Multinational Corporations, Patenting, and Knowledge Flow: the case of Singapore*

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Abstract

We examine in this paper the nature of multinational corporations' (MNC) R&D activity in Singapore and whether it facilitates knowledge flow from MNCs to local inventors using U.S. patent and patent citations data. Comparing the quality of patents taken out by Singapore local inventors, MNC inventors in Singapore, and MNC inventors elsewhere using various patent citations-based measures, we do not find any difference between these three groups of patents. We also find that Singapore local inventors cite MNC patents significantly more intensively than a random rest-of-the-world patent does. Regression analysis reveals that the intensity of a Singapore local patent citing a non-Singapore MNC patent is significantly correlated with the number of MNCs' patents invented in Singapore, suggesting that MNCs' Singapore subsidiaries facilitate knowledge flow from MNCs to local inventors.

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I. Introduction

There has been an increase in the incidence of multinational corporations (MNCs) conducting research and development (R&D) in their overseas subsidiaries[1]. In deciding where to locate R&D activity, MNCs factor into consideration different forces that influence the costs and benefits of R&D. Caves (1996, p.186) argued that "R&D is pulled toward the parent's headquarters by the need for efficient supervision and scale economies in the R&D process itself." In the meantime, it is pushed toward the subsidiaries by the need for local product customization and the opportunity to take advantage of the R&D resources and economic incentives provided by the host country[2].

The decentralization of R&D by the MNCs can potentially generate international knowledge spillover, which obviously has significant welfare implications for both source and recipient countries. Although there is increasing evidence documenting the magnitude and the significance of international knowledge spillover (Coe and Helpman 1995, Coe, Helpman, and Haiffmaster 1997, Keller 2002), the role of MNCs as an agent in the spillover process is less clear. The large literature that indirectly investigates the issue often shows a positive relationship between the productivity of domestic firms and foreign direct investment, which is interpreted as evidence that MNCs generate technology spillover. Using Singapore as a case, we investigate whether the R&D that MNCs conduct in their overseas subsidiaries facilitates knowledge flow from MNCs to

[1] Mowery (1998) reported that the share of US companies' R&D performed in subsidiaries abroad remained at around 10 percent from the 1980's to the mid 1990's, while foreign financing of R&D activities in the U.S. had increased over the same period. However, Swedish MNCs conduct 23 percent of the R&D abroad (Håkanson and Nobel, 1993).

[2] Florida (1997) indicated that the main objective of foreign R&D investment in the U.S. is to secure access to its scientific and technical talent. Hines (1994) showed that tax holiday plays a role in influencing the location of MNCs' R&D operations.

local inventors in a more direct way than previous studies by using patent citations as an indicator of knowledge flow.

MNCs have been playing an overwhelming role in Singapore's economic development. As Singapore moves up the international value chain, MNCs in Singapore have also been redefining the role of their operations in Singapore – from pure manufacturing to regional headquarters services. Various MNCs have established R&D centers in Singapore to take advantage of the highly skilled local engineers, strong local research and tertiary educational institutions, and various incentive schemes the local government has offered. Some authors (Amsden, Tschang and Goto, 2001) have questioned the nature of the R&D conducted by MNCs in Singapore and argued that it is more of the adaptive type and closer to manufacturing than R&D conducted by these MNCs at home. The objective of MNCs is largely to take advantage of the various incentive schemes the Singapore government offers such as tax holiday, local university and research institution linkages, etc.

Using patent citations data and corporate information collected from various sources, we seek to answer two questions. First, is the R&D that MNCs carry out in their Singapore subsidiaries different from that conducted elsewhere? Second, does the R&D activity of the MNCs' subsidiaries facilitate knowledge flow from MNCs to the local Singaporean inventors? To answer the first question, we use a number of citations-based measures to compare the technological significance of patents taken out by MNCs' Singapore subsidiaries and their other patents. We take two steps to investigate the second question. We first compare the frequency of a Singapore local patent citing a non-Singaporean MNC patent with that of a random rest-of-the-world patent citing such a patent controlling for differences due to the technological area and the age of patents. We then use a Probit model to examine whether the intensity of local Singaporean patents citing non-Singaporean MNC patents is related to the number of patents MNCs' Singapore subsidiaries take out.

The rest of the paper is organized as follows: Section II discusses the U.S. patent data used in our analysis. The section that follows documents the basic patterns of the patenting behavior of MNCs' Singapore subsidiaries and the local Singaporean inventors. Section IV examines how patents taken out by MNCs' Singapore subsidiaries are different from their other patents. Section V tests the hypothesis whether MNCs' Singapore subsidiaries facilitate knowledge flow from MNCs to local inventors using patent citations as an indicator of knowledge flow. The final section concludes.

II. Data

The main data used in this paper is a subset of the NBER patent database (Hall, Jaffe, and Trajtenberg, 2001). Therefore, all the patents we refer to hereunto are patents granted in the U.S. by the U.S. Patent and Trademark Office (U.S. P.T.O.) up to December 1999. The variables we use include the country of residence of the first inventor of a patent, patent numbers of cited and citing patents, grant year and application year of cited and citing patents, patent assignee name and code of citing and cited patents, and the 3-digit technology class variables[3].

The limitations of using patent and patent citations data in the study of R&D and technology innovation are thoroughly analyzed in the literature. Griliches (1990)

[3] We have excluded individual patents from our analysis as cited patents, but our computation of the number of citations a cited patent receives includes those made by individual patents.

discussed comprehensively the pros and cons of using patent data in economic analysis. Hall, Jaffe, and Trajtenberg (2001) laid out a number of potential problems related to using patent citation data and how these might be tackled with statistical methods. These concerns apply to our study as well. Not all inventions are patented. Not all Singapore inventors turn to the U.S. P.T.O. for protection of their intellectual property rights. As a newly industrialized and small economy, Singapore gives us a limited stock of U.S. patents to analyze. Patent citations are a noisy measure of knowledge flow. While acknowledging these potential concerns, we think that analyzing the U.S. patents and patent citations data can provide us with useful information regarding the nature of R&D conducted by the MNCs' subsidiaries in Singapore and the intensity of knowledge flow, if any, between the local inventors and MNCs.

