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WHERE CAN CAPABILITIES COME FROM? NETWORK TIES AND CAPABILITY ACQUISITION IN BUSINESS GROUPS

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While strategy researchers have devoted considerable attention to the role of firm-specific capabilities in the pursuit of competitive advantage, less attention has been directed at how firms obtain these capabilities from outside their boundaries. In this study, we examine how firms' multiplex network ties in business groups represent one important source of capability acquisition. Our focus allows us to go beyond the traditional focus on network structure and offer a novel contingency model that specifies how different types of network ties (e.g., buyer-supplier, equity, and director), individually and in complementary combination, will differentially affect the process of R&D capability acquisition. We also offer an original analysis of how other aspects of network structure (i.e., network density) in business groups affect the efficacy of network ties on R&D capability. Empirically, we provide an original contribution to the capabilities literature by utilizing a stochastic frontier estimation to rigorously measure firm capabilities, and we demonstrate the value of this approach using longitudinal data on business groups in emerging economies. We close by discussing the implications of our supportive results for future research on firm capabilities, organizational networks, and business groups.

INTRODUCTION

Business groups make up a type of interfirm network that is commonly found in developing economies. These groups frequently dominate a substantial share of a country's productive assets and strongly influence its economic development. Faced with rivalry from domestic and foreign competitors, business groups continuously upgrade their capabilities to pursue competitive advantage by combining local markets with foreign capital and technologies, executing projects in multiple industries, and developing indigenous technologies and brands (Amsden and Hikino, 1994; Kock and Guillén, 2001).

The fact that some groups outperform others implies that there is substantial variation in capabilities across business groups. Moreover, as business groups are sets of legally independent companies under common administrative and financial control (Khanna and Rivkin, 2001), the variation in group capability can be attributed to the differences in the capability of the individual affiliates within a specific business group. Several studies that use mostly anecdotal evidence suggest that group affiliates also differ in their capabilities with some member businesses operating at the leading edge of productivity and others lagging behind their affiliates (e.g., Chang, 2003). This raises at least two important questions for business group research: How do group affiliates differ in

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their capabilities, and where do these differences originate?

Prior research on capability building has examined internal sources of firm capabilities such as skills and routines (Nelson and Winter, 1982). External sources, such as formal and informal relationships with other firms (Gulati, Nohria, and Zaheer, 2000) have also been studied. The focus of this latter stream of work has primarily been on how the structural attributes of network ties affect the acquisition of capabilities. However, findings in this area are not convergent: some research has found that networks rich in structural holes are conducive to the capability building of firms embedded in the networks (Burt, 1992; McEvily and Zaheer, 1999), while others contend that more dense networks would promote capability building by facilitating internal coordination and recombination (Coleman, 1990; Ahuja, 2000).

Group affiliates are closely linked to each other through persistent informal links and formal relationships (Hamilton and Biggart, 1988; Granovetter, 1995), and the network literature has suggested that different types of network ties may exert differential effects. The divergent findings in prior studies may be explained by the relative overemphasis on network structure relative to an emphasis on differences in the types of network ties linking group firms. In this study, rather than viewing network ties as generic conduits for information and resource exchange between firms, we suggest, instead, that different types of ties characterized by distinct content will have differential effects on a firm's acquisition of capabilities through network ties (see also McEvily and Marcus, 2005), both individually and in interaction with each other. Some types of ties may exert a direct effect on capability building while others, owing to the differences in their content, may cause only an indirect affect

In developing this line of argument, we offer a contingency model that specifies whether and how different types of intragroup ties can influence capability building of group affiliates. These business groups are viewed as networks in which the behavior and the performance of individual affiliates are intertwined through various formal and informal relationships within the group (Granovetter, 1995). One important difference between intragroup networks and general interfirm networks is the likelihood of multiplex ties between group affiliates. For instance, it is not uncommon for two group affiliates to be connected through ties with buyers-suppliers, equity, and directors simultaneously, whereas two firms in more general networks are more typically (but not necessarily) linked to each other via a uniplex tie, for example, a joint venture, collaborative agreement, or licensing contract. This valuable characteristic of intragroup networks allows us to consider the potential synergies between different types of network ties, which have been understudied in prior literature. We consider three types of interfirm ties prevalent in business groups: buyer-supplier, equity, and director, and we propose that each gives affiliates differential opportunities to acquire capabilities from their networks.

In terms of the capabilities themselves, our primary focus is on examining how group-affiliated firms enhance their research and development (R&D) capability by advantageously utilizing different types of network ties—individually and in combination. Our focus on R&D capability seems sensible insofar as business groups have often been characterized as important technology importers and creators in many emerging economies (Amsden and Hikino, 1994; Chang, Chung, and Mahmood, 2006) and by analyzing the role of varied intragroup network ties as conduits for information and resources, we seek to shed additional light on how firms in emerging economies develop this capability.[1]

Finally, we seek to contribute to the capabilities literature through our empirical methodology. Clearly, there are several ways to conceptualize firm capability (Ethiraj *et al*., 2005), but there remains a challenging empirical issue as to how to measure it. In this study, we measure firm capability using a novel econometric approach called the stochastic frontier estimation (SFE). Following SFE, 'capabilities are conceived as the [technical] efficiency with which a firm employs a given set of resources (inputs) at its disposal to achieve certain objectives (outputs)' (Dutta, Narasimhan, and Rajiv, 2005: 277). While the use of the input-output approach to capability is relatively new in strategic management research, this approach to operationalizing firm capability captures the notion of capability as the ability of a firm to *efficiently*

[1] Given the likelihood that the importance of R&D capability varies among group affiliates in different industries, we control for the industry of each affiliate when measuring its R&D capability and when estimating the impact of its network ties on its R&D capability.

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combine a number of resources to attain a certain goal (Amit and Schoemaker, 1993; Majumdar, 1998). This approach is also consistent with the extant view of capabilities as intermediate goods aimed at improving the productivity of resources possessed by the firm (Makadok, 2001). Compared to conventional measures of R&D capability that focus either on inputs (e.g., R&D intensity) or outputs (e.g., patent count), the capability measure using SFE has the advantage of taking both inputs and outputs into account. It can effectively differentiate two firms with the same R&D intensity but with a different number of patents, and two firms with the same number of patents but a different level of R&D intensity, which conventional measures cannot.

Our empirical analysis is conducted using an extensive longitudinal dataset involving 694 cases of affiliates belonging to 123 unique business groups in Taiwan between 1981 and 1998. Business group affiliates, which are characterized by overlapping embeddedness in various types of intragroup networks, provide a particularly appropriate setting in which to examine our research questions. The results of our analysis are supportive of our hypotheses: the effect of network ties on the acquisition of new affiliate capabilities is clearly and predictably contingent on the type of the ties studied, the combination of those ties, and the overall structure of the network within which those ties exist.

A CONTINGENCY PERSPECTIVE ON NETWORK TIES

Our theoretical contribution builds logically on the dual literatures on firm capabilities and social networks, and we address both literatures in this section. We begin by noting that while there is strong agreement among strategy scholars that a firm with superior capabilities enjoys a competitive advantage (Peteraf, 1993; Teece and Pisano, 1994), there is weaker agreement or understanding as to how such capabilities originate. According to Amit and Schoemaker (1993), capabilities represent the ability of firms to deploy resources to attain a desired goal using organizational processes. The enhancement of capabilities needs continuous investment in organizational systems (Zollo and Winter, 2002).

As important external sources of capabilities, interorganizational ties are often seen as facilitating the development of R&D capability, which requires access to resources and assimilation of externally acquired knowledge. As an example, consider all the affiliates of Samsung Group in Korea, which can obtain timely and sufficient financial support for their R&D projects, ensuring their ability to be at the technological frontier (Chang, 2003). The interorganizational learning and knowledge transfer in joint ventures and strategic alliances exemplify the importance of network ties in the acquisition of R&D capability (Powell, Koput, and Smith-Doerr, 1996). Prior network research has also shown that network ties may obstruct, rather than facilitate, the development of firm capabilities. For example, while firms may develop popular new products when networks provide them with access to complementary resources and information on customers' needs (Srinivasan, Lovejoy, and Beach, 1997), excessive interorganizational ties can also interfere with the development of firm capabilities by promoting insularity and information leakage (Uzzi, 1997; Burt, 2000). A substantial number of research studies have focused on how the extent that a firm is embedded in a network of formal and informal ties (i.e., a key aspect of network structure) will influence its capabilities. The efficacy of network ties in capability building is largely attributed to the structural features of ties.

In contrast, relatively little is known about the effect of different types of ties. Network ties are clearly heterogeneous in this regard, and key differences among types of ties can influence the types of resources and information exchanged. A few studies have addressed this issue in different contexts. For example, Gulati and Westphal (1999) find that the impact of board interlocks on the formation of strategic alliances is contingent on the content of CEO-board relationships, and McEvily and Marcus (2005) show that joint problem-solving ties with suppliers (but not ties with customers) are strongly related to the acquisition of capabilities. This suggests the value in offering a theoretical and empirical analysis that addresses how different types of ties (both individually and in combination) can influence the process of capability building (Ahuja, 2000; Gnyawali and Madhavan, 2001; Zaheer and Bell, 2005). We offer such an analysis in our study by explicitly elaborating the mechanisms by which the individual and

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combinations of network ties influence capability building.

Since both the type of ties and the broader network structure within which they are embedded are likely to influence the value of ties (Ahuja, 2000), the form of network structures that are beneficial to network outcomes may vary depending on the type of ties. In the context of interpersonal networks, Podolny and Baron (1997) show that ties conveying information and resources are more conducive to an individual's promotion in networks rich in structural holes, while ties that transmit identity and expectations are more facilitative to promotion when they are densely connected. The match of the type of ties with the form of social structure (an open vs. a closed network) sheds additional light on the effects of network ties. Building upon these insights, we further speculate that the synergistic/substitutable effects between distinct types of ties may also be contingent on the structures of these ties. A focal firm can enjoy more complementarities (or less substitutability) between its multiplex ties by shaping them in favorable configurations. By exploring both the multiplex and structural contingencies in the network-capability building relationship, we provide insights into the design of networks beneficial to the development of R&D capability. We contextualize our discussion by considering how these issues materialize in business groups in emerging economies.

