of contemporaneous regressors as well as two and three-year lagged values yield similar results.

[8] Assuming a lagged structure mitigates also the potential problem of the regressors being endogenously related to the explained variables.

[9] Reason for including broad region instead of country dummies is that statistical software used to estimate likelihood functions are sensitive to the number of variables. The maximum likelihood estimations failed to converge on the inclusion of country-specific dummies. However we believe that our classification scheme of countries minimizes inter-country variations within regions. We confirmed this by comparing the results of OLS regressions with both the full set of country and region–specific dummies.

From the decomposition, one effect works by changing the probability that R&D will be undertaken and the second by changing the conditional mean of R&D expenditures, given that R&D is observed (greater than zero). While the first is about the effect of a unit change in any of the regressors on the probability of having any (positive) level of R&D, the second is about the effect of a unit change in any of the regressors on the level of R&D (once it is positive).

Next, we test the relationship between the explanatory variables of (1) and patents of American overseas subsidiaries by employing a variation of the zero-inflated Poisson (ZIP) regression model originally proposed by Lambert (1992) and developed by Greene (1994). Like Tobit, this specification appeals to our application because it allows us to estimate the impact of explanatory variables on (a) the probability of U.S. patenting, and (b) the number of subsidiary patents once the activity has begun. In other words, the model allows us to test a process in which the factors that determine zero or positive U.S. overseas patents are qualitatively different from those determining the magnitude of patents once the activity has been established.

The Poisson specification however is rather unrealistic as it imposes (or rather assumes) the restriction that the variance of the data is equal to its (conditional) mean. When this is not true and the variance far exceeds the mean as in the case of our data, over-dispersion can result in the Poisson under-predicting outcomes at the "tails" of the distribution.[10] Despite the fact that we account for the large number of zeros by estimating a model that assumes different underlying processes for the zero and positive outcomes, over-dispersion among positive patent counts suggests that the negative-binomial model (negbin), is more appropriate.

The negbin model is a more general version of the Poisson model with less strict assumptions and is widely used in estimations using patent and publication counts as the dependent variable (cf. Hausman et al 1984). Substituting the Poisson with a negative binomial distribution for our specification yields a "zero-inflated negative binomial model" (ZINB). The

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[10] for our data, mean = 35.63 and Variance = 7815.6

logistic portion of the zero-inflated negative binomial yields the conditional expectation of the probability of y falling into the zero group, or $\Pr[y_{i,k,t} = 0 \mid X]$ and the negative binomial part estimates $\Pr[y_{i,k,t} = n \mid X], n = 1,2,3,...$ or the conditional expectation of y taking on any positive value.

4.2 Results

Table 2 presents results of the Tobit and zero-inflated negative binomial regression models. Columns 1-3 are Tobit estimates that explain the R&D expenditures of U.S.-owned overseas subsidiaries. The first column presents standard Tobit coefficients which can be interpreted as the effect of a unit change in regressors on the expected value of an R&D expenditures latent variable. Column 2 presents the effects of a unit change in explanatory variables on the conditional mean of R&D expenditures, given that it is observed (greater than zero); a third column lists the probability that R&D will be undertaken for unit changes of the explanatory variables. Local sales of overseas subsidiaries directly influence both the probability and level of R&D expenditures of the industry. Foreign country patents, as well as S&E papers affect the probability of R&D only negligibly. The latter has a marginally higher impact on the level of R&D, on controlling for sales and other factors.[11]

The ZINB model can be interpreted as a "count-hurdle" model where the logit function estimates impacts of the various explanatory variables in overcoming the patenting hurdle (this part treats *USPAT* as a dichotomous variable set to 1 for a positive number of patents and 0 when no patents are observed) and the negative binomial estimates the weight of the variables on the number of patents once the threshold is crossed (this part treats the conditional number of patents

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[11] To clarify trends in the impact of regressors, we also examined their effects across four 3-year windows spanning the years 1991 through 2002. We found no evidence for the changing effect of explanatory variables over time.

above zero as a dependent variable).[12] That the estimated effects of such a model are fair

predictors of the actual distribution of patents is evidenced from the plot of predicted v/s observed

probabilities in Figure 1.