We determine the nationality of a patent by the country of residence of the first inventor. Therefore a Singaporean patent is a patent whose first inventor resides in Singapore at the time of the application of the patent. There are a total of 747 U.S. patents granted to inventors in Singapore as of December 1999. Of these 108 patents remain unassigned and are classified as individual patents. We identify whether a Singapore patent is assigned to a multinational corporation by examining the name of the assignee of a patent and determining whether the company is a subsidiary of an MNC using various sources of company information[4]. For the remaining 639 patents, 349 patents or 55 percent of all assigned patents have been assigned to MNCs. The local Singaporean institutions account for the rest 290 patents.

[4] These include the Singapore Registry of Companies and Businesses, online databases (Factiva and Osris), and the Internet (google.com, yahoo.com, and msn.com).

For the rest of our analysis, we will classify all patents into four categories, the Singapore local (SGL) patents – patents that have been granted to a local Singapore institution; the Singapore MNC (SGM) patents – patents that have been assigned to an MNC or its Singapore subsidiary, but the first inventor resided in Singapore at the time of application; MNC (MNC) patents – patents that have been assigned to MNCs but the first inventor did not reside in Singapore at the time of application; and the rest of the world (ROW) patents – all the other patents excluding unassigned or individual patents.

[Insert Table 1 here]

In Table 1, we list the top 10 inventors in terms of the number of patents taken out by both local Singaporean companies and MNCs in Singapore. There are several noticeable features. First of all, the patents are concentrated in a handful of companies. There are 66 local institutions that have taken out U.S. patents, but the top five patenting institutions account for 206 or 71 percent of all local patents. Although patents granted to MNCs in Singapore are less concentrated, 42 percent of them belong to the top five MNC inventors. Second, R&D activity is highly centralized. Our calculation indicates that over 90 percent of MNCs' U.S. patents are taken out by inventors in the MNCs' headquarter countries. Patents taken out by their Singapore subsidiaries are only a tiny fraction of MNCs' total patent portfolio, even though many of the top MNC inventors have large R&D work forces in Singapore by local standards[5]. Only 43 of the 6322 patents of Hewlett-Packard were contributed by the company's inventors in Singapore. Singapore local patents show similar patterns too. The only exception is Creative Technology, the world leading sound card maker, which has 13 of all of its 17 U.S. patents invented in the

[5] For example, Amsden et al reported that ST Microelectronics' lab in Singapore hires as many as 1900 staff. HP employs 300 (including marketing) staff in its R&D operation in Singapore.

U.S. Finally, it is worth noting that local higher education and research institutions take out a substantial number of U.S. patents. The National University of Singapore and various research institutes account for 18 percent of all local patents.

III. Multinational Corporations, R&D, and patenting in Singapore

Multinational corporations have played a significant role in the development of the economy of Singapore. At independence in 1965, Singapore had little natural resources, primitive manufacturing activity if any, a tiny domestic market, and an unskilled labor force. The government made it a central part of its economic development strategy to attract multinational corporations to locate their manufacturing operations in Singapore as a way to induce capital and technology inflow.

[Insert Table 2 here]

Table 2 shows the magnitudes of the manufacturing and R&D activities of MNCs relative to those of local corporations in Singapore in 2000. MNCs clearly dominate in the manufacturing industries. Total manufacturing sales of MNCs are over five times that of the local firms. MNCs' manufacturing activity is highly concentrated in the electronics industry, which accounts for 70 percent of total MNC local manufacturing sales. The local manufacturing firms only manage to play a more significant role in two small sectors, Engineering and Other Manufacturing, where their shares of total sales reach 43 percent and 82 percent respectively. The dominance of MNCs is less striking in terms of R&D expenditures and personnel. In fact Singapore local firms invest more in R&D and hire more R&D scientists and engineers relative to their sales volume than MNCs, but the latter still overpower the former in absolute amounts. For example, in the Electronics industry, local firms are responsible for 31 percent of total industry R&D expenditure, although their share of sales is only 12 percent. In services, the pattern of sales is reversed – it is likely to be contributed largely by the local telecommunication companies, but R&D expenditure is not much different between the two groups. The overwhelming presence of MNCs in the economy of Singapore is quite exceptional.

[Insert Figure 1 here]

The number of patents inventors in Singapore take out in the U.S. has been growing rapidly. Figure 1 shows that Singapore's U.S. patents started taking off in the early 1990's, from 12 in 1990 to 144 in 1999 – a 12 times increase. The absolute number is still very small, but the increase has been substantial. The local corporate inventors and the subsidiaries of MNCs are the main contributors to this increase, with SGL patents overtaking SGM patents after 1998. The surge in R&D expenditure over the same period obviously parallels the take-off of patenting. R&D expenditure as a share of GDP more than doubled from 0.84 percent in 1990 to almost 1.9 percent in 1999[6].

[Insert Figure 2 here]

We examine in Figure 2 the technological area distribution of the three groups of patents, SGL, SGM, and MNC. The U.S. P.T.O. classifies each patent into one or more of over 400 three-digit technology classes according to the technological nature of the invention. Adam Jaffe and Manuel Trajtenberg have grouped the 400 plus classes into 35 two-digit classes and 6 one-digit classes on the basis of the technological similarity of the 3-digit classes. In Figure 2, we plot the distribution of the three groups of patents over the two-digit subclasses. Not surprisingly both SGL and SGM patents are highly

[6] For the 1980s, R&D expenditure data are only available for 1981, 1984, and 1987. We interpolated R&D figures for the other years in the 1980s using the growth rates of R&D expenditures in the 1990s.

concentrated. Around 34 percent of SGL patents belong to subclass 46, which is "Semiconductor devices." This is largely contributed by Chartered Semiconductor Manufacturing, which takes out 98 patents in this subclass. The SGM patents on the other hand concentrate in subclass 41, or "Electrical devices," which accounts for 17 percent of the total. Comparing the SGM distribution with the MNC distribution clearly indicates that the R&D effort of MNCs' Singapore subsidiaries is much more specialized than that of their parent companies.

One of the questions we set out to explore in the beginning is whether the R&D conducted by MNCs' subsidiaries in Singapore is different in nature from that of their parents. That is, is the former less research based and more oriented towards manufacturing than the latter? If this is true, then we should expect the MNC subsidiary inventions to be more idiosyncratic and less applicable to other situations than their parents' inventions. An implication of this is that SGM patents are likely to be less often cited than MNC ones. We compute the average number of citations (excluding self-citations) received by patents granted in a certain year and plot the series for the three groups of patents in Figure 3.

