The Evolving Impact of Combinatorial Opportunities and Exhaustion on Innovation by Business Groups as Market Development Increases: The Case of Taiwan, 1981-2000

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Abstract: Business groups are key sources of innovation in emerging market economies, but we understand little about why innovativeness differs across groups and over time. Variation in the density of intra-group buyer-supplier ties, which are common structural linkages among group affiliates, can help explain both cross-sectional and temporal heterogeneity of group innovativeness. We argue that greater buyer-supplier density within a group initially creates combinatorial opportunities that contribute to group innovativeness but ultimately generates combinatorial exhaustion that constrains innovation. Combinatorial exhaustion sets in at lower levels of density as the market environment becomes more developed and the opportunity costs of local search increase. The research introduces a dynamic argument to studies of business group innovation.
1. INTRODUCTION

Business groups are key sources of innovation in emerging market economies (Amsden and Hikino, 1994; Amsden and Chu, 2003; Kim, 1997), but we understand little about why innovativeness differs across groups and over time. Business groups are sets of legally independent firms, operating in multiple industries, which are connected to each other by buyer-supplier ties and other structural linkages such as director interlocks and financial investments (Granovetter, 1995; Khanna and Thomas, 2009). Business group innovativeness is an important issue because innovation is a major driver of growth as emerging markets evolve; groups are key players in many emerging markets, which are now the center of much of the world’s economic activity.

A few studies have examined how group membership and firm-level position within a group affect affiliates’ performance (Keister, 1998; Khanna and Rivkin, 2001; Chacar and Vissa, 2005). The studies commonly show that group membership and central positions within a group’s linkages help firms gain access to resources when environments lack external institutions that otherwise provide capital, legal protection, technology, human talent, and commercial supply chains. However, no studies have examined how variation in the structure of intra-group ties that are common elements of internal group relationships affect group innovativeness, despite the fact that the ties create potential access to resources that might contribute to innovative activity in emerging markets as well as induce inertia and costs that may inhibit groups’ innovative activity (Lincoln, Gerlach, and Ahmadjian, 1996; Khanna and Palepu, 2000a). This study argues that the density of intra-group buyer-supplier ties both facilitates and constrains group innovativeness, with the constraints increasing over time as the groups’ home environment adopts more extensive market-based institutions.

The study draws insights about intra-group ties and innovativeness from studies of business groups, technology, and social networks. The business group literature argues that early in the development of a market environment, intra-group buyer-supplier ties offer alternatives to external supply chains (Leff, 1978; Keister, 2001). Technology studies research implies that stable operating linkages such as ongoing buyer-supplier ties can contribute to innovation by helping groups learn about and combine resources that are distributed across their affiliates (Nelson, 1959; Monteiro, Arvidsson, and Birkinshaw, 2008), but also suggests that such linkages can constrain innovative activity by creating tendencies toward local search (Nelson and Winter, 1982; Helfat, 1994). The concept of network density (Coleman, 1988; Burt, 1992) helps assess when the benefits of buyer-supplier ties, which we refer to as combinatorial opportunities, will outweigh the constraints, which we refer to as combinatorial exhaustion. Density is the proportion of potential ties that members of a network actually form with each other (Freeman, 1977). We predict that the density of intra-group buyer-supplier ties will have an inverted-U

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1 Although other intra-group linkages such as equity and director ties also may influence innovative activity by shaping financial flows and strategic attention, this paper focuses on the impact of buyer-supplier ties, which involve different mechanisms and can arise independently of other linkages.
impact on the innovative activity of the groups’ affiliates: Initial benefits arising from combinatorial opportunities, countered by combinatorial exhaustion as buyer-supplier tie density increases. In turn, we expect the benefits of buyer-supplier density to decline as market-based institutions that support innovation become stronger and the opportunity costs of local search increase. We test the argument with 263 Taiwanese business groups from 1981 to 1998, when business groups helped Taiwan transform itself into an innovation powerhouse (Amsden and Chu, 2003; Einhorn, 2005).

This study is the first to consider how buyer-supplier ties affect business group innovativeness. In contrast to the traditional focus of business group studies on performance differences between group affiliates and independent firms, this study investigates how variation in groups’ internal structure helps explain why groups that operate in similar institutional settings differ in their innovative activity and why the activity varies over time. The argument that market development creates a transition toward greater benefits of outward search introduces a dynamic aspect to studies of group innovation.