BUSINESS GROUPS AS NETWORKS

Although the precise definition varies across countries, business groups combine elements of conglomerate holding companies and multidivisional corporations, which create a type of multibusiness firm that some theorists refer to as a network form of organization (Nohria and Eccles, 1992; Podolny and Page, 1998).

Group affiliates coordinate business activities with each other, but also are responsible to their own governance bodies including shareholders, directors, and auditors. Like conglomerates, a group provides a corporate financial structure that controls businesses in multiple industries (Williamson, 1985). Like multidivisional corporations, meanwhile, businesses within a group operate with a substantial degree of interdependence (Chandler, 1997). Yet groups also differ from conglomerates and multidivisional corporations in that groups are more stable and coordinated than conglomerates, while less centralized than their typical multidivisional counterparts (Granovetter, 1995). Thus, in this study, we define business groups as networks of loosely coupled, legally independent firms, linked by persistent formal and informal ties.

The network ties that connect group affiliates range from informal ties based on family, friendship, religion, language, and ethnicity (Khanna and Rivkin, 2006) to formal economic arrangements such as equity cross holdings, director interlocks, and buyer-supplier agreements (Lincoln, Gerlach, and Ahmadjian, 1996). The multiplexity of intragroup ties enables us to examine the potentially differential effect of each type of tie and its synergy on capability building. In this study, we consider all three types of intragroup ties commonly found among group-affiliated firms: (1) buyer-supplier ties, when affiliates within a group engage in buyer-supplier relations, (2) equity ties, when affiliates own equity stakes in each other through cross holdings, and (3) director ties, when an individual sits on the board of multiple affiliates. We then specify our expected contingency relationships, highlighting how different types of ties—individually and in combination—will have differential effects on R&D capability acquisition.

HYPOTHESES

Buyer-supplier ties and the acquisition of R&D capability

While it would be unsurprising to suggest that the successful building of R&D capability requires access to a set of tangible and intangible resources, identifying in a more systematic way the types of resources critical for R&D capability building is less self-evident. We draw upon prior work that has addressed the dual topics of innovation and capability building to assist in this task.

We begin by recalling the definition of R&D capability as the set of organizing processes and principles that a firm uses to deploy its resources to develop new products and improve manufacturing processes in response to the change in external environment (Kogut and Zander, 1992; Grant, 2002). Given this accepted definition, it follows that an essential building block of R&D capability is the technological knowledge base of a firm. By shaping the ways in which knowledge, skill, and expertise are coordinated and deployed, this technological knowledge base fundamentally determines what the firm can achieve from its R&D inputs. Therefore, to enhance their R&D capability, firms need to continually accumulate and update their technological knowledge base. The advantages that accrue to firms that make such efforts include: (1) the more efficient utilization of available resources, based on either reduction of trial/error times and/or maximization of the utility of inputs (Zander and Kogut, 1995); and (2) the more effective absorption of new ideas and knowledge that generate new products or improvement in existing products (Cohen and Levinthal, 1990; Garud and Kumaraswamy, 1993). As Helfat's (1997) study has empirically shown, U.S. petroleum firms with larger amounts of technological knowledge accumulated more R&D capability than their rivals with less technological knowledge.

We suggest that *buyer-supplier ties* can be particularly useful in providing affiliates with the specific technological knowledge necessary for enhancing R&D capability. A buyer or supplier likely has opportunities, given its position in the same supply chain, to leverage its partner's complementary resources—especially the knowledge accumulated from prior R&D operations (Shan, Walker, and Kogut, 1994; Koza and Lewin, 1998). Buyers may make significant contributions to suppliers' R&D capability building by providing valuable product ideas and information about future industry trends (von Hippel, 1988). Suppliers can enhance their R&D process by creating 'open systems' for buyers (Garud and Kumaraswamy, 1993) or setting up communities of users (Jeppesen and Frederiksen, 2006). Suppliers can also become involved in customers' new product development processes and help them solve technical problems (Ring and Van de Ven, 1992). Such joint problem-solving arrangements have been demonstrated to facilitate the transfer of complex, specific, and tacit knowledge, and thus firms can learn more when such joint problem-solving arrangements with exchange partners exist (Hansen, 1999; McEvily and Marcus, 2005).

The role of the buyer-supplier tie as a vehicle for technological knowledge may be particularly salient in emerging economies where the infrastructures for innovative activities are usually underdeveloped. The relatively weak institutions for arms-length relationships to facilitate the exchange of information and knowledge gives member firms of business groups an advantage in the acquisition of R&D capability when they are embedded in intragroup buyer-supplier networks. Moreover, intragroup buyer-supplier ties are likely to provide more specific and fine-grained technological knowledge relative to ties between independent firms because connected affiliates often interact with each other intensively so as to attain their common goals, including the maximization of group profitability (Chang and Hong, 2000). Infused by information about product quality and implementation of techniques, intragroup buyer-supplier ties enable focal affiliates to develop superior R&D capability by providing (1) diverse and new technological knowledge held by other affiliates and (2) experience in the incorporation of the acquired knowledge into projects aimed at R&D capability building. The discussion above suggests that a group affiliate that occupies a more central position in the intragroup buyer-supplier network (i.e., having more direct buyer-supplier ties with other affiliates) is more likely to develop superior R&D capability than a group affiliate that is peripheral in the buyer-supplier network (i.e., having fewer direct buyer-supplier ties with other affiliates). Thus, we hypothesize:

Hypothesis 1: The centrality of a group affiliate's position in the intragroup buyer-supplier network is positively related to its R&D capability.

Complementarities in the acquisition of R&D capability

R&D capability is a product of collective activity, requiring a combination of a complementary set of resources within 'a context of consistent interactions' (Antonelli, 1998: 101; Hayek, 1945). While Hypothesis 1 emphasizes how buyer-supplier ties can provide foundational support for building R&D capability, other types of ties containing resources complementary to technological knowledge may also facilitate the acquisition of R&D capability (Helfat, 1997). We consider how buyer-supplier ties may be most useful when used in combination with director ties and equity ties.

Beyond the presence of a strong, specific technological knowledge base, more generic knowledge that concerns the effective implementation of practices and techniques is also important to the development of R&D capability. Such a generic

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knowledge base can determine how efficiently available resources can be combined with administrative arrangements in a firm to achieve its innovative goals. Whereas specific technological knowledge tends to be more localized and is characterized by strong idiosyncratic and product-specific features (Antonelli, 1998; Dyer and Nobeoka, 2000), generic knowledge is more macro, encompassing an understanding of broad technological paradigms, best practices, firm resource profiles, and external market opportunities (Eccles, Nohria, and Berkley, 1992). Access to generic knowledge provides firms with an opportunity to integrate, build, and also reconfigure their resources efficiently when responding to changing environments. Thus, generic knowledge may enable firms to sustain innovativeness by well exploiting available specific technological knowledge.

Director ties may promote R&D capability by providing affiliates with generic knowledge complementary to technological knowledge provided by buyer-supplier ties. Prior research suggests that director interlocks function as an important mechanism for the diffusion of innovative practices (Rogers, 1983; Granovetter, 1985). Through interlocks, executives can learn more about the uncertainties facing other firms engaged in innovative activities, as well as how other firms have exploited technological knowledge (Lorsch and MacIver, 1989: 27). Amsden and Hikino (1994) found that the project execution capability (a typical generic knowledge) mastered by key executives from some business group affiliates enabled other group affiliates that had those key executives on their boards to successfully exploit advanced knowledge and novel ideas obtained from buyers and suppliers, and thus to gradually upgrade their technological positions from imitators to innovators (Kim, 1997).

Interlocking director ties among business group affiliates tend to provide richer and more credible information about innovative practices than those among independent firms, primarily due to the higher level of trust between interlocked directors. The majority of business groups are family owned and managed by members of the founding family and trusted friends (Hamilton and Kao, 1990; Luo and Chung, 2005). The same small number of executives of the focal affiliate often sit on the board of other group affiliates, in many cases as the chairman of the board of directors. The higher level of trust between interlocked directors (Peng, 2004) and the pursuit of common goals, such as maximizing the interests of the founding family and the profitability of the group as a whole (Chang and Hong, 2000), enable group affiliates connected by director ties to avail themselves of a more strategic information exchange. The content of strategic information may include (1) where the generic knowledge of innovation resides; (2) how the connected affiliates usually manage their innovation by creating, maintaining, and updating routines that govern product and process innovations; (3) the extent to which the acquired generic knowledge is applicable to, and how to customize such knowledge for, the focal affiliate.

Studies have also shown that the emergence of collaborative relations depends to a great extent on the level of trust between involved parties (Gulati and Singh, 1998; Gulati and Westphal, 1999). In this way, compared to nonconnected ones, group affiliates connected by director ties have a higher likelihood of engaging in joint projects to exploit the technological knowledge and new ideas that emerge from buyer-supplier ties. Thus, the advantage of buyer-supplier ties can be more fully realized when accompanied by the presence of multiple director ties. This leads to:

Hypothesis 2a: The centrality of a group affiliate's position in the intragroup director network reinforces the positive relationship between its centrality in the buyer-supplier network and its R&D capability.

Another complementarity that can enhance the value of the technological knowledge provided by buyer-supplier ties stems from enhanced access to financial capital. While financial capital by itself is not likely to generate R&D capability in the direct way that buyer-supplier ties can, the uncertainty inherent in R&D implies that successful R&D does benefit from continuous financial investment in laboratories, equipment, and manpower. With sufficient financial support, firms are better able to generate innovations through numerous trials and experiments under the guidance of technological knowledge. Moreover, financial resources are necessary to develop the infrastructure for conducting R&D activities. With an efficient organizational system for innovative activities, firms can better exploit the technological knowledge base.

