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How the Content of Network Ties Affects
Capability Acquisition"*

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Where Can Capabilities Come From?

How the Content of Network Ties Affects Capability Acquisition

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ABSTRACT

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 a firm's boundaries. This study analyzes how firms' network ties represent one important source of capability acquisition. Theoretically, we go beyond the traditional focus on network structure and offer a novel contingency model that specifies how differences in the *content* of network ties (e.g., buyer-supplier, equity, and director ties) will differentially affect the process of R&D capability acquisition. Empirically, we also seek to 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. The supportive results of our analysis show that the effect of network ties on the acquisition of new affiliate capabilities is clearly and predictably contingent on the content of the ties.

Growing recognition of the criticality of organizational capabilities to the pursuit of competitive advantage (Nelson, 1991; Teece, Pisano, and Shuen, 1997) has raised at least two important questions for strategy research: how do firms differ in their capabilities, and where do these differences originate? Prior research has examined internal sources of firm capabilities such as skills and routines (Nelson and Winter, 1982), as well as externally derived capabilities obtained through formal and informal relationships with other firms (Gulati, Nohria and Zaheer, 2000). The focus of this latter stream of work has primarily been on how the structural attributes of network ties affects 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).

We suggest that a possible explanation of these divergent findings on the network ties-to-capabilities relationship may reside in the relative overemphasis on network structure relative to an emphasis on the *content* transmitted through different types of network ties. Content here refers to the material and immaterial substance conveyed through a tie (Podolny and Baron, 1997). It also refers to the behaviors and interactions between firms that characterize the nature of the inter-firm relationship (Gulati and Westphal, 1999). 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 (offering different content) will have differential effects on a firm's acquisition of capabilities through network ties (see also McEvily and Marcus, 2005).

In developing this line of argument, we offer a contingency model that specifies whether and how different types of network ties with distinctly different content can influence capability building of firms. We situate our theoretical arguments using business groups in emerging economies. These business groups, defined as coherent business organizations composed of formally independent firms under a common administrative and financial control (Chang and Hong, 2000; Khanna and Rivkin, 2001), are networks in which the behavior and the performance of individual affiliates are intertwined through various formal and informal relationships within the group (Granovetter, 1995). To the extent that affiliated firms presumably benefit from access to complementary resources, economies of scope and scale, shared costs and risks, and market access to distribution channels, one might expect that affiliates in the same business group would exhibit similar capabilities and performance. However, studies have shown that there is substantial variation in capabilities and performance of the individual affiliates within a specific business group, with some member businesses operating at the leading edge of productivity and others lagging their affiliates (e.g. Chang, 2003). Thus, business groups offer a desirable empirical context in which to address the existence of differences in the capabilities of individual affiliates in a group (after controlling for the effect of an affiliate's internal resources).

As implied from the discussion above, our analysis will focus on the role of the intra-group social network to explain variation in affiliates' capabilities. We consider three types of inter-firm ties prevalent in business groups: buyer-supplier ties, equity ties, and director ties, and we propose that the diverse content found in different types of ties gives affiliates differential opportunities to acquire capabilities from their networks. Rather than aggregating across these different types of ties, we first disaggregate and posit the likely differential influence of each type of ties on the acquisition of capabilities.

In terms of the capabilities themselves, our primary focus is on examining how group affiliated firms enhance their R&D capability by advantageously utilizing different types of network ties that can offer different tie content. Our focus on R&D capabilities 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). By analyzing on the role of varied intra-group network ties as conduits for information and resources, we seek to shed additional light on how firms in emerging economies develop their R&D capability.

Finally, we seek to contribute to the capabilities literature through our empirical methodology, as well. 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 capability. In this study, we measure firm capabilities using a novel econometric approach called the stochastic frontier estimation (SFE). Following SFE, we view capabilities as the *technical efficiency* with which a firm employs a given set of resources or inputs at its disposal to achieve certain outputs (Dutta, Narasimhan, and Rajiv, 2005). 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 *combine efficiently* 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).

Our empirical analysis is conducted using an extensive longitudinal dataset involving 101 cases of affiliates belonging to 48 unique business groups in Taiwan between 1990 and 1998. The results of our analysis are largely supportive of our hypotheses: the effect of network ties on the acquisition of new affiliate capabilities is clearly and predictably contingent on the content of the ties.

A CONTINGENCY PERSPECTIVE ON NETWORK TIE CONTENT

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).

Before presenting our contingency argument, we first address prior arguments regarding the role of network ties in capability building. 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 technological frontier (Chang, 2003). The inter-organizational 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 it with access to complementary resources and information on customers' needs (Srinivasan, Lovejoy, and Beach, 1997), excessive inter-organizational ties can also interfere with the development of firm capabilities by promoting insularity and information leakage (Uzzi, 1997; Burt, 2000). In any event, 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.

In contrast, relatively little is known about the effect of tie *content*. Network ties are clearly heterogeneous in their content, and key differences in content among types of ties can influence the types of resources and information exchanged. A few studies have addressed this issue in different context. For example, Gulati and Westphal (1999) find that the content of CEO-board relationships affects the formation of alliances by influencing the trust between corporate leaders, 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 importance of identifying the content transmitted through each type of ties to further improve our understanding of the role of networks in the process of capability building (Ahuja, 2000; Gnyawali and Madhavan, 2001; Zaheer and Bell, 2005).