[Insert Figure 3 here]

The MNC series shows a smooth downward trend – younger patents receive fewer cumulative citations than older patents. This is clearly an artifact resulted from the truncation of the citation data. Since the last year of the citation data is 1999, we are not able to observe citations made to any patent after 1999. Given that it takes time for knowledge to diffuse and that knowledge becomes obsolete over time, it may well be that the younger cohorts of patents in Figure 3 are as significant as the older patents if not more. However, assuming that these forces evenly affect these three groups of patents, the difference in citation count among the three can still provide useful information regarding the relative technological significance of the patents.

The SGL and SGM series are a bit erratic in the early years, probably due to the limited number of patents each series contains in the early years and that patents from different technological classes may have different propensity to cite other patents. But from the mid 1990's onwards, the SGL and the SGM series settle into the smooth downward sloping pattern of MNC with the SGM and MNC series essentially indistinguishable. This seems to suggest that patents of MNCs' Singapore subsidiaries are no less significant than those of their home parents. One caveat is that we have not controlled for the technology class of a patent. The propensity to cite may vary across technological areas. We shall take up the issue in the next section.

IV. Are MNCs' Singapore patents inferior to other MNC patents?

There are a number of citation-based measures one can use to gauge the technological significance of a patent. An obvious candidate is the number of non-self citations a patent receives in its lifetime, although the interpretation of this measure is confounded by the age of the patent – older patents receive more cumulative citations and that the citation data is always truncated – we do not observe all the citations a patent receives in its lifetime. Nevertheless, we first present mean non-self citations for SGL, SGM, and MNC patents over the six broad technological categories in Table 3.

There are a total of 246, 314 MNC patents. Instead of including all the MNC patents in the regression, we draw a 0.2 percent random sample of MNC patents, which generates 493 patents. Overall and in all six technological categories, SGM patents receive fewer citations than MNC patents. For example, in the Drugs and Medical category, MNC patents receive almost three times as many citations as SGM patents. But this is largely due to the age difference between the three groups of patents. MNC patents are much older than both SGM and SGL patents. For instance, MNC Drug and Medical patents are over two times older than SGM ones. This may in part explain the differences in the number of citations received between SGM and SGL.

[Insert Table 3 here]

In the last two columns of Table 3, we also report the averages of the "Generality" and "Originality" measures as defined by Trajtenberg, Jaffe, and Henderson (1997)[7]. A more general patent is one that receives citations from more diverse technology fields. In other words, a patent that receives 10 citations, each coming from a different technology field scores higher on Generality than a patent receiving all 10 of its citations from the same technology field. Likewise, a more original patent cites patents from more diverse technology fields. As Hall, Jaffe, and Trajtenberg cautioned, care should be taken in interpreting these measures. In our case, since they are on average much older than the other two groups and therefore receive more citations, MNC patents are expected to have a higher score on Generality. The age difference should have the opposite effect on the Originality measure all else equal. In the overall case ("All") of Table 3, MNC patents do have the highest score on Generality, although the difference between MNC and SGM is

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[7] Trajtenberg, Jaffe, and Henderson (1997) defines the measure as $Generality_i = 1 - \sum_j^{n_i} s_{ij}^2$, where S_{ij} is the share of citations received by patent I that belong to patent class j out of n_i patent classes. Originality is defined in the same way except that s_{ij} is now the share of citations made to other patents.

not significant in the Chemical and Mechanical groups. The younger age of SGL and SGM patents may have contributed to their relatively high originality score.

Before moving on to the regression analysis, we make a first attempt to control for differences in the age and the technological area of patents in the last four rows of Table 3. Instead of drawing a 0.2 percent random sample, we find a random matching MNC patent for each of the SGL and SGM patents. Each random MNC patent has the same application year and technology subclass as the matched SGL or SGM patent. So we effectively have two random matching samples, one for SGL patents (MNC-SGL) and one for SGM patents (MNC-SGM). The slight difference in age is due to the fact that we use the grant year of a patent to compute its age, whereas the matching is based on application year. There is very little difference between the four groups in all three measures, except that SGL patents receive more citations than their MNC random counterparts.

Correcting for the bias introduced by the age and the technological area of a patent, we specify an exploratory model to systematically investigate whether technological significance varies among the three groups of patents:

$$E(S) = \exp(\alpha_0 + \alpha_1 D_{SGM} + \alpha_2 D_{MNC} + \alpha_3 AGE + \alpha_4 AGE^2 + \sum_{1}^{35} \beta_j T_j) \qquad (1)$$

There are three candidates for the measure of the technical significance of a patent, *S*, i.e., the number of non-self cites received, generality and originality. The D's are the dummy variables indicating whether a patent is an SGL, SGM, or MNC patent. The AGE of a patent (as of 1999) and AGE^2 are included to control for the influence of the lapse of time on patent citations: the obsolescence and diffusion of knowledge and the fact that citation data is truncated. The term AGE^2 accounts for a potential nonlinear relationship between

S and the age of a patent. Finally the *T*'s are the patent subclass dummies. The non-linear specification reflects features of the dependent variables, which we will address below.

The regression sample consists of the 0.2 percent random sample of MNC patents, SGL patents and SGM patents. About 40 percent of the patents have not received any citation. Estimating equation (1) using citation count as the dependent variable requires an estimator that accommodates the features of the dependent variable: non-negative integer values with a large fraction of zeros. We first estimate equation (1) with citation count as the dependent variable using ordinary least square (OLS), Poisson and Negative Binomial models. The Poisson model has the disadvantage of making the equal mean and variance assumption, whereas the Negative Binomial model accommodates for over-dispersion (Hall, Hausman, Griliches, 1984) by assuming that the mean follows a gamma distribution. The regression results presented in Table 4 are robust to these different distribution assumptions.

[Insert Table 4 here]

The age variables in all three regressions give consistent results – the number of citations a patent receives increases as it ages but at a decreasing rate. According to the Poisson estimate, patents that are 12.5 years old, i.e., those granted between 1986 and 1987, receive on average the largest number of cumulative citations. The two patent group identity dummies, SGM and MNC, remain insignificant through out, reaffirming our earlier observation that SGL, SGM, and MNC patents receive similar numbers of citations. We did not report the technology class dummy results. A number of subclasses consistently receive substantially more citations than others, such as communications, computer hardware & software, information storage, surgery and medical instruments, semiconductor devices, and miscellaneous electronics. Controlling for these technology class differences does not change the result that SGL, SGM and MNC patents are similar in technical significance as measured by the number of non-self citations received.