Access to *equity ties* provides firms with financial support to capitalize on technological knowledge transferred through buyer-supplier ties. To the extent that equity ties help firms insulate themselves from the pressures of short-term profit volatility, managers may be more willing to invest in the development of facilities necessary for R&D activities. Taking advantage of the internal capital market composed of equity ties between network partners, firms are able to make continuous investment in updating and refreshing organizational skills, routines, and systems, which makes firms more likely to succeed in generating innovations based on their technological knowledge.

Equity ties within business groups are particularly conducive to the exploitation of technological knowledge transmitted through buyer-supplier ties. Since there are scant external sources of capital in emerging economies (Khanna and Palepu, 1997), group affiliates heavily rely on the intragroup capital market for investment in innovative activities (Mahmood and Mitchell, 2004). Furthermore, due to the existence of common goals, group affiliates with sufficient financial resources are willing to subsidize those with novel ideas but little financial resources to develop new products and services. The internal capital market within a business group may function as a *de facto* venture capitalist and allocate financial resources for innovative opportunities effectively (Chang, Chung, and Mahmood, 2006). Therefore, we propose that:

Hypothesis 2b: The centrality of a group affiliate's position in the intragroup equity network reinforces the positive relationship between its centrality in the buyer-supplier network and its R&D capability.

Furthermore, group affiliates are likely to obtain an extra boost to R&D capability building out of the three types of ties with complementary contents. Compared to those with only buyer-supplier and equity ties, affiliates simultaneously maintaining three types of ties are able to make better use of financial resources in the guidance of generic knowledge provided by director ties. For example, they may invest in those projects with higher propensity to succeed based on the experiences of other affiliates. They are also more likely to establish an efficient organizational infrastructure to exploit their technological base by investing in the key components through guidance provided by experienced interlocked partners.

Similarly, relative to those with only buyer-supplier and director ties, affiliates keeping three types of ties are in an advantageous position to develop R&D capability. With sufficient financial resources provided by equity ties, affiliates are able to invest more in the development of physical and human resources, as well as organizational infrastructures that promote the synergies between technological knowledge and generic knowledge. They are more likely to figure out how to customize the acquired generic knowledge to their specific technological base through numerous trials and errors. Accordingly, we hypothesize that:

Hypothesis 2c: The centralities of a group affiliate's position in the intragroup equity and director networks reinforce the positive relationship between its centrality in the buyer-supplier network and its R&D capability.

Contingent effect of network structure

While our analytical focus has been on how different types of ties maintained by a focal firm can affect the development of its R&D capability, we now further investigate how the effects of distinct types of ties on R&D capability may be influenced by the overall network structure.

Network scholars have emphasized that network structure is a key determinant to a firm's innovativeness (Zaheer and Bell, 2005). In particular, network density, which captures the degree of connectivity between network partners, plays an important role. Network density is maximized (minimized) when all (no) network partners are connected to each other. There are differing views on the value of dense vs. sparse networks. Some emphasize how a highly dense network can more easily allow network participants to leverage each others' resources, based on more intensive interactions and higher levels of trust (Coleman, 1988), while others emphasize how a sparse network can facilitate access to nonredundant and boundary-spanning information (Burt, 1992). The empirical findings are also divergent. For instance, Hargadon and Sutton (1997) found that a firm at the confluence of several industries was able to come up with new business concepts by taking the advantage of access to knowledge derived from various industries. However, in a study of the effect of network connectivity on firms' innovation, Ahuja (2000) shows that firms that are more intensively connected are also more innovative.

To the extent that both types of ties and network density affect R&D capability building, we propose that the optimal intragroup network depends on the match between types of ties and network structure. We expect that some types of ties may be more beneficial to R&D capability when they are densely intertwined with each other, while some types of ties may be more conducive to R&D capability when they are sparsely distributed. Specifically, we consider how the effect of a focal firm's buyer-supplier ties may vary depending on the network density of director ties and equity ties.[2] As noted earlier, director ties provide generic knowledge and strategic information to firms. The value of such resources does not dissipate when more network partners share these resources—indeed, it will likely grow synergistically. A dense director network (relative to a sparse director network) is more able to provide abundant generic knowledge and strategic information, given its higher level of interaction and mutual trust among network partners.

Prior research suggests that dense ties between network partners may help improve trust by encouraging cooperation and reciprocity, and curbing opportunism (Coleman, 1988; Uzzi, 1997; Gulati, 1999; Rowley, Behrens, and Karckhardt, 2000). Trust can serve as an effective filtering device for assessing the quality and reliability of information received. Taking advantage of reliable information, firms embedded in dense director networks are more likely to pay attention to, act on, and benefit from the generic knowledge of R&D activities received from trusted partners (McEvily, Perrone, and Zaheer, 2003). Moreover, firms in dense director networks are more likely to have access to detailed, sensitive, and proprietary information, given the greater trust between and among those firms. Interlocked firms may be more open with their partners by revealing certain details about their operations and the keys to problem solving. In contrast, in a sparse director network, firms may be reluctant to disclose such information for fear that it may be used against the firm by other firms. In sum, firms in dense director networks may benefit from information advantage rooted in highly trusted network partners, and thus obtain more generic knowledge that complements the specific knowledge transferred through buyer-supplier ties. Even if focal firms have no direct director ties but only buyer-supplier ties, a focal firm may still indirectly benefit from being embedded in a dense director network.

From the perspective of structural holes theory (Burt, 1992), however, dense director networks may constrain the development of new generic knowledge by making firms entrenched in the network and insulated from advances and improvements beyond the network (Nelson and Winter, 1982; Rosenkopf and Nerkar, 2001). The problem of insulation may make firms in dense director networks less efficient in managing R&D activities. In contrast, networks rich in structural holes will be able to provide nonredundant information and novel ideas from the outside. Firms embedded in sparse director networks may timely upgrade their routines and organizational rules for assimilating and exploiting the technological knowledge acquired through buyer-supplier ties. They may also create advanced generic knowledge as novel responses to technological development by taking advantage of the heterogeneous knowledge base of interlocked directors. Considering the characteristics of intragroup networks, however, we argue that the potential benefits of structural holes are not likely to be realized. Unlike the generic director networks among independent firms, intragroup director networks are relatively small in terms of number of network partners,[3] and interlocking directors include a small group of executives who are closely linked. The diversity and novelty of generic knowledge and information transferring in such networks are likely to be low. Thus, we propose that a dense director network is more beneficial than a sparse one to the exploitation of technological knowledge provided by buyer-supplier ties.

Hypothesis 3: The impact of buyer-supplier ties that a group affiliate maintains on the affiliate's R&D capability will be moderated by the density of the director network: the denser the director network, the greater the benefits from buyer-supplier ties.

[2] We did not examine the potential effect of network density of buyer-supplier ties due to its high correlation with the centrality of buyer-supplier ties (0.72, significant).

[3] For instance, in our sample, the average number of affiliates in a business group is 13.

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Another type of ties important to R&D capability is equity ties, which are valuable in providing financial resources to firms. When firms are intensively connected by equity ties, the financial resources may flow relatively freely among them and can be efficiently allocated within the network due to the high level of trust among connected firms. It has been shown that firms tend to make more relational investments when they are tied closely and trust each other (Dyer and Singh, 1998). In emerging economies where the external capital market is underdeveloped, the dense equity networks of business groups function as an internal capital market (Khanna and Palepu, 2000). The availability of financial resources protect group affiliates from the pressures of short-term profit volatility, enabling them to engage in activities that are beneficial to the long-term development, such as improving R&D capability. Taking advantage of sufficient financial resources, firms embedded in dense equity networks are more likely to make continuous investment in updating and refreshing organizational skills, routines, and systems, and thus make better use of the technological knowledge provided by buyer-supplier ties.

However, an important characteristic of financial resources is that the benefits of a given amount of financial resources will dissipate when shared with more network participants. A dense equity network will generate more intense competition for financial resources between focal firms and their partners than will a sparse equity network. In addition to the negative effect of intense competition for resources, dense equity networks may also be harmful to R&D capability building by protecting poorly performing firms from external acquisition, thus making firms in the network less motivated to engage in innovative activities. Moreover, firms embedded in dense networks may over rely on financial resources within the network, losing opportunities to capitalize on external financial resources and being vulnerable to turbulence in the equity network.

Indeed, given that external capital markets in emerging economies are often missing or underdeveloped (Khanna and Palepu, 1997), we expect that the intragroup capital market functioning through the equity network will play an important role in funding affiliates for their R&D activities. As a result, the negative impact of dense equity ties on R&D capability building is likely to be exaggerated due to intensified competition for limited financial resources and the heavy reliance of affiliates on the internal capital market. In line with the discussion above, we propose the following hypothesis regarding the moderating effect of equity network density on the efficacy of focal firms' buyer-supplier ties on their R&D capability development.

Hypothesis 4: The impact of buyer-supplier ties that a group affiliate maintains on the affiliate's R&D capability will be moderated by the density of the equity network: the denser the equity network, the smaller the benefits from buyer-supplier ties.

MODEL

Our empirical analyses involve two steps. First, we estimate firm R&D capability using the SFE methodology. Second, we explore the impact of different types of intragroup network ties on the acquisition of R&D capability.