2. BACKGROUND ON BUSINESS GROUPS AND INNOVATION

Business groups, intra-group ties, and innovation in emerging markets

Business groups have been common in most emerging economies, from the U.S. of the 19th century, to Western Europe and Japan in the 20th century, to many Asian, Latin American, and African economies of the late 20th and early 21st centuries (Leff, 1978; Granovetter, 2005). Like conglomerates, groups provide corporate financial structures for businesses in multiple industries. Like multidivisional corporations, businesses within groups function with substantial operating interdependence. Yet groups involve more coordination than conglomerates because members of founding families commonly exert strong influence, while being less centralized than most multidivisional firms because affiliates have their own governance bodies of shareholders, directors, and auditors (Granovetter, 1995).

Exchange within business groups involves several types of inter-firm linkages (Gerlach, 1992; Keister, 2001), including buyer-supplier, financial, and director ties. Buyer-supplier ties are operating linkages by which affiliates produce components and/or distribute group members’ products (Lincoln et al., 1996). Financial ties arise when affiliates hold cross-shareholdings or lend each other money. Director ties arise when an individual sits on the board of multiple affiliates. Intra-group ties help coordinate group-wide strategies (Khanna and Thomas, 2009) and act as conduits for sharing resources (Granovetter, 1995), where resources include tangible financial assets and physical goods as well as intangible assets such as knowledge and information that can contribute to innovative activity.

Intra-group ties are valuable in emerging economies as substitutes for market-based relationships. Chang and Hong (2000) show that group affiliation in Korea allows resource pooling that assists the financial performance of member firms. Khanna and Palepu (2000a, 2000b) demonstrate that groups in Chile and India create value for their members through product, labor, and capital market intermediation.

A few studies suggest that business groups may help newly industrialized countries increase their innovative ability (Kim, 1997; Chang, Chung, and Mahmood, 2006). Scholars studying knowledge
diffusion and industrialization argue that groups offer business reputations and government ties that attract foreign technology providers (Amsden and Hikino, 1994; Hobday, 1995). Claessens, Djankov, and Lang (2000) suggest that family ownership in East Asian business groups provides long-term perspectives and willingness to undertake R&D investments. Mahmood and Mitchell (2004) show that a mix of groups and independent firms provides a combined infrastructure that facilitates innovation within a sector. Chang et al. (2006) find that group affiliation in Korea and Taiwan offers significant firm-level innovation benefits when a country has limited market institutions.

**Intra-group buyer-supplier ties: Combinatorial opportunities and exhaustion**

Intra-group buyer-supplier ties are an important element of group structure. Buyer-supplier ties arise when groups create or acquire affiliates that serve as reliable producers of parts or semi-finished products and/or distributors of finished goods, due to lack of availability of external vendors or concerns about quality and reliability (Chang et al., 2006). In either case, many firms in the buyer-supplier network within the group undertake ongoing exchanges. Studies have examined how financial ties and interlocking directorates affect group performance (e.g., Keister, 1998; Khanna and Thomas, 2009), but none explore how buyer-supplier ties affect innovation or other aspects of group performance.

Ongoing intra-group buyer-supplier relationships create both benefits and constraints for group innovativeness. Benefits arise from combinatorial opportunities, which are opportunities to combine existing knowledge and other resources in novel ways (Schumpeter, 1934; Galunic and Rodan, 1998; Fleming, 2001). The technology studies literature suggests that ongoing operating ties between firms can contribute to innovativeness by increasing both the scope of innovative activity (Nelson, 1959; Teece, 1989; Dyer, 1996) and incentives to invest in innovation (Cohen and Klepper, 1996; Ryall and MacDonald, 2004). The potential and incentives for recombination will be greatest in ongoing ties because the knowledge that underlies innovative opportunities often involves tacit information, complex organizational relationships, and the need for trust in using resources (Kogut and Zander, 1992).

Combinatorial opportunities are relevant for business groups with buyer-supplier ties. Managers of tied affiliates will interact with each other over time as they carry out operating tasks, helping diffuse fine-grained information about diverse technologies, products, people, and markets, as well as gain trust in each others’ skills and intentions (Chang and Hong, 2000). Affiliates that engage in innovative activities can draw on the information in their R&D efforts. Buyer-supplier ties provide information that is relevant to innovation because new goods and services commonly combine knowledge of components and activities from existing products as well as knowledge of multiple market environments; ongoing buyer-supplier relationships help transfer such knowledge among the partners’ technical and operating staff. Analogously, Amsden and Hikino (1994) argue that groups develop what they refer to as project execution capabilities when people from different affiliates work together over time; project execution capabilities both facilitate current activities and help firms combine ideas that arise from the activities.