We address this need in the present study by analyzing how the different types of network ties (which imply different resource flows) will affect the acquisition of firm capabilities, and furthermore, we explicitly elaborate the mechanisms by which the content of network ties may influence capability building. To contextualize our discussion, we consider how these issues materialize in business groups in emerging economies.

BUSINESS GROUPS AS NETWORKS

Business groups are a common type of multi-business firm in developing economies, frequently dominating a substantial fraction of a country's productive assets and influencing their countries' technological development (Amsden and Hikino, 1994; Granovetter, 1995). Although their precise definitions vary across countries, groups combine elements of conglomerate holding companies and multidivisional corporations, creating a type of multi-business 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 conglomerate and multidivisional corporations. Groups are more stable and coordinated than conglomerates, while being 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, direct interlocks, and buyer-supplier agreements (Lincoln, Gerlach, and Ahmadjian, 1996). In this study, we consider all three types of intra-group 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-shareholdings, and (3) director ties, when an individual sits on the board of multiple affiliates. We then specify our expected contingency relationship, highlighting how these different types of ties imply different tie content and therefore different effects on capability acquisition.

HYPOTHESES

Focal affiliates interested in developing superior R&D capability have the opportunity to access new ideas and resources possessed by other affiliates and then incorporate them into projects related to R&D capability building. Intra-group network ties represent an important vehicle for this process for a number of reasons. First, buyer-supplier ties the focal affiliate maintains can promote its R&D capability by providing information advantages and facilitating resource-sharing. Buyer-supplier ties may serve as information conduits through which news of customers' needs, new solutions to problems, or breakthroughs achieved by rivals travels from one affiliate to another. Studies have shown that buyer-supplier ties allow firms to take advantage of ideas from customers (von Hippel, 1988) or suppliers (Teece, 1989; Cusumano and Takeshi, 1991). Moreover, being in the same supply chain, the buyer or the supplier may have opportunities to leverage partner's complementary resources (Shan, Walker, and Kogut, 1994; Koza and Lewin, 1998). Suppliers may even get involved in customers' new product development process by taking advantage of their technological know-how and managerial expertise (Ring and Van de Ven, 1992).[1]

Second, access to equity ties provides group affiliates with financial support for the improvement of R&D capability through continuous investment in updating and refreshing organizational skills, routines and systems. Moreover, to the extent that equity ties help firms insulate themselves from the pressures of short-term profit volatility, managers may be more willing to engage in activities which are beneficial to the long-term development, such as improving R&D capability. Equity ties among affiliates may also promote R&D capability by improving the functioning of an internal capital market and provide a mechanism for nurturing new ventures (Khanna and Palepu, 2000).

Despite of its benefits, equity ties may exert potential negative effects by

[1] Some have suggested that buyer-supplier ties can also constrain the development of capabilities by making affiliates entrenched in the intra-group relationships and insulated from advances and improvements beyond the group ((Nelson and Winter, 1982; Rosenkopf and Nerkar, 2001). Group firms may also force members to buy from other group members at prices and quality that are inferior to market terms. Indeed, early research on networks often identified constraints that networks impose on their members (Lincoln, Gerlach and Ahmadjian, 1996).

insulating less capable group members from acquisitions, and thus reducing their incentives to enhance their capabilities. In addition, majority shareholders such as the controlling family may use cross shareholding to extract financial resources from minority shareholders, which may interfere with the capability building of group affiliates.

Third, director interlocks may assist R&D capability building by enhancing information flow. Useem's (1984) work on the inner-circle of well-connected directors in the U.S. and Britain emphasizes that interlocks facilitate environmental scanning. Evidence from developing economies suggests that director interlocks sometimes assist performance by providing information that is not generally available in the market (Keister, 1998). Conversely, though, the acquisition of R&D capability might suffer when directors hold positions in multiple companies. Information overload may inhibit their ability to share useful information and coordinate business operations timely.

While the discussion above suggests that intra-group network ties of any of the three types could positively or negatively affect the development of R&D capability of group affiliates, we see the pooled critical resources and the efficient internal intermediation provided by business groups as perhaps the cornerstone of the development of R&D capability. Emerging economies typically suffer from relatively weak institutions for arms-length relationships to facilitate the exchange of information and resources, and affiliates often lack resources for external acquisitions of capabilities. Given the presence of an underdeveloped infrastructure for innovative activities in emerging economies and the need for access to flows of ideas and resources for R&D capability, one might expect a generally positive relationship between network ties and R&D capability acquisition. However, we believe that this overall relationship will mask significant differences based on the type of tie (and the content implied by that tie), and we develop this contingency argument immediately below.

We begin by noting work in the technology literature that suggests that the buyer-supplier ties that a focal affiliate maintains may be of greatest importance for the development of its R&D capability. To improve R&D capability requires access to a constant flow of ideas that can be recombined to create new ideas (Schumpeter, 1934; Fleming, 2001). The recent development of new economic growth theory similarly emphasizes how knowledge spillovers across firms inspire further innovation (Romer, 1990). To the extent that buyer-supplier ties act as conduits for flows of ideas and resources between affiliates within the group, they may greatly promote the enhancement of affiliates' R&D capability.