In the last four columns of Table 4, we report the results from estimating equation (1) using Generality and Originality as the dependent variable respectively. Each specification is estimated with OLS and non-linear least square (NLS). There are a considerable number of patents that have either received only one citation or made one citation to another patent. The generality and originality measures will be zero for such patents given the way the two measures are constructed. The NLS estimator accommodates this feature in estimating equation (1).

Overall the generality estimation performs better than the originality estimation. Both AGE and AGE^2 carry the expected sign and are statistically significant in the former estimation. In the originality regressions, the age variables also have the expected qualitative effects – younger patents tend to score higher on originality and such effect dwindles as the patent ages, but the estimates are not statistically significant. None of the group identity dummies are significant in any specification, which again leads us to conclude that the three groups of patents are indistinguishable in technical significance.

V. Do MNCs facilitate knowledge flow?

The second question we set out to explore in the introduction is whether there is knowledge spillover from MNC to local inventors? Patent citations have been widely used as an indicator of knowledge flow to study such issues as the geographical localization of knowledge spillover (Jaffe, Henderson, and Trajtenberg, 1993) and international knowledge spillover (Jaffe and Trajtenberg 1999, Branstetter 2000). As Jaffe, Fogarty and Banks (1998) show, although patent citations may be a coarse measure of knowledge spillover, it does provide an important tool to study the direction and intensity of knowledge flow.

There are various channels through which MNCs can act as an agent of technology spillover. One of these is the demonstration effect. Findlay (1978), for example, used the "contagion" analogy to illustrate the importance of MNCs in facilitating technological diffusion by creating individual contact between MNCs and local inventors. Observing the technologies that the local subsidiaries of MNCs use and through personnel turnover, local inventors may be exposed to the more advanced technologies of MNCs and over time learn to innovate and patent in the same area. In other words, knowledge flows from MNCs to local inventors through the (perhaps unintended) intermediary role of the local subsidiaries of MNCs. To the extent that the origin of the knowledge flow is the parent of MNCs' local subsidiaries, local inventors are likely to cite the parent's patents rather than those of the subsidiaries[8].

5.1 Frequency of citing MNC patents: SGL patents vs. ROW patents

To investigate the existence of such knowledge spillover, we examine the citations made by Singapore local inventors to MNC patents. To operationalize the test, we construct a random control sample from the rest of the world (ROW) patents, which consist of non-Singapore and non-MNC patents. For each SGL patent, we randomly draw a patent from the ROW pool that meets the following criteria: it has the same application year as the SGL patent and it has the same technology subclass. Therefore we obtain a

[8] In our case, there is not a single citation made by an SGL patent to an SGM patent, or vise versa.

random sample of 290 ROW patents. Our test for knowledge spillover is based on the comparison of the intensity of SGL patents citing MNC patents and that of these random ROW patents citing MNC patents. If the former is greater than the latter, we interpret this as evidence that there is abnormal knowledge flow from MNCs to local Singaporean inventors and that this corroborates the hypothesis that the presence of MNCs in Singapore generates knowledge spillover.

The 290 random citing patents have been taken out by inventors from 18 countries. The top five include the U.S. (146), Japan (71), Taiwan (16), Germany (14), and Korea (11). It is not surprising that the U.S. and Japan dominate the sample given their overall innovative strength. The strong representation of Taiwan and Korea in this sample indicates their rapidly growing technological capability and patenting in semiconductors in particular and electronics in general (Hu and Jaffe, 2001). We then identify all the patents these 290 random ROW patents cited and all those cited by the 290 SGL patents. This gives us 4654 citations or citing – cited patent pairs after excluding self-citations. Of these SGL patents made 2045 citations with the rest 2609 citations contributed by ROW patents.

[Insert Table 5 here]

The first column of Table 5 shows the distribution of both SGL patents and the random ROW patents over the six one-digit technology classes. Nearly half of the patents concentrate in the Electrical and Electronics class. We then compute the average number of all patents a SGL or ROW patent cites in the next two columns. Overall ROW patents made more citations than SGL patents, particularly for the Chemical, Computers & Communications, and Others classes.

We test for the hypothesis that SGL patents cite MNC patents more intensively than random ROW patents in the last three columns of Table 5. First, the proportion of citations that are made to MNC patents is computed for SGL and ROW patents in each of the six technology classes. To test whether the probability of SGL citing MNC (P_{SGL}) is greater than that of random ROW citing MNC (P_{ROW}), we implemented a t-test of the two proportions[9] and report the t-statistic in the last column of Table 5. Overall and in each of the six technology classes, P_{SGL} is greater than P_{ROW}. And we can reject the null at the one percent level both for the whole sample and in three of the six classes. The difference is also significant at the 5 percent significance level for chemical patents. For the whole sample, 21 percent of all the citations made by SGL patents are made to MNC patents, whereas the random ROW patents cite MNC patents 15 percent of the times. The difference is highly statistically significant suggesting that SGL patents cite MNC patents more intensively than a random ROW patent. In the class of Computers & Communications, the difference is particularly significant. This may not be a coincidence, given that MNCs' Singaporean subsidiaries took out a disproportionate number of patents in this area.

5.2 Are MNC subsidiaries intermediaries of knowledge flow?

To investigate more explicitly whether MNCs play any role in facilitating knowledge flow, we estimate a probit model using the sample of SGL citations. This sample consists of all citation pairs, where the citing patent is an SGL patent. The cited patent can be an MNC patent or an ROW patent. We assume that the probability of an SGL patent citing an MNC patent is determined by:

[9] The null hypothesis is - H_0: $P_{SGL} = P_{ROW}$ - and the alternative is - H_a: $P_{SGL} > P_{ROW}$.

$$\Pr(MNC = 1) = \Phi(\alpha_0 + \alpha_1 NP_{SGM} + \alpha_2 RP + \alpha_3 AGE + \alpha_4 LAG + \alpha_5 D_M + \sum_g \beta_g D_g + \sum_t \gamma_t D_t) \quad (2)$$

where Φ is the cumulative Normal distribution function. NP_{SGM} is the number of SGM patents granted in the year of application and in the main technology class of the citing SGL patent. For example, if the citing pair is an SGL-1996-chemical patent citing an MNC patent, NP_{SGM} is the number of SGM chemical patents granted in 1996. The coefficient α_1 then provides a test of the knowledge spillover hypothesis. If MNCs' R&D operation in Singapore does not have any effect on Singapore local inventors' learning experience, we should not expect NP_{SGM} to have any impact on the probability that an MNC patent is cited. On the other hand, a significant and positive α_1 corroborates the hypothesis that MNCs facilitate knowledge flow to the local inventors.