In conducting this research, we spoke with executives with experience in about ten business
groups about their companies, as well as with knowledgeable scholars and industry professionals in Taiwan. The discussions, together with archival public data, provided background information as well as relevant examples. The Formosa Plastics Group (FPG) in Taiwan offers an example of the benefits of buyer-supplier ties. FPG was founded in 1958. A daughter of FPG’s founder created First International Computer (FIC) in 1980. In 1987, a second daughter established VIA Technologies, which supplied chipsets to FIC. Ties between FIC and VIA contributed to ongoing innovation at the two firms. For instance, ongoing supply chain exchanges and collaboration between FIC and VIA personnel led to the development of a series of motherboards for the Intel Pentium 4 platform. Such intra-group relationships contrast with buyer-supplier relationships between independent companies because trading ties between independent firms often lack sufficient stability and trust to exchange ideas over time. For instance, many auto manufacturers have struggled to use their suppliers as sources of innovation. Examples such as Toyota and its relatively stable network of suppliers come closer to the intra-group relationships, as do buyer-supplier relationships among subsidiaries of multi-business corporations (e.g., the Pratt & Whitney and Sikorsky units within the United Technologies Corporation).

The Eternal Chemical Group provides a second example of combinatorial opportunities from an internal supply chain (Appendix 1 contains a more detailed version of this example). Eternal Chemical Company, the core firm in the group, was founded in 1964 as a producer of commodity resins. Over the past five decades, the Eternal Group has evolved into a specialized electronic chemical and optical-electronic innovator that is one of the world’s leading suppliers of dry film photo-resistant materials for printed circuit boards. Eternal’s development of alternative materials for radio-frequency identification device (RFID) antennas illustrates recombination benefits. In the early 2000s, a specialized materials affiliate saw an opportunity for an alternative to costly metal RFID antennas by combining its materials knowledge with coating and lamination technologies of affiliates within the group. The R&D team at the materials affiliate created an initial prototype product using existing group technology, including the initiator’s own adhesives and production processes, plus resins and lamination techniques from affiliates along the intra-group buyer-supplier chain; the team drew on knowledge about where different skills resided that the materials affiliate had gained during its purchasing interactions. The R&D team and purchasing staff at a resin affiliate next suggested a different kind of resin and production process that led to a second prototype. The original team then designed a new adhesive and production process and worked with staff from a lamination affiliate to produce a new laminating technique to make a marketable product. The R&D team at the materials affiliate also designed two variants of the product using different adhesive technology and revised production processes based on conversations with external customers that had specialized needs. At this point, the only piece of prior art left from the original prototype was one of the adhesives. The final products reflected extensions of Eternal’s original internal knowledge, along with external knowledge that the internal base had helped the lead affiliate’s R&D team recognize they could use. By 2006, the interactions among R&D personnel and purchasing staff at affiliates along
Eternal’s buyer-supplier chain had helped the firm create successful alternative materials for RFID antennas, with substantial sales potential.

Buyer-supplier ties can also constrain innovation by generating combinatorial exhaustion. Combinatorial exhaustion is the point at which combinatorial opportunities reach their limits, which can arise from three sources: Resource redundancy, resource depletion, and organizational saturation. Resource redundancy occurs when new ties connect to resources that are already available via existing ties (Dosi, 1988). Resource depletion occurs when firms use up the innovative potential of internal resources and yet are constrained by existing routines from searching externally for new insights (Rosenkopf and Nerkar, 2001; Rosenkopf and Almeida, 2003; Fleming and Sorenson, 2004). The established organizational practices are rooted in the firm’s experience and often drive the firm’s search toward existing knowledge bases (Nelson and Winter, 1982). Organizational saturation occurs when firms reach the limit of managerial capacity to use resources available for new activity (Portes, 1998; Hansen, 1999). Combinatorial exhaustion from redundancy, depletion, and/or saturation can reduce both investment incentives and innovative productivity.

The FPG case offers an example of combinatorial exhaustion. In 1997, VIA’s founder established Xander International as a supplier of electronic components. FIC, VIA, and Xander shared purchasing and technical staff who spent extensive time coordinating activities within the FPG affiliates. This organizational saturation left only limited time to look for innovative opportunities in the external environment, creating challenges of internal resource depletion.