Furthermore, buyer-supplier ties may also facilitate the absorption, utilization, and exploitation of externally acquired resources, which are critical to the enhancement of innovativeness (Cohen and Levinthal, 1990). Compared to equity ties, firms involved in buyer-supplier ties are more closely related to each other in the sense that they have more opportunities to engage in specific research projects and solve problems jointly (Heide and Miner, 1992). The more they work together, the more they are likely to communication, interplay, and thus understand each other better. In this process, they may develop a set of shared routines of behavior and rules of exchange that greatly reduce opportunism and share resources more efficiently. The improved mutual trust not only guarantees the quality and validity of resources and ideas provided to each other, but also promotes a freer and more fine-grained exchange of ideas and resources (Uzzi, 1997), and thus make it easier for the firms to incorporate them into R&D capability building. Connected firms may also be better able to transfer and learn about situation-specific knowledge by developing relationship-specific heuristics (Hansen, 1999). Therefore, buyer-supplier ties may be more important than the other two types of ties to the acquisition of R&D capability.

Another indispensable condition of successful R&D capability building is sufficient capital to support trial and error in innovative activities. Equity ties among group affiliates provide access to internal capital markets and credibility, making it easier for an affiliate to access complementary resources from other affiliates. They are of particular importance in the context of emerging economies where there are scant capital resources available beyond business groups.

Relative to buyer-supplier ties and equity ties, director ties are likely to be less important to the development of R&D capability because there are alternative accesses to the benefits provided by such ties. For instance, while family interlocking directorates can promote internal coordination through family authority relationships (Hamilton, 1997; Chung, 2003), when interlocking arises from a central family's desire to control multiple companies, interlocking may lead to crony capitalism, i.e., where a small number of people, often family members or friends, sit on the boards of multiple affiliates with little consideration about the board members' governance capability (Morck and Yeung, 2004). Such crony capitalism inhibits capability building because top managers focus on reinforcing family control and maximizing family objectives such as rent seeking rather than developing new goods and services that would require outside professionals who might dilute family control (Morck and Yeung, 2004). Given the heterogeneity in the content of intra-group network ties across these three types of ties, we propose the following hypothesis:

> **Hypothesis 1:** The effect of network ties between a focal affiliate and other group members on an affiliate's R&D capability will be contingent on the type of tie: The strongest positive effect will be for buyer-supplier ties, followed by equity ties, and then director ties.

Hypothesis 1 captures our contingent perspective on how the differential content of network ties (i.e., alternative types of ties) will have a predictably differential effect on firm capability. The basis for this contingent perspective, as presented above, is rooted in differences in the underlying mechanisms by which each type of tie could enhance R&D capability. Before proceeding with the testing of this hypothesis, however, we would like to extend our reasoning to consider more deeply how the specific mechanisms we posit are at work. To do this, we propose several additional hypotheses that focus on our proposed mechanisms more precisely.

For example, recall that the underlying mechanism by which buyer-supplier ties are supposed to benefit R&D capability is by providing focal firms with access to valuable information. We can theorize further that not all buyer-supplier ties have equally valuable information. Specifically, information is typically more valuable if it is non-redundant (Burt, 1992; McEvily and Zaheer, 1999). Two direct contacts are redundant if an indirect tie exists between them (Hansen, 1999). In contrast, if the two contacts are not connected with each other, they are likely to provide diverse and novel information from their own distinct sources (Burt, 1992). Therefore, the characteristics of the focal firm's network structure may influence the non-redundancy of information. Specifically, focal firms bridging structural holes are likely to benefit more from buyer-supplier ties by accessing non-redundant information from remote or unique parts of the network.

> **Hypothesis 2:** A firm's network structure (ego network) is likely to moderate the effects of buyer-supplier ties on R&D capability; specifically, the richer the structural holes, the higher the benefits of buyer-supplier ties on R&D capability.

Information can also be more valuable if it is boundary-spanning. Prior research has indicated that the transfer of information and knowledge across boundaries, such as organizational, social, and institutional boundaries, improves firm performance (Epple, Argote and Devadas, 1991; Stuart and Podolny, 1996).To the extent that truly novel ideas often come from areas quite different from a firm's own area of operation (Burt, 2004), the information benefits of buyer-supplier ties are likely to be higher when the focal firm's partners operate in a diverse set of industries. Moreover, being exposed to various pools of information and knowledge through its partners operating in different industries, the focal firm is more capable of understanding tacit, complex information and ideas from distinct industries (Tsai, 2001; Reagans and McEvily, 2003). Taking advantage of efficient knowledge transfer and high absorptive capacity, the focal firm with partners in different industries tends to be more innovative by better recognizing, assimilating, and exploiting novel ideas and information conveyed through buyer-supplier ties. Thus, we propose the following:

> **Hypothesis 3:** Diversity in one's partners' industries (alter-diversity) is likely to moderate the effects of buyer-supplier ties on R&D capability; specifically, the greater a firm's alter-diversity in industry, the higher the benefits of buyer-supplier ties on R&D capability.

To recap, the inclusion of H2 and H3, which address the possibility that some ties have higher versus lower information value, provides us with additional and more direct tests of the mechanisms invoked in our theoretical arguments for H1. In other words, with H2 and H3, we are establishing a second-order contingency for H1. Before testing these hypothesized contingencies, we can complete our contingency perspective by taking this approach even further by positing how the information-value arguments underlying H2 and H3 would apply differentially to buyer-supplier ties, relative to equity ties and director ties. More specifically, our earlier theorizing regarding the content of ties suggested that information is the key resource of buyer-supplier ties (hence our focus on buyer-supplier ties in H2 and H3). We also theorized that finances are the key resource component of equity ties, and that authority is the key resource component of director ties. Therefore, it follows that our arguments of the contingencies regarding information value (H2 and H3) should be most applicable for buyer-supplier ties, relative to the other types of ties. This suggests the following final hypothesis:

> **Hypothesis 4:** The hypothesized relationships in H2 and H3 regarding information value will be more strongly positive for buyer-supplier ties than for equity or director ties.