We have also controlled for other determinants of citation intensity in equation (2). The probability of a MNC patent being cited by an SGL patent may be higher or lower whether there are a larger number of potentially citable MNC or ROW patents for SGL patents to cite. Instead of using the numbers of MNC and ROW patents in the grant year and the 2-digit technology subclass of the cited patent, we use the ratio of the two numbers, *RP*, in the regression. The age of the cited patent (*AGE*) is included to control for the possibility that citation frequency may change over time. A negative effect of the citation lag (*LAG*) would suggest that Singapore inventors tend to learn from more recent MNC technologies. We also include a dummy variable (D_M) to indicate whether the citing patent and the cited patent are from the same three-digit patent class. The purpose is to examine whether knowledge flow from MNCs to Singapore inventors is localized in technology space. Finally, we also include dummies that indicate the one-digit technology class of the cited patent (D_g) and the application year of the citing patent (D_t). The estimation results are reported in Table 6. In column (1) we do not control for the citing year effect but do so in column (3). Columns (2) and (4) report the marginal effects of the coefficients for columns (1) and (3) respectively.

[Insert Table 6 here]

The role of MNCs' local R&D in facilitating knowledge flow is as expected in both equations and quite significant in our preferred model in column (3). The coefficient of NP_{SGM} implies that if the number of MNCs' Singapore patents increases by 10, the probability of a Singapore local patent citing an MNC patent is increased by 0.06. Given the speed at which SGM patents have been growing – from 20 in 1992 to 60 in 1999, this suggests quite intensive knowledge flow from MNCs to local inventors with the MNCs' local R&D effort playing an important intermediary role.

The ratio of the numbers of MNC patents and ROW patents is highly significant in both equations. This reaffirms our expectation that more MNC patents relative to ROW patents increases the likelihood of MNC patents being cited. None of the *AGE*, *LAG*, and D_M variables are significant, which suggests that Singapore inventors learn from both new and old MNC technologies and that they also benefit from MNC inventions in areas that are not their own. Including the application year dummies of the citing patents only marginally improves the fit of the model, but it substantially increases the statistical and economic significance of NP_{SGM}. None of the technology class and year dummies are significant.

In summary, we have shown that the intensity of Singapore local patents citing MNC patents is overall significantly greater than that of random ROW patents. In the meantime, the intensity of a Singapore local patent citing an MNC patent is significantly correlated with the number of MNCs' patents invented in Singapore.

VI. Conclusion

Multinational corporations are increasingly conducting R&D in their overseas subsidiaries, including those in developing countries. The nature of such R&D activity is not well understood. How is it different from the R&D conducted by MNCs at home and other developed countries? Developing country governments are offering incentives to induce MNCs to carry out R&D in these countries with the hope of such R&D activity generating knowledge spillover to the local economy. A question with important policy implications therefore is does the R&D activity of the local subsidiaries of the MNCs facilitate knowledge flow from MNCs to the host country inventors? These are the questions that motivated this study.

Using Singapore as a case, we have examined the nature of MNCs' R&D in a newly industrialized country and whether it facilitates knowledge flow from MNCs to local inventors. Comparing various citation-based measures of the technical significance of a patent, we find virtually no difference between indigenous local patents, local MNC patents, and other MNC patents. Our first step in investigating whether Singapore local inventors benefit from the presence of MNCs in Singapore is to compare the relative frequency of indigenous Singapore patents and random rest-of-the-world patents citing MNC patents. Indigenous Singapore patents cite MNC patents significantly more intensively than a random ROW patent, particularly in Computers & Communications, Electrical & Electronics, and Others.

We use patent citations as an indicator of knowledge flow and investigate whether the intensity of patent citation made by an indigenous Singapore patent to a (non-Singapore) MNC patent is related to the number of patents taken out by MNCs' subsidiaries in Singapore. There is a significant statistical relationship between the two. In other words, in technical field where MNCs' Singapore subsidiaries take out more patents, it is more likely for an indigenous Singapore patent in that field to cite an MNC patent, even though the MNC patent was not invented in Singapore. We interpret this as evidence that MNCs' subsidiaries in Singapore do facilitate knowledge diffusion from MNCs to local Singapore inventors.

Singapore is unique in terms of the overwhelming role of multinational corporations in its national economy. It is also special in that it is a very small economy with a relatively small absolute amount of R&D effort. We certainly want to extend the current analysis to a wider context in our future research in order to gain a deeper understanding of the role of MNCs in international knowledge spillover.

Reference:

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Figure 1
R&D and patenting in Singapore