FIGURE 1 HERE

The fourth column of Table 2 produces zero-inflated probabilities for the patent "hurdle".

These can be interpreted like the normal logistic coefficients (which yield logged odds), the

difference being that these predict zeros. Hence, coefficients with negative signage mean that

changes in the related variable are inversely related to the likelihood of belonging to the zero-

patent group. For example, an increase in the local sales of U.S. overseas industry over a given

year makes it less likely for it to exist in the "zero-patent" state in the next year.[13] So also, a

country with U.S. patents in a given industry is more likely to see U.S. owned subsidiaries in that

industry engaged in patenting. S&E capability of foreign countries appears to have negligible

influence on the probability of U.S. industry patenting, after controlling for the effect of other

regressors.

TABLE 2 HERE

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[12] The Vuong statistic $m_i = LN\left[\dfrac{f_1(y_i \mid X_i)}{f_2(y_i \mid X_i)}\right]$ where $f_1(y_i \mid X_i)$ and $f_2(y_i \mid X_i)$ are the

probability density functions of the zero-inflated negative binomial and zero-inflated Poisson

respectively. In our case, it yielded a value of 10.79 with (Pr> Z = 0.00) justifying our choice of

the ZINB over ZIP.

[13] We confirmed the broad results of our models by ensuring that they were not sensitive to

plausible alternative specifications and that the independent variables were not seriously collinear

by estimating Variance Inflation Factors for baseline OLS regressions. They were well within the

permissible bounds (in the range of 1.2 to 2.5).

The fifth column of Table 2 presents the impact estimates of the explanatory variables on the level of U.S. industry patents, given that they are already engaged in that activity. The neg-bin coefficients are presented as incidence rate ratios (IRR) for ease of interpretation. The coefficient on *SALES* (1.08) indicates that a unit (billion $) increase in the annual local sales can be expected to yield an 8% increase in the number of patents in the U.S. subsidiary's industry (subject to the condition that it has already started patenting). A unit increase (1 unit = 1,000 S&E articles) in the annual S&E publication output of a country for the same period is expected to increase American patents in the country by 5%, holding constant the effect of other variables. Because of the disparate nature of units, much meaning cannot be derived from a direct comparison of the estimated magnitude of coefficients. Normalized coefficients[14] and t-statistics (presented in parenthesis under the coefficients), confirm the relatively large and positive effect of the scientific knowledge pool of countries on the intensity of American patenting.[15]

4.3 Inter-industry differences

The preceding exercise estimated the effect of foreign markets, technological strength, and S&E capability on the probability and level of U.S. subsidiary R&D, by holding constant differences across industry sectors. However, we can expect important inter-industry differences in the balance of factors that determine the nature and extent of U.S. R&D overseas. The early observation that overseas laboratories are geared towards customizing products to foreign markets was developed with labor-saving consumer- and industrial goods in mind (Vernon 1966). Industries like oil, natural gas, minerals, and others have always found it viable to conduct a

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[14] Normalized coefficients measure changes in the outcome variable in response to a standard deviation change in the explanatory variable and are not reported here.

[15] F-tests for the absolute equality of coefficients confirmed that the impact of *SEPUBS* on *USPATS* were significantly different for the hurdle and count models.

portion of their research where the resources naturally occur. During the 1970s and 1980s, U.S. automobile, electrical, and electronics firms started research facilities in Germany and Japan undeterred by the scarce pool of skilled workers in those nations. Trends over the last decade have seen China and India emerge as attractive R&D destinations for U.S. industries ranging from chemicals to computers.