In summary, we have argued that network ties will have specific benefits for R&D capability. The relative benefits of network ties, however, are likely to vary depending on the type of content which flows through these ties. Hypothesis 1 provides an original, first-order contingency addressing the differential effects of three of types of network ties, and Hypotheses 2, 3, and 4 offer original, second-order contingencies that address one of the underlying mechanisms assumed to be responsible for the differential effects (i.e., information value).

MODEL

Our empirical analyses involve two steps. First, we estimate firm R&D capability using the stochastic frontier estimation (SFE) methodology. This approach views 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).[2]

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[2] 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 detail project level data limits the applicability of this approach to a single industry, or sometimes a single firm. More recently, capabilities are conceived as the

SFE enables us to empirically estimate the efficient frontier (i.e. desired goal) and thus the level of productive efficiency (i.e. firm's capability) achieved by each firm in the study. We expect that firms efficient in deploying its resources (i.e. network resource) have superior capabilities than those less efficient competitors. Second, we explore the impact of the content of intra-group network ties on the acquisition of R&D capability.

Stochastic Frontier Analysis

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 inter-firm variation in capabilities.

Specifically, the SFE model is specified as

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

where Y_{it} denotes the appropriate function (e.g. logarithm) of the output for the *i*th sample firm in the *t*th time period, *i*= 1, 2, …, N, and *t* = 1, 2, …, 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 their product lines. Since the failure to control for unobserved heterogeneity may lead to inconsistent parameter estimates, we apply a random parameter

efficiency with which a firm employs a given set of resources (inputs) to achieve whatever goals (outputs) it want to accomplish. Following this perspective, capabilities are "intermediate transformation ability" between resources (such as, R&D expenditure) and objectives (such as, developing innovative technologies) (Dutta, et. al., 2005).

stochastic frontier model which accounts for heterogeneity in both the inefficiency term and the coefficients of the inputs affecting the frontier.[3]

The consistent maximum likelihood estimates of all parameters in Equation [1][4] can be obtained by maximizing the log likelihood function given by the following equation:

$$\ln L = constant - \frac{N(T-1)}{2}\ln\delta_v^2 - \frac{N}{2}\ln(\delta_v^2 + T\delta_u^2) - N\ln\left[1-\Phi\left(\frac{-\mu}{\delta_u}\right)\right] + \sum_{i=1}^{N}\ln\left[1-\Phi\left(\frac{-\tilde{\mu}_i}{\delta_*}\right)\right],$$

$$-\frac{\sum_{i=1}^{N}\varepsilon_i'\varepsilon_i}{2\delta_v^2} - \frac{N}{2}\left(\frac{\mu}{\delta_u}\right)^2 + \frac{1}{2}\sum_{i=1}^{N}\left(\frac{\tilde{\mu}_i}{\delta_*}\right)^2 \qquad [2] \quad where$$

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

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 $E\{exp(-u_{it}) \mid \varepsilon_{it}\}, \varepsilon_{it} = Y_{it} - X_{it}\beta$, *i*= 1, 2, …, N, and *t* = 1, 2, …, T. The specific models used to measure R&D capability are discussed in Appendix 1 and Appendix 2.

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 intra-group network ties. Formally, the model we estimate is the following:

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[3] Specifically, we assume that β is randomly distributed over the population as $N(\bar{\beta}, \delta_\beta^2)$. Since the mean of β is a function of firm-specific variables, we have $E[\beta_i \mid z_i] = \beta + \Delta z_i$, 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 $\mu_{it} = \delta_i' z_{it}$.

[4] $f(X_{it}, \beta)$ 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 $\mu > 0$.

$$\textbf{\textit{Affiliate R\&D capability}}_{it} = f\,(\textbf{\textit{Buyer-supplier ties, equity ties, director ties, Controls}}) + \varepsilon_{it} \quad [3]$$

We estimate model [3] using OLS. As a robustness check, we control for within-group serial-correlations and heteroskedasticity by using random effects generalized least square (GLS) models.

DATA AND MEASURES

While Taiwan is famous for its small and medium sized enterprises, groups are important players in the country (Hamilton and Biggart, 1988; Hamilton and Kao, 1990). The importance of group sales of top-100 groups as a percentage of GDP increased from 28% in 1981 to 54% 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).

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 intra-group ties on affiliates' innovative activity. In Japan, for instance, a lack of family solidarity and governmental encouragement of inter-group activities obscures *keiretsu* boundaries (Saxonhouse, 1993; Weinstein and Yafeh, 1995). In Taiwan, by contrast, strong cultural foundations such as patrilineal family connections and regional kinship delineate group boundaries clearly (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 boundary which makes groups in Taiwan attractive for examining how the content of intra-group ties affects capability acquisition.