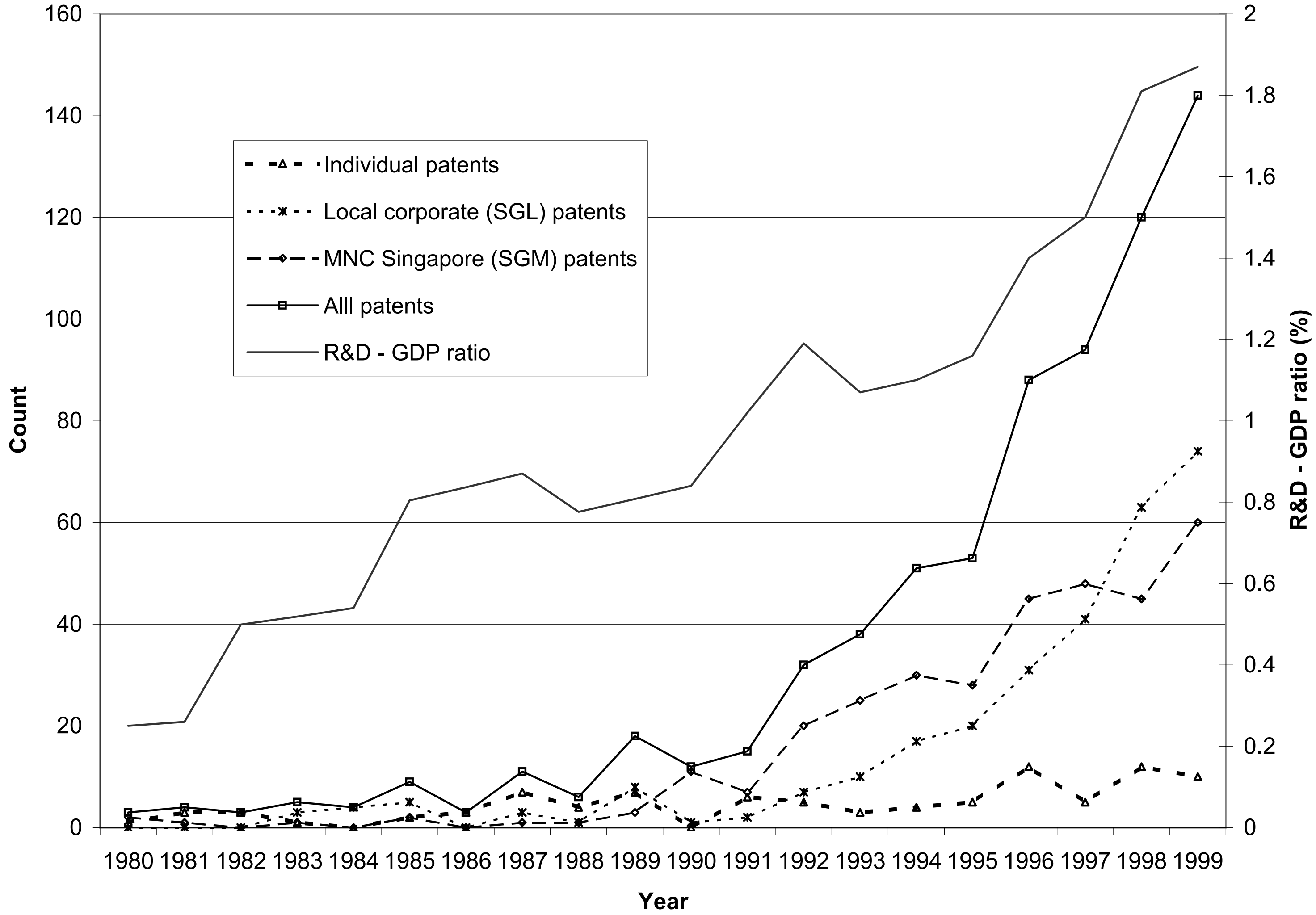

Figure 2
Technology sub-class (2-digit) distribution of patents

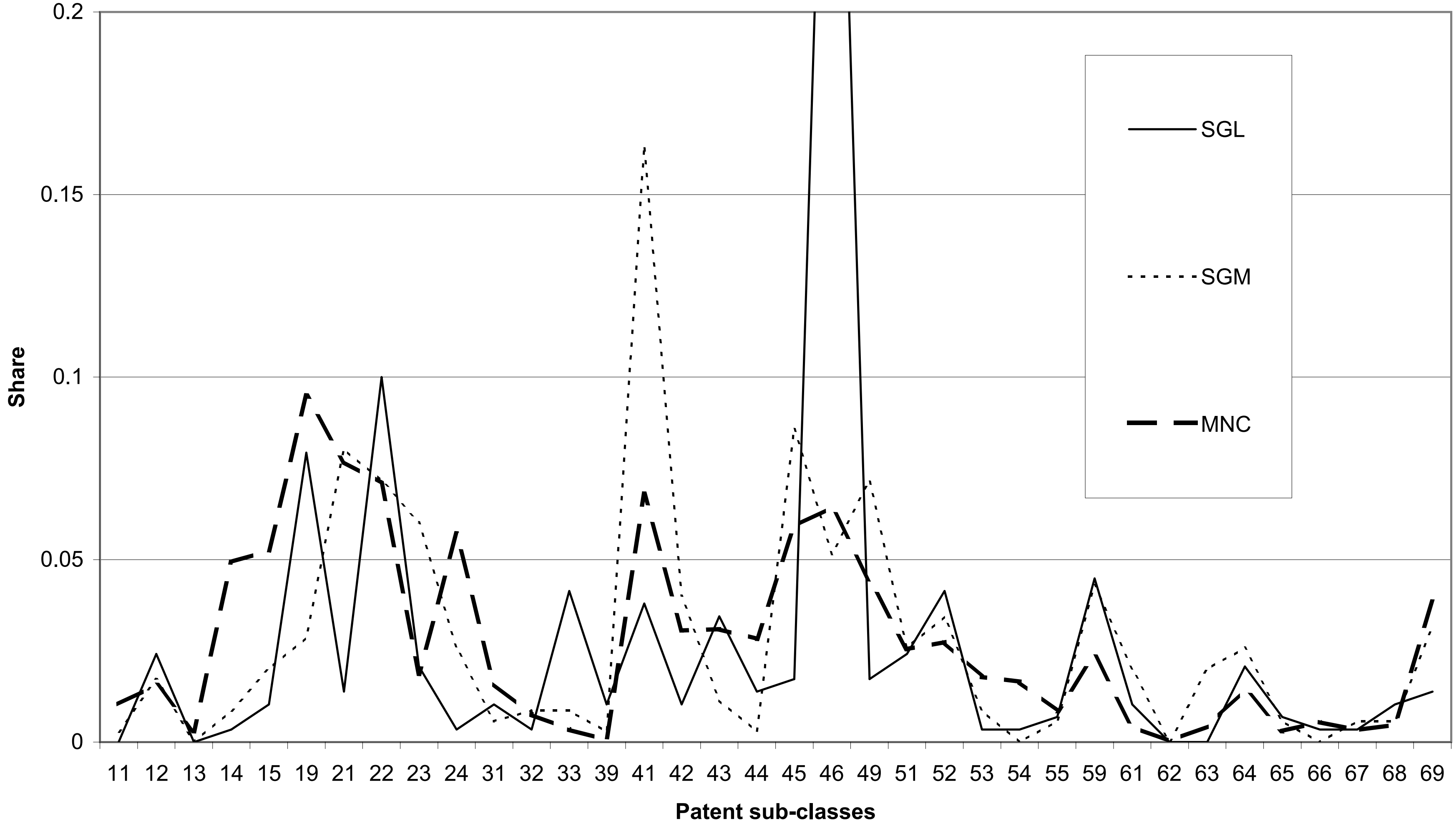

Figure 3
Average number of citations received
(excluding self-citations)

