Global R&D and Firm Innovation*

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Global R&D and Firm Innovation

Abstract

This study explores how firms can strategically overcome the challenges of global innovation by capitalizing on scientific connections of their home country to the host countries of their R&D locations. We focus on the scientific connectedness fostered by the countries' joint participation in learning-oriented Inter-Governmental Organizations (IGOs). We propose that when a firm locates its R&D units in countries with greater scientific connectedness to its home country, greater commonality in knowledge approaches among the firm's R&D units allows it to capitalize on diverse sources of knowledge for greater innovation. We expect firm collaborative capability to moderate this relationship as it allows firms to derive greater value from accessed knowledge resources. A sample of U.S. semiconductor firms from 2000-2005 provide support for our hypotheses.

Introduction

Establishing overseas R&D locations offers a firm the opportunity to access diverse, distinct, and useful knowledge (Bartlett and Ghoshal, 1986; Almeida and Phene, 2004). Combining and utilizing knowledge from different national contexts can play a vital role in the creation of new technologies and products (Kuemmerle, 1997; Blomkvist, Kappen and Zander, 2010). As a result, firms internationalize their R&D in an attempt to create a competitive advantage over their rivals (Lahiri, 2010; Berry, 2014).

However, to derive innovation benefits from global R&D, it is necessary to successfully unify, integrate, and co-ordinate locally developed knowledge and capabilities from the dispersed sites (Dellestrand and Kappen, 2012). This is a significant challenge for firms. As a growing literature indicates, realizing synergies between R&D locations and managing dispersed knowledge activities within the firm pose substantial difficulties (Capozzi, Biljon and Williams, 2013; Mors, 2010; Gupta and Govindarajan, 2000; Nobel and Birkinshaw, 1998).

In this paper, we explore how firms can strategically overcome the difficulties associated with global R&D. In particular, we examine how firms can enhance their innovation by capitalizing on scientific connections of their home country to the host countries of their R&D locations. We focus on the scientific connectedness fostered by the countries' joint participation in learning-oriented Inter Governmental Organizations (IGOs). Prior research has indicated that such scientific connectedness promotes the development of similar rules, practices, and common frames in knowledge based activities among participants (Meyer, Boli, Thomas and Ramirez, 1997; Drori, Meyer, Ramirez and Schofer, 2003). Thus, when a firm locates its R&D units in countries with greater scientific connectedness to its home country, a foundation of commonality in approaches to knowledge creation is established among the firm's R&D units. This facilitates leveraging novel foreign knowledge

(Levin and Barnard, 2013). Consequently, the firm can enhance innovation by capitalizing on foreign sources of knowledge.

We extend our analysis by examining how firm collaborative capability can moderate the above relationship. Prior research indicates that collaborative capability enables the creation of rich mechanisms and routines that facilitate the utilization and integration of complex knowledge (Rosenkopf and Almeida, 2003; Davis and Eisenhardt, 2011). We propose that collaborative capability of the firm complements the commonality advantage of scientific connectedness, by enabling the firm to derive greater value from accessed knowledge resources through better utilization and mobilization.

We test our hypotheses in a panel of U.S. semiconductor firms observed over the period 2000 to 2005. We find that firms with R&D centers in host countries that are scientifically connected countries to the home country are more innovative. We also find that firm collaborative capability positively moderates this relationship and strengthens the effect.

Theory

The attraction of cross-border knowledge for the firm is evident - the presence of diverse set of technical inputs, varying expertise, and embedded capabilities enable worldwide operations to generate new innovations and technologies (Berry, 2014; Blomkvist et al, 2010). Consequently firms often establish overseas R&D subsidiaries to access foreign knowledge (Almeida and Phene, 2004). However, in order to enable the development of technological and cognitive capabilities that permit better knowledge sourcing and absorption, firms encourage subsidiaries to specialize in the technological areas that represent national advantages of the host country (Belderbos, 2003; Zander, 1997), and the firm's R&D units become embedded in their host environments.

Since the manner in which knowledge is formed and used within an organization is powerfully shaped by its institutional context (Lam, 2000; Boisot, 1995), overseas subsidiaries develop distinct roles, routines, capabilities, and technological expertise and become differentiated across countries (Pearce, 1989; Frost et al, 2002). Despite the common organizational context, the practices of foreign subsidiaries reflect the regulatory, cognitive, and normative aspects of the institutional environment of their host country (Scott, 1995; Kostova, 1999; Busentz, Gomez and Spencer, 2000). This includes the manner in which external stimuli are perceived, interpreted, understood, and evaluated, as well as approaches to knowledge and information (Nooteboom, 2009; Bertrand and Mol, 2012). For example, De Camprieu, Desbiens and Feixue (2007) demonstrate that participants in the same project management program located in China and Canada relied on different factors to assess the risk of a large electricity project. Similarly, managers based in China and Finland working together on a project for the same company developed separate and distinct responses to an unexpected event in the project (Tukiainen, Aaltonen and Murtonen, 2010). Thus individuals and managers in different countries within a firm may demonstrate varying approaches and practices. As a result, the firm has been conceptualized as consisting of semi-autonomous entities in dispersed locations taking on various missions and controlling heterogeneous stocks of knowledge (Bartlett and Ghoshal, 1989; Foss and Pedersen, 2002).

