International R&D and Firm Performance: A Contingency Approach

Rene Belderbos
Katholieke Universiteit Leuven
Managerial Economics, Strategy and Innovation
rene.belderbos@econ.kuleuven.be

Bart Leten
Katholieke Universiteit Leuven
Managerial Economics, Strategy and Innovation
bart.leten@vlerick.com

Shinya Suzuki
National Institute of Science and Technology Policy
ssuzuki@nistep.go.jp

ABSTRACT

Although prior studies have given ample attention to the internationalization of R&D by multinational firms, only a limited number of empirical studies have examined the performance consequences of R&D internationalization, and these have provided mixed results. In this study, we propose a set of environmental and organizational factors that shape the relationship between R&D internationalization strategies and firms' technological performance. We focus on the role of the technological strengths and scientific research strength of host countries, the effectiveness of the firms' international knowledge integration network, and the presence of economies of scale in firms' R&D activities, and the tacitness of firms' technologies, using a panel dataset of the R&D and patent activities of 175 US, EU and Japanese firms that are among the largest R&D spenders in five industries. The empirical result indicates that the technological strengths of host countries, the effectiveness of the firms' international knowledge integration network, and tacit nature of firms technologies enhance the effectiveness of internationally distributed R&D in improving performance, while the presence of economies of scale in firms' R&D activities reduces it. The scientific research strengths of host countries also increase the performance-improving effect of distributed R&D only if the firm has strong scientific absorptive capacity.

Introduction

R&D has for long been the least internationalized business function in multinational firms. Firms centralize R&D activities at home to reap economies of scale and scope in R&D and to facilitate the transfer and integration of tacit and sticky technological knowledge between headquarters, R&D laboratories and core manufacturing plants (Pearce, 1989; Patel and Pavitt, 1991). Due to a number of changes in the technological, international and business environment, firms have however increasingly internationalized their R&D activities in the past two decades (UNCTAD, 2005; OECD, 2007). The literature has considered two main motives for firms to conduct R&D activities outside their home countries (Kuemmerle, 1997; Belderbos, 2003; von Zedtwitz and Gassmann, 2002; Ambos, 2005). First, multinational firms set up foreign R&D activities to adapt and tailor home-developed products to local market conditions, and provide technical support to foreign manufacturing operations (home-base exploiting R&D). A second motive for foreign R&D is to harness geographically distributed scientific and technological expertise abroad and develop new technologies for world markets (home-base augmenting R&D). The latter motivation has also been termed "knowledge sourcing" and appears to have gained in importance in recent years.

The literature on R&D internationalization has mainly focused on the motives behind R&D internationalization (Kuemmerle, 1997; von Zedtwitz and Gassmann, 2002) and the role of host country factors in attracting foreign R&D investments (e.g. Belderbos et al, 2006; Kumar, 2001; Branstetter et al, 2006; Cantwell and Piscitello, 2005; Hegde and Hicks, 2008). These studies have pointed to the importance of a number of host country characteristics attracting inward R&D investments, such as large and sophisticated local markets, labour costs, IPR regimes, and technological and scientific strengths of countries. In contrast, relatively little is known about the impact of R&D internationalization on the performance of firms. Examining the impact of R&D internationalization on firm performance is not trivial as both benefits and costs are expected to be related to R&D internationalization. Benefits relate to sourcing foreign technological and scientific expertise and information on local demand. Internationalization costs include increased coordination and integration complexities, possible redundancies in the R&D mandates and efforts of dispersed laboratories, and reduced scale and scope economies. In recent years, a limited number of empirical studies have examined the R&D internationalization - performance relationship, providing mixed results. Some studies (Furman et al, 2006; Singh, 2008) found negative effects, while other studies (Iwasa and Odagiri, 2004; Penner-Hahn and Shaver, 2005; Todo and Shimizutani, 2008; Criscuolo and Autio, 2008; Griffith et al, 2006) found qualified positive effects of R&D internationalization on firm performance.

In this study, we propose a set of environmental and organizational factors that are expected to shape the relationship between R&D internationalization and firms' technological performance. We focus on the role of the technological strengths and scientific research strengths of host countries, the effectiveness of the firms' international knowledge integration network, the presence of economies of scale in firms' R&D activities, and the tacitness of firms' technologies. By studying the moderating effect of environmental and organizational factors, the aim of this study is to develop a more thorough and complete understanding of the conditions under which R&D internationalization can improve the technological performance of multinational firms. We test our hypotheses on panel data (1995-2003) on the R&D and patent activities of 175 European, Japanese and US firms that are among the top R&D spenders in five industries. The empirical result indicates a positive impact of international dispersion of R&D on firms' technological performance. Moreover, the technological strengths of host countries, the effectiveness of the firms' international knowledge integration network, and tacit nature of firms' technologies enhance the effectiveness of internationally distributed R&D in improving performance, while the presence of economies of scale in firms' R&D activities reduces it. The scientific research strengths of host countries also increase the performance-improving effect of internationally distributed R&D only if the firm has a strong absorptive capacity for scientific research.

The remainder of this paper is organized as follows. In the next section we provide a brief overview of the relevant theory and derive hypotheses. The following section describes the data, empirical methods and variables. We then present the empirical results. In the final section we discuss the results and provide our conclusions.

Theoretical Background and Hypotheses

The evolutionary view of the multinational firm emphasizes the importance of the firm's capability to learn from foreign activities and to build up experience on the transfer of tacit knowledge across borders in different geographic locations (Penner-Hahn, 1998; Kogut and Zander, 1993 and 1995; Martin and Salomon, 2003). In this theoretical perspective, international experience is a prime source of organizational learning in multinational firms, and geographically diversified operations generate valuable learning opportunities for firms (Barkema and Vermeulen, 1998) by providing access to the knowledge bases and innovation systems in different locations (Zahra et al, 2000). These innovation systems may have particular strengths that are not or not to the same extent present in the home country, providing the firm opportunities for complementary technology development. By setting up international R&D activities in multiple foreign locations, firms have opportunities to learn and to improve their technological performance in different respects. For example, conducting R&D in multiple foreign locations allows firms to access local technological knowledge, and to use this knowledge to develop new technologies for worldwide markets (home-base augmenting R&D). Because of the tacit and sticky nature of much technological knowledge (Polanyi, 1966), the absorption of valuable technological knowledge that is present in foreign locations is not effective at distant locations but requires the creation of own R&D facilities in these locations (Penner-Hahn and Shaver, 2005).

Nevertheless, there are also several disadvantages of dispersing R&D activities over multiple foreign locations. First of all, economies of scale and scope in R&D will decrease when R&D activities are spread over multiple locations outside the home country. The largely indivisible nature of R&D investments leads to economies of scale and makes it less effective for firms to expand their R&D to new laboratories without fully utilising assets and personnel of the existing R&D sites (Pearce, 1999; Hirschey and Caves 1981; Hewitt 1980). At the same time, firms' R&D activities are also subject to economies of scope due to knowledge spillovers between R&D activities in different technological fields (Henderson and Cockburn, 1996; Leten et al, 2007). Spillovers take place more easily if R&D activities in different fields are collocated (Argyres, 1996). Second, coordination and integration of R&D activities become increasingly difficult and costly if they are conducted in different locations. R&D is an activity which requires a high level of communication between involved parties (Nobel and Birkinshaw, 1998) and efficient communication often necessitates face-to-face interaction and therefore centralization of R&D activities in one location.