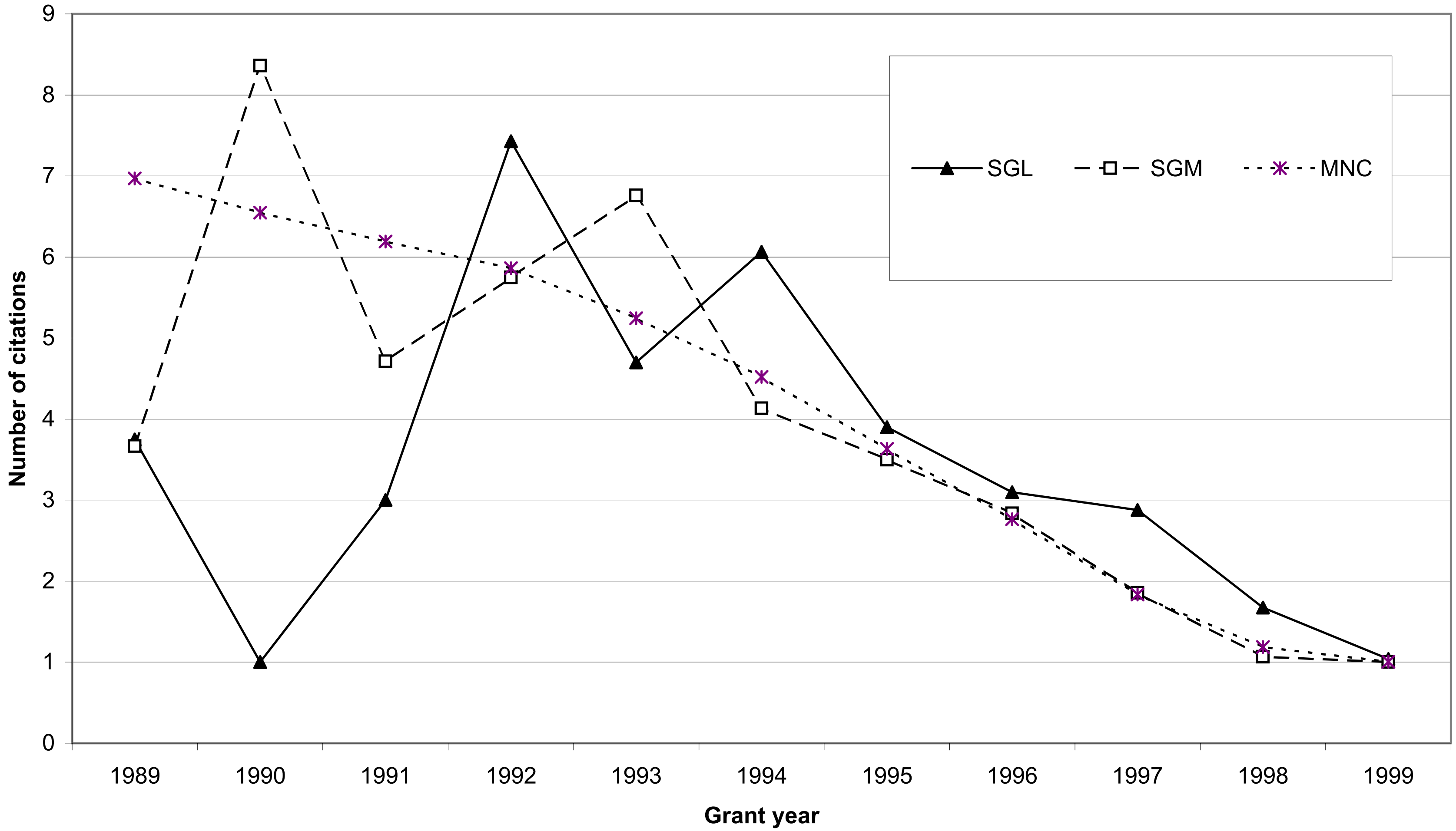

Table 1. Top Local and MNC Inventors

Name of assignee	Singapore patents	All US patents
Top 10 Local Inventors		
CHARTERED SEMICONDUCTOR MANUFACTURING PTE LTD	122	139
NATIONAL UNIVERSITY OF SINGAPORE	35	35
TRITECH MICROELECTRONICS INTERNATIONAL PTE LTD.	29	32
INSTITUTE OF MICROELECTRONICS	12	15
SUN INDUSTRIAL COATINGS PRIVATE LTD.	8	8
CHARTERED INDUSTRIES OF SINGAPORE PRIVATE LIMITED	7	9
EASTERN OIL TOOLS PTE, LTD.	5	7
SINGAPORE COMPUTER SYSTEMS LIMITED	5	5
SUNRIGHT LIMITED	5	5
ADVANCED SYSTEMS AUTOMATION LIMITED	5	5
Top 10 MNC Inventors		
HEWLETT-PACKARD COMPANY	43	6322
TEXAS INSTRUMENTS, INCORPORATED	35	8911
MOTOROLA, INC.	28	13682
MOLEX INCORPORATED	23	869
MATSUSHITA ELECTRIC INDUSTRIAL CO., LTD.	18	11782
THOMSON CONSUMER ELECTRONICS, S.A.	18	71
ST MICROELECTRONICS, INC.	14	1415
U.S. PHILIPS CORPORATION	11	14575
SEAGATE TECHNOLOGY, INCORPORATED	6	803
NESTEC, S.A.	6	739
BERG TECHNOLOGY, INC.	6	169