While subsidiary differentiation within the firm is useful for accessing distinctive local knowledge with the potential for recombination and innovation (Gupta and Govindarajan, 2000), it nonetheless poses difficulties for leveraging knowledge within the firm. Differentiation and the underlying variation in approaches hinder the ability to understand and engage in cross border knowledge transfers (Bhagat, Kedia, Harveston, Triandis, 2002). Lam (1996, 1997) documents the differences in approaches to technical work and knowledge organization in Japan and Great Britain. The two countries developed distinct approaches to knowledge due to national differences in skill formation, education systems, labor market structures, and technological heritage. Engineers trained in the British system tended to emphasize theoretical knowledge and specialized in conceptual design and development activities. In contrast, Japanese engineers were more focused on practical knowledge with a broader industry emphasis. She further demonstrates that these differences led to arduous knowledge interactions, inhibiting collaboration and impeding knowledge transfer in global co-operative ventures between Japanese and British high technology firms. Similarly, in a case study of a learning alliance between Chinese and Singaporean teams to develop an industrial park, Inkpen & Pien (2006) found that the knowledge transfer between the teams was fraught with challenges despite the seeming similarities of culture and language. The two sides emphasized different norms and criteria reflecting their respective national systems. The Singapore team aimed to transfer the ‘software’ of how to do things the Singaporean way, with their emphasis on financial discipline, long-term master planning and continuing service to investors. The Chinese side, however, was looking for the ‘hardware’ such as buildings, roads, infrastructure that they could build to attract foreign investors as Chinese government officials were often evaluated on the FDI they brought to their cities. As a result, the initial years were a struggle for both sides. As these examples indicate, the incompatibility between the knowledge approaches across countries leads to poor communication, misunderstanding of specifications, and clashes in approaches to development. Correspondingly, diverse subsidiaries are less receptive to knowledge from other parts of the firm (Ambos & Ambos, 2009; Berry, 2014). Such differences limit internal transfer and deployment of knowledge within the firm, challenging transnational product development (Subramaniam and Venkatraman, 2001).

A related, but different, stream of literature also highlights similar challenges of knowledge integration in firms. The absence of prior related knowledge or absorptive capacity hinders knowledge absorption and transfer (Hansen, Mors and Lovas, 2005; Lane and Lubatkin, 1998) within the firm (Song and Shin, 2008). Absorptive capacity is the ability to recognize the value of new information, assimilate it, and apply it to commercial ends (Cohen & Levinthal, 1990). It depends not only on a stock of related scientific or technological knowledge, but also on similarities in the organization and processing of knowledge, reflected in problem solving approaches and heuristics (Cohen and Levinthal, 1990). Drawing an analogy, Lane and Lubatkin (1998) note that just as a computer program functions correctly only on other computers using the same operating system on which the program was built, knowledge transfer between (or within) firms is enhanced in the presence of similar ground rules or knowledge processing systems. Similarly, Dyer & Singh (1998) propose that in addition to overlapping knowledge bases, socio-technical interactions that develop common ground rules are an important component of knowledge transfer. Common approaches and norms for organization and processing of knowledge not only facilitate access to new information, but also provide a shared conceptual apparatus for evaluating the likely benefits of exchange and combination (Nahapiet & Ghoshal, 1998).

Thus, as firms internationalize their R&D functions, they are faced with a particular challenge of enabling commonality in approaches to knowledge processing across their subsidiaries in order to successfully leverage and share knowledge acquired and developed by R&D subsidiaries. Our study explores the role of scientific connectedness across countries in establishing this critical foundation for commonality. We propose that firms with R&D structures that build on this foundation are able to overcome barriers to knowledge transfer and are more effective at leveraging distinctive knowledge thereby enhancing innovation. We further posit that firms with greater collaborative capability are better able to derive greater value from the knowledge accessed through the common foundation of scientific connectedness, increasing innovation.

Firm R&D locations and home-host country scientific connectedness

Studies in world polity and international business have shown that actors in countries with dense international ties tend to adopt similar behavior, policies, and practices (Simmons and Elkins, 2004; Meyer et al, 1997). The global links provide an avenue for communication and interaction among actors across countries and establish a common regulatory, cognitive and normative framework (Perez-Aleman, 2011; Finnemore and Sikkink, 1998). As a result, an important source of commonality across countries arises from international connectedness.

Intergovernmental organizations (IGOs) have been identified as one of the key institutions facilitating global integration and connectedness (Dobbin, Simmons and Garrett, 2007; Meyer et al, 1997). With countries as members (Pevehouse, Nordstrom and Wanke, 2004), IGOs serve as venues for information exchange and where people come to appreciate others' points of view (Dorussen and Ward, 2008). Through activities like workshops and meetings, they not only promote repeated interactions among actors from different member countries, but also shape values and norms, create social knowledge, and coordinate government policy (Cao, 2009; Barnett and Finnemore, 1999; Finnemore, 1993).

We explore IGO linkages between the firm's home country and host countries of its R&D locations. This is because the home country exerts an important influence on R&D operations of firms by shaping their capabilities, outlook, and practices (Belderbos, Leten and Suzuki, 2013; Kogut, 1991) and home country IGO linkages have been shown to have an important influence on the strategic behavior of firms (Soule, Swaminathan and Tihanyi, 2014). Further, firms concentrate a vast majority of their R&D activities in their home countries (Berry, 2014). Thus, firms typically need to integrate knowledge of their overseas R&D units with that at the home country location.