As there are both benefits and costs related to R&D internationalization, the existing literature has emphasized roles of the moderating factors which impact the performance effect of R&D internationalization rather than the level of international dispersion itself (e.g. Singh, 2008). In the next set of hypotheses, we formulate the moderating effects of environmental and organizational factors on the relationship between R&D internationalization and the technological performance of firms.

The benefits of international R&D and knowledge sourcing at foreign R&D locations are expected to depend on the host country environment and in particular the technological strengths of the host countries where firms conduct their R&D activities. In locations (regions/countries) in which there is substantial R&D activity and a large stock of technological knowledge in technical disciplines that are relevant for a firm[1], firms have more opportunities to find source relevant technological knowledge, to find valuable partner firms or organisations to conduct joint R&D activities, or to hire talented and experienced scientists and engineers for their R&D laboratories (Iwasa and Odagiri, 2004; Griffith et al. 2006). This leads to the following hypothesis:

Hypothesis 1: The impact of R&D internationalization on firms' technological performance is positively moderated by the technological strength of the host countries in which firms conduct R&D activities.

The existing literature has shown that locating close to academic research and conducting formal collaborative research with academia increase the innovative performance of firms (e.g. Jaffe, 1989; Acs et al, 1991 and 1994; Gambardella, 1992; Mansfield, 1995; Cockburn and Henderson, 1998; Cohen et al, 2002; Zucker et al, 2002; Belderbos et al, 2004; Fleming and Sorenson, 2004; Link et al, 2007; Leten al, 2007; Cassiman et al, 2008). Empirical studies, mostly in the domain of regional economics, have furthermore shown that academic research stimulates the growth of industrial R&D and the set-up of new research intensive ventures in the region (e.g. Jaffe, 1989; Bania et al., 1992; Anselin et al., 1997; Zucker et al. 1998 and 2001; Abramovsky et al, 2007). Moreover, quality university research also enhances innovative performance of firms. Zucker et al (2002) found that firms can improve their R&D productivity by collaborating with academic 'star' scientists in their fields of expertise, pointing to the crucial role of the quality of academic research.

Such roles of scientific research by academia are gaining increasing importance in the context of foreign R&D by multinational firms. Empirical studies have suggested that R&D

[1] Regions with a large stock of technological knowledge are called technology clusters in economic geography literature (see, for example, Lecocq et al, 2012).

conducted in foreign affiliates is becoming more important vehicles to access local technological expertise abroad and to create new technologies, although it is traditionally focused on adaptation of home-developed technologies to foreign markets (Kuemmerle, 1997). As the importance of technology-sourcing type foreign R&D increases, strong scientific research in host countries is expected to raise the productivity of firms' foreign R&D since interaction and collaborative research with academia can play a critical role in the creation of new technologies.

However, the benefits of academic research are likely to differ across firms since firms possess different capacities to recognize, absorb and utilize academic scientific knowledge (Cohen and Levinthal, 1990; Gambardella, 1992; Liebeskind et al, 1996; Cockburn and Henderson, 1998; Cockburn, 1999; Fabrizio, 2009). Firms that want to take advantage of research conducted outside their organizations need to invest in an 'absorptive capacity' in the sense of accumulating knowledge and skills to understand and utilize externally generated knowledge (Cohen and Levinthal, 1990; Cassiman and Veugelers, 2006). The creation of an absorptive capacity for external scientific knowledge involves recruiting scientists, granting them resources and providing the right organizational structures for the scientists to identify and absorb external scientific knowledge (Rosenberg, 1990; Pavitt, 1991). Science oriented firms which acquired high absorptive capacities through these efforts are expected to benefit more from scientific research. This leads to following hypothesis.

Hypothesis 2***:*** *The impact of R&D internationalization on firms' performance is positively moderated by the scientific research strength of the countries in which firms conduct R&D activities if the firms have high scientific absorptive capacity.*

Effective knowledge transfer of locally sourced knowledge within the MNE knowledge network is an important condition to reap the full benefits from dispersed R&D activities.

International management studies have pointed out that knowledge integration of globally dispersed R&D activities of the multinational firm is a key success factor for international R&D (Singh, 2008). Knowledge integration requires substantial coordination and communication efforts (Nobel and Birkinshaw, 1998; De Meyer, 1991). Communication between different R&D sites across borders may be hindered by obstacles such as geographic, cultural and temporal distances (Sosa et al., 2002; Allen, 1977). Due to the tacit and sticky nature of much technological knowledge (Polanyi, 1966), effective communication often requires face-to-face contacts, which are hindered by the geographic, temporal and cultural distances of different R&D facilities of firms. Firms may undertake various activities to overcome these barriers to communication and improve the efficiency of the intra-firm international knowledge transfer network, such as rotating firm personnel across different R&D facilities (located in different countries) and setting up joint R&D activities between people in different R&D facilities (Singh, 2008; Frost and Zou, 2005). The more effective the firm is in stimulating and realizing knowledge transfers between R&D activities in different units, the more firms benefit from international R&D:

Hypothesis 3: *The impact of R&D internationalization on firms' technological performance is positively moderated by the effectiveness of the intra-MNE knowledge integration network of the firms.*

The presence of economies of scale is another environmental factor playing an important role in determining the productivity of firms' knowledge generating activities. R&D activities are typically characterized by substantial scale economies, although the extent of these scale economies differs across technologies and industries (Kuemmerle, 1998; Ambos, 2005). A main source of scale economies in R&D is the indivisible nature of R&D projects. It is more efficient for a firm to fully utilize indivisible assets such as research equipment, research teams and talented personnel at a large central laboratory rather than at multiple dispersed small-scale R&D sites (Pearce, 1999; Herschey and Caves 1981; Hewitt 1980). When scale economies are large in firms' R&D activities, firms need to organize their R&D activities in sufficiently large laboratories to achieve the minimum efficient scale (Perrino and Tipping, 1991). This implies that firms that are active in scale intensive and diversified technology domains benefit most from centralization of R&D activities and are more likely to experience negative repercussions of spreading their R&D activities over multiple foreign locations. This leads to the following hypotheses:

<u>Hypothesis 4</u>*: The impact of R&D internationalization on firms' technological performance is negatively moderated by the extent to which scale economies are present in firms' technologies.*

Knowledge is often tacit with little codification and thus the usefulness and applicability of the knowledge is highly context-dependent (Hedlund and Nonaka, 1993). This also applies to technological knowledge in industrial activities, especially in science-based industries (Cantwell and Santangelo, 2000). Tacit knowledge is difficult to be transferred across different people or organizations and to be absorbed and utilized by the receivers of the knowledge than codified one. Therefore, more intensive communication in the direct manner such as face-to-face contacts is required to effectively transmit tacit knowledge (Winter, 1987).