Data Source and Sample

Our conceptual framework offers a contingency model that specifies how differences in the content of network ties will differentially affect the process of capability acquisition. To test this, we needed 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 directory Business Groups in Taiwan is compiled by China Credit Information Service in Taipei (CCIS), the oldest and most prestigious credit-checking agency in Taiwan and an affiliate of Standard & Poor of the United States. CCIS started publishing data for the top 100 business groups (in terms of annual sales) biennially in 1972. For credit checking in the private sector, CCIS maintains a database containing more than 30,000 largest firms in Taiwan. It constructs the database of business groups by examining the inter-organizational relationships such as shared identity, cross-shareholding and interlocking directorate among these firms. In addition to self-identification, firms have to meet the following objective criteria to be considered as member firms, including having overlaps of shareholders, directors, auditors, or decision-makers with the core firm and having substantial proportion of shares held by other group members. BGT defines a business group as "coherent business organization including several independent firms." Since its second edition (which was published in 1974), BGT has consistently maintained the following criteria in selection of business groups: (1) more than 51 percent of the ownership was native capital; (2) the group had three or more independent firms, (3) the group had more than NT$100 million group total sales, and (4) the core firm of the group was registered in Taiwan.[5] This directory is the most comprehensive and reliable source for business groups in Taiwan. According to BGT, the top 100 groups contributed 42% of national GDP in the 1990s, representing material business activity within Taiwan. Several previous studies rely on this source (Claessens *et al.*, 2000; Khanna and Rivkin, 2001), although none has translated and coded the intra-group ties data. A unique feature of the BGT directories is that the volumes include figures for each group that depict intra-group buyer-supplier relationships, shared directorships, and equity cross-holdings. We used these figures to code buyer-supplier, director, and equity ties between affiliates. Moreover, the BGT directory provides detail information both about the groups and their affiliates. When coding the data, we identified the groups and their affiliates, and manually transcribed financial information about each group and each affiliate.

Our focal firms are group affiliates that are listed on 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[6] (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 1990. Our sample consisted of 101 observations for 61 listed firms belonging to 48 business groups for the years of 1990, 1994, and 1998. We chose to use the four-year window to allow sufficient variance in the focal firm's network structure over different periods.

Dependent Variable ---Affiliate R&D Capability

Affiliate-level R&D capability is calculated in the way consistent with Dutta, Narasimhan, and Singh (1999). The details of measuring R&D capability are exhibited in Appendix 1[7] and Appendix 2.

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[5] The criterion (3) changed over the years as groups become bigger.

[6] This database provides verified, consistent, and timely data about Taiwan listed companies.

[7] The results in Appendix 2 are consistent with our expectations. For example, based on the magnitude of the coefficients, TECHBASE is a more important input than CUM_R&DEXPENSE (0.550 vs. 0.195). Moreover, there is significant unobserved heterogeneity in both TECHBASE (0.021, $p<0.01$) and CUM_R&DEXPENSE (0.013, $p<0.05$).

Independent Variables and Controls

For each group, we use information on the number of intra-group buyer-supplier ties, equity ties, and director ties to measure network centrality. The *Centrality* measure uses degree centrality, which gauges the number of direct partners with which a focal affiliate has relationships. We did not use other centrality measures, such as closeness centrality and betweenness centrality (Freeman, 1977), due to the small size of our networks. We created four degree-centrality measures, one for each type of tie (buyer-supplier, equity, and director centrality) and one for the sum of equity tie and director tie (equity-director centrality).

We included three 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. Affiliates with higher ROA are likely to be equipped with superior internal capabilities already, making it easier to develop new capabilities. 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 three group-level variables that address group level influences on the development of affiliate capability. *Group Size* records total group assets (in thousands New Taiwanese dollars). *Group ROA* refers to the annual group return on assets. We also control for the connectivity between affiliates using group network density of the three types of ties. Specifically, *buyer-supplier density* is defined as the ratio of actual buyer-supplier ties among affiliates within a business group to the total number of potential buyer-supplier 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 main effects of three moderators involved in Hypothesis 2 to Hypothesis 4. *Structural hole of buyer-supplier network* is measured as the ratio of nonredundant partners to total partners in the *i*th affiliate's buyer-supplier network. *Structural hole of equity and director network* is defined as the ratio of nonredundant partners to total partners in the *i*th affiliate's equity network and director network. *Alter diversity in industry* is measured in an entropy-based index, $-\sum P_i(\ln P_i)$, for i =1 to 19, where P_i is the proportion of partners in the buyer-supplier network operating in 2-digit SIC industry i.

ANALYSES

Summary Statistics

Table 1A and Table 1B report summary statistics and correlations between variables. Table 1A shows significant heterogeneity in R&D capability across firms, with the minimum R&D capability at 0.814 and maximum R&D capability at 0.976. It also shows that the mean centrality across affiliates is highest for equity centrality (0.546), followed by director centrality (0.396) and buyer-supplier centrality (0.241). The rank ordering of mean density is director density first (0.339), followed by equity density (0.246) and buyer-supplier density (0.126).

**** **Table 1A and Table 1B about here** *****

Regression results

Table 2a provides regression results on affiliates' R&D capability using the random effects models for panel data using the Weighted Generalized Least Squares (WGLS) estimation. We applied the Lagrange Multiplier test for unobserved heterogeneity to justify the use of panel estimation, and we applied the Hausman test (which ascertains the validity for using a random effects specification) to ensure that our choice of model was justifiable (random effects models are less costly relative to fixed effects models in terms of degrees of freedom). We also cluster by groups to address the possibility that affiliates share group-specific attributes.