Stochastic frontier analysis

Consistent with the view that capabilities are intermediate goods aimed at improving the productivity of resources possessed by the firm (Makadok, 2001), stochastic frontier analysis measures capabilities as an 'intermediate transformation ability' that allows a firm to convert inputs available to the firm (i.e., its resources) into desired outputs (i.e., its objectives).[4] Based on the production function[5] in neoclassical economics, SFE enables us to empirically estimate the efficient frontier, which depicts the maximum feasible output from any quantity of input, and the level of productive efficiency (i.e., firm's capability) achieved by each firm in the study. As illustrated in Figure 1, the curve is

[4] Because capabilities reside at the operational level inside the firms, we recognize that aggregate firm-level measures mask some of the important sources of within-firms variance. An alternative is to rely on project-level data to measure capability at a more micro-level (Henderson and Cockburn, 1994; Ethiraj *et al*., 2005). However, the difficulty in obtaining detailed project level data limits the applicability of this approach to a single industry, or sometimes a single firm.

[5] The general form of production function is Y = f(K, L), where Y denotes a firm's output, and K and L are its capital and labor inputs. It indicates the relationship between inputs K and L, and output Y.

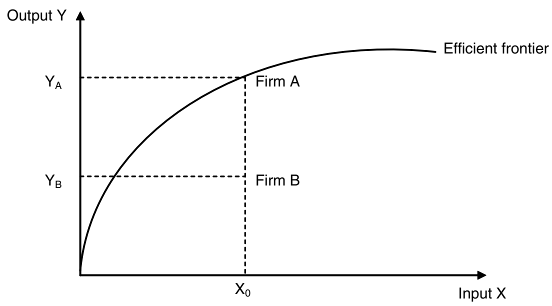

Figure 1. Efficient frontier and firm capability

the efficient frontier. Firm A is fully efficient in deploying its resources, so it lies on the efficient frontier. In contrast, Firm B is less efficient in utilizing its resources, so it falls below. Thus, Firm A has superior capabilities than Firm B.

While the use of SFE to measure firm capability is relatively novel in strategy research, SFE has certain advantages over traditional econometric approaches (Dutta *et al*., 2005). In contrast to conventional least squares-based regression techniques where all firms are assumed to operate on the efficient frontier and departures from the efficient frontier are attributed exclusively to random statistical noise (Kumbhakar and Lovell, 2000), SFE allows not only for the inherent randomness in production, but also for the firm-specific inefficiency in production, which provides a potential source of interfirm variation in capabilities. Therefore, SFE models explicitly recognize firm heterogeneity in capability, whereas more traditional econometric approaches assume it away.

We adopt the SFE models to measure R&D capability of group affiliates. Compared to the conventional measures of R&D capability (e.g., R&D intensity and number of patents), which focus on either inputs or outputs of R&D activities, the SFE approach captures firms' R&D capability more accurately by establishing the conversion relationship between inputs and outputs. For instance, the two firms shown in Figure 1 invest the same level of input (e.g., R&D intensity), but Firm A achieves a higher level of output (e.g., patents) than Firm B. This difference in R&D capability between the two firms can be easily captured by the SFE approach rather than conventional measures, such as R&D intensity. The specific models used to measure R&D capability are discussed in the Appendix.

Final model

Armed with the measure of R&D capability, we now examine how an affiliate's R&D capability is driven by the three types of intragroup network ties. Formally, the baseline model we estimate is the following:

$$\begin{aligned}&\textbf{\textit{Affiliate R\&D capability}}_{it}\\&\quad = f(\textbf{\textit{Buyer}} - \textbf{\textit{supplier ties}}, \textbf{\textit{equity ties}}, \textbf{\textit{director}}\\&\qquad \textbf{\textit{ties}}, \textbf{\textit{Controls}}) + \varepsilon_{it}\end{aligned}$$

BUSINESS GROUPS IN TAIWAN

While Taiwan is well known for its many small and medium sized enterprises, business groups have been shown to be very important players in the country (Hamilton and Biggart, 1988; Hamilton and Kao, 1990). The importance of group sales of the top-100 groups as a percentage of gross domestic product increased from 28 percent in 1981 to 54 percent in 1998 (Chung and Mahmood, 2004).

Business groups in Taiwan demonstrate a rich variety of network ties as well as variation in innovativeness within and across the groups. Affiliates of Taiwanese groups are linked together by economic and social ties including buyer-supplier relations, equity holdings, and director interlocks (Numazaki, 1986). Affiliate firms of Taiwanese groups commonly engage in buyer-supplier relationships with each other in order to take advantages of economies of scale and scope. Taiwanese business groups commonly set up chains of equity shareholding ties among their member firms (La Porta, Lopez-de-Silanes, and Shleifer, 1999; Claessens, Djankov, and Lang, 2000), which allow information access and control over selecting key personnel such as boards of directors and CEOs in affiliate firms. Taiwanese groups typically hire professional managers to oversee routine administration of affiliates (Chung, 2001), while exercising strategic control through interlocking directorates of family members who often hold the position of board chairs of the affiliates. These intertwined interlocking-directorate ties provide a channel for the group to coordinate key business matters such as goal setting, strategic planning, resource allocation, institution building, and personnel selection (Chen, 2001).

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Taiwan also offers clear definitions of group membership. Group boundaries are ambiguous in some countries, implying that it is difficult to examine the effects of intragroup ties on affiliates' innovative activity. In Japan, for instance, a lack of family solidarity and governmental encouragement of intergroup activities obscures *keiretsu*[6] boundaries (Saxonhouse, 1993; Weinstein and Yafeh, 1995). In Taiwan, by contrast, strong cultural foundations such as patrilineal family connections and regional kinship clearly delineate group boundaries (Numazaki, 1986). One can identify the largest private owners and directors of group affiliates in Taiwan, along with detailed data on buyer-supplier, director, and equity ties. It is the heterogeneity of ties, coupled with the clarity of group boundaries that makes groups in Taiwan attractive for examining how various types of intragroup ties affect capability acquisition differently.

DATA AND MEASURES

Data source and sample

Our conceptual framework offers a contingency model that specifies how different types of network ties will differentially affect the process of capability acquisition. To test this, we need data on a firm's network ties and its capabilities. There are three sources that we refer to. Our major data source is the *Business Groups in Taiwan* (BGT) directory, compiled by the *China Credit Information Service* (CCIS) in Taipei, the oldest and most prestigious credit checking agency in Taiwan and an affiliate of Standard & Poor's of the United States. CCIS started publishing data for the top 100 business groups (in terms of annual sales) biennially in 1972. It constructs the database of business groups by examining the interorganizational relationships such as shared identity, cross holding, and interlocking directorate among these firms. In addition to self-identification, firms have to meet the following objective criteria to be considered as members (1) more than 51 percent of the ownership is native capital; (2) the group has three or more independent firms; (3) the group has more than NT$100 million group total sales; and (4) the core firm of the group is registered in Taiwan.

This directory is the most comprehensive and reliable source for business groups in Taiwan. Several previous studies rely on this source (e.g., Claessens *et al*., 2000; Khanna and Rivkin, 2001), although none has translated and coded the intragroup ties data. Therefore, we collected data of intragroup network ties by reading the figures for each group in the BGT directory that depicted intragroup buyer-supplier relationships and equity cross holdings, which we used to code buyer-supplier and equity ties between affiliates. The BGT directory also provided the list of names of directors for each affiliate, which we used to code director ties between affiliates. Moreover, we collected detailed financial information about both the groups and their affiliates from the BGT directory.

Our focal firms are group affiliates that are listed on the Taiwan stock market. To measure firms' R&D capability, for each focal firm in our sample we collected information pertaining to its R&D expenditure from the *Taiwan Economic Journal Data Bank* (http://www.tej.com.tw), and the number of successful patent applications of each firm from an online database of the *Intellectual Property Office of Taiwanese Government* (http://www.patent.org.tw), which provides the information about patent applications of Taiwan firms since 1980.

Our sample consists of listed group firms (rather than all group firms) of each business group. This is because this kind of detailed data of R&D expenditure, which is necessary for measuring R&D capability, is only available for listed group affiliates. Thus, our sample consists of 694 observations for 188 listed firms belonging to 123 business groups across nine years (1981, 1983, 1986, 1988, 1990, 1992, 1994, 1996, and 1998).[7] Because of the BGT publication schedule, we collected information about intragroup networks for each two-year period. Table 1 provides detailed information about the number of business groups and their affiliate firms for each year and for the whole sample. It also shows the average number of affiliates per group, the number of listed group firms, and the average number of listed group firms per group.

[6] 'A Japanese term describing a loose conglomeration of companies organized around a single bank for their mutual benefit. The companies sometimes, but not always, own equity in each other' http://www.investorwords.com/2691/keiretsu.html#ixzz12uzMT1KK (20 October 2010).

[7] Some of the 188 listed firms did not appear in all of the nine years due to emergence of new listed firms and the changes in the list of top-100 business groups. As a result, the total number of firm-year observations are less than 1,692 (= 188 × 9).

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Table 1. Sample composition: Intragroup network ties of Taiwanese business groups (1981–1998)

Year	Number of groups	Number of group affiliates	Average number of group affiliates per group	Number of listed group affiliates	Average number of listed group affiliates per group	Average number of buyer-supplier ties per focal firm	Average number of equity ties per focal firm	Average number of director ties per focal firm
1981	28	279	10	36	1.3	2.8	4.4	4.8
1983	27	313	12	40	1.5	3.1	5.2	4.5
1986	28	353	13	42	1.5	2.8	5.9	4.9
1988	42	452	11	55	1.3	2.5	5.2	4.0
1990	46	454	10	64	1.4	2.2	4.9	3.6
1992	62	611	10	90	1.5	1.8	5.2	3.9
1994	67	718	11	100	1.5	1.8	5.5	4.4
1996	79	911	12	120	1.5	1.7	6.5	4.1
1998	106	1357	13	147	1.4	2.1	7.0	5.1
Whole sample	485	5448	11	694	1.4	2.3	5.5	4.4

On average, there are 11 affiliates per sample group, meeting the criterion for Taiwanese business groups, which should have three or more independent firms.

Dependent variable—affiliate R&D capability

Affiliate-level R&D capability is calculated in the way consistent with Dutta, Narasimhan, and Rajiv (2005). The details of measuring R&D capability are exhibited in the Appendix.