Given our focus on innovation, we examine the scientific connectedness of the home country to the host countries of firm R&D locations, by considering their joint participation in learning-oriented IGOs. Learning-oriented IGOs have a specific mandate for knowledge sharing and transfer, by enhancing information access among members, or increasing international linkages in the scientific realm, or facilitating economic transactions (Jandhyala and Phene, 2013).

Learning-oriented IGOs foster a similar approach to science and technology among participants (Drori, Meyer, Ramirez and Schofler, 2003).As Jandhyala and Phene (2013) note, country connectedness through learning-oriented IGOs facilitates the development of shared science and technology related policies and practices in several ways. First, connectedness creates convergence across legal, regulatory and contractual issues across member countries. Participant countries establish similar science bureaucracies (Finnemore, 1993) and coordinate science policy responses. They also normalize technological standards[1] and intellectual property protection. For example, the common terms of intellectual property protection for layout designs of integrated circuits are established through the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization and the Washington Treaty facilitated by the World Intellectual Property Organization. Second, IGO connectedness creates greater cognitive overlap among members. This is facilitated through the organization of regular and repeated interactions for the purpose of policy formulation and technology development and exchange, via scientific meetings, conferences, and other events that bring together a group of diverse constituents, including policy makers and representatives from national laboratories and firms from member countries. Third, IGO bureaucracies also help to develop shared normative frames. The bureaucracies consist of a permanent secretariat and a staff of international civil servants that not only embody institutional, scientific, and technical knowledge but also control the flow of

[1]By establishing industry wide procedures and standards, IGOs fulfill functions similar to cooperative technical organization (CTO) identified by Rosenkopf & Tushman (1998). However, they also differ from CTOs in that they typically have a broader agenda than technical coordination, membership is limited to countries (rather than firms, academia, etc.), and members (governments) have the sovereign authority to implement coordinated rules or standards through legal, institutional or bureaucratic means.

information, values, and cultures among participants through administrative, scientific, and diplomatic activities. Training and professionalization programs push forth these common norms among diverse participants. Scientific connectedness across countries, through participation in learning-oriented IGOs, therefore reflects the extent to which constituents in these countries share science and technology related policies, practices, and values.

The development of shared policy, cognitive and normative frames facilitated by IGO activities is important to creating a foundation of scientific commonality and shared understanding across actors from participating countries. This common frame of reference improves the salience of cross-border knowledge and increases diffusion of knowledge and practices across countries. Nonetheless, the literature has shown that diversity among countries is far from extinct, even among internationally connected countries (Guillen, 1994; Berry, Guillen & Hendi, 2014). As a result, establishing R&D centers even in scientifically connected countries provides access to unique, distinct, and useful knowledge to the firm which can be leveraged for greater innovation.

Consequently, we posit that when a firm's overseas R&D centers are located in countries that have more scientific connections to its home country, the common frames of reference lower the barriers to integrating overseas knowledge. As a result, such firms are better able to exploit the distinctive knowledge from the overseas R&D units for increased innovation. In contrast, firms with R&D centers in less connected countries have to overcome significant barriers to leveraging knowledge, and are less innovative. Thus, we propose the following

H1: Firms with R&D locations in host countries that have greater learning-oriented IGO connections to their home country are more innovative than firms with R&D locations in host countries with fewer learning-oriented IGO connections.

Moderating effect of collaborative capability

Although learning-oriented IGOs can help to lower barriers to cross-border knowledge transfer for all firms, we propose that the extent of the effect is likely to be higher in the presence of firm capability to complement the process. In particular, we expect a firm's collaborative capability to play a moderating role. This capability arises from prior inter-organizational relationships focused on joint technological development and indicates the firm's ability to manage different sets of innovation processes. Firms with greater levels of collaborative capability have established rich supporting mechanisms such as social capital or norms (Walker, Kogut and Shan, 1997) to govern and improve the coordination of technology and knowledge sharing (Oxley and Wada, 2009). Collaborative capability also indicates experience with reconciling decision making rules for managing R&D, aligning objectives, and working with groups having different expertise (Brown & Eisenhardt, 1997; Davis and Eisenhardt, 2011). This experience is likely to be useful in knowledge exchanges between teams characterized by international differences (Haas and Cummings, 2014). Thus, firms with high collaborative capabilities are not only better able to access and leverage external knowledge, but are also better positioned to take advantage of the lowered barriers to cross-border knowledge transfer arising from IGO connectedness. By enabling better usage of accessed knowledge resources, collaborative capability can serve as a useful complement to the commonality advantage of scientific connectedness and result in stronger innovation outcomes.

H2: Firm collaborative capability strengthens the relationship proposed in H1, such that firms with R&D locations in host countries that have greater IGO connections to their home country are more innovative the greater the firm's collaborative capability.