****** Table 2a about here *******

Model 1 tested the effect of three types of network ties on the development of R&D capability. It shows that both buyer-supplier centrality and equity centrality (but not director centrality) lead to significant increases in R&D capability. This result suggests that network ties can clearly affect firm capability, but also that the content of the tie matters, as hypothesized. Regarding the relative magnitude of impacts of three types of ties on R&D capability, as predicted, buyer-supplier ties is highest (0.028) and followed by equity ties (0.016) and director ties (-0.003). To test our relative magnitude prediction more precisely, we conducted a Wald test to examine the equality of coefficients of the three types of ties. The results indicate that, as predicted by our H1, the effect of buyer-supplier ties is significantly greater than that of director ties ($P<0.01$). However, neither the difference between the coefficients of buyer-supplier ties and equity ties nor the difference between the coefficients of equity ties and director ties is significant. Therefore, H1, which proposes differential effects of different types of ties on capability building, is partially supported.

Model 2 tests Hypothesis 2, which is one of our second-order contingency hypotheses. It proposes a positive moderating effect of structural hole on the relationship between buyer-supplier centrality and development of R&D capability. Consistent with H2, we find that buyer-supplier ties are more valuable when the buyer-supplier network is rich in structural holes ($P<0.01$). In addition, Model 3 shows that alter diversity in industry also appreciates the value of buyer-supplier ties ($P<0.01$), supporting Hypothesis 3.

Recall that H4 posited our final second-order contingency, stating that the hypothesized relationships in H2 (structural holes) and H3 (alter diversity) regarding information value should be more strongly positive for buyer-supplier ties than for equity or director ties. We use Models 4 and 5 to test the two components of this hypothesis.

Model 4 examines the relative impacts of structural holes in the network of specific type of ties on R&D capability building. It shows that structural holes in buyer-supplier network significantly increases the value of buyer-supplier ties, while structural holes in the network of equity ties and director ties do not. To compare their relative impacts, we adopt the Wald test, and the result indicates that the moderating effect of structural holes on buyer-supplier ties is significantly greater than on the other two types of ties, consistent with H4. Model 5 tests the moderating effect of alter diversity in industry on different types of ties. Consistent with our prediction, the coefficient of interaction term between buyer-supplier centrality and alter diversity in industry is positive and significant at 1% level, and there is no moderating effect of alter diversity in industry on the other two types of ties. The result of Wald test shows that alter diversity in industry imposes significantly greater moderating effect on buyer-supplier ties relative to equity ties and director ties. Thus, the results in Model 4 and Model 5 offer strong support for H4.

Robustness checks for endogeneity

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 affiliate[8]. We have addressed the issue of causality in three ways. First, we identified two specific contingencies where the informational value of buyer-supplier ties is likely to be stronger (H2 and H3). By scrutinizing the underlying theoretical channels by which buyer-supplier ties affect R&D capability, we provide a stronger case for causality (Rajan and Zingales, 1998). Second, we use the instrumental variable approach (Table 2b) to check if there is serious endogeneity problem. The results were similar to Table 2a, suggesting that affiliates' R&D capability is not associated with the change of their network positions. Third, we ran a set of regressions using the change of affiliate centrality between period t and t+1 as dependent variable, and R&D capability in period t as independent variable. The regression results show that none of the coefficients of R&D capability in the models is significant. Thus, while a central network position would contribute to the improvement of an affiliate's

[8] 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).

R&D capability, an affiliate is not likely to become central simply because of its superior R&D capability.

DISCUSSION AND IMPLICATIONS

We began by noting that the study of firm capabilities and their acquisition and transfer has emerged as a central issue in the strategic management literature, and that while recent research has begun to establish the role of network ties in capability acquisition, there have been some contradictory findings. We proposed that one way to advance this research agenda is to eschew the traditional view of network ties as generic conduits for information and resource exchange between firms, and to instead consider how different types of ties offer different tie content, and to consider further how this difference in content can more accurately explain the extent to which a firm can acquire capabilities through network ties.

We conceptualized and tested this perspective in the context of business groups in Taiwan, and we showed how differences in the content of group affiliates' ties in business groups related to the development of their internal capabilities. Specifically, we argued that given the ability of buyer-supplier ties to provide stimuli for innovation, we predicted and found that affiliate firms in business groups with buyer-supplier ties were better able to acquire R&D capabilities than those without such ties. We predicted and found that other types of ties (e.g., equity and director ties) were less valuable in R&D capability acquisition. We also found support for other hypotheses that addressed how the informational value of buyer-supplier ties was itself contingent on other network characteristics of the tie (ego network and alter diversity). Support for these second-order contingency hypotheses that address differences in the information value of certain ties gives us greater confidence in our focus on the likely content differences within different types of ties. In addition, these additional hypotheses allow us to establish how R&D capability is a function of both the structure *and* the content of network ties.

By offering a theoretical and empirical analysis of how different types of intra-group ties influence the acquisition of firm capabilities, we see our integrative study as having implications for three separate streams of prior research: research on firm capabilities, social networks, and business groups. 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 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. Our research extends this stream of research by highlighting the how and why some network ties (and not others) can serve as conduits for accessing external resources and capabilities. In other words, the heterogeneity in firm capabilities can be accounted for by not only differences in resources internal to the firm, but also variation in the content of a firm's specific network ties. In essence, the content of network ties a firm maintains has a strong influence on its exposure to new ideas, opportunities, and resources, and therefore has 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 the stochastic frontier estimation (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)." One promising alternative that builds on our approach is to use semiparametric methods based on a combination of both Stochastic Frontier Estimation (SFE) and Data Envelope Analysis (DEA).