Independent variables and controls

For each group, we use information on the number of intragroup buyer-supplier ties, equity ties, and director ties to measure network centrality. Specifically, our measure of centrality is the count number of direct partners with which a focal firm has relationships normalized by the number of network-member firms, which nicely captures the number of ties a focal firm maintains relative to the maximum number of potential ties it can have. We created three degree-centrality measures, one for each type of tie (buyer-supplier, equity, and director). We did not use other centrality measures, such as closeness centrality (Freeman, 1977), due to the small size of our networks.

We include four affiliate-level variables to capture other influences exerted by affiliates on the acquisition of capability. *Affiliate size* denotes the total assets of the affiliate (thousands of New Taiwanese dollars). Large affiliates may be better positioned to acquire capabilities. Scale economies, in terms of spreading costs of implementing capabilities over a large base of operations, are greater in larger affiliates. *Affiliate age* refer to the number of years from the establishment of the firm. Older affiliates may be less innovative due to organizational inertia. *Affiliate ROA* denotes the annual affiliate return on assets (ROA). Affiliates with higher ROA are likely to already be equipped with superior internal capabilities, making it easier to develop new capabilities. *Alter diversity in firm age* captures the extent to which the focal affiliate's direct partners connected through any one of the three types of ties varies in their firm age. It is measured by the ratio of coefficient of variation to 2(1-1/n), where n is the number of affiliates in a group (Simon, Pelled, and Smith, 1999). Focal affiliates connected to partners with different firm age and thus distinct resource profile may have a better access to diverse resources conducive to R&D capability building. Moreover, 19 industry categories of affiliates are included to control for variations in competitive capabilities in distinct industries.

To the extent that firms within a group may share certain common group-specific attributes, error terms across affiliates within a group may correlate with each other. Thus, a failure to control for group-specific heterogeneities might lead to problems of autocorrelations among affiliates within the same group. We address this problem by including several group-level variables that address group-level influences on the development of affiliate capability. *Number of group affiliates* denotes the number of firms within a specific business group. Groups with a larger number of affiliates may show greater diversity than those with fewer affiliates, and hence exert greater impact on capability acquisition. *Group other ROA* refers to the annual return on assets of all the non-focal group affiliates. Well-performing group members may facilitate the capability building of focal affiliates by providing complementary resources. *Group other assets* measures the aggregate assets of all group affiliates except for the ones included in our sample. Large groups may facilitate capability building by providing sufficient supportive resources. *Group unrelated diversification* has been a widely adopted strategy by business groups. It is found to enhance group performance by promoting economies of scope (Amsden and Hikino, 1994; Khanna and Palepu, 1997). We use the following formula to measure it: $\sum P_j \times \ln(1/P_j)$, where P_j is defined as the percentage of group sales in industry sector j (Palepu, 1985). The identification of industry sector is based on two-digit standard industrial classification codes for Taiwan.

We also control for the connectivity between affiliates using group network density of different types of ties.[8] Specifically, *density of all ties* denotes the ratio of actual buyer-supplier, equity, and director ties among affiliates within a business group to the total number of potential ties in that group. *Equity density* is defined as the ratio of actual equity ties among affiliates within a business group to the total number of potential equity ties in that group. *Director density* is defined as the ratio of actual director ties among affiliates within a business group to the total number of potential director ties in that group. In addition, we control for the *strength of equity ties* and the *strength of director ties* to account for any potential correlation between tie strength and network density. We capture the strength of ties between two affiliates by focusing on the intensity of their interactions, indicated by the number of ties connecting them. We then average this number across all of the focal affiliate's partners. This operationalization has been used in previous empirical research (Hansen, 1999; McFadyen and Cannella, 2004). In addition, 12 industry dummies are included in regressions to control for the interindustry variations in R&D capability.

ANALYSES

Summary statistics

Table 2A and Table 2B report summary statistics and correlations between variables. Table 2A shows significant heterogeneity in R&D capability across firms, with the minimum R&D capability at 0.569 and maximum R&D capability at 0.998. It also shows that the mean centrality across affiliates is highest for equity centrality (0.510), followed by director centrality (0.378), and buyer-supplier centrality (0.232).

Regression results

Due to the nature of panel data, we applied the Lagrange multiplier test for unobserved heterogeneity to justify the use of panel estimation. Both fixed-effects models and generalized least squares (GLS) random-effects models are able to cope with unobserved heterogeneity. However, we primarily rely on random-effects models because our theoretical interest focuses on the variation in network position and network structure. These network characteristics, by their nature, primarily vary between organizations, as opposed to within organizations, over time. In addition, we applied the Hausman test (which ascertains the validity for using a random-effects specification) to ensure that our choice of model was justifiable.[9] Table 3 provides regression results on affiliates'

[8] We did not use buyer-supplier density in our empirical analysis because it is highly correlated with buyer-supplier centrality.

[9] While fixed-effects methods have the virtue of eliminating potentially large sources of bias by controlling for all time-invariant characteristics of the affiliates, they can only take into

Table 2A. Summary statistics

	Mean	Standard deviation	Minimum	Maximum
Dependent variable				
R&D capability	0.818	0.089	0.569	0.998
Independent variables				
Buyer-supplier centrality	0.232	0.260	0	1
Equity centrality	0.510	0.330	0	1
Director centrality	0.378	0.295	0	1
Control variables				
Density of all ties	0.350	0.152	0.027	1
Equity density	0.248	0.179	0	1
Director density	0.323	0.274	0	1
Affiliate size (logged assets)	22.60	1.395	13.311	26.038
Affiliate age	29.733	11.508	3	82
Affiliate ROA	7.145	6.549	−13.000	88.790
Number of group affiliates	12.782	8.895	3	52
Group other ROA	5.069	5.547	−8.450	45.569
Group other assets (logged)	9.575	1.913	−2.501	13.790
Group unrelated diversification	0.956	0.503	0	2.310
Alter diversity in firm age	0.394	0.152	0	0.950
Strength of equity ties	1.027	0.306	0	2
Strength of director ties	0.830	0.376	0	1

R&D capability using the GLS random-effects model.

Model 1 serves as a baseline model that includes only control variables. Model 2 tested the effect of buyer-supplier ties on the development of R&D capability. It shows that buyer-supplier centrality leads to significant increases in R&D capability. This result suggests that buyer-supplier ties can clearly enhance firm capability. Therefore, Hypothesis 1, which proposes that buyer-supplier ties are conducive to R&D capability building, is supported.

Model 3 to Model 5 test Hypotheses 2a, 2b, and 2c, which propose complementarities between buyer-supplier ties and the other two types of ties. In Model 3, we add in the interaction term between buyer-supplier centrality and director centrality. Consistent with our expectation, we find that buyer-supplier ties are more valuable when the focal affiliate keeps director ties ($P < 0.05$). Similarly, Model 4 shows that buyer-supplier ties are more beneficial when the focal affiliate has equity ties ($P < 0.05$). In Model 5, we include the three-way interaction between the centralities of three types of ties and find that affiliates having three types of ties may benefit even more ($P < 0.10$).

Recall that Hypothesis 3 posited that buyer-supplier ties maintained by a focal affiliate are likely to be more valuable when the focal affiliate is embedded in a dense director network. To test this hypothesis, we introduce the interaction term between buyer-supplier centrality and the density of director ties in Model 6. The interaction term takes on a positive sign and is statistically significant ($P < 0.10$), suggesting that dense director networks increase the value of buyer-supplier ties.

Hypothesis 4 focuses on the moderating effect of the density of equity ties on R&D capability, positing that the value of buyer-supplier ties is likely to decrease when the focal affiliate is embedded in a dense equity network. We added the interaction term between buyer-supplier centrality and the density of equity ties in Model 7. The coefficient of the interaction term is negative and statistically significant ($P < 0.10$), indicating that dense equity networks depreciate the value of buyer-supplier ties. Thus, the result in Model 7 offers support for Hypothesis 4.

Since network density and tie strength are correlated to the extent that open networks are often accompanied by weak ties while closed networks are accompanied by strong ties (Burt, 1992), one issue is worthy of further investigation: whether

account the within-organization variation, ignoring the between-organization variation. In our sensitivity tests, we reestimate our models using both fixed effects as well as GEE. We also cluster by groups within the GEE models to address the possibility that affiliates share group-specific attributes.

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Table 2B. Correlation matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. R&D capability	1.00																
2. Buyer-supplier centrality	0.19*	1.00															
3. Equity centrality	0.14*	0.17*	1.00														
4. Director centrality	−0.01	0.12*	0.09*	1.00													
5. Density of all ties	−0.01	0.44*	0.16*	0.51*	1.00												
6. Equity density	−0.04	0.24*	0.42*	0.19*	0.70*	1.00											
7. Director density	−0.05	0.11*	0.01	0.79*	0.78*	0.26*	1.00										
8. Affiliate size (logged assets)	0.15*	−0.01	0.19*	−0.01	−0.17*	−0.13*	−0.08*	1.00									
9. Affiliate age	−0.10*	0.10*	0.18*	0.00	−0.14*	−0.13*	−0.11*	0.24*	1.00								
10. Affiliate ROA	0.25*	0.07	−0.11*	−0.02	−0.03	−0.11*	−0.01	0.01	−0.16*	1.00							
11. Number of group affiliates	0.01	−0.26*	−0.21*	−0.17*	−0.44*	−0.47*	−0.24*	0.26*	0.18*	0.02	1.00						
12. Group other ROA	0.01	−0.10*	−0.04	−0.02	0.03	0.03	0.03	0.01	0.01	−0.03	0.01	1.00					
13. Group other assets (logged)	−0.12	−0.34*	−0.29*	−0.23*	−0.43*	−0.36*	−0.23*	0.28*	−0.01	−0.04	0.59*	0.23*	1.00				
14. Group unrelated diversification	−0.06	−0.43*	−0.16*	−0.12*	−0.44*	−0.38*	−0.19*	0.17*	0.08*	−0.06	0.63*	0.07	0.38*	1.00			
15. Alter diversity in firm age	0.07	−0.15*	0.16*	0.08*	−0.07	−0.01	0.03	0.00	−0.05	−0.07	0.02	0.04	−0.01	0.02	1.00		
16. Strength of equity ties	0.01	−0.03	0.39*	0.02	0.07	0.30*	0.02	0.13*	0.06	−0.12*	0.00	0.00	0.06	0.05	0.11*	1.00	
17. Strength of director ties	−0.01	0.02	0.12	0.47	0.15	−0.01	0.32	0.05	0.11	0.02	0.10*	−0.02	−0.10*	0.03	0.15	0.07	1.00