Data and Methods

Our data setting is firms from the U.S. semiconductor industry. Innovation is very important in this industry (Sorenson and Stuart, 2000) and there has been a movement towards global R&D by semiconductor firms who seek to utilize knowledge from across the world (Almeida, Grant and Song, 2002). Patenting is actively pursued in this industry and every major firm regardless of national origin has an extensive portfolio of patents granted under the U.S. patent system (Almeida and Kogut, 1999) that include innovations created in the U.S. and overseas (Phene and Almeida, 2008). Although there are limitations associated with using patent data to represent innovation, patent portfolios of semiconductor firms provide an accurate representation of their innovation (Almeida and Phene, 2004). We utilize data from the Fleming Patent Dataverse Network (Lai, D'Amour, Yu, Sun and Fleming, 2011), Compustat North America, the Correlates of War dataset, the Yearbook of International Organizations and the UN Comtrade dataset. To construct our sample, we first used the Fleming Patent Dataverse Network to identify U.S. firms[2] that filed for at least one patent in one of the semiconductor technology classes[3] during the period 2000 to 2005. Next, we retained those firms that were matched to the semiconductor firms listed in Compustat North America with primary SIC code 3674 or NAICS code 334413 (Ceccagnoli, 2009). This resulted in a set of 92 firms that are observed from 2000 to 2005. Our unit of analysis is a firm-year with a sample size of 362 observations[4].

Variables

We use patent and citation data to construct several variables. We follow prior researchers (Rosenkopf and Almeida, 2003; Phene and Almeida, 2008) in using information regarding the geographic location of the first inventor to identify the country where innovation is created, the assignee name to determine the firm that generates the innovation, and the application date to represent the year of innovation.

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[2] We used the USPTO classification on assignee type to identify a U.S. firm. USPTO classifies assignees into several types, with assignee type 2 representing U.S. firms (Lai, D'Amour, Yu, Sun, Torvik and Fleming, 2011).

[3] Semiconductor technology classes included 25 primary classes categorized as belonging to the semiconductor industry by the USPTO Technology Profile Report (Jiang, Tan and Thursby, 2011)

[4] We have an unbalanced panel because some firms had missing financial data in Compustat in some years and not all firms began patenting in 2000.

Dependent Variable

Firm innovation is measured as the total number of semiconductor patents applied for by (and subsequently granted to[5]) the firm in year t. Patents are externally validated by patent examiners, and provide a valid and robust representation of organizational innovation (Joshi and Nerkar, 2011; Schilling and Phelps, 2007).

Independent Variables

We measure our independent, moderator and control variables at time t-1 to avoid contemporaneous correlations.

Scientific connectedness of home country to host countries of firm R&D locations is constructed as follows. We use patent data to identify all the foreign locations[6] in which the firm undertakes R&D in a year, by determining if the firm filed for a patent with an inventor location in the foreign country in that year. Next we collect data on all IGOs formed by the home country of the firms (i.e the U.S.) from the Correlates of War Database, the most extensive source on IGO memberships (Pevehouse, Nordstrom and Warnke, 2004). Since our focus is on the sub-set of learning-oriented IGOs, we collected additional data on each IGO's principal objectives/aims from the Yearbook of International Organizations[7]. We reviewed these objectives/aims and classified IGOs as learning-oriented[8] if they had a specific mandate for knowledge sharing and transfer, facilitating economic transactions, or enhancing information access among members. IGOs that did not demonstrate these objectives were classified as "others" and not included in our analysis. Our coding scheme and examples of learning-oriented and other IGOs are indicated in Table 1.

[5] We follow prior research in using the patent application year to determine the year of innovation (Almeida, Phene and Li, 2014; Rosenkopf and Almeida, 2003). Patents applied for by the firm could be granted in the same or subsequent years (Popp, Juhl and Johnson, 2003)

[6] Since our sample includes only U.S. firms, all foreign countries are non-U.S.

[7] In cases where this information was not available in the Yearbook, we supplemented it with information from the IGO website.

[8] Two independent coders read the primary aims of each IGO to classify it as a learning-oriented IGO with an inter-rater reliability of ~0.75. The coders then discussed differences to come to a consensus.

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Next, we gathered information on the number of learning-oriented IGOs existing between the home country and each of the foreign countries identified as being part of the firm's R&D locations in the earlier step. We also collected information on the total number of learning-oriented IGOs existing between the home country and all foreign countries (regardless of whether they were part of the firm's R&D locations for each year). Our measure of alignment at time t-1 is then constructed as:

$$\frac{\sum_{c=0}^{N} K_{c,t-1}}{N_{t-1}K_{t-1}}$$

where $K_{c,t-1}$ is the number of learning-oriented IGOs that the U.S. has with country c in year t-1, c is a foreign country in which the firm undertakes R&D in year t-1 and ranges from 0 to N. N is the total number of countries in which the firm undertakes R&D and K is the total number of learning oriented IGOs formed by the U.S at time t-1[9]. A higher value on this measure reflects greater scientific connectedness among a firm's R&D locations.

Moderator variable

Collaborative capability of the firm: Collaborative capacity is measured as the percentage of patents generated through collaboration in year t-1.Since collaborative R&D can take many forms (Sakakibara, 1997) and can also include informal mechanisms, we focus on the outcomes of such collaboration, i.e. by identifying collaborative patents or patents co-filed with at least one other assignee firm (Lechevalier, Ikeda and Nishimura, 2011).

Control variables

Our model includes a number of control variables that have implications for firm innovation. As a *firm's knowledge stock* has implications for future innovation (Eggers, 2012), we control

[9] We create our measure by dividing by K, the total number of learning oriented IGOs that exist between the U.S. and all other countries in that year, in order to scale our measure and account for the general increase in IGO formation over the years.

for this using [10] the five year stock of patents generated by the firm till year t-1. *Technological breadth of firm knowledge* enables the firm to pursue innovation (Miller, Fern and Cardinal, 2007) and is manifested in the firm's patenting profile (Srivastava and Gynawali, 2011). Following prior researchers we control for this using the distribution of the firm's patents in each year across the different semiconductor classes (Almeida and Phene, 2004). The measure is calculated as follows:

$$1-\left(\sum_{k=1}^{N}F_{k,t-1}^{2}\right)$$

Where $F_{k,t-1}$ represents the fraction of the firm's patents filed in semiconductor patent class k in year t-1, and k varies from 1 to N. High values of this variable represent greater technological breadth.