<div align="center">TABLE 3 HERE</div>

Table 3 captures the weight (percentage) of each U.S. industry in our overseas sales, R&D, and patenting data. Out of total foreign sales of 4712 B$ by U.S. subsidiaries, the chemical industry accounted for 23%. The importance of R&D in this industry is indicated by the heavier weight it carries in the R&D data. Of the total 113 B$ of R&D expenditures by U.S. overseas subsidiaries, 36% was spent by the chemicals industry which also accounted for 35% of the nearly 72,500 patents assigned to U.S. overseas subsidiaries during the period. The high propensity to patent in the IT industries (Hicks, et al. 2001) is suggested by the 19% share of R&D spent by the U.S. electrical, electronics, and computer based industry compared to their 31% of patents abroad.

We formally test for inter-industry differences in the effect of the explanatory variables of equation (1), by estimating models for the eight different industrial sectors separately, instead of controlling for the effect of industries by allowing their intercepts to vary as we did previously. Since most of our identification came from the non-zero U.S. subsidiary patenting equation (estimated by the negative binomial part of the ZINB); we here report models with the positive count of U.S. subsidiary patents as the dependent variable.

<div align="center">TABLE 4 HERE</div>

Table 4 produces negative-binomial regression estimates with all industrial sectors pooled in column 1 (this establishes consistency of our modified model with the model and results discussed in section 4.2), and individually for the eight industries in columns 2-9. All coefficients have the usual *ceteris paribus* interpretation. S&E publications strongly and directly

determine U.S. subsidiary patenting in the electrical, electronics and computers, transport, metals, and industrial machinery industry. Surprisingly, neither this, nor the technology strength variable predicts the patenting activity of U.S. subsidiaries in the chemical industry. The technological strength variable is a very strong predictor of U.S. subsidiary patenting in the oil, natural gas and mining industries whose immovable, naturally occurring resource base nurtures local as well as foreign owned innovative engineering capacity.

5.0 Discussion and Conclusions

This industry-level study examined the relative importance of foreign country factors – markets, technological strength, and S&E capability - in determining both the probability and extent of U.S. multinational R&D and patenting activities on their shores. The striking aspect of our result is the significance of nations' S&E capability for the intensity of U.S. patenting, over and above what can be explained by local market and technological strength variables. We found the effect to be particularly significant in the relatively new electronics and computers industry, as well as in the traditional sectors of transport, metals, and industrial machinery. We call this the S&E capability premium of nations. Our results suggest that the importance of this premium increases with the level and sophistication of innovative activity carried out by U.S. industry (holding market and technology strength factors fixed).

There is evidence for both the old and the new in our study. We confirmed that the size of local markets strongly predict both firms' engagement in and subsequent commitment to overseas R&D. The novelty from this exercise is that while markets and technological strengths initially attract multinational enterprises to set up R&D activities, the growth of innovation as measured by U.S. patents invented abroad, is predicated on the country's S&E capability base. While we cannot directly compare point estimates across regressions with different dependent variables, the significance of sales "within" the regressions was highest in predicting the probability of R&D, and decreased in predicting the level of R&D, the probability of patenting, and the level of

patenting, in that order. S&E articles on the other hand, had the greatest impact on the level of patents and a negligible effect on influencing the establishment of U.S. R&D.

Our insight into the S&T capability premium of nations aligns with the findings of a recent survey by the Economist Intelligence Unit (EIU 2004). The EIU interviewed 104 senior corporate executives reporting that MNCs now seek to establish and manage "global research networks" of geographically dispersed units that contribute more or less equally to the company's research enterprise. The desire to exploit highly skilled researchers wherever they are located is the key driver of this development. In response to the EIU survey question on the main benefits of globalized R&D, the "global search for expertise" function showed an edge over traditional business factors such as reducing R&D costs and tailoring goods and services to particular markets. It also trumped newer factors such as access to 24/7 global R&D processes and reduced time to market. The survey concluded that combined with the emergence of world class technological capability in East Asian countries outside Japan, the global search for R&D talent is changing the nature and extent of MNC overseas R&D.