Interviews with executives of the Fabgarm Group (disguised name) highlight combinatorial exhaustion arising from the three mechanisms (also see Appendix 1). Fabgarm has many textile affiliates with multiple garment brands, with a dense set of buyer-supplier ties. Redundancy arose across buyer-supplier ties, respondents noted, because much of the affiliates’ knowledge was homogeneous and so generated diminishing marginal returns to recombination. Resource depletion arose across Fabgarm’s affiliates because the exchanges tended to use up novel knowledge quickly, such as how to increase yarn counts in their textiles, while the emphasis in internal sourcing inhibited their ability to look for new external ideas. Saturation applied, one respondent noted, owing to limited time to seek ideas; at some point, meeting with people from affiliates just wasted time, particularly when the knowledge was largely redundant. One respondent said the groups with fewer intra-group ties found it easier to use external sources to identify new knowledge for their innovative activities because they did not have so many internal demands on their time and faced fewer pressures to use internal relationships whether or not they had useful knowledge. We next use the social network concept of network density to assess how the balance of combinatorial opportunities and exhaustion will affect business group innovativeness.

Density and network innovativeness: Benefits and constraints
The density of structural ties within a network is the ratio of the actual number of ties within a given network to the number of potential ties that could be forged within the network (Freeman, 1977). For
instance, the density of a four-member group with two ties between members would be 2/6 possible ties = 0.33. Intra-group buyer-supplier density is a form of structural cohesion (Moody and White, 2003).

Sociologists have divergent views about how cohesive versus sparse networks affect network performance. The cohesive view is optimistic about density. Actors within a dense network have many direct and indirect paths to reach each other, which can create social capital that generates increased communication, trust, shared expectations, and group norms across a network (Coleman, 1988). By contrast, structural holes arguments (Burt, 1992) expect benefits from sparse networks, which arise when each actor’s network partners have few direct ties to each other. In this view, actors that bridge diverse sub-networks gain by playing the role of broker, while possibly also contributing to network innovativeness. Most studies in this literature examine the innovative activity of individual actors in a network, while the few studies that even indirectly examine how density affects network innovativeness have varying results (e.g., Hansen, 2002; Reagans, Zuckerman, and McEvily, 2004; Hargadon and Sutton, 1997; Burt, 2004; Obstfeld, 2005). In the most direct study, Uzzi and Spiro (2005) find that small-world networks, i.e., networks with short paths between members (Watts, 1999), initially lead to greater artistic creativity in collaborating teams but ultimately result in lower creativity. In the hypotheses below, we will draw on ideas from this literature to consider how buyer-supplier density affects group innovativeness.

3. HYPOTHESES

We argue that the benefits of combinatorial opportunities increase at a decreasing rate with density and eventually reach negative marginal returns as the impact of combinatorial exhaustion increases. We first develop the base logic and then turn to market evolution.

**Variation across groups: Impact of buyer-supplier tie density on group innovativeness**

Operating density creates combinatorial opportunities that arise from two related sources: First, creating widespread knowledge of resources distributed throughout the group and, second, building trust in using the resources. Resources that can contribute to innovation often reside in different group affiliates. Gaining access to affiliates will create combinatorial opportunities, especially if there is variety in the knowledge that resides at different points within the group. Rodan and Galunic (2004), for instance, find that heterogeneous knowledge within a firm enhances individual performance. Nonetheless, it is not enough simply that the knowledge exists within a group. Indeed, any focal firm with the potential to conduct innovative activities may not know that such resources exist and where they are located. The firm faces the task of identifying useful knowledge and transferring it to and from actors within the group. Searching the whole group can be time consuming and costly.

The presence of a network of ongoing buyer-supplier ties creates an information channel that facilitates search for knowledge. Granovetter (1985) argues that a benefit of ongoing ties lies in creating channels for information exchange; in business groups, this includes information about where resources reside in member firms. Moreover, ongoing relationships help avoid degradation of information over time (Moody and White, 2003). The operating linkages among affiliates provide fine-grained understanding,
tacit knowledge, learning, and feedback about each others’ skills that generate privileged access to resources relative to actors that do not have ongoing relationships (Uzzi, 1997). Such access facilitates knowing when and how to combine knowledge across affiliates in order to create new goods and services. In turn, ongoing operating ties help firms coordinate and implement innovative activities that require shared resources (Useem, 1984), plus solve problems that arise during activities (Uzzi, 1996).

At least initially, increasing density of buyer-supplier ties will generate more opportunities to gain knowledge of innovative opportunities and improve a group’s ability to realize the opportunities. Greater density means that there are more direct and indirect paths that connect different affiliates and, as a result, more channels for information flow as well as greater potential heterogeneity in available resources. Moreover, the resource opportunities that arise from buyer-supplier density differ from high vertical integration (high internal sales), because vertical integration can involve only a few suppliers that do not create the variety of resources that can connect though multiple linkages.