Prior research has also indicated that firms with extensive internal and external linkages – i.e. firms with high within-firm and external citations – can better access knowledge resources to be used for innovation (Phene and Almeida, 2008). Thus, we control for these two factors as follows. *Firm internal linkages* are measured as the percentage of within firm cross country citations, to total citations made by the firm patent portfolio at time t-1[11]. *Firm external linkages* are measured as the percentage of citations to external constituents by the firm, to total citations made by the firm patent portfolio at time t-1. The technological richness of the foreign countries in which the firm has global R&D locations can enhance firm innovation (Almeida and Phene, 2004). We therefore control for the *technological richness of the firm's global R&D locations*[12] in the prior year, as follows:

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[10] We present means and correlations for the actual five year stock of patents in Table 2 and 3. For the regression analysis in Tables 4 and 5, we use a scaled measure dividing patent stock by 100 to obtain meaningful coefficients.

[11] Within-firm citations do not include pure self-citations, i.e. citations by patents filed by the firm in one country to itself. As an example, our within firm citations do not include Texas Instruments (TI) France citing itself. They do include TI France citing TI Japan or TI U.S. citing TI Japan.

[12] Since we are interested in the technological richness of the overseas locations in the firm's R&D network, we do not include the technological richness of the home country, i.e. the U.S.

$$\frac{\sum_{c=0}^{N} P_{c,t-1}}{N_{t-1}}$$

Where P_{ct-1} is the percentage of world semiconductor patents filed by country c in year t-1, c is a foreign country in which the firm undertakes R&D in year t-1 and ranges from 0 to N. N is the total number of countries in which the firm undertakes R&D in year t-1.

In addition, we control for *firm size* measured as the natural log of total assets, with larger size reflecting greater access to resources to support innovative efforts. *Firm R&D intensity*, the percentage of R&D expenses to total sales, influences the extent to which the firm pursues innovation (Cohen and Levinthal, 1990). *Firm leverage,* measured as the ratio of long term debt to common equity, is included to control for the firm's risk orientation and propensity to engage in innovation. Finally, *firm profitability*, reflected by the percentage return on equity, can influence availability of resources for innovation.

Methods

Negative binomial regression models are particularly well suited to dependent variables such as patent counts that take on only non-negative integer values (Hausman, Hall & Griliches, 1984). We follow prior researchers (Lahiri, 2010; Phene and Almeida, 2008) and use a negative binomial regression with a random effects specification[13] that includes firm effects and year controls.

Results

The summary statistics for our variables are presented in Table 2 and our results in Table 3.

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[13] We conducted a Hausman test to determine whether a random or fixed effects specification is appropriate. The test with a Chi square statistic of 10.15 and a p value of 0.8971, indicated that a random effects specification was appropriate for our data. Nonetheless, we include a fixed effects specification in our robustness tests.

We find a significant and positive effect of scientific connectedness of the home country to the host countries of the firm's global R&D locations on innovation. Thus, H1 is supported. Locating R&D sites in countries with greater scientific connectedness increases firm innovation. Examining the co-efficient of scientific connectedness reveals that a one standard deviation increase in this measure, while holding other variables at their mean values, results in an increase in firm innovation by 13%. This corresponds to about 11 additional patents for an average firm whose R&D units are in highly scientifically connected countries compared to a firm with R&D units in countries with average scientific connectedness.

We also find support for the positive moderating effect of firm collaborative capability, which enhances the effects of scientific connectedness on innovation. H2 is supported. Brambor, Clark and Golder (2006) suggest that true interaction effects between continuous variables in non-linear models need to be assessed by performing additional analysis of marginal effects. We adopt this approach and conduct additional analysis of the marginal effects at different levels of firm collaborative capability. Figure 1 presents these results.

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We find that the average marginal effect of scientific connectedness on innovation is higher as firm collaborative capability increases. Figure 1 validates the significance for our interaction term. We consider the magnitude of our interaction effect at different levels of collaborative capability. A one standard deviation increase in scientific connectedness (Model 3, holding all other variables including collaborative capability at their mean values) results in an increase in innovation of 13%. However, a similar one standard deviation increase in scientific connectedness when collaborative capability is high (1 SD above the mean for collaborative capability, other variables at mean values), results in an increase in innovation of 17%. Thus firm collaborative capability serves as a complement to the commonality provided by scientific connectedness, with a stronger effect of scientific connectedness on innovation at higher levels of collaborative capability.

Our control variables demonstrate expected patterns with positive and significant effects of firm characteristics - collaborative capability, knowledge stock, technological breadth, internal linkages through citations and size – as well as the technological richness of the host countries of firm R&D locations.

Robustness tests

We conduct a series of additional robustness tests and present these in Table 4.