That Asian S&T capability has rapidly strengthened in recent years is evident in science and technology indicators which show sharp increases in international journal literature sourced from Asian countries and in U.S. patents invented there (Hicks 2004). The cases of India and China, and the contrasting experience of Western European nations serve well to illustrate the point. In 1990, Europe accounted for nearly 70% of all U.S. overseas subsidiary patenting, while China and India together accounted for less than 0.1% of the amount. Thirteen years later, Europe's share had declined to 65% while that of China and India had increased to 2.3%. Considering the very small number of patents for India and China to start with, this translates into a huge growth, while from the initial large numbers for Europe, an even more striking decline. During the comparable period, China and India increased their S&E publication output from about 4.5% to 7.2% while Europe's numbers hovered around half the total share of non-U.S.

articles. This aligns with the conventional notion of Europe's technology strength and the recent focus on the potential of China and India's vast S&E talent pools. [16]

Several Asian nations, notably India and China, have long had substantial S&T capability. However, this resource was relatively unproductive in their economies. Why can we now view it as an S&T capability premium? Key here may be the transformation wrought on communication by information technology. Recall that the need for intense communication was always adduced in support of arguments that research must be kept at home. Vernon speculated on a type of firm he called a "global scanner" able to search the world for the best and brightest and take advantage of resources wherever they were found. The factor limiting his vision to fantasy was, he said, the high cost of acquiring and processing information (Vernon 1979). Now that global communication is so much easier, faster and cheaper, this fundamental limit on managing and integrating geographically dispersed R&D has considerably diminished.

That multinational R&D is evolving in response to shifts in communication technology and strengthening national R&D capability should not be not surprising. Scholars have tracked foreign subsidiary R&D for four decades, beginning with Vernon's work in the 1960s. In the 1970s, Vernon pointed out that multinational's foreign R&D evolves recursively (becoming easier as firms gain experience abroad) and in response to environmental factors (changes in the sophistication of markets for example). Work since can be seen as a series of snapshots that when taken together speak to the evolution of MNCs' overseas R&D over time. Table 5 summarizes this.

TABLE 5 HERE

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[16] Our example is consistent with the diminishing returns to investment argument. Countries like Europe and Japan, with nowhere near the human capital endowments of China or India, may already be operating in the leveled-off part of the R&D productivity equation. This idea is consistent with Scherer (1997) and Helpman (2002).

The first theories of globalization, up to about 1980, suggested that R&D followed manufacturing to adapt products and processes to local markets. Scholars added the listening post functions to account for the increase and variety of overseas R&D during the 1980s and early 90s. In both models, overseas R&D sites were auxiliary outposts, subservient to home R&D laboratories. Recently scholars have focused on taxonomies of innovative roles played by MNC laboratories (see for example, Almeida and Phene 2004). Birkinshaw and Hood (2000) for example, argue that subsidiaries play two distinct roles. "Product specialist" subsidiaries have limited expertise and focus, while those with a "world mandate" have broad responsibilities, considerable autonomy within the MNC, and extensive capabilities in R&D. Our table responds to this development by dividing subsidiary innovative capability into three categories of increasing sophistication – incremental innovation, multi-technology product innovation and use-inspired basic research. Although basic research may not be under discussion at the moment, this projection into the future would seem to complete the natural progression as it has developed thus far. We know such research exists in Europe, where IBM's Zurich laboratory discovered high temperature superconductivity a few decades ago. Hence, we suspect that laboratories of different firms, at different times and in different places will be found in each of these categories. What changes over time is that we find more laboratories of leading firms, in more places at more advanced levels. Our results lead us to argue that the scientific capability of countries will be a critical factor in deciding how innovative their MNC laboratories become.