As well as creating knowledge about opportunities, dense ties encourage affiliates to share knowledge and risks with each other by building intra-group trust. Affiliates within a group often have differences in objectives that may make them reluctant to share their knowledge. The existence of multiple direct and indirect linkages in dense operating networks generates knowledge of each other via repeated interactions. The knowledge helps engender trust by creating shared understandings and norms of reciprocity (Granovetter, 1985; Uzzi, 1996) and developing sanctions for deviant behavior (Coleman, 1988). In turn, trust encourages people to share information that will allow units to generate more innovations from a given investment while also creating incentives to invest in innovative activities because there is less need to invest in safeguarding assets (Williamson, 1985; Lincoln et al., 1996). Hence, greater operating density will create combinatorial opportunities that facilitate innovative activities owing to increased knowledge and trust.

Our interviews at Eternal Chemical highlighted several organizational processes involving buyer-supplier ties that create knowledge and trust needed for recombination activity at the Eternal Group. Respondents said that different affiliates can have ideas that initiate the innovation process, leading to back-and-forth interactions that combine knowledge across affiliates. Personnel involved in knowledge transfer involve both technical and purchasing staff members, who work at the interface between affiliates. In turn, a respondent said that even though any one innovation sequence may not create equal rewards in the form of knowledge learned by all parties, the affiliates expect that they will benefit eventually, whether via revenue from the output of the sequence or from later innovation sequences; this expectation of long-term mutual benefit helps maintain the trust necessary for knowledge sharing.

At some point, however, dense internal ties within a group will reach the limits of combinatorial opportunities and additional density will generate constraints that arise from the three elements of combinatorial exhaustion: Redundancy, depletion, and saturation. Redundancy of ties reflects duplicated resources (Rodan and Galunic, 2004), so that greater tie density does not offer new innovative potential.
Tie redundancy occurs in groups if some suppliers and buyers provide similar services or markets. Greater density of buyer-supplier ties leads to greater likelihood of simply reaching the same type of knowledge, generating redundant ties and consequent diminishing marginal returns for innovativeness.

Resource depletion occurs when firms use up opportunities from internal resources without obtaining new knowledge from external search. The technology literature views this as an over-emphasis on local search (Nelson and Winter, 1982; Helfat, 1994). For business groups, local search means emphasizing knowledge within group affiliates rather than seeking ideas beyond group boundaries. Greater density of buyer-supplier ties will induce affiliates to focus their attention on intra-group activities, consistent with the idea that highly embedded relationships that arise in dense networks tend to generate local insularity (Uzzi, 1996; Grayson and Ambler, 1999). For business groups, any such insularity will limit the scope of learning and reduce innovative opportunities relative to less insular groups. As a result, density will eventually create negative marginal returns for innovativeness, as groups use up internal resources and do not replace them.

Organizational saturation arises from limits on managerial time and attention (Hansen, 1999). Whereas redundancy and depletion reduce the degree to which internal resources are available for innovation, organizational saturation means that firms lack time to take advantage of available internal opportunities or to search for external knowledge. Saturation is analogous to the notion of urban congestion that inhibits development activity (e.g., Bloom and Khanna, 2007). For business groups, organizational saturation means that affiliates run out of the capacity to take advantage of ideas that arise from additional ties. Saturation can occur in densely tied groups if operating managers need to spend so much effort managing operating relationships that they lack the time to follow up innovative opportunities in their partners. Moreover, organizational saturation arising from density will reinforce the tendencies toward local search that arise from insularity because operating managers in groups with many buyer-supplier ties will have little time to seek ideas beyond those ties. In turn, resource depletion that arises from the reliance on local search will create a vicious cycle of negative marginal returns in which firms invest less in innovative activity because they have fewer resources to work with.

Overall, redundancy, depletion, and saturation reflect two aspects of combinatorial exhaustion. First, redundancy and depletion reduce the stock of novel knowledge within a group, while saturation reduces a group’s ability to take advantage of the group’s stock of knowledge. Second, redundancy leads to diminishing marginal innovative returns to density, while depletion and saturation can generate negative marginal returns.

In sum, the benefits of combinatorial opportunities combined with the costs of combinatorial exhaustion suggest that buyer-supplier density initially facilitates but eventually inhibits innovative activities within a group. Greater density initially provides access to resources and generates trust about sharing resources among affiliates, generating combinatorial opportunities. At some point of buyer-supplier density, though, combinatorial exhaustion arising from tie redundancy, resource depletion, and
organizational saturation will produce decreasing returns. Ultimately, the constraints that arise from combinatorial exhaustion will become so strong that buyer-supplier density produces negative marginal returns on group innovativeness compared to groups with lower density. Hence, buyer-supplier density will have an inverted-U impact on group innovativeness.