Since the intensive contacts facilitate the sourcing of tacit knowledge from external actors, firms have incentives to be located close to the possible sources of useful technologies in conducting innovative activities. Benefiting from local innovation networks requires firms to know local actors, share information and knowledge, and cultivate mutual trust in the local technical community (Furman, 2003). The deeper and more extensive a firm's relationships with local economic actors, the stronger will be its ability to access complex and tacit technological knowledge from the local environment (Lane and Lubatkin, 1998). Despite the recent development of information and communication technologies, it is still difficult to coordinate transfer of tacit knowledge across long distances. Thus, it is important for foreign firms to maintain the local presence in a host country if firms intend to source tacit knowledge from local firms and organizations. This leads to following hypothesis.

Hypothesis 5: *The impact of R&D internationalization on firms' technological performance is positively moderated by tacit nature of firms' technologies.*

Data and Empirical Methods

Sample

To investigate the technological performance and R&D internationalization of firms, a panel dataset is constructed (1995-2002) on the R&D and patent activities of 175 R&D intensive EU, US and Japanese firms in five different industries (Pharmaceuticals and Biotechnology, IT Hardware, Electronics and Electrical Machinery, Chemicals, and Non-Electrical Machinery). The sample firms are selected as top R&D spenders in their sectors and countries based on the 2004 EU Industrial R&D Investment Scoreboard. Patent datasets of firms are constructed at the consolidated level, i.e. all patents of the parent firm and all its consolidated (majority-owned) subsidiaries are taken into account. The consolidation was conducted on a yearly basis to take into account frequent changes in the group structure of the sample firms due to acquisitions, mergers, green-field investments and spin-offs. Patent data are taken from the European Patent Office (EPO).

Patent data have the advantage of being easy to access, covering long time series and containing detailed information on the technological content, owners, and inventors of patented inventions. They also have shortcomings. For instance, not all inventions are patented and patent propensities vary across industries and firms (Basberg, 1987; Griliches, 1990), although this concern may be mitigated by the fact that patent propensities in the industries that we examine tend to be relatively high (Arundel and Kabla, 1998). Given the novelty requirement for patents, patent-based indicators of foreign R&D are perhaps more likely to represent foreign research activities than foreign development activities directed at local adaptation. In the context of our research, a disadvantage is that patents are a form of 'intermediate output' of the R&D process rather than an input measure. Patent counts not only differ due to differences in the scale of R&D operations, but also because of differences in R&D productivity. Despite these drawbacks, patents are extensively used as indicator of the location of inventive activities (Patel and Vega, 1999; Belderbos, 2001; Guellec and Van Pottelsberghe, 2001; Le Bas and Sierra, 2002; Cantwell and Piscitello, 2005; Branstetter and Kwon, 2004; Allred and Park, 2007), given that systematic data (certainly at the firm level) on R&D expenditures by location are not collected or not generally available for analysis.

Address information of the patent inventors of firms' patents are used to determine the country of origin of patented inventions and to calculate the indicator of the level of R&D internationalization of firms. Inventor addresses give a much more accurate indication of patents' geographic origin than company addresses as firms tend to register the headquarter address with the patent office instead of the address of the subsidiary or unit where the invention originated as assignee address (Deyle and Grupp, 2005; Khan and Dernis, 2006). If a patent lists multiple inventors based in more than one country, we assigned the patent to each country. We examine international dispersion of R&D locations across 40 countries, including all major developed countries in the world and the larger and more R&D intensive developing and emerging economies in South-East Asia, South-America, and South Africa.

Dependent variable and Methodology

To measure the technological performance of the sample firms (dependent variable) in a particular year, we count the number of patent applications by a sample firm in the year, weighted by the number of forward patent citations that are received by the patents over a fixed time window of 4 years. The 'weighting' by the forward citations allows controlling for variation in the technological and economical importance of patented inventions (Harhoff et al, 1999; Hall et al, 2005). Since the dependent variable only takes non-negative integer values, a Negative Binomial count data model is estimated to relate the dependent variable to the set of explanatory variables. To control for the impact of unobserved firm-specific characteristics (characteristics that may correlate with, and bias the effect of explanatory variables), fixed effects panel data analyses are performed. To examine the moderating effect of the environmental and organizational factors on the relationship between R&D internationalization and firms' technological performance, we include interaction effects of R&D internationalization and the moderating variables.

Explanatory variables

The variable of interest is the level of internationalization of firms' R&D activities. This variable is measured as the inverse of the Herfindahl index of the geographic distribution of firms' patents over all the countries, based on EPO patents[2]. This index takes larger values when firms' R&D activities are spread more equally over a larger number of countries.

The technological strength of host countries variable (Hypothesis 1) is constructed as the average relevant technological strength of all host countries in which firms conduct R&D activities, weighted by the share of the patents invented in each host country. The host country's technological strength is measured by the number of patent applications (weighted by forward

[2] To check possible bias due to the use of EPO patents, we recalculated the level of the sample firm's R&D internationalization based on 'triadic' patents. This R&D internationalization measure by the triadic patents is quite similar to the one by EPO patents, showing the high correlation of 90 percent.

patent citations) in technology fields that are relevant to firm's main industry.[3] Technology fields are linked to industries using the concordance table of Schmoch et al (2003).

The average of the scientific research strengths of all host countries is used to test the hypothesis on the host country's scientific research strength (Hypothesis 2). The variable is constructed as the average scientific research strength of all host countries in which firms conduct R&D activities, weighted by the share of the firm's patents invented in each host country in the total firm patents. The host country's academic research strength is measured as the number of scientific publications in science fields that are relevant to firm's main industry. The scientific publications are extracted from the Web of Science database of Thomson Scientific and only papers of the document type article, letter, note and review have been selected. To obtain the number of scientific publications relevant to a firm's industry, we first calculate for each host country the number of scientific publications at the level of 240 scientific disciplines. Then, the number of publications at the level of technology field is calculated by using publication numbers by scientific field and the science-technology concordance table developed by Van Looy et al. (2004). Finally the publication counts at the industry level are calculated with the number of publications in the technology field relevant to the industry, using the technology-industry concordance table of Schmoch et al (2003).

The variable scientific absorptive capacity of firms is created to test whether the moderating effect of host countries' scientific research strengths on the R&D internationalization performance relationship depends on the absorptive capacity of firms. The scientific absorptive capacity of firms is measured by the average number of scientific non-patent references per patent in the firm's three year prior portfolio of patents invented in the home country. We classify the sample firms into high and low science orientation groups on a yearly basis by using the median value of the absorptive capacity variable as cut-off point. A

[3] Patents of the focal firm are subtracted from these patent counts.

binary variable of high (low) science orientation is constructed, which takes the value one if a firm has a high (low) science orientation. We interact the two dummy variables with the interaction term between international R&D dispersion and host countries' academic research strengths to examine whether the moderating effect of the host countries' scientific research strengths depends on the scientific absorptive capacity of firms.