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Two of our variables, firm size and firm external linkages, have variance inflation factors above the commonly recommended value of 10 (Kennedy, 1992). We therefore run our regression by omitting each of these variables in Models 4 and 5 and find that our results are the same. Second, firm innovation may be a consequence of the global dispersion of R&D activity rather than the scientific connectedness of R&D. We construct a control that measures global dispersion of R&D activity as follows:

$$1-\left(\sum_{c=0}^{N} S_{c,t-1}^{2}\right)$$

Where $S_{c,t-1}$ represents the fraction of the firm's patents filed in country c in year t-1, and c varies from 0 to N. We add this control in Table 4, Model 6 and find that our results stay the same. Third, in order to ensure that the outcomes are attributable to scientific connectedness and not to other forms of international connections such as through exports or imports, we construct two additional controls that determine trade connectedness between the home country and host countries of R&D locations. We collected additional data on a) total trade and b) trade in semiconductors[14] between the home country and each of the countries in which the firms in our sample had R&D locations, by using the UN Comtrade database. We then constructed a measure of trade connectedness in a manner similar to that used for our independent variable as follows:

$$\frac{\sum_{c=0}^{N} T_{c,t-1}}{N_{t-1}}$$

where Tc,t-1 is the share of trade between the U.S. and country c, compared to total U.S. trade in year t-1, c is a foreign country in which the firm undertakes R&D in year t-1 and ranges from 0 to N; and N is the total number of countries in which the firm undertakes R&D in year t-1. An additional measure of trade connectedness was similarly constructed by using trade in semiconductors. We add each of these controls, trade connectedness to Model 7 and semiconductor trade connectedness to Model 8, and present our results. We find that our results are robust to the inclusion of these controls.

Fourth, we drop the observations of firms that do not have overseas R&D and retain only those observations of firms with at least one overseas R&D location in the prior year, resulting in a reduced sample of 48 firms and 230 observations, in Model 9. Again we find that our results are robust. Finally, we include a negative binomial regression with fixed effects (in Model 10). We also use a quasi-maximum likelihood model with fixed effects (in Model 11) that is a good alternative to the negative binomial regression model (Kaul, 2012) and overcomes drawbacks associated with conditional fixed effects negative binomial regression (Allison and Waterman, 2002). Our results remain robust.

Discussion and Conclusions

Our study complements research on globalization of innovation by the firm. Penner- Hahn and Shaver (2005) argue that although global R&D can enable innovation, it appears to do so

[14] Trade in semiconductors was defined as trade in the Harmonized System (HS) category 85, which encompasses semiconductor devices, light-emitting diodes, printed circuits, electronic integrated circuits, carbon electrodes, electric resistors, transformers and capacitors, static converters, electromagnets, electric storage batteries and primary cells

only for some firms. Consequently they call for an exploration of the conditions under which global R&D enhances firm innovation. We respond to this call and demonstrate that locating R&D in countries that are scientifically connected to the home country increases innovative output by creating a foundation of commonality. Since knowledge diffusion across national boundaries is difficult (Jaffe, Trajtenberg and Henderson, 1993; Keller and Yeaple, 2009) and these challenges exist even within the firm (Haas and Cummings, 2014), strategic choices regarding the location of R&D centers are important for maximizing benefits from global R&D. Our findings regarding R&D locations and scientific connectedness complement existing research that suggests firm organizational design shapes interactions with external knowledge sources to facilitate opportunity exploitation (Foss, Lyngsie and Zahra, 2013) and innovation (Argyres and Silverman, 2004). We also demonstrate that firm collaborative capability enables the firm to derive greater value from commonality and enhances the relationship between scientific connectedness and innovation. Thus knowledge access and co-ordination appears to be a complex process that operates at both the firm and country levels, supporting the proposition of a more integrated framework for examining knowledge transfer (Song, 2014).

By considering the firm's global R&D network, our study leads to holistic insights that would not be possible in an examination of individual elements (Gruber, Heinemann, Brettel and Hungeling, 2010). Therefore our study complements the growing body of literature on the important role of foreign subsidiaries in innovation (Almeida and Phene, 2004; Cantwell and Mudambi, 2005), by examining their location in the context of a larger setting (IGOs that encompass the home country and host countries of R&D locations of the home country) and exploring the complementary relationships between firm collaborative capability and the broader premise of scientific connectedness. Our finding regarding the utility of scientific connectedness for firms in enhancing knowledge transfer and innovation offers an interesting complement to studies that have focused on subsidiary characteristics and mechanisms that enable knowledge flows (Minbaeva, Pedersen, Bjorkman, and Fey, 2013; Gupta and Govindarajan, 2000). While there has been a significant emphasis in the literature on the heterogeneity provided by knowledge from international sources and foreign innovation systems (Bartholomew, 1997; Phene, Fladmoe-Lindquist and Marsh, 2006) our study takes a unique approach by highlighting the importance of commonality in the sourcing and transfer of knowledge and ultimately for innovation.

The evaluation of scientific connectedness and collaborative capability resonates with the resource based view of the firm (Barney, 1991). Resource value is determined by how the firm bundles its resources (Sirmon, Gove and Hitt, 2008). All resources do not hold equal value for all firms and their value generation potential can be enhanced by enabling complementarities with existing resources (Adegbesan, 2009). However we know little about how firms can configure resources to achieve superior performance (Sheehan and Foss, 2007). Our study provides a step in this direction by exploring the location of R&D resources and the complementarities enabled through scientific connectedness and collaborative capability to generate greater value from innovation.