* $p < 0.05$

Table 3. The effect of intragroup network on group affiliates' R&D capability using GLS random-effects models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Independent variables	Baseline model	H1	H2a	H2b	H2c	H3	H4	H3, H4
Buyer-supplier centrality		0.067***	0.060***	0.106***	0.092***	0.052***	0.060***	0.055***
		(0.015)	(0.016)	(0.022)	(0.023)	(0.015)	(0.015)	(0.015)
Director centrality		0.009	0.005	0.011	0.004			
		(0.013)	(0.013)	(0.013)	(0.013)			
Equity centrality		0.014	0.013	0.030**	0.024**			
		(0.011)	(0.011)	(0.014)	(0.013)			
Buyer-supplier centrality* Director centrality			0.007**		0.007**			
			(0.003)		(0.003)			
Buyer-supplier centrality* Equity centrality				0.065**	0.058**			
				(0.028)	(0.028)			
Buyer-supplier centrality* Director centrality* Equity centrality					0.005*			
					(0.003)			
Buyer-supplier centrality* Director density						0.006*		0.007**
						(0.003)		(0.003)
Buyer-supplier centrality* Equity density							−0.006*	−0.007**
							(0.003)	(0.003)
Control variables								
Density of all ties	−0.010**	−0.015***	−0.015***	−0.016***	−0.015***			
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)			
Director density						−0.030**		−0.021
						(0.014)		(0.015)
Equity density							−0.035	−0.028
							(0.024)	(0.026)
Director centrality* Equity centrality					−0.001			
					(0.003)			

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Strength of director tie								−0.006
								(0.009)
Strength of equity tie								−0.001
								(0.011)
Affiliate size (logged assets)	0.008***	0.006**	0.007***	0.006**	0.006**	0.008***	0.007***	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Affiliate age	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Affiliate ROA	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Alter diversity in firm age	0.033*	0.043**	0.044**	0.043**	0.045**	0.053**	0.048**	0.055***
	(0.019)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)	(0.021)
Number of group affiliates	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Group other ROA	0.001**	0.002**	0.002**	0.001**	0.001**	0.001**	0.002**	0.001**
	(0.000)	(0.001)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.001)
Group other assets (logged)	−0.015***	−0.012***	−0.013***	−0.011***	−0.012***	−0.013***	−0.013***	−0.013***
	(0.003)	(0.003)	(0.003)	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)
Group unrelated diversification	−0.005	−0.001	−0.001	−0.001	−0.001	−0.003	−0.001	−0.001
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Constant	0.807***	0.792***	0.795***	0.778***	0.786***	0.759***	0.771***	0.780***
	(0.056)	(0.056)	(0.056)	(0.056)	(0.056)	(0.055)	(0.056)	(0.056)
Wald chi-square	200.72***	226.62***	232.39***	232.72***	240.66***	219.66***	221.77***	230.69***
R-square	19.78%	24.04%	25.66%	25.73%	26.95%	24.21%	24.46%	25.91%
Number of observations	694	694	694	694	694	694	694	694

Note: *** Significant at 1% level; ** significant at 5% level; * significant at 10% level;
Standard errors are in the parentheses;
Dummy variables for industry are included in the models, but not shown in the table.

the open vs. closed network distinction will still have an independent effect once we control for tie strength. To address this issue, we control for tie strength while examining the moderating effects of network density on R&D capability in Model 8. It turns out that the moderating effect of network density is still significant ($P < 0.05$) after controlling for the strength of equity ties and director ties.

Robustness checks

We recognize the possibility that innovative affiliates can position themselves more centrally in the networks in which they are embedded, since other affiliates might be keen to build relationships with the capable affiliates.[10] We address the issue of causality in the following ways. First, we carried out Hausman endogeneity tests to check the problem of endogeneity. As a result, we did not find systematic differences between estimates using OLS and two-stage least squares, which suggest that the previous regression results do not suffer from serious problems of endogeneity. Second, we ran a set of regressions using the change of affiliate centrality between period t and $t + 1$ as the dependent variable, and R&D capability in period t as the independent variable. The regression results show that none of the coefficients of R&D capability in the models is significant.

We also address the concern about unobserved heterogeneity by using fixed-effects models. The results are very similar to those in random-effects models. In addition, we use a flexible method known as the generalized estimating equations (GEE) for panel data (Liang and Zeger, 1986) to specify within-group correlation structures as well as to correct for heteroskedasticity. Our results using GEE remain materially unchanged (Table 4). Finally, when using GEE estimation as a robustness check, we cluster group affiliation across affiliates in the sample to control for the correlation between observations for affiliates from the same business groups. The results of such analysis are similar to those using random-effects models.

In addition, we use the number of patents as an alternative measure for the R&D capability of group affiliates. Since there is an excessive number of zeros in the number of patents (525 observations out of 694 observations), we adopt a zero-inflated negative binomial model to test the impact of intragroup ties on the number of patents achieved by group affiliates. As shown in Table 5, the results are qualitatively similar except that the results for Hypothesis 2c and Hypothesis 4 are weaker. These differences may be due to the differential extent to which the two measures (i.e., R&D capability by SFE and number of patents) capture the heterogeneity in the innovative capability of affiliates.

[10] Prior studies have handled this causality issue by comparing the emergence of capabilities of interest to the duration of network ties between organizations and observed that the network ties came about much earlier than the emergence of capabilities (McEvily and Zaheer, 1999; McEvily and Marcus, 2005).

DISCUSSION AND IMPLICATIONS

We began by noting that firms affiliated with business groups in emerging economies differ in their capabilities and are widely connected to each other through a variety of intragroup ties. Drawing on network literature about the heterogeneity in the content of ties, we proposed that one way to explain the variation in affiliates' capabilities is to eschew the traditional view of network ties as generic conduits for information and resource exchange between firms, and to instead consider how a focus on different types of ties can more accurately explain the extent to which an affiliate can acquire capabilities through network ties with other group members.

Using longitudinal data of business groups in Taiwan, we show how differences in the type and mix of group affiliates' ties in business groups relate to the development of their internal capabilities. Specifically, we argue and find that given the ability of buyer-supplier ties to provide stimuli for innovation, affiliate firms in business groups with buyer-supplier ties were particularly better able to acquire R&D capabilities than those without such ties. Moreover, we found that buyer-supplier ties combined synergistically with other types of ties, that is, when buyer-supplier ties were coupled with director ties, the effect of buyer-supplier ties was even stronger. We also found that the informational value of buyer-supplier ties was additionally contingent on other aspects of network structure (network density), and that this contingency itself depended on the type of tie studied. The finding of this second-order contingency in the capability-network tie relationship is a particularly original contribution to the literature, we believe, and our evidence on the differences in the information value of certain ties gives us greater confidence

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Table 4. The effect of intragroup network on group affiliates' R&D capability using generalized estimating equations (GEE)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Independent variables	Baseline model	H1	H2a	H2b	H2c	H3	H4	H3, H4
Buyer-supplier centrality		0.068***	0.061***	0.107***	0.092***	0.053***	0.061***	0.056***
		(0.015)	(0.016)	(0.022)	(0.023)	(0.015)	(0.015)	(0.015)
Director centrality		0.007	0.004	0.010	0.004			
		(0.013)	(0.013)	(0.013)	(0.013)			
Equity centrality		0.014	0.013	0.030**	0.024*			
		(0.011)	(0.011)	(0.013)	(0.013)			
Buyer-supplier centrality* Director centrality			0.007**		0.007**			
			(0.003)		(0.003)			
Buyer-supplier centrality* Equity centrality				0.066**	0.058**			
				(0.028)	(0.028)			
Buyer-supplier centrality* Director centrality* Equity centrality					0.005*			
					(0.003)			
Buyer-supplier centrality* Director density						0.006**		0.007**
						(0.003)		(0.003)
Buyer-supplier centrality* Equity density							−0.006**	−0.007**
							(0.003)	(0.003)
Control variables								
Density of all ties	−0.010**	−0.015***	−0.015***	−0.016***	−0.015***			
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)			
Director density						−0.031**		−0.022
						(0.014)		(0.014)
Equity density							−0.036	−0.029
							(0.024)	(0.025)

Table 4. (*Continued*)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Independent variables	Baseline model	H1	H2a	H2b	H2c	H3	H4	H3, H4
Director centrality* Equity centrality					−0.001			
					(0.003)			
Strength of director tie								−0.007
								(0.009)
Strength of equity tie								−0.001
								(0.011)
Affiliate size (logged assets)	0.008***	0.007***	0.007***	0.006**	0.006***	0.008***	0.008***	0.008***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Affiliate age	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***	−0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Affiliate ROA	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***	0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Alter diversity in firm age	0.033*	0.044**	0.044**	0.043**	0.045**	0.054***	0.048**	0.056***
	(0.020)	(0.021)	(0.020)	(0.021)	(0.020)	(0.020)	(0.020)	(0.020)
Number of group affiliates	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Group other ROA	0.001**	0.001**	0.002**	0.001**	0.001**	0.002**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Group other assets (logged)	−0.016***	−0.012***	−0.013***	−0.011***	−0.012***	−0.013***	−0.012***	−0.013***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Group unrelated diversification	−0.005	−0.001	−0.001	−0.001	−0.001	−0.003	−0.001	−0.001
	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)	(0.010)
Constant	0.809***	0.786***	0.791***	0.774***	0.787***	0.751***	0.761***	0.772***
	(0.056)	(0.056)	(0.055)	(0.055)	(0.055)	(0.054)	(0.055)	(0.055)
Wald chi-square	204.12***	227.96***	236.19***	235.50***	247.70***	221.12***	221.82***	235.41***
Number of observations	694	694	694	694	694	694	694	694

Note: *** Significant at 1% level; ** significant at 5% level; * significant at 10% level;
Standard errors are in the parentheses;
Dummy variables for industry are included in the models, but not shown in the table.