An indicator is constructed to capture the effectiveness of the intra-firm international knowledge integration network (Hypothesis 3) based on intra-firm self-citations on patents. The indicator is measured as the average frequency by which firm's patents invented in different countries cite each other (bilaterally between home and host country)[4]. The frequency of the bilateral self-citations in the firm's patents are calculated as the number of the firm's self-citations between home and host countries (in both directions) divided by the number of patent applications by the firm originated from both home and host countries. Formally, the frequency of the bilateral self-citations of firm k between countries h and j is calculated as follows:

$$\text{frequency of the bilateral self-citations}_{hj,\,k} = \frac{\text{Self Citations}_{hj,k} + \text{Self Citations}_{jh,k}}{\text{Patents}_{h,k} + \text{Patents}_{j,k}}$$

where Self Citations $_{hj,k}$ is the number of self-citations in patents of firm k invented in country h (the home country of the firm) to its own patents invented in host country j, and Patents $_{h,k}$ and Patents $_{j,k}$ are the number of patent applications of firm k invented in respectively countries h and j.

The importance of scale economies in the R&D activities of a firm (Hypothesis 4) is measured as the weighted average level of scale economies characterizing the technologies that are present in the firm's 5 year patent portfolio. The level of scale economies in a technology field is measured by the observed share of large R&D laboratories in a technology field, based

---

[4] Patent citations also occur laterally between firms' foreign subsidiaries located in different host countries. However, only 18% of the international patent citations within MNEs are the lateral knowledge transfer between two host countries according to the patent data for our sample firms. Thus the current measure of intra-firm knowledge transfer would be constructed based on the sufficient majority of the international knowledge flows within the firms.

on the assumption that scale intensive R&D activities are undertaken in large laboratories. Data on the laboratory size for different technologies is taken from surveys conducted by Ambos (2005), Kuemmerle (1998) and Perrino and Tipping (1991).

To test Hypothesis 5, the tacitness of firms' technologies is captured by the weighted average level of tacitness characterizing the technologies that are present in the firm's 5 year foreign-invented patent portfolio. The level of tacitness in a technology field is measured by the observed share of self-citations in total backward citations in the technology field, calculated by technology field based on all patents in the EPO database (1978-2006). The assumption is that intra-firm knowledge flows, measured by self-citations on patents, are observed more frequently in a technology field with a highly tacit nature because transmission of tacit knowledge between different firms is more difficult in these fields. All of the explanatory variables that constitute the interaction terms are mean-centered to reduce potential multicollinearity problems in regression analyses.

Control Variables

We also control for other time-variant firm characteristics that might impact on the technological performance of firms. We first control for a firm's research and development expenditures in the past year, since the technological performance of firms is influenced by the amount of money invested in R&D activities. Second, we include an indicator of firms' patenting propensity measured by firm's patent applications per R&D expenditure in the past year. As technological performance is measured by (citation-weighted) patent counts in this research, we need to take into consideration the degree to which R&D activities of each firm are likely to leads to patent output. Third, we also control for firm size by the number of employees. Finally, the empirical models include time dummies to account for time-specific factors that may affect the number of firms' patents.

Summary statistics and correlations for the variables in the analysis are provided in Table 1 and 2. Summary statistics is based on the original values of the variables before mean-centered, while the mean-centered values (actually used in the regression analysis) are used for the explanatory variables in the correlation table. The average level of international R&D dispersion is 1.79, implying that the average firm has foreign R&D activities of the equal sizes in slightly fewer than two countries. This variable ranges from 1 to 6.26. Extremely strong correlations between variables are not observed according to the correlation table. However, relatively high correlation (0.63) can be found between Country Technological Strength and Country Scientific Research Strength. This would reflect the fact that countries with strong industrial technologies tend to have high-level scientific research bases as well.

Insert Table 1 and 2 about here

Empirical Results

Table 3 reports results of the regression analysis explaining firms' technological performances by the level of international dispersion of firms' R&D and a set of firm characteristics.

Model 1 only includes the control variables to serve as reference case for the other regression models. In Model 2, the variable of the international dispersion of firms' R&D and the main effects of the hypothesis-testing variables are added. Then, a set of hypotheses (H1, H3, H4, H5) on the moderating effects of firm traits on the relationship between international dispersion of R&D and firms' technological performance are tested with interaction terms in Model 3. A positive and significant coefficient for the main effect of international dispersion level of R&D activities is observed suggesting the overall positive impact of R&D internationalization on firms' technological performance after considering the moderating factors. Concerning the moderating effects, the positive and significant coefficient for the interaction between dispersion level and technological strengths of host countries where firms conduct R&D activities confirms Hypotheses 1. The interaction with intra-firm knowledge integration has a positive and significant coefficient as expected (Hypothesis 3). This indicates that effective knowledge transfer network allows a firm to conduct more effective R&D through internationalization. The interaction with scale economies shows a negative and significant coefficient as expected by Hypothesis 4. When there are strong scale economies in a firm's technological portfolio, concentrating its R&D activities in fewer countries leads to the higher technological performance. The coefficient of the tacitness variable is also positive and significant, in support of Hypothesis 5.

To test hypothesis 2, we interact dummy variable of science orientation in Model 4. As expected, interaction effect between international dispersion of R&D and host academic research strengths shows a positive and significant effect only for high science orientation firms. This result confirms the role of firms' scientific absorptive capacity in exploiting scientific knowledge in host countries.

Insert Table 3 about here

In non-linear models, like the Negative Binomial regression models, the sign and significance of the interaction variables are no definitive indication of the sign and significance of the interaction effects. Therefore, we have calculated, for all interaction effects, the value and standard error of the cross-derivative for all sample observations in the main model. The results are presented in Table 4. For all the interaction variables, the cross-derivatives took values with the expected signs for the majority of the sample observations (80, 97, 93, 97, and 96 percent, respectively) and were significant at the 10 percent level for a high percentage of the sample observations. These results confirm that the sign and significance of the above discussed interaction variables reflect the interaction effects.

Moreover, the moderating effect of each hypothesis-testing variable on the relationship between R&D internationalization and firms' technological performance is illustrated in Figures 1 to 5. The mean predicted values of technological performance obtained with the base model and all the observations in the sample are plotted corresponding to varying values of the international R&D dispersion variable and the testing variable of interest (90 percentile, median, and 10 percentile), with keeping the values of the other variables unchanged. For example, to obtain the predicted technological performance of firms with dispersed R&D and low levels of knowledge integration, the 90 percentile value of the R&D dispersion variable and the 10 percentile value of the knowledge integration variable are used for all the observations in the sample. The figures demonstrate that the impact of R&D internationalization on the technological performance of firms depends on the moderating variables. For instance, the performance of firms with weak knowledge integration ranges between 120 (when the firm's R&D is concentrated) and 160 citation-weighted patents (when R&D is dispersed). The predicted technological performance of a firm with strong knowledge integration network varies between 100 when the firm has concentrated R&D, while it rises to 170 when the firm's R&D is international dispersed. This suggests that the effect of internationalizing R&D activities on firm performance is increased if the firm has a strong knowledge integration network. According to the figures, such an effect can be observed (through the slopes of the lines in the figures) for all of the hypothesis-testing variables that are included in the regression models.