We also contribute to the broader study of how international institutions influence the strategic behavior of firms. The globalization of the world economy has been accompanied by the proliferation of international organizations – organizations which themselves transcend national boundaries – to facilitate and govern cross-border activity. International organizations are a part of a broader, evolving global environment; an additional level of analysis beyond the single country shaped by states, economic actors and civil society (Westney, 2011). Yet, only recently have researchers begun to examine how international institutions influence the strategic choices of firms (see, for example, Soule et al, 2013; Rangan and Sengul, 2009; Jandhyala and Weiner, 2014). By integrating the effects of IGO linkages between home and host countries and firms' innovation outcomes, we contribute to research on unpacking international institutions and their effects on firm behavior.

Our study has several limitations. We consider innovation to be the result of knowledge access and transfer enabled by scientific connectedness and collaborative capability. However we do not directly measure the intermediate step of knowledge access or transfer. A within-firm analysis would help to test this step and is proposed for future work. Further, determining the relative importance of scientific connectedness and collaborative capability for knowledge transfer may be an interesting avenue for future work. While we establish the role of scientific connectedness in influencing firm innovation, we are unable to determine the type of connectedness (political, economic, social) that matters the most (or if at all). We choose a setting that is likely to be important in the scientific realm. But the empirical challenge of establishing this is that most measures of country connectedness are highly correlated. Finally, our focus is on one sector, the semiconductor industry, leading to issues of generalizability.

Our research offers practical implications for managers. R&D locations are very important for firms that aspire to global strategies (Porter and Stern, 2001**;** Feinberg and Gupta, 2004), but a key concern associated with managing global R&D, is enabling innovation through the transfer and leveraging of diverse knowledge available to the firm from its various sites (Mors, 2010). Our study offers new insights for managers in enhancing innovation, by making strategic location choices for R&D centers and the development of collaborative capability.

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Table 1: Coding Scheme for IGO Function

IGO Type	Description of Organizations	Examples
Learning-oriented	Education, scientific research & technology organizations; provide standards and harmonization of transactions; protect property rights; technical exchange or cooperation; facilitate information exchange	Council for Technical Cooperation in South & South-East Asia; Latin American Center for Physics; World Intellectual Property Organization; World Meteorological Organization
	Monitor, enforce, and help process international economic transactions; perform trade related functions; enhance information access; address issues of structure and operation of specific industries	International Cotton Advisory Committee, World Trade Organization, African Petroleum Producers Association
Others	Umbrella organizations that focus on administration of governments, perform multiple functions, or administer international agreements	UN, Nordic Council, South Asian Association for Regional Cooperation
	Regional political or military alliances; organizations for military/security/defense purposes	Council of Baltic Sea States, Euro-Atlantic Partnership Council, Wassenaar Arrangement
	Address health, disease, disaster, or social welfare; cultural or humanitarian organizations; environmental conservation	International Labor Organization, International Coral Reef Initiative; African Cultural Institute; International Organization for Migration

Source: Adapted from Ingram et al (2005); Jandhyala and Phene (2013)

Table 2: Summary Statistics and Correlations

Sr. No	***Variables***	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***	***12***
	Mean	84.18	0.10	0.47	364	0.53	0.28	60.02	1.44	2.85	16.42	0.12	8.16
	Std. Dev	222.40	0.12	1.83	1008	0.25	0.92	17.39	3.85	0.79	7.75	1.58	63.92
	Dependent Variable												
1	Firm innovation	1.00											
	Independent Variable												
2	Scientific connectedness of firm global R&D locations	0.39	1.00										
	Moderators												
3	Firm collaborative capability	0.09	0.03	1.00									
	Controls												
4	Firm knowledge stock	0.95	0.38	0.09	1.00								
5	Technological breadth of firm knowledge	0.34	0.42	0.10	0.32	1.00							
6	Firm internal linkages	0.14	0.33	0.0002	0.12	0.21	1.00						
7	Firm external linkages	0.02	-0.29	-0.01	0.01	-0.05	-0.15	1.00					
8	Technological richness of countries of firm's global R&D locations	0.31	0.53	0.12	0.30	0.21	0.05	-0.09	1.00				
9	Firm size	0.55	0.57	0.16	0.54	0.51	0.20	-0.16	0.32	1.00			
10	Firm R&D intensity	-0.10	-0.07	-0.02	-0.07	0.06	-0.02	0.20	-0.13	-0.12	1.00		
11	Firm leverage	0.04	0.01	0.04	0.04	-0.01	0.05	0.01	0.03	0.09	-0.04	1.00	
12	Firm profitability	0.03	0.07	-0.03	0.02	-0.06	0.01	-0.03	0.12	0.07	-0.21	-0.15	1.00