Table 5. The effect of intragroup network on group affiliates' patents using zero-inflated negative binomial model

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Independent variables	Baseline model	H1	H2a	H2b	H2c	H3	H4	H3, H4
Buyer-supplier centrality		0.576***	0.609***	0.593***	0.574***	0.521***	0.533**	0.558***
		(0.185)	(0.213)	(0.202)	(0.198)	(0.172)	(0.214)	(0.190)
Director centrality		0.209	0.205	0.204	0.202			
		(0.174)	(0.153)	(0.143)	(0.139)			
Equity centrality		0.413	0.398	0.386	0.395			
		(0.302)	(0.274)	(0.281)	(0.302)			
Buyer-supplier centrality* Director centrality			0.104***		0.101**			
			(0.037)		(0.044)			
Buyer-supplier centrality* Equity centrality				0.235**	0.218**			
				(0.118)	(0.104)			
Buyer-supplier centrality* Director centrality* Equity centrality					0.037			
					(0.021)			
Buyer-supplier centrality* Director density						0.102***		0.103***
						(0.033)		(0.029)
Buyer-supplier centrality* Equity density							−0.069	−0.072
							(0.042)	(0.051)
Control variables								
Density of all ties	−0.457**	−0.376***	−0.383**	−0.367**	−0.382**			
	(0.185)	(0.121)	(0.147)	(0.139)	(0.157)			
Director density						−0.237**		−0.211*
						(0.114)		(0.104)
Equity density							−0.152	−0.128
							(0.087)	(0.104)
Director centrality* Equity centrality					0.129			
					(0.224)			

Table 5. (*Continued*)

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Independent variables	Baseline model	H1	H2a	H2b	H2c	H3	H4	H3, H4
Strength of director tie								−0.018
								(0.022)
Strength of equity tie								−0.027
								(0.014)
Affiliate size (logged)	0.052	0.056	0.057	0.056	0.047	0.058	0.063	0.054
	(0.086)	(0.071)	(0.072)	(0.072)	(0.065)	(0.072)	(0.068)	(0.062)
Affiliate age	−0.019*	−0.020**	−0.018**	−0.019**	−0.022**	−0.020**	−0.020**	−0.021***
	(0.011)	(0.009)	(0.008)	(0.008)	(0.009)	(0.009)	(0.008)	(0.008)
Affiliate ROA	0.008	0.009	0.009	0.008	0.009	0.008	0.009	0.010
	(0.021)	(0.018)	(0.020)	(0.019)	(0.022)	(0.020)	(0.017)	(0.013)
Alter diversity in firm age	0.308	0.291	0.306	0.302	0.305	0.353	0.324	0.311
	(0.664)	(0.605)	(0.621)	(0.617)	(0.584)	(0.601)	(0.611)	(0.592)
Number of group affiliates	0.009	0.012	0.011	0.010	0.010	0.011	0.012	0.014
	(0.022)	(0.016)	(0.017)	(0.014)	(0.016)	(0.014)	(0.015)	(0.013)
Group other ROA	−0.029**	−0.029**	−0.029**	−0.029**	−0.029**	−0.029**	−0.029**	−0.029**
	(0.012)	(0.011)	(0.012)	(0.010)	(0.011)	(0.011)	(0.012)	(0.011)
Group other assets (logged assets)	0.339***	0.351***	−0.346***	−0.351***	−0.322**	−0.309***	−0.314***	−0.343***
	(0.094)	(0.113)	(0.105)	(0.118)	(0.115)	(0.096)	(0.106)	(0.118)
Group unrelated diversification	−0.833**	−0.783**	−0.812**	−0.823*	−0.811*	−0.747*	−0.822*	−0.794**
	(0.396)	(0.356)	(0.384)	(0.409)	(0.404)	(0.372)	(0.413)	(0.362)
Constant	−3.327*	−4.867***	−4.795***	−4.872***	−4.586***	−3.624***	−3.875**	−3.471***
	(1.921)	(1.502)	(1.516)	(1.496)	(1.573)	(1.043)	(1.422)	(1.182)
LR chi-square	283.15***	290.21***	299.84***	298.71***	305.24***	288.39***	285.64***	293.84***
Number of observations	694	694	694	694	694	694	694	694

Note: *** Significant at 1% level; ** significant at 5% level; * significant at 10% level;
Standard errors are in the parentheses;
Dummy variables for industry are included in the models, but not shown in the table.

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in our focus on how different types of ties can combine to generate R&D capability.

By offering a theoretical and empirical analysis of how different types of intragroup ties influence the acquisition of firm capabilities, we see our integrative study as having implications for three separate streams of prior research, specifically, firm capabilities, business groups, and social networks. With respect to research on firm capabilities, we see this study as deepening our understanding of the fundamental question of the possible origin of capabilities (Ethiraj *et al*., 2005). Extant literature on capabilities has typically emphasized capabilities as being internally generated, with heterogeneity primarily arising from imperfections in factor markets (Barney, 1986), distinct organizational skills and routines (Nelson and Winter, 1982), causal ambiguity and uncertain imitability (Dierickx and Cool, 1989), and deliberate investment in learning and making improvements (Zollo and Winter, 2002). While we do not deny internal sources of capability acquisition, we do challenge the implicit assumption that firms are autonomous and atomistic in their pursuit of capabilities. This atomistic approach, with its focus on the characteristics of firms, neglects the importance of the network in which firms are embedded (McEvily and Zaheer, 1999; Gulati *et al*., 2000). Our research redresses this imbalance by highlighting the significance of network ties in the development of firm capabilities. It emphasizes the value of adding an embeddedness perspective when studying the acquisition of firm capabilities.

We find it noteworthy that although there are numerous studies in the strategic management literature aimed at explaining variations in performance in terms of resources and capabilities, there are many fewer studies of how firms identify, develop, and improve their capabilities. Focusing on the variation in R&D capability of group affiliates, our research extends this stream of research by highlighting how and why some network ties (and not others) among group firms can serve as conduits for accessing external resources and capabilities. In other words, the heterogeneity in group affiliates' capabilities can be accounted for not only by differences in resources internal to an affiliate, but also by variation in the affiliate's specific network ties. This finding also sheds light on the general interorganizational networks that consist of multiplex ties. In essence, differences in type and mix of ties maintained by a firm have a strong influence on the firm's exposure to new ideas, opportunities, and resources, and therefore have important implications for its acquisition of capabilities.

Finally, we hope that our study has also contributed to the capabilities literature from a measurement perspective, based on our novel application of SFE to measure R&D capability. The measurement of capabilities has long been a contentious issue in the literature, but we see some important advantages in our method, as discussed earlier. Of course, others have suggested that 'as far as limitations go, the most obvious one is the use of a parametric approach to estimating capabilities (Dutta *et al*., 2005: 284).' One promising alternative that builds on our approach is to use semiparametric methods based on a combination of both SFE and data envelope analysis.

We also seek to contribute to research on business groups (particularly in emerging economies) by examining how group network ties shape the specific development of focal affiliates' capabilities. We find that some group network ties provide benefits on affiliates' capabilities, whereas some do not. Business groups can assist in the acquisition of capabilities in the sense that they facilitate resource sharing and information exchange among affiliates, which is hard to achieve via market systems in emerging economies (Khanna and Palepu, 2000). The focal affiliate's configuration of linkages with other group members is an important vehicle through which the affiliate's competences, routines, and concepts are continually updated and improved. Moreover, intragroup networks that are beneficial to R&D capability building are characterized by multiplex ties with complementary content and appropriate network densities of specific types of ties. A group affiliate that is central in the buyer-supplier network and is embedded in a dense director network and a sparse equity network, enjoys the highest innovative benefits resulting from its network ties.

While our study primarily focuses on the network within business groups, we also hope to provide implications for general interfirm networks by highlighting the differential role of alternative types of ties in the acquisition of capabilities when the networks involve different types of ties. Extant network literature primarily focuses on the link between network structure and performance-related outcomes (Uzzi, 1996; Ahuja, 2000; Zaheer and Bell, 2005). However, less attention has been

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paid to the impact of network ties on firm capabilities, which are an important source of competitive advantage (Nelson, 1991; Dosi, Nelson, and Winter, 2000). Moreover, most of the relevant studies treat all interorganizational ties equally, without identifying the specific resources and information transmitted through distinct types of ties. We have sought to provide specific and differentiated identification of the value of different types of ties. We have also investigated how the type and the structure of ties jointly determine their impact on capability building. It turns out that the optimal network structure is contingent on types of ties. Dense network ties transferring knowledge contribute to capability building by improving trust and facilitating the sharing of fine-grained knowledge among network partners, while sparse network ties containing financial resources are conducive to capability building by restricting competition among network partners and providing more opportunities for capitalizing external financial resources. Our study provides support for the notion that the value of network ties is contingent on the outcome examined, the nature of the ties, and the context being studied (Ahuja, 2000). In addition, by using business groups to contextualize our theoretical and empirical analysis, our study also sheds light on the role of *internal networks* in capability acquisition, which has been understudied in prior network research focusing on external networks.