While our study is primarily focused on explaining differences in firm capabilities, we also hope to contribute to the large existing body of network research by providing a more discriminating understanding about the differential role that alternative types of ties in the acquisition of distinct capabilities. 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 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 inter-organizational 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 content implied by different types of ties. Our study provides support for the notion that the value of network ties is contingent on the interested outcome, the nature and content of ties, and the context being studied (Ahuja, 2000).

We do so by our in-depth examination of the specific contingencies that affect the value of network ties. We highlight how certain types of ties, such as buyer-supplier ties (as opposed to equity or director ties) have particular value in terms of tie content that would be particularly conducive to a firm's acquisition of R&D capability (H1). In addition, we provide second-order contingent hypotheses (H2, H3, and H4) and empirical tests to test the underlying mechanisms that provide the logic for the first main hypothesis.

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 to not. Business groups can assist in the acquisition of capabilities in the sense that it facilitates resource-sharing and information exchange among affiliates, which are hard to be achieved via market system 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.

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 focuses on individual projects (Ethiraj et. al, 2005; Henderson and Cockburn, 1994). Such indicators may be particularly useful for identifying the underlying process through which network structure benefits or constrains 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 addressed the issue of causal direction in multiple ways. Future research examining the potential simultaneous relationship between networks and capabilities may be a useful next step. Finally, while believe that our empirical context was well-suited for our study question, we would welcome extensions of our work using samples of business groups from other countries. Given the growing importance of firm capabilities and network ties, we believe that additional research 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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Tables and Figures

Table 1A. Summary Statistics

	Mean	Standard Deviation	Minimum	Maximum
Dependent Variables				
R&D capability	0.946	0.029	0.814	0.976
Independent Variables				
Buyer-supplier centrality	0.241	0.277	0	1
Equity centrality	0.546	0.362	0	1
Director centrality	0.396	0.300	0	1
Equity-director centrality	0.917	0.484	0	2
Control Variables				
Buyer-supplier density	0.126	0.187	0	1
Equity density	0.246	0.181	0	1
Director density	0.339	0.273	0	1
Affiliate assets	62797.240	114421.600	237.000	832674.000
Affiliate age	28.030	11.410	1	80
Affiliate return-on-asset	5.098	5.725	-13.300	45.560
Group assets	85974.520	139161.000	1452.000	978455.000
Group return-on-asset	5.069	5.547	-8.450	45.569
Structural hole of buyer-supplier network	0.705	0.188	0.067	0.971
Structural hole of equity-director network	0.578	0.184	0.067	0.935
Alter diversity in industry	1.838	0.669	0	3.312

Table 1B. Correlation Matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1.R&D capability	1.00															
2.Buyer-supplier centrality	0.06	1.00														
3.Equity centrality	0.09	0.20*	1.00													
4.Director centrality	-0.03	0.16*	0.14*	1.00												
5.Equity-director centrality	0.05	0.24*	0.79*	0.72*	1.00											
6.Buyer-supplier density	-0.01	0.80*	0.03	0.15*	0.12*	1.00										
7.Equity density	-0.11	0.29*	0.44*	0.20*	0.43*	0.38*	1.00									
8.Director density	-0.04	0.18*	0.10	0.86*	0.60*	0.25*	0.27*	1.00								
9.Firm size	0.06	-0.06	0.04	-0.11*	-0.04	-0.04	-0.04	-0.08	1.00							
10.Firm age	-0.09	0.11*	0.19*	0.011	0.14*	-0.05	-0.09	-0.10	0.03	1.00						
11.Firm ROA	-0.08	0.13*	-0.05	0.12*	0.04	0.04	0.00	0.06	-0.04	-0.01	1.00					
12.Group size	0.20*	-0.43*	-0.30*	-0.27*	-0.37*	-0.41*	-0.42*	-0.28*	0.20*	0.04	-0.01	1.00				
13.Group ROA	0.08	0.14*	-0.06	0.09	0.01	0.091	0.051	0.02	-0.09	-0.11*	0.37*	-0.14*	1.00			
14.Structural hole of buyer-supplier network	0.02	-0.47*	0.04	-0.22*	-0.11*	-0.70*	-0.51*	-0.33*	0.07	0.16*	-0.02	0.36*	-0.10	1.00		
15. Structural hole of equity-director network	0.01	-0.28*	-0.07	-0.62*	-0.43*	-0.42*	-0.57*	-0.68*	0.10*	0.18*	-0.09	0.35*	-0.09	0.66*	1.00	
16. Alter diversity in industry	0.11	-0.42*	-0.26*	-0.22*	-0.32*	-0.49*	-0.58*	-0.27*	0.13*	0.23*	-0.10*	0.64*	-0.17*	0.54*	0.53*	1.00

* p<0.05

Table 2a. The effect of intra-group network on group affiliates' R&D capability using Random Effect GLS