**Hypothesis 1:** Group innovativeness first increases with the density of intra-group buyer-supplier ties and then declines after density crosses a threshold.

**Variation in innovation thresholds as the institutional environment evolves**

Business group buyer-supplier structures in emerging economies are embedded in dynamic contexts, including development of market infrastructure, deregulation of industries and public enterprises, and inflow of foreign capital. This is an intrinsically important context and also helps assess how dynamic environments affect organizational performance more generally. Scholars have begun to recognize that changing environmental contexts shape how networks affect strategy and performance (Luo and Chung, 2005; Entwistle, Faust, Rindfuss, and Kaneda, 2007). We develop this idea by considering how the evolution of an institutional environment shapes the way that buyer-supplier density affects group innovativeness. We argue that greater market development of the institutional environment in which a group operates will exacerbate the impact of combinatorial exhaustion.

The market development of the institutional environment is the degree to which a country possesses market institutions needed for commercial activity (North, 1990; Khanna and Palepu, 1997). At least four aspects of the institutional environment support innovative activity. Capital markets offer financial support for innovative ideas (Lundvall, 1992). Labor markets facilitate movement of people needed to transfer, develop, and commercialize new ideas (Saxenian, 1994). Vertical intermediaries such as suppliers, complementary firms, and distributors help firms identify and take advantage of innovative ideas (Porter and Stern, 2002; Mahmood and Singh, 2003). Reliable legal frameworks create incentives to innovate because firms believe they will profit from successful efforts (Edquist, 1997).

The growth of market institutions in a country will reduce the marginal benefits of intra-group buyer-supplier ties. Firms that emphasize internally generated innovation will miss opportunities to use resources that are increasingly available in the external environment. Thus, the opportunity costs of local search will increase as the environment becomes more market oriented. This will both reduce the benefits from drawing on internal knowledge and reduce the tendency to do so. Belenzon and Berkovitz (2010), for instance, find only limited cross-citations among affiliates of diversified companies in the developed markets of Western Europe.

Market development generates increased opportunity costs of local search for two reasons. First, it is difficult to conduct local and distant search simultaneously. Hansen (1999) argues that limits on managerial time restrict the ability to add search activities that would identify opportunities beyond the boundaries of an operating unit. Second, path dependencies create constraints in substituting distant search for local search, because firms become embedded in prior relationships and established ways of
operating (Granovetter, 1985; Uzzi, 1997). Faced with limited time, money, and people to use for search activities, coupled with path dependencies in traditional local search activities, local search will tend to crowd out distant search activities (Dosi, 1988; Uzzi, 1996). If high reliance on intra-group buyer-supplier ties causes inward focus on internal operations, then a group will incur innovation constraints relative to groups that have less internal focus when the number of external opportunities increases. By contrast, groups that have few buyer-supplier ties and so are less likely to emphasize local search will have more alternative resources that they can use for innovation as market development proceeds. The growth of market-based institutions will exacerbate the impact of resource depletion and, in turn, of combinatorial exhaustion, thereby reducing the net innovative benefits of buyer-supplier density.

**Hypothesis 2.** The greater the market development of the institutional environment in which a group operates, the lesser the net innovative benefits of intra-group buyer-supplier density.

Comparing Samsung and Daewoo illustrates the impact of market evolution. Historically, both groups were innovative leaders in Korea. As the market environment of the country strengthened during the 1970s and 1980s, Samsung reduced its dependence on internal supply, while Daewoo remained internally focused. Samsung forged ahead as a more innovative firm (the U.S. Patent Office reports that Daewoo received 1,480 U.S. patents from 1976 until undergoing reorganization in 2000; Samsung received 6,633 patents in the same period). Chang (2008) attributes part of Samsung’s innovativeness to its ability to search externally in order to take advantage of market and technical opportunities.

We note that an alternative explanation for results consistent with Hypothesis 2 might reflect the passage of time rather than greater market development. Resource depletion might set in as a set of buyer-supplier relationships ages and exhausts novel opportunities. The analysis will address this possibility.

In sum, we argue that buyer-supplier density has both a main effect and a market-varying impact on group innovativeness. Density creates combinatorial opportunities that increase at a decreasing rate, with the marginal impact on innovativeness eventually becoming negative as combinatorial exhaustion takes hold. Internal combinatorial opportunities offer greatest benefits when developed market institutions are limited, while combinatorial exhaustion becomes increasingly salient as markets develop.