LIMITATIONS AND DIRECTIONS FOR FUTURE RESEARCH

This study has several limitations. First, when measuring the R&D capability of group affiliates, we use the number of patents as a proxy for technological outputs, overlooking variations in the quality of patents. If the information of citations for patents is available, a better approach would be to weight patents by the number of citations they have received (Dutta *et al*., 2005). Second, we capture three types of formal ties that are prevalent among group affiliates, but other formal and informal intragroup ties may also affect the acquisition of capabilities. Moreover, group affiliates might also maintain external linkages with organizations beyond groups, which may affect both the effect of intragroup ties (e.g., external linkages may substitute or complement intragroup ties) and acquisition of R&D capability (e.g., linkages with high tech multinational enterprises provide group affiliates with access to superior R&D capability). Although our robust results suggest that our stringent empirical analysis has taken into account unobserved heterogeneity arising from omitted variables, future research may investigate more varieties of network ties, including both internal and external. Third, our arguments and findings are specific to the networks within business groups in emerging economies. Caution should be taken when generalizing these findings to generic interorganizational networks.

Despite the foregoing limitations, we see our study as advancing our understanding of the relationship between networks and capabilities, and we propose several extensions for future research. For example, we would welcome additional disaggregated measures of capability that go beyond functional domains and focus on individual projects (Henderson and Cockburn, 1994; Ethiraj *et al*., 2005). Such indicators may be particularly useful for identifying the underlying process through which interorganizational networks benefit or constrain the acquisition of firm capabilities. Second, just as we have shown that network ties affect firm capabilities, others might study how superior capabilities can also influence the configuration of networks. In this study, as noted earlier, we carefully address the issue of causal direction. Future research examining the potential simultaneous relationship between networks and capabilities may be a useful next step. Finally, while we view our empirical context as particularly well suited for our research questions, we would welcome extensions of our work using samples of other types of interorganization networks in multiple countries. Given the growing importance of firm capabilities and network ties, we believe that additional studies linking these two topics and extending our study in any of these directions would represent valuable contributions to strategic management research and practice.

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APPENDIX: MODELING R&D CAPABILITY USING STOCHASTIC FRONTIER ESTIMATION MODEL

The SFE model is specified as

$$Y_{it} = f(X_{it}, \beta) + v_{it} - u_{it} \quad [1]$$

where Y_{it} denotes the appropriate function (e.g., logarithm) of the output for the ith sample firm in the tth time period, $i = 1, 2, \ldots,$ N, and $t = 1, 2, \ldots,$ T; X_{it} represents the vector of appropriate functions of inputs of firm i in time period t; β is the vector of unknown coefficients to be estimated. In Equation [1], we implicitly assume that firms are identical in terms of their expected capabilities given the same level of inputs because they share the same level of expected inefficiency error term u. However, it is likely to be violated due to the unobserved heterogeneity in firms' capabilities. The model parameters β are also assumed to be the same across all the firms. This, too, is a restrictive assumption in the sense that the impact of the same inputs on the outputs may be different due to the nature of the product lines. Since the failure to control for unobserved heterogeneity may lead to inconsistent parameter estimates, we apply a random parameter SFM, which accounts for heterogeneity in both the inefficiency term and the coefficients of the inputs affecting the frontier.[11]

The consistent maximum likelihood estimates of all parameters in Equation [1][12] can be obtained by maximizing the log-likelihood function given by the following equation:

$$\ln L = cons\ \tan t - \frac{N(T-1)}{2}\ln\delta_v^2 - \frac{N}{2}\ln(\delta_v^2 + T\delta_u^2) - N\ln\left[1 - \Phi\left(\frac{-\mu}{\delta_u}\right)\right] + \sum_{i=1}^{N}\ln\left[1 - \Phi\left(\frac{-\tilde{\mu}_i}{\delta_*}\right)\right] - \frac{\sum_{i=1}^{N}\varepsilon'_i\varepsilon_i}{2\delta_v^2} - \frac{N}{2}\left(\frac{\mu}{\delta_u}\right)^2 + \frac{1}{2}\sum_{i=1}^{N}\left(\frac{\tilde{\mu}_i}{\delta_*}\right)^2, \quad [2]$$

where

$$\tilde{\mu}_i = \frac{\mu\delta_v^2 - T\overline{\varepsilon}\delta_u^2}{\delta_v^2 + T\delta_u^2}, \delta_*^2 = \left(\frac{\delta_u^2\delta_v^2}{\delta_v^2 + T\delta_u^2}\right), \overline{\varepsilon} = \frac{1}{T}\sum_{t=1}^{T}\varepsilon_{it}$$

and $\Phi(.)$ denotes the standard normal cumulative distribution function. Based on the parameter estimates, we calculate the R&D capability for firm i in year t by estimating the efficiency via $E\{\exp(-u_{it})|\varepsilon_{it}\}$, $\varepsilon_{it} = Y_{it} - X_{it}\beta$, $i = 1, 2, \ldots,$ N, and $t = 1, 2, \ldots,$ T.

We estimate R&D capability of firms using the SFE model. We define a firm's R&D capability as its ability to allocate resources to achieve the maximum level of technological output given a certain level of its deployed resources. Resources influential to the technological output (TECHOUTPUT) include *technological base* (TECHBASE), and *accumulated R&D expenditure* (CUM_R&DEXPENSE) (Dutta *et al.*, 2005). Using Cobb-Douglas production function, we specify the innovation frontier as follows:

$$\ln(TECHOUTPUT) = \beta_0 + \beta_1 \times \ln(TECHBASE_{it}) + \beta_2 \times \ln(CUMR\&DEXP_{it}) + v_{it} - u_{it}{}^{13}$$

We use the number of successful patent applications to measure a firm's technological output (TECHOUTPUT).[14] We use local patents to

[11] Specifically, we assume that β is randomly distributed over the population as $N(\overline{\beta}, \delta_\beta{}^2)$. Since the mean of β is a function of firm-specific variables, we have $E[\beta_i|z_i] = \beta + \Delta z_i$, where z_i denotes firm-specific variables for firm i. Moreover, we capture unobserved heterogeneity across firms in their capabilities by positing that the parameter μ is a function of z_i as well. That is $u_{it} = N^+(\mu_{it}, \delta_{uit}^2)$ where $\mu_{it} = \delta'_i z_{it}$.

[12] $f(X_{it}, \beta)$ in Equation [1] represents an idealized efficient frontier common to all sample firms and it defines the maximum level of expected output in the absence of uncertainty, given that firm i deploys X_{it} level of inputs efficiently. The v_{it} denotes the intrinsic randomness affecting output in a typical regression, assumed to be independently and identically distributed as $N(0, \delta_v^2)$. The u_{it} denotes the firm-specific inefficiency making the realized output fall short of the efficient frontier, assumed to be independently and identically distributed as $N^+(\mu, \delta_u^2)$ with $\mu > 0$.

[13] To control for variations in R&D activities across industries, industry dummies for firms in the sample are also included in the estimation of innovation frontiers.

[14] This measure treats all patents as equally important. We recognize that a better approach would be to use quality-adjusted

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measure firms' innovative output. Meanwhile, U.S. patents are used for our robustness check, which shows that the results are qualitatively the same. As R&D expenditures are likely to have a lagged impact on patent application, we use a two-year lag with respect to the dates of R&D expenditures. For robustness purposes, we experiment with concurrent and three-year lag structures. The results are very similar.

Technological base (TECHBASE) is defined as the stock of technological output, with a lower weight on the technological output in earlier years than in later years. Specifically, technological base results from the estimation of a Koyck lag function on technological output. Technological base for period t is specified as $TECHBASE_t = \sum_{k=1}^{k=t} \delta^{t-k} \times TECH\_OUTPUT_k$, where $t = 1, 2 \ldots 5$ periods. Here parameter δ indicates the weight assigned to the technological output in previous years. The higher the value of δ, the greater the spillover effect from past levels of technological output.

Accumulated R&D expenditure (CUM_R&DEXPENSE) is defined as the stock of R&D expenditures, with lower weights on earlier R&D expenditures than on later R&D expenditures in a Koyck lag structure. Specifically, the accumulated R&D expenditure for period t is specified as $CUM\_R\&DEXPENSE_t = \sum_{k=1}^{k=t} \gamma^{t-k} \times R\&DEXPENSE_k$, where $t = 1, 2 \ldots 5$ periods. Here γ is the weight assigned to R&D expenditures in previous periods. The higher the value of γ, the greater the spillover effect from R&D expenditures in previous periods. We expect both β_1 and β_2 to be positive. The table below shows the SFE results of R&D capability. The results are consistent with our expectations. For example, based on the magnitude of the coefficients, TECHBASE is a more important input than CUM_R&DEXPENSE (0.578 vs. 0.203). Moreover, there is significant unobserved heterogeneity in both TECHBASE (0.024, $p < 0.01$) and CUM_R&DEXPENSE (0.018, $p < 0.05$).

patent counts, which assign a weight to a firm's patent based on the number of citations the patent has received (Dutta *et al*., 1999). Due to the unavailability of patent citation information for local patents, we use the raw patent counts as a measure of technological output.

Parameter estimates of R&D capability

Random parameters stochastic frontier model

Variables	Population average effect	Variance of unobserved heterogeneity component
$\hat{\beta}_1$ [ln(TECHBASE)]	0.578***	0.024***
	(0.129)	(0.009)
$\hat{\beta}_2$ [ln(CUM_R&DEXPENSE)]	0.203**	0.018**
	(0.024)	(0.003)
Composite error variance ($\delta_e{}^2 = \delta_v{}^2 + \delta_u{}^2$)	1.792**	
	(0.039)	
Variance of inefficiency error term ($\delta_u{}^2$)	1.047**	
	(0.016)	
Log-likelihood function	−2856.20***	

Note: *** Significant at 1% level; ** significant at 5% level; * significant at 10% level;
Standard errors are in the parentheses;
The likelihood ratio test is used to test the overall significance of the model.

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