	Model 1	Model 2	Model 3	Model 4	Model 5
Independent variables					
Buyer-supplier centrality	0.028**	0.040***	0.053***	0.040***	0.051***
	(0.013)	(0.014)	(0.015)	(0.015)	(0.016)
Equity centrality	0.016*	0.011	0.022***		
	(0.009)	(0.009)	(0.009)		
Director centrality	-0.002	0.006	-0.002		
	(0.014)	(0.014)	(0.013)		
Buyer-supplier centrality*Structural hole		0.007**		0.006**	
		(0.003)		(0.003)	
Buyer-supplier centrality*Alter diversity in industry			0.008***		0.007***
			(0.003)		(0.003)
Equity-director centrality*Structural hole				-0.001	
				(0.004)	
Equity-director centrality* Alter diversity in industry					0.001
					(0.003)
Control variables					
Equity density	-0.020	0.003	0.003	0.004	0.003
	(0.031)	(0.035)	(0.034)	(0.036)	(0.034)
Structural hole of buyer-supplier ties		0.018		0.012	
		(0.030)		(0.032)	
Structural hole of equity and director ties				0.016	
				(0.031)	
Alter diversity in industry			0.005		0.006
			(0.008)		(0.008)
Equity-director centrality				0.012	0.015**
				(0.008)	(0.007)
Affiliate size	0.001	0.001	0.001	0.001	0.001
(logged assets)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Affiliate age	-0.001	-0.001	-0.001	-0.001	-0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Affiliate return-on-assets	-0.001**	-0.001**	-0.001*	-0.001**	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Group size	0.009**	0.010**	0.010***	0.010***	0.011***
(logged assets)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Group return-on-assets	0.001**	0.001*	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	0.795***	0.788***	0.776***	0.774***	0.768***
	(0.061)	(0.064)	(0.057)	(0.067)	(0.059)
R-square	56.06%	60.25%	62.87%	60.48%	61.91%
Number of observations	101	101	101	101	101

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 2b. The effect of intra-group network on group affiliates' R&D capability using random effects instrumental variable model

	Model 1	Model 2	Model 3	Model 4	Model 5
Independent variables					
Buyer-supplier centrality	0.040**	0.056***	0.089***	0.055***	0.083***
	(0.016)	(0.017)	(0.015)	(0.017)	(0.019)
Equity centrality	0.017*	0.012	0.025***		
	(0.009)	(0.010)	(0.010)		
Director centrality	0.001	0.007	-0.002		
	(0.014)	(0.014)	(0.014)		
Buyer-supplier centrality*Structural hole		0.007**		0.008***	
		(0.003)		(0.003)	
Buyer-supplier centrality*Alter diversity in industry			0.011***		0.010***
			(0.003)		(0.003)
Equity-director centrality*Structural hole				-0.001	
				(0.004)	
Equity-director centrality* Alter diversity in industry					0.001
					(0.003)
Control variables					
Equity density	-0.037	-0.012	0.001	-0.012	-0.017
	(0.033)	(0.035)	(0.036)	(0.037)	(0.035)
Structural hole of buyer-supplier ties		0.020		0.018	
		(0.032)		(0.032)	
Structural hole of equity and director ties				0.009	
				(0.031)	
Alter diversity in industry			0.011		0.010
			(0.009)		(0.008)
Equity-director centrality				0.010	0.014*
				(0.008)	(0.007)
Affiliate size	0.001	0.001	0.001	0.001	0.002
(logged assets)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Affiliate age	-0.001	-0.001	-0.001**	-0.001**	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Affiliate return-on-assets	-0.001**	-0.002***	-0.001*	-0.002***	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Group size	0.009**	0.010***	0.010**	0.010***	0.010***
(logged assets)	(0.004)	(0.003)	(0.004)	(0.004)	(0.004)
Group return-on-assets	0.001**	0.001**	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Constant	0.802***	0.788***	0.765***	0.776***	0.771***
	(0.061)	(0.064)	(0.060)	(0.063)	(0.056)
R-square	56.05%	60.20%	61.08%	60.56%	61.16%
Wald chi2	87.42	103.77	111.94	118.70	127.85
Number of observations	101	101	101	101	101

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.

APPENDIX 1: MODELING R&D CAPABILITY

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.*, 1999). Using Cobb-Douglas production function, we specify the innovation frontier as follows:

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

We use the number of successful patent applications to measure a firm's technological output (TECHOUTPUT).[9] We use local patents to measure firms' innovative output. Meanwhile, U.S. patents are used for 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 purpose, 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 $TECHBASE_t = \sum_{k=1}^{k=t} \delta^{t-k} * TECH\_OUTPUT_k$, where *t*=1, 2…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 $CUM\_R\&DEXPENSE_t = \sum_{k=1}^{k=t} \gamma^{t-k} * R\&DEXPENSE_k$, where *t*=1, 2…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.

[9] This measure treats all patents equally important. We recognize that a better approach would be to use quality-adjusted 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 patent citation information for local patents, we use the raw patent counts as a measure of technological output.

APPENDIX 2: MEASURING R&D CAPABILITY

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)]	0.550*** (0.135)	0.021*** (0.006)
$\hat{\beta}_2$ [ln(CUM_R&DEXPENSE)]	0.195** (0.024)	0.013** (0.002)
Composite Error Variance ($\delta_e^{\ 2} = \delta_v^{\ 2} + \delta_u^{\ 2}$)	1.786** (0.032)	
Variance of Inefficiency Error Term ($\delta_u^{\ 2}$)	1.052** (0.018)	
Log-likelihood Function	-2740.39***	

- *** 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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