Our paper has not explicitly treated factors which influence the decision to locate R&D at home (U.S.) or in a foreign country, yet we can pose the question: how much U.S. subsidiary R&D abroad can be attributed to a shifting of existing activity from home to foreign locations? While it is hard to tease out these effects, our data (graphed in FIGURE 2) suggest that the extent of and growth in innovative activity (patents and R&D) of U.S. MNCs abroad, trails employment, investment (fixed assets), and sales abroad. This is in line with the work of early economists who argue that R&D tends to be "sticky" and innovation still represents a case of "non-globalization".

FIGURE 2 HERE

However, our result that when growing beyond the necessity to serve overseas markets, innovation intensity follows S&E capacity calls for a reexamination of the received wisdom. Concerns are already being raised about the depleting pool of U.S. scientists and researchers and the vast endowments of countries like China and India in this regard. Increasingly footloose and behaving like Vernon's "global scanners." similar factors can be expected to influence the decisions of American firms to locate R&D in one of two overseas locations and to locate R&D at home or abroad. This threat, and indeed the spirit of our results, is succinctly captured in the words of Craig Barrett, the former chief of Intel Corporation: "If the world's best engineers are produced in India or Singapore, that is where our companies will go. This is the reality in the modern world. We locate facilities where we can find or import talent" (*Times of India* 2005). Technological change is a highly dynamic process that may quickly relocate to take advantage of optimum conditions for growth.

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TABLE 1: COUNTRY-LEVEL DESCRIPTIVES

Variable	Description	1991-2002		1991		2002	
		Mean	Median	Mean	Median	Mean	Median
USPAT	Patents assigned to US subsidiaries	1506 [3488.9]	175 [43]	84 [206.7]	4 [40]	253 [538.1]	36 [38]
USRAND	R&D by US subsidiaries in M$	2450 [5867.8]	187 [43]	150 [404.2]	3 [40]	366 [786.7]	34 [38]
SALES	Local sales by US subsidiaries in B$	100.1 [193.53]	15.4 [43]	8.1 [16.99]	0.8 [40]	10.7 [20.04]	2.3 [38]
PATENT	Patents assigned to overseas- firms	7980 [26799.1]	469 [43]	609 [2064.1]	11 [40]	1196 [3651.3]	98 [38]
SEPUB***	S&E publication of overseas nations	86.9 [133.68]	28.8 [43]	6.6 [10.51]	2.4 [40]	10.5 [13.76]	5.0 [38]

* Standard Errors

** Number of observations (countries)

***Latest year for SEPUB is 2001

TABLE 2: REGRESSION RESULTS

	Tobit with Moffit decomposition	Marginal Effects at Observed Censoring Rate Conditional		Zero-inflated neg-binomial Zero-inflated logit	Neg-bin
	USRAND	on being censored	Probability uncensored	Pr(USPAT=0)	USPAT(#)
SALES	28.04 [19.91]***	12.63	0.06	-0.57 [2.41]**	1.08 [8.12]***
SEPUB	3.03 [5.80]***	1.36	0.01	-0.05 [1.09]	1.05 [14.34]***
PATENT	2.20 [2.78]***	0.99	0.00	-25.84 [5.25]***	1.02 [3.22]***
YEAR DUMMIES	***			***	
REGION DUMMIES	***			***	
TECH DUMMIES	***			***	
CONSTANT	-462.77 [13.55]***				
OBSERVATIONS	1817			1817	1817
DEGREE OF FREEDOM	25			25	
LOG LIKLIHOOD	-7863.54			-4936.22	
PROB > CHI2	0			0	

Observation summary for Tobit: 650 left-censored at RAND<=0; 1167 uncensored.

Observation summary for ZINB: 747 with USPAT<=0; 1070 nonzero observations.