Insert Table 4 about here

Insert Figure 1-5 about here

Conclusion

In this paper, we examined the impact of the level of dispersion of international R&D activities using a dataset on patenting activities of 175 high R&D spending European, American and Japanese firms active in five high-tech industries for the period 1995-2002. We developed a set of hypotheses on the firm-level determinants of technological performance and tested these hypotheses by estimating a model explaining the firms' technological performances by firm characteristics.

Our empirical result shows that, on average, the international dispersion of R&D activities has a positive impact on firms' technological performance. Moreover, several environmental and organizational characteristics are found to impact on the relationship between R&D internationalization and firm performance. We find that firms benefit more from an internationally dispersed R&D base when they locate their activities in countries with a strong technology base, and -if they have a sufficient absorptive capacity for scientific research- when the host countries have strong scientific research strengths. Furthermore the benefits of R&D internationalization are larger when firms have an effective intra-MNE knowledge transfer network, and when firms conduct R&D activities in technology fields that are characterized by high levels of tacitness. On the other hand, firms benefit less from R&D internationalization if scale economies are important in firms' technology portfolios.

These results confirm that the relationship between R&D internationalization and firm technological performance is a complex one, which is moderated by a set of environmental and organizational factors. This observation is consistent with the findings of a small set of prior studies that also found qualified evidence for a positive relationship between R&D internationalization and firm performance. As shown in Singh (2008), the present research also shows that an intra-MNE knowledge integration capability is an important condition to benefit technologically from the internationalization of R&D.

Our study adds to the existing literature by unveiling several moderating factors which have been overlooked in the existing literature. Importantly, it sheds light on the role of the characteristics of the technologies that firms have in their portfolio. More specifically, our results show that it is more difficult for firms that operate in scale intensive technologies to benefit from internationally dispersed R&D. To the contrary, firms that are active in technologies that are characterized by high levels of tacitness benefit more from setting up a global R&D network than their counterparts that conduct R&D in more codified technologies. Hence, before firms set up an international R&D network they need to assess the scale-intensive and tacit nature of the technologies that they have in their technology portfolios, as the benefits of R&D internationalization depend strongly on these characteristics.

References

Allen, T. J. 1977. Managing the flow of technology. Cambridge, MA: M.I.T. Press.

Ambos, B. 2005. Foreign direct investment in industrial research and development: a study of German MNCs. Research Policy, 34(4): 395-410.

Argyres, N. 1996. Capabilities, technological diversification and divisionalization. Strategic Management Journal, 17: 395-410.

Argyres, N. 1999. The impact of information technology on coordination: Evidence from the B-2 “Stealth” bomber. Organization Science, 10(2) March-April: 162-180.

Barkema, H. G., & Vermeulen, F. 1998. International expansion through start-up or acquisition: A learning perspective. Academy of Management Journal, 41(1): 7-26.

Belderbos, R. A. 2003. Entry mode, organizational learning, and R&D in foreign affiliates: Evidence from Japanese firms. Strategic Management Journal, 24(3): 235-259.

Belderbos, R., Fukao, K., & Kwon, H. U. 2006. Intellectual Property Rights Protection and the Location of Research and Development Activities by Multinational Firms. ICSEAD Working Paper 2006-02, KitaKyushu.

Branstetter, L., Fisman, R. and Foley, C.F. (2006). Do stronger intellectual property rights increase international knowledge transfer? Empirical evidence from US firm-level data. Quarterly Journal of Economics, 121(1), 321-349.

Cantwell, J., & Piscitello, L. 2005. Recent location of foreign-owned research and development activities by large multinational corporations in the European regions: The role of spillovers and externalities. Regional Studies, 39, 1-16.

Cantwell, J. and Santangelo, G. (2000) Capitalism, profits and innovation in the new techno-economic paradigm. Journal of Evolutionary Economics, 10: 131-157.

Criscuolo, P., & Autio, E. 2008. The impact of internationalisation of research on firm market value. (Mimeo).

De Meyer, A. 1991. Tech talk: How managers are stimulating global R&D communication. Sloan Management Review. 33, Spring: 49-58.

Fors, G. 1997. Utilization of R&D Results in the Home and Foreign Plants of Multinationals. Journal of Industrial Economics, 45(3): 341-358.

Frost, T. 2001. The geographic sources of foreign subsidiaries’ innovation. Strategic Management Journal, 22: 101-124.

Frost, T. and Zou, C. 2005. R&D co-practice and ‘reverse’ knowledge integration in multinational firms. Journal of International Business Studies, 36, 676-687.

Furman, J. 2003. Location and organizing strategy: exploring the influence of location on the organization of pharmaceutical research. In J. A. C. Baum & O. Sorenson (Eds), Geography and Strategy; Advances in Strategic Management, 20: pp. 49-88. Amsterdam: JAI Press.

Furman, J., Kyle, M., Cockburn, I., & Henderson, R. 2006. Public & private spillovers, location and the productivity of pharmaceutical research. NBER Working Paper No. 12509, National Bureau of Economic Research, Massachusetts.

Griffith, R., Harrison, R., & Van Reenen, J. 2006. How special is the special relationship? Using the impact of US R&D spillovers on UK firms as a test of technology sourcing. American Economic Review, 96(5): 1859-1875.

Gupta, A., & Govindarajan, V. 2000. Knowledge Flows within Multinational Corporations. Strategic Management Journal, 21: 473-496.

Hall, B., Jaffe, A., & Trajtenberg, M. 2005. Market value and patent citations. Rand Journal of Economics, 36(1): 16-38.

Harhoff, D., Narin, F., Scherer, F., & Vogel, K. 1999. Citation frequency and the value of patented inventions. Review of Economics and Statistics, 81(3): 511-515.

Hedlund, G. and Nonaka, I. (1993) Models of Knowledge Management in the West and Japan. In Lorange, B., Chakravarthy, B., Roos, J. and Van de Ven, H. (Eds) Implementing Strategic Process, Change, Learning and Cooperation. Macmillan, London.

Hegde, D., & Hicks, D. 2008. The maturation of global corporate R&D: Evidence from the activity of US foreign subsidiaries. Research Policy, 390-406.

Henderson, R., & Cockburn, I. 1996. Scale, scope, and spillovers: the determinants of research productivity in drug discovery. Rand Journal of Economics, 27(1), Spring: 32-59.

Herschey, R., & Caves, R. 1981. Research and transfer of technology by multinational enterprises. Oxford Bulletin of Economics and Statistics, 43(2): 115-130.

Hewitt, G. 1980. Research and Development performed abroad by U.S. manufacturing multinationals. Kyklos, 33(2): 308-327.

Howells, J. R. 1995. Going global: the use of ICT networks in research and development. Research Policy, 24(2): 169-184.

Iwasa, T., & Odagiri, H. 2004. Overseas R&D, knowledge sourcing, and patenting: An empirical study of Japanese investments in the US. Research Policy, 33(5): 807-829.

Kogut, B., & Zander, U. 1993. Knowledge of the firm and the evolutionary theory of the multinational corporation. Journal of International Business Studies, 24(4): 625–645.