Table 2. R&D and sales revenue of local firms and MNCs in 2000

Industry sector	Local sales ($m)			R&D expenditure ($m)			RSE (person)		
	Total	Local	Foreign	Total	Local	Foreign	Total	Local	Foreign
Manufacturing	94292.0	16%	84%	1563.6	39%	61%	5851.0	33%	67%
Electronics	63004.6	12%	88%	984.5	31%	69%	3715.0	24%	76%
Chemicals	14998.7	14%	86%	104.3	22%	78%	449.0	35%	65%
Engineering	10308.8	43%	57%	373.4	67%	33%	1313.0	57%	43%
Precision Engineering	6288.5	36%	64%	298.6	69%	31%	883.0	52%	48%
Life sciences	5001.2	11%	89%	83.5	23%	77%	295.0	27%	73%
Other manufacturing	978.7	82%	18%	17.9	68%	32%	79.0	73%	27%
Services	10728.7	56%	44%	302.5	58%	42%	2146.0	64%	36%
IT and communications	6284.9	85%	15%	198.4	71%	29%	1434.0	72%	28%
Finance and Business	420.7	30%	70%	46.4	45%	55%	345.0	57%	43%
Other services	4023.1	14%	86%	57.8	28%	72%	367.0	40%	60%
All	105020.6	20%	80%	1866.0	42%	58%	7997.0	42%	58%

Note: Local - 30% or more locally owned
Foreign - less than 30% locally owned
RSEs - Research Scientists and Engineers whol hold formal university qualifications and are principally employed in a research capacity.
Source: National Survey of R&D in Singapore 2000

Table 3. Citations, generality and originality

	Number of patents	Average age	Average cites	Generality	Originality
Chemical					
SGL	34	4.56	2.24	0.28	0.50
SGM	27	9.37	1.89	0.36	0.46
MNC	130	16.27	5.43	0.37	0.42
Computers & Communications					
SGL	40	2.88	3.30	0.32	0.46
SGM	83	4.52	2.69	0.26	0.38
MNC	106	8.24	5.84	0.37	0.44
Drugs & Medical					
SGL	19	3.32	1.42	0.11	0.15
SGM	9	4.56	1.67	0.22	0.16
MNC	18	15.33	5.50	0.29	0.29
Electrical & Electronics					
SGL	141	2.71	2.68	0.19	0.33
SGM	149	5.46	3.95	0.27	0.30
MNC	139	12.58	5.24	0.32	0.35
Mechanical					
SGL	36	7.22	2.89	0.28	0.36
SGM	41	7.22	2.37	0.31	0.49
MNC	56	12.64	3.98	0.32	0.39
Others					
SGL	20	7.85	2.95	0.25	0.24
SGM	40	4.93	1.35	0.13	0.27
MNC	44	17.02	6.02	0.35	0.33
All					
SGL	290	3.90	2.68	0.23	0.36
SGM	349	5.66	2.95	0.27	0.35
MNC	493	13.12	5.35	0.34	0.39
All - random matching					
SGL	290	3.90	2.68	0.23	0.36
MNC-SGL	290	3.78	1.96	0.25	0.37
SGM	349	5.66	2.95	0.27	0.35
MNC-SGM	349	5.65	2.99	0.27	0.37

Table 4. Cites, generality and originality regressions

	Number of cites			Generality		Originality	
	OLS	*Poisson*	*Neg. Binomial*	*OLS*	*NLS*	*OLS*	*NLS*
constant	-4.87*	-1.67***	-1.66***	-0.26*	-2.23*	0.51*	-0.70**
	(1.58)	(0.94)	(0.96)	(0.10)	(0.47)	(0.11)	(0.35)
age	0.92*	0.25*	0.27*	0.04*	0.11*	-0.006	-0.01
	(0.08)	(0.02)	(0.01)	(0.01)	(0.02)	(0.005)	(0.01)
age2	-0.03*	-0.01*	-0.01*	-0.001*	-0.003*	5.00E-07	0.0001
	(0.003)	(0.001)	(0.001)	(0.0002)	(0.001)	(0.0002)	(0.0001)
SGM	0.15	0.04	0.002	0.03	0.12	-0.01	-0.06
	(0.31)	(0.10)	(0.08)	(0.03)	(0.12)	(0.02)	(0.06)
MNC	0.61	0.08	0.03	0.03	0.08	0.03	-0.01
	(0.39)	(0.11)	(0.10)	(0.03)	(0.12)	(0.03)	(0.06)
Number of obs.	1132	1132	1132	742	742	1042	1042
Adjusted/Pseudo R^2	0.22	0.23	0.1	0.26	0.11	0.11	0.07

Note: Dependent variable is the number of citations each patent receives excluding self-citations.
All regressions include 35 technology sub-class dummies.
* Significant at 1% level; ** Significant at 5% level; *** Significant at 10% level

Table 5. Frequency of citing an MNC patent

Technology Class	Number of patents	Mean citations made *ROW*	Mean citations made *SGL*	Proportion of MNC citations *ROW*	Proportion of MNC citations *SGL*	*t-stat*
Chemical	34	8.94	6.88	0.07	0.12	1.82**
Computers & Communications	40	10.33	6.93	0.15	0.25	3.24*
Drugs & Medical	19	4.47	4.84	0.01	0.02	0.52
Electrical & Electronics	141	8.23	7.16	0.24	0.28	2.46*
Mechanical	36	8.03	6.67	0.05	0.08	1.26
Others	20	17.95	9.80	0.03	0.09	2.71*
All	290	9	7.06	0.15	0.21	5.19*

Note: * Significant at 1% level; ** Significant at 5% level; *** Significant at 10% level

Table 6. Probit estimate of the MNC citation equation

	(1)	(2)	(3)	(4)
Constant	-1.56*		-3.71	
	(0.20)		(3.60)	
NP_{SGM}	0.01***	0.004***	0.02*	0.006*
	(0.007)	(0.002)	(0.008)	(0.002)
RP	1.80*	0.51*	1.87*	0.53*
	(0.38)	(0.10)	(0.35)	(0.10)
AGE	0.02	0.006	0.12	0.03
	(0.02)	(0.006)	(0.22)	(0.06)
LAG	-0.02	-0.006	-0.12	-0.03
	(0.02)	(0.006)	(0.22)	(0.06)
D_M	-0.04	-0.01	-0.05	-0.01
	(0.08)	(0.02)	(0.08)	(0.02)
D_g's	Yes	Yes	Yes	Yes
D_t's	No	No	Yes	Yes
Number of obs.	1917	1917	1917	1917
Log likelihood	-945	-945	-937	-937

Note: Dependent variable is whether the cited patent is an MNC patent.
* Significant at 1% level; ** Significant at 5% level;
*** Significant at 10% level