Absolute value of z statistics in brackets

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

TABLE 3: WEIGHT (%) OF U.S INDUSTRY IN VARIOUS OVERSEAS ACTIVITIES

INDUSTRY	SALES	R AND D	PATENTS
Chemicals	23.4	35.8	34.6
Oil, Minerals, and Natural Gas	15.1	0.3	1.6
Transportation & equipment	14.5	30.6	6
Food	12.5	2.5	1
Computers, Electrical & electronics	10.9	18.8	30.8
Industrial Machinery	10.9	10.5	14.5
Other	8.4	0.1	10.3
Primary and Fabricated metals	4.3	1.4	1.3

TABLE 4: REGRESSION RESUTS BY INDUSTRY

	All sectors USPAT	Chemicals USPAT	Electrical, Electronics and Computers USPAT	Transport USPAT	Industrial Machinery USPAT
SALES	1.08	1.27	1.21	1.07	1.06
	[6.61]***	[7.28]***	[5.23]***	[4.68]***	[2.46]**
SEPUB	1.047	0.999	1.061	1.066	1.06
	[13.06]***	[0.13]	[11.98]***	[6.37]***	[7.56]***
PATENT	1.03	1.01	1.00	1.11	1.08
	[3.15]***	[0.73]	[0.08]	[3.38]***	[5.28]***
YEAR DUMMIES	***				
REGION DUMMIES	***				
TECH DUMMIES	***				
OBSERVATIONS	1070	254	233	82	177
DEGREE OF FREEDOM	25	18	18	18	18
LOG LIKLIHOOD	-4440.83	-1164.15	-1038.39	-284.66	-714.51
PROB > CHI2	0	0	0	0	0

TABLE 5 CONTINUED

	Primary & Fabricated metals *USPAT*	*Oil, NG, minerals* *USPAT*	*Food* *USPAT*	*Others* *USPAT*
SALES	0.96	1.04	1.03	1.03
	[0.50]	[3.47]***	[0.69]	[2.46]**
SEPUB	1.05	1.00	1.00	1.05
	[4.43]***	[0.20]	[0.12]	[4.62]***
PATENT	1.36	32.47	7.80	1.04
	[3.73]***	[3.33]***	[3.45]***	[1.31]
YEAR DUMMIES				
REGION DUMMIES				
OBSERVATIONS	97	64	89	74
DEGREE OF FREEDOM	18	18	18	18
LOG LIKLIHOOD	-263.80	-189.84	-224.95	-315.42
PROB > CHI2	0	0	0	0

Robust z statistics in brackets

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

TABLE 6 EVOLVING GLOBAL R&D

Timeline (circa)	*Subsidiary R&D Function*	*Foreign country drivers*	*Facilitating factors*	*Role in MNC R&D*
-1980	Market customization	Consumer demand	Learning to operate abroad	Asset exploiting/home-base exploiting
1980-1990	Listening post activities	Industrial & technological strength	Decreased communication costs	Asset seeking/home-base augmenting
1990-	Sources of innovation:		Increased variety in means of communication	
	Incremental	S&T human capital strengthens		Integration into global R&D strategy
	Multi-technology product innovation		Proximity to manufacturing and to industrial customers	World-wide product brief
	Frontier innovation			Use-inspired basic research laboratory

FIGURE 1: OBSERVED & PREDICTED VALUES OF USPATENT COUNTS FROM ZINB REGRESSION MODELS
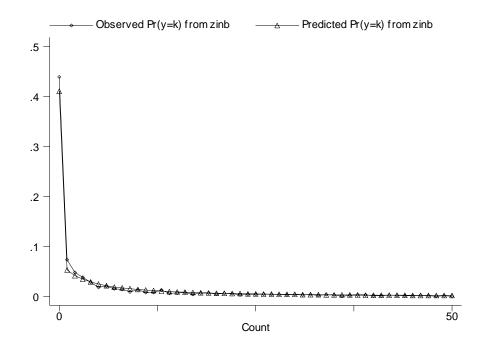

FIGURE 2: TRENDS IN THE PROPORTION OF ACTIVITIES CARRIED OUT BY US SUBSIDIARIES ABROAD