Table 3: Scientific Connectedness, Collaborative Capability and Innovation

Dependent Variable: Firm Innovation

		Model 1	Model 2	Model 3
Independent Variable				
Scientific connectedness of firm global R&D locations	H1		2.001*** (0.416)	1.751*** (0.422)
Moderating effect				
Scientific connectedness * Firm collaborative capability	H2			0.404*** (0.117)
Control variables				
Firm collaborative capability		0.035*	0.049***	0.023
		(0.014)	(0.014)	(0.018)
Firm knowledge stock		0.011*	0.010*	0.011*
		(0.005)	(0.005)	(0.005)
Technological breadth of firm knowledge		0.546**	0.458*	0.449*
		(0.196)	(0.195)	(0.191)
Firm internal linkages		0.140***	0.118***	0.121***
		(0.033)	(0.032)	(0.031)
Firm external linkages		-0.002	0.000	-0.000
		(0.003)	(0.003)	(0.003)
Technological richness of countries of firm's global R&D locations		0.018** (0.007)	-0.004 (0.008)	-0.005 (0.008)
Firm size		0.625***	0.530***	0.531***
		(0.102)	(0.101)	(0.101)
Firm R&D intensity		-0.003	-0.005	-0.005
		(0.006)	(0.006)	(0.006)
Firm leverage		0.006	0.020	0.022
		(0.021)	(0.021)	(0.021)
Firm profitability		0.000	0.001	0.001
		(0.000)	(0.000)	(0.000)
Firm, random effects		Yes	Yes	Yes
Year dummies		Yes	Yes	Yes
Wald Chi Squared		100.04***	131.43***	161.15***
# of firms		92	92	92

Notes: Standard errors in parentheses
*p<0.05, **p<0.01, ***p<0.001

Table 4: Robustness Checks

Dependent Variable: Firm Innovation

	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9	Model 10	Model 11
Robustness check	Omitting firm size	Omitting firm internal linkages	Adding global dispersion of firm R&D	Adding trade connectedness based on total trade	Adding trade connectedness based on semiconductor trade	Subsample – Drops firms with purely domestic innovation	Negative binomial regression with fixed effects	QML Poisson regression with fixed effects
Method	Xtnbreg, re	Xtnbreg, re	Xtnbreg, re	Xtnbreg, re	Xtnbreg, re	Xtnbreg, re	Xtnbreg, fe	Xtpqml, fe
Independent Variable								
Scientific connectedness of firm global R&D locations	2.145*** (0.424)	1.754*** (0.417)	2.096*** (0.461)	2.022*** (0.500)	2.002*** (0.494)	1.457*** (0.442)	1.532*** (0.430)	1.237* (0.610)
Moderating effect								
Scientific connectedness * Firm collaborative capability	0.441*** (0.128)	0.404*** (0.117)	0.402*** (0.116)	0.406*** (0.117)	0.406*** (0.117)	0.407*** (0.122)	0.396** (0.124)	0.403* (0.192)
Control variables								
Firm collaborative capability	0.025 (0.018)	0.023 (0.018)	0.022 (0.018)	0.022 (0.018)	0.022 (0.018)	0.020 (0.019)	0.022 (0.018)	0.058 (0.031)
Firm knowledge stock	0.016** (0.005)	0.011* (0.005)	0.011* (0.005)	0.011* (0.005)	0.011* (0.005)	0.011* (0.005)	0.004 (0.006)	-0.006 (0.006)
Technological breadth of firm knowledge	0.578** (0.189)	0.449* (0.191)	0.455* (0.191)	0.433* (0.191)	0.432* (0.192)	0.565* (0.266)	0.227 (0.184)	0.203 (0.269)
Firm internal linkages	0.108*** (0.033)	0.121*** (0.031)	0.130*** (0.032)	0.122*** (0.032)	0.123*** (0.032)	0.113** (0.034)	0.102** (0.033)	0.125*** (0.036)
Firm external linkages	-0.002 (0.003)	Omitted	-0.001 (0.003)	-0.000 (0.003)	-0.000 (0.003)	0.001 (0.004)	-0.002 (0.003)	-0.003 (0.004)
Technological richness of countries	-0.014 (0.009)	-0.005 (0.008)	-0.006 (0.008)	-0.003 (0.009)	0.000 (0.010)	-0.004 (0.009)	-0.009 (0.009)	0.014 (0.015)

of firm's global R&D locations								
Firm size	Omitted	0.532*** (0.100)	0.527*** (0.100)	0.536*** (0.101)	0.535*** (0.101)	0.460*** (0.136)	0.257* (0.124)	(0.074) (0.262)
Firm R&D intensity	-0.006 (0.006)	-0.006 (0.006)	-0.006 (0.006)	-0.005 (0.006)	-0.005 (0.006)	-0.007 (0.007)	-0.003 (0.007)	-0.007 (0.007)
Firm leverage	0.040 (0.022)	0.022 (0.021)	0.018 (0.021)	0.023 (0.021)	0.022 (0.021)	0.027 (0.022)	0.023 (0.020)	0.001 (0.033)
Firm profitability	0.001 (0.000)	0.001 (0.000)	0.001 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.001)
Additional controls								
Global dispersion of firm R&D			-0.554 (0.321)					
Trade connectedness (total trade)				-1.313 (1.336)				
Trade connectedness (semiconductors)					-0.020 (0.020)			
Firm effects	Random effects	Random effects	Random effects	Random effects	Random effects	Random effects	Fixed effects	Fixed effects
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wald ChiSquared	107.59***	161.10***	165.86***	162.81***	163.03***	98.37***	72.76***	764.68***
N	362	362	362	362	362	230[@]	347[@]	347[@]

Notes: Standard errors in parentheses
*p<0.05, **p<0.01, ***p<0.001
[@]Sample sizes are different in these models because firms with only domestic innovations are dropped in Model 9 and fixed effects models (Model 10 and Model 11) drop observations of firms that contribute a single year

Figure 1 Interaction Effect of Scientific Connectedness and Firm Collaborative Capability