4. DATA, MEASURES, AND STATISTICAL METHOD

**Business groups in Taiwan**

Business groups play important roles in the Taiwanese economy. Chung and Mahmood (2006) report that the sales of the top 100 groups accounted for as much as 85% of the country’s GDP in 2002, up from a 28% share in 1980. Business activity in Taiwan involves a wide range of industries, including electronic and electrical devices, industrial equipment, chemicals, plastics, construction, wholesale trade, data processing, food manufacturing, financial services, real estate, and life sciences (Chung, 2001).

Groups played key roles as innovators during a period in which Taiwan became an important global source of technical advance in several industries (Hobday, 1995; Ernst, 1998). As part of this research, we examined U.S. patenting trends of Taiwan inventors. Between 1984 and 2001, group
affiliates received 97% of the U.S. patents awarded to Taiwanese applicants; eight of the top ten recipients were affiliates of business groups (TSMC, UMC, Hon Hai, Walsin Lihua, Acer, Advanced Semiconductor, Umax, and Giant). Many of the patentees operated in the semiconductor, electronics, and industrial equipment sectors; groups also were leaders in bicycles (Giant), metals (China Steel), and chemicals (Formosa Plastics). There is substantial variation in patenting among groups within industries.

Taiwan offers a rich context in which to examine how intra-group operating linkages affect group innovativeness. The groups have extensive variety in the structure of buyer-supplier ties. Moreover, Taiwan offers clear definitions of group membership for identifying ties. Khanna and Rivkin (2006) suggest that group boundaries are ambiguous in some countries, such as Chile, while Saxonhouse (1993) notes that governmental encouragement of inter-group activities plus a lack of family solidarity obscures keiretsu boundaries in Japan. In Taiwan, by contrast, strong cultural foundations such as regional kinship and patrilineal family connections delineate group boundaries clearly (Numazaki, 1986).

Taiwan underwent a substantial market-based evolution in its institutional environment during the study period. Amsden and Chu (2003) and Chung and Mahmood (2006) highlight advances in capital markets and other elements of market infrastructure that occurred between the 1970s and the late 1990s. These changes offer an opportunity to study how market development affects group innovativeness.

Data sources

Our major data source is the Business Groups in Taiwan (BGT) directory, compiled by the China Credit Information Service (CCIS), which is a Taipei affiliate of Standard & Poor’s. CCIS is the oldest and most prestigious credit-checking agency in Taiwan, while BGT offers the most comprehensive and reliable source of business group data. CCIS defines a business group as a coherent business organization including several independent enterprises. BGT reports data on the top 100 or more groups (highest sales), assessing groups whose principal firms are registered in Taiwan. According to BGT, the top 100 groups contributed 42% of the national GDP in the 1990s. BGT records supply links, interlocking directorates, and cross-shareholdings. Several studies use BGT data (Claessens et al., 2000; Khanna and Rivkin, 2001; Luo and Chung, 2005), although none has translated the intra-group ties.

BGT provides information about groups in Taiwan for five calendar years: 1981, 1986, 1990, 1994, and 1998. Our initial sample included 592 group-year cases (267 unique groups, with 3,500 unique affiliates). Manufacturing sector affiliates produce about three-quarters of total group revenue, with the balance from service sector affiliates. We included service firms in the measures of ties because service activities can contribute knowledge needed for innovation, such as information about customer preferences. The final sample, after excluding cases with missing data, included 576 group-year observations (263 unique groups).

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2 Groups in Taiwan lie at a mid-point of Granovetter’s (1995:114) continuum of power centralization. Orru, Biggart, and Hamilton (1991) note that Taiwanese groups exert less hierarchical control than Korean chaebol, but more than Japanese keiretsu. Coordination mechanisms inside Taiwanese groups tend to involve relationships among leaders rather than strong control by a group president (Chang and Hong, 2000).
BGT includes figures for each group that depict intra-group buyer-supplier relationships, shared directorships, and equity cross-holdings. The figures report the information in traditional Chinese script, Fan-ti-zi (mainland China uses a simplified form of Mandarin script, Jian-ti-zi). One of the co-authors, who reads Fan-ti-zi fluently, led the translation. Translators read the volumes, identified groups and affiliates, and transcribed financial information about each affiliate.

**Dependent variable**

We use Taiwan patent data to measure innovative activity. Scholars commonly use patents as objective measures that compare innovative activity across organizations. At the same time, patents are imperfect measures that require cautious interpretation because they record only portions of firms’ innovative activities (Griliches, 1990; Schilling and Phelps, 2007). Patents do not suit some types of innovative activity, either in different technological conditions or because of differences in strategy across firms, industries, countries, and time. Moreover, patents record innovative activity as much as or more than they do innovative success, so they are most relevant for industrial sectors that rely on relatively discrete innovation in products and processes rather than innovation in more complex business models. Nonetheless, patents provide a useful comparison of activities across firms so long as one both controls for as many sources of heterogeneity as possible and interprets the results carefully.