Kogut, B., & Zander, U. 1995. Knowledge, Market Failure, and The Multinational Enterprise: A Reply. Journal of International Business Studies, 26(2): 417-426.

Kuemmerle, W. 1997. Building effective R&D capabilities abroad. Harvard Business Review, March/April: 61-70.

Kuemmerle, W. 1998. Optimal scale for research and development in foreign environments—an investigation into size and performance of research and development laboratories abroad. Research Policy, 27(2): 111–126.

Kumar, N. 2001. Determinants of location of overseas R&D activity of multinational enterprises: The case of US and Japanese corporation. Research Policy, 30, 159-174.

Lane, P. J., & Lubatkin, M. 1998. Relative absorptive capacity and interorganizational learning. Strategic Management Journal, 19: 461-477.

Lecocq, C., Leten, B., Kusters, J. and Van Looy, B. 2012. Do firms benefit from being present in multiple technology clusters? The case of biotechnology. Regional Studies, forthcoming.

Leten, B., Belderbos, R. and Van Looy, B. 2007. Technological diversification, coherence and performance of firms. The Journal of Product Innovation Management, 24(6), 567-579.

Martin, X., & Salomon, R. 2003. Tacitness, learning, and international expansion: A study of foreign direct investment in a knowledge-intensive industry. Organization Science, 14(3): 297-311.

Nesta, L., & Saviotti, P. P. 2005. Coherence of the knowledge base and the firm's innovative performance: evidence from the U.S. pharmaceutical industry. Journal of Industrial Economics, LIII: 123-142.

Nobel, R., & Birkinshaw, J. 1998. Innovation in multinational corporations: control and communication patterns in international R&D operations. Strategic Management Journal, 19(5): 479-496.

OECD 2007. Intellectual Assets and International Investment: A stocktaking of the evidence, Report to the OECD Investment Committee DAF/INV/WD(2007)6. Paris: OECD.

Patel, P. and Pavitt, K. 1991. Large firms in the production of the world's technology: An important case of 'non-globalization'. Journal of International Business Studies, 22(1), 1-21.

Pearce, R. 1989. The internationalization of research and development of multinational enterprises. New York: St. Martin's Press.

Pearce, R. 1999. Decentralised R&D and strategic competitiveness: globalised approaches to generation and use of technology in multinational enterprises. Research Policy, 28: 157-178.

Penner-Hahn, J. 1998. Firm and Environmental Influences on the Mode and Sequence of Foreign Research and Development Activities. Strategic Management Journal, 19: 149-168.

Penner-Hahn, J., & Shaver, M. 2005. Does international research and development increase patent output? An analysis of Japanese pharmaceutical firms. Strategic Management Journal, 26: 121-140.

Perrino, A. C., & Tipping, J. W. 1991. Global Management of technology: a study of 16 multinationals in the USA, Europe and Japan. Technology Analysis & Strategic Management, 3(1): 87-98.

Polanyi, M. 1966. The tacit dimension. Doubleday Anchor, New York.

Singh, J. 2007. Asymmetry of knowledge spillovers between MNCs and host country firms. Journal of International Business Studies, 38(5): 764-786.

Singh, J. 2008. Distributed R&D, cross-regional knowledge integration and quality of innovative output, Research Policy, 37(1): 77-96.

Sosa, M. E., Eppinger, S. D., Pich, M., McKendrick, D. G., & Stout, S. K. 2002. Factors that influence technical communication in distributed product development: An empirical study in the telecommunications industry. IEEE Transactions on Engineering Management, 49(1): 45-58.

Todo, Y., & Shimizutani, S. 2008. Overseas R&D activities and home productivity growth: Evidence from Japanese firm-level data. Journal of Industrial Economics, 56(4): 752-777.

UNCTAD 2005. World Investment Report 2005. New York: United Nations.

von Zedtwitz, M., & Gassmann, O. 2002. Market versus technology drive in R&D internationalization: Four different patterns of managing research and development. Research Policy, 31(4): 569-588.

Winter, S. (1987) Knowledge and competence as strategic assets. In Teece, D. (ed.), The Competitive Challenge. Cambridge, MA: Ballinger.

Zahra, S. A., Ireland, R. D., & Hitt, M. A. 2000. International Expansion by New Venture Firms: International Diversity, Mode of Market Entry, Technological Learning, and Performance. Academy of Management Journal, 43(5): 925-950.

Table 1: Descriptive Statistics

(obs=1222)

	Variable	Mean	Std. Dev.	Min	Max
1	Forward Patent Citation Counts (Dep. Var.)	124.79	234.11	0	1780
2	International Dispersion	1.79	0.91	1	6.26
3	Int. Disp. * Country Tech Strength	4.04	2.46	0.11	12.48
4	Int. Disp. * Country Scientific Research Strength	1.38	1.24	0.03	6.33
5	Int. Disp. * Knowledge Integration	0.05	0.09	0	1.23
6	Int. Disp. * Scale Economies	40.60	24.13	8.52	169.44
7	Int. Disp. * Technological Tacitness	0.28	0.15	0.09	0.98
8	Country Technological Strength	2.55	1.56	0.08	6.31
9	Country Scientific Research Strength	0.83	0.74	0.02	3.15
10	Knowledge Integration	0.02	0.04	0	0.30
11	Scale Economies	23.86	10.07	6	50
12	Technological Tacitness	0.16	0.03	0.08	0.25
13	R&D Expenditures	12.41	1.43	7.23	15.63
14	Firm Size by Employee	9.78	1.36	4.85	13.09
15	Firm Patent Stock / R&D exp	0.30	0.31	0	3.61
16	High Science Oriention Firm Dummy	0.51	0.50	0	1

Table 2: Correlations

(obs=1222)

	Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Forward Patent Citation Counts (Dep. Var.)															
2	International Dispersion	-0.02														
3	Int. Disp. * Country Tech Strength	0.03	-0.60													
4	Int. Disp. * Country Scientific Research Strength	0.10	-0.50	0.71												
5	Int. Disp. * Knowledge Integration	0.04	0.19	-0.02	0.13											
6	Int. Disp. * Scale Economies	0.11	-0.39	0.62	0.33	0.21										
7	Int. Disp. * Technological Tacitness	0.03	-0.08	0.00	0.38	0.28	-0.09									
8	Country Technological Strength	0.04	-0.36	-0.01	0.02	-0.01	0.12	0.10								
9	Country Scientific Research Strength	-0.10	-0.16	0.03	-0.20	-0.03	0.09	-0.06	0.63							
10	Knowledge Integration	0.04	0.22	0.01	-0.02	0.32	0.06	0.05	-0.02	0.18						
11	Scale Economies	0.14	-0.22	0.11	0.10	0.04	0.12	0.00	0.33	0.01	0.02					
12	Technological Tacitness	-0.11	-0.04	0.07	-0.09	0.04	-0.01	-0.18	-0.03	0.41	0.28	-0.07				
13	R&D Expenditures	0.59	-0.09	0.00	0.10	0.14	0.15	0.01	0.31	0.06	0.06	0.31	-0.09			
14	Firm Size by Employee	0.54	0.13	-0.10	0.08	0.11	0.04	0.01	0.04	-0.10	0.01	-0.16	-0.17	0.73		
15	Firm Patent Stock / R&D exp	0.02	0.12	-0.06	-0.09	-0.01	-0.06	0.00	-0.17	-0.05	0.06	-0.31	-0.03	-0.35	-0.05	
16	High Science Oriention Firm Dummy	0.09	-0.21	0.15	0.15	0.07	0.10	0.01	0.21	0.03	0.03	0.47	0.03	0.27	-0.02	-0.15

Table 3: Fixed Effect Negative Binomial Analysis of Impact of International Dispersion of R&D Activities and Moderating Factors on Firms' Technological Performance

Dependent Variable: Forward Patent Citation Counts	Model 1	Model 2	Model 3	Model 4
International Dispersion		0.0680	0.1771***	0.1713***
		(0.0438)	(0.0506)	(0.0508)
Int. Disp. * Country Tech Strength (H1)			0.0984**	0.1116**
			(0.0473)	(0.0477)
Int. Disp. * Country Scientific Research Strength			0.1602	
			(0.1013)	
Int. Disp. * Country Scientific Research Strength				0.2327**
* High Science Oriention Firm Dummy (H2)				(0.1074)
Int. Disp. * Country Scientific Research Strength				0.0749
* Low Science Oriention Firm Dummy				(0.1081)
Int. Disp. * Knowledge Integration (H3)			2.1623***	1.9734***
			(0.6375)	(0.6472)
Int. Disp. * Scale Economies (H4)			-0.0090**	-0.0099**
			(0.0046)	(0.0046)
Int. Disp. * Technological Tacitness (H5)			2.0228*	2.0895*
			(1.2294)	(1.2366)
Country Technological Strength		-0.2263***	-0.2269***	-0.2296***
		(0.0378)	(0.0393)	(0.0393)
Country Scientific Research Strength		0.3410***	0.4394***	
		(0.0845)	(0.0873)	
Country Scientific Research Strength				0.4746***
* High Science Oriention Firm Dummy				(0.0912)
Country Scientific Research Strength				0.4290***
* Low Science Oriention Firm Dummy				(0.0911)
Knowledge Integration		-0.5814	-2.0203***	-1.8917***
		(0.6576)	(0.7076)	(0.7103)
Scale Economies		0.0019	0.0022	0.0024
		(0.0054)	(0.0053)	(0.0053)
Technological Tacitness		6.8723***	7.8278***	7.5488***
		(1.3649)	(1.4341)	(1.4459)
R&D Expenditures	0.1788***	0.2843***	0.3164***	0.3184***
	(0.0443)	(0.0491)	(0.0499)	(0.0497)
Firm Size by Employee	0.2850***	0.2460***	0.2667***	0.2709***
	(0.0419)	(0.0463)	(0.0475)	(0.0477)
Firm Patent Stock / R&D exp	0.6642***	0.6904***	0.7152***	0.7243***
	(0.0728)	(0.0744)	(0.0754)	(0.0753)
High Science Oriention Firm Dummy				-5.0836***
				(0.4924)
Low Science Oriention Firm Dummy				-5.0678***
				(0.4885)
Year Dummies	Included	Included	Included	Included
Constant	-3.5002***	-4.4973***	-5.0209***	
	(0.4600)	(0.4780)	(0.4896)	
No. of Observations	1222	1222	1222	1222
No. of Firms	175	175	175	175
Log Likelihood	-4393***	-4343***	-4321***	-4318***
LR test	N.A.	2.34	44.90***	N.A.

Notes: ***, **, * indicate significance of coefficients at the 1, 5 and 10 percent levels. Standard errors are reported in parentheses.

Table 4: Signs and Significance of Interaction Effects by Positive and Negative Values of Cross-derivatives

Variable	Total Obs.	Positive	Positive at 10% Significance	Negative	Negative at 10% Significance
Int. Disp. * Country Tech Strength	1222	971	512	251	66
		79.5%	41.9%	20.5%	5.4%
Int. Disp. * Country Sci. Res. Strength	1222	1188	868	34	5
		97.2%	71.0%	2.8%	0.4%
Int. Disp. * Knowledge Integration	1222	1134	973	88	9
		92.8%	79.6%	7.2%	0.7%
Int. Disp. * Scale Economies	1222	36	6	1186	814
		2.9%	0.5%	97.1%	66.6%
Int. Disp. * Technology Tacitness	1222	1178	771	44	5
		96.4%	63.1%	3.6%	0.4%

Figure 1: Predicted Values of Firms' Technological Performance in function of International Dispersion of R&D Activities and Country Technology Strength

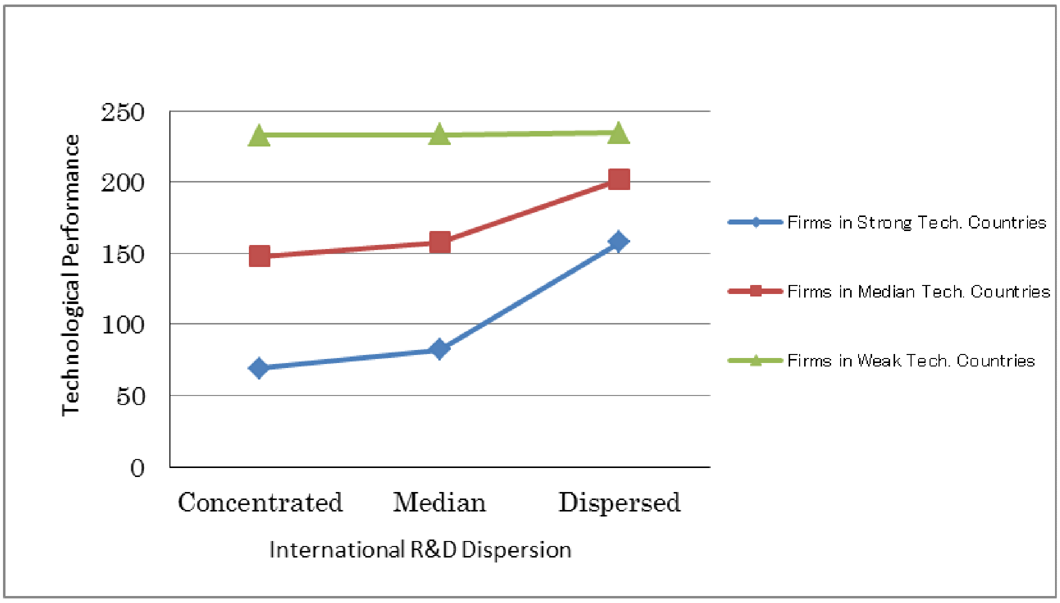

Figure 2: Predicted Values of Firms' Technological Performance in function of International Dispersion of R&D Activities and Country Scientific Research Strength

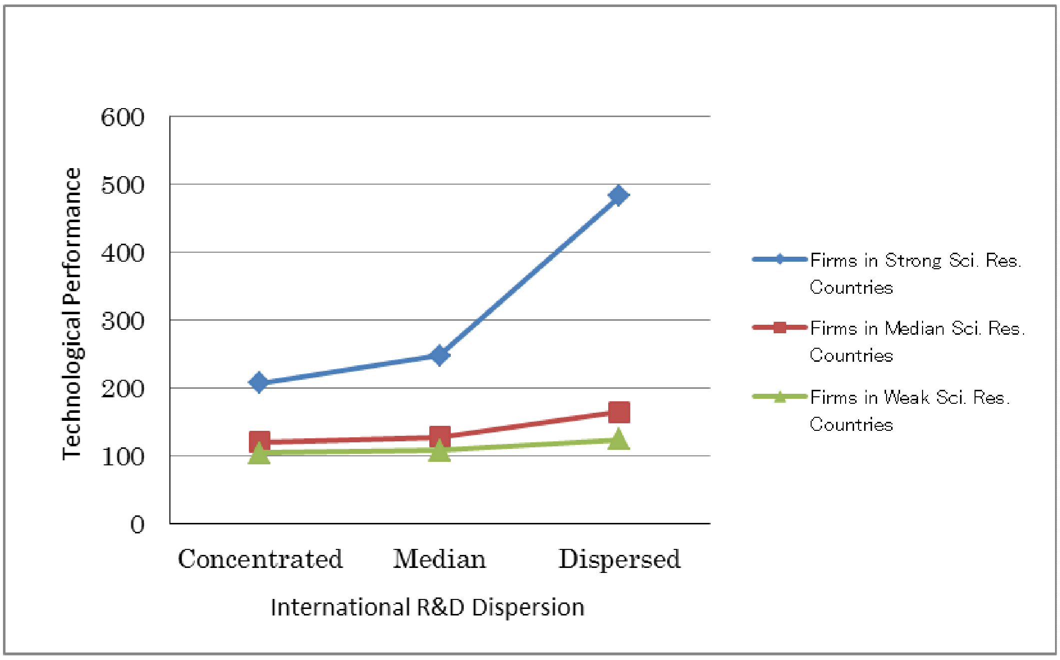

Figure 3: Predicted Values of Firms' Technological Performance in function of International Dispersion of R&D Activities and Intra-Firm Knowledge Integration

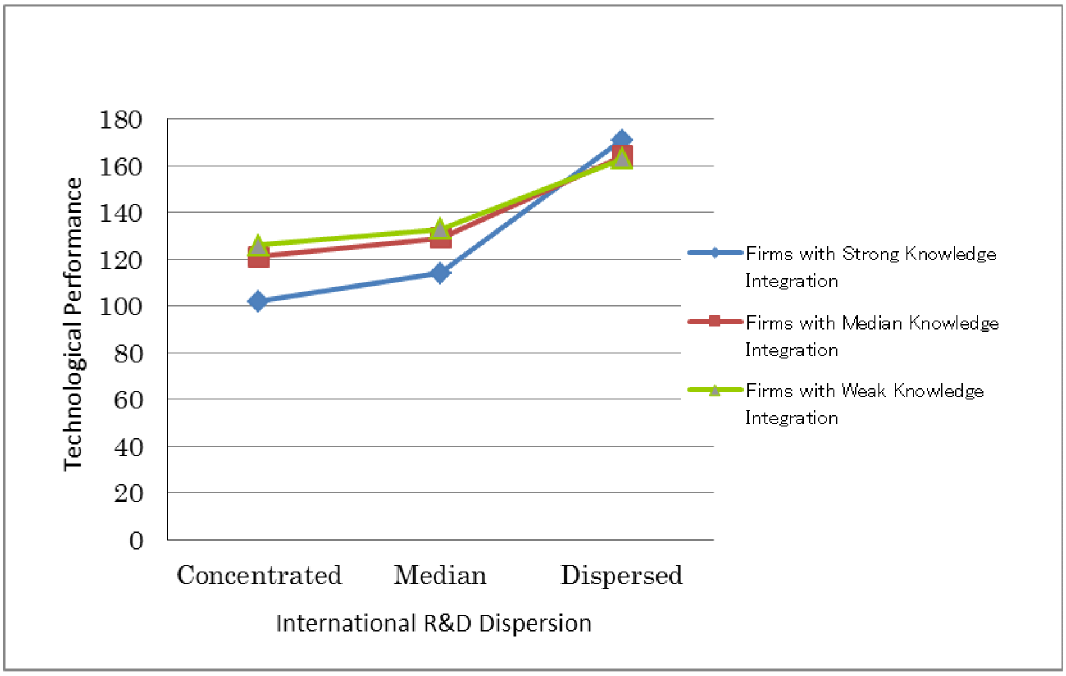

Figure 4: Predicted Values of Firms' Technological Performance in function of International Dispersion of R&D Activities and Scale Economies in Firm Technologies

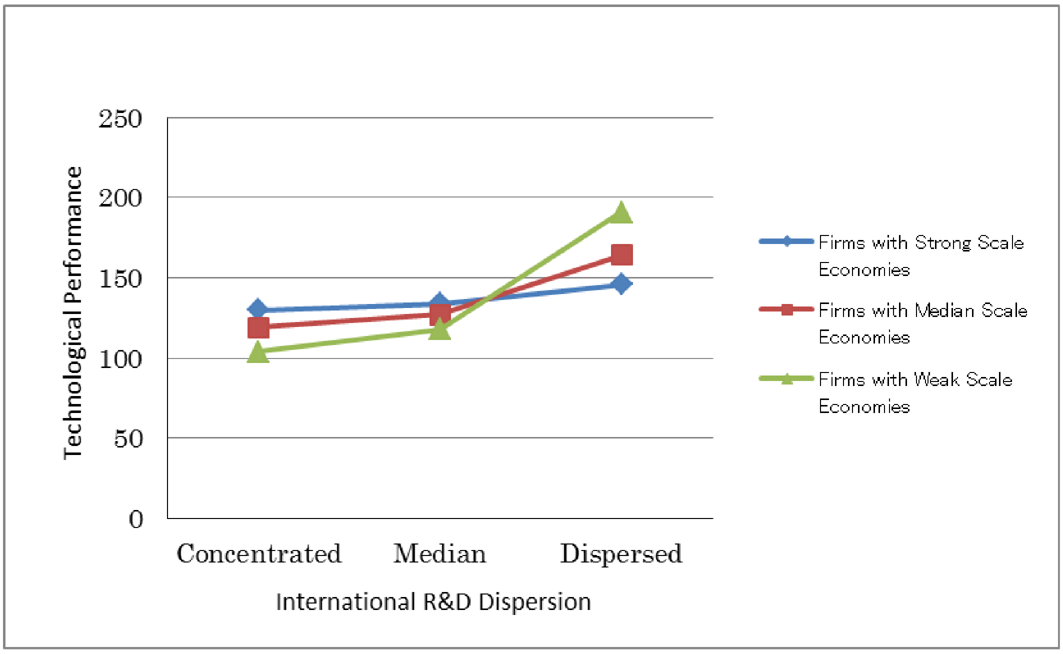

Figure 5: Predicted Values of Firms' Technological Performance in function of International Dispersion of R&D Activities and Technological Tacitness