Patent activity is common across many sectors in Taiwan. Yu’s (1998) study of Taiwan’s Hsinchu Science Park found use across a wide variety of industries. We focus on local patents because we are interested in overall innovative activity. Because patenting and operating abroad is more expensive than patenting domestically, focusing on U.S. patents would bias the analyses toward larger firms.

Taiwan established its patent system in 1945. Taiwanese patent examiners follow standards similar to U.S. examiners regarding patentable inventions (Yang, 2004). In accordance to the Trade-Related Aspects of Intellectual Property Rights agreement of the World Trade Organization, Taiwan restructured its patent systems in 1994, extending a patent’s life from 15 to 20 years.

We collected information about patenting by business group affiliates from online databases of the Intellectual Property Office (http://www.patent.org.tw), which covers all patents filed in Taiwan since 1950. We entered the name of each affiliate in traditional Chinese script into the database to identify patent applications. We coded patent identification numbers, application and approval dates, and patent types. We focused on “New Invention Patents”, which the Intellectual Property Office of Taiwan defines as innovations involving wholly new products, materials, or manufacturing processes.

The dependent variable (Group patent applications) is the aggregate patent application counts by all affiliates of each group over a two-year period following each of the five years for which the BGT provided data. We identified new invention patent applications for ten years (1982-1983, 1987-1988, 1991-1992, 1995-1996, and 1999-2000; we found similar results with other patent windows). We aggregated at the group level because information arising on buyer-supplier ties can flow throughout the group and affect innovative activity in any connected affiliate. In sensitivity analyses, we examined the
impact of buyer-supplier centrality on affiliate-level patent counts, to assess whether innovative-relevant resources tend to aggregate in more central firms. We lagged the focal independent variables and control variables because patent applications typically correspond to activity preceding the application (Schilling and Phelps, 2007). For covariates variables in 1981, for instance, the dependent variable includes patent applications for 1982 and 1983. In total, the study uses 2,562 new-invention applications.

Table 1 summarizes the sample, reporting time trends in number of groups, affiliates, and patent applications, as well as measures for intra-group buyer-supplier density and market development that the next section describes. The later periods, especially 1998, include more groups because the BGT increased its reporting coverage; the results were not sensitive to this difference. The mean number of affiliates per group increased slightly over time. The number of patent applications grew substantially during the last two periods of the study.

********** Table 1 about here **********

Focal covariates: Buyer-supplier density and market development
The key conceptual variables are buyer-supplier density and market development. Buyer-supplier density measures intra-group buyer-supplier ties. Density is the ratio of buyer-supplier relationships to the number of potential ties among affiliates in a given year. Greater density means a higher number of direct and indirect ties among affiliates. Table 1 shows that buyer-supplier tie density dropped substantially during the study period, which reflects the increase in the mean number of affiliates. We used density and the square of density to test the non-monotonic impact on innovativeness.

Market development used four aspects of the national innovation infrastructure, based on the discussions that we cited earlier, measuring each of the items in each period of the study. Early studies often used time trends to measure market development (e.g., Khanna and Palepu, 2000a), but more recent research has begun to develop more direct measures of market development (e.g., Khanna, Palepu, and Srinivasan, 2004; Chakrabarti, Vidal, and Mitchell, 2011). We used four elements to measure market development of the institutional environment in Taiwan. Stock market trading volume assessed capital market development. The number of for-profit organizations operating in the country assessed the availability of commercial intermediaries. The number of graduates of universities in Taiwan indicated the extent of the external labor market. The number of points that the World Competitiveness Report awarded Taiwan assessed the strength of legal protection. The market development measure recorded the mean value of the growth multipliers after the first time period for each item.

Table 1 shows that each of the four elements of the institutional environment grew substantially during the study period, resulting in a non-linear increase in the market development measure. We found robust results with a market development variable that deflated the impact of stock market trading volume, which exhibited the most explosive growth. Stock market trading volume had strong correlations with several measures of capital market development in the World Competitiveness Report, including venture capital availability (r=0.98), cost of capital (r=0.97), credit flow (r=0.92), and local capital market
We created an interaction variable to test H2. *BSD-squared x Market* is buyer-supplier density times market development. This produces equation [1], where D=Density, M=Market development, and X is a vector of other influences.

\[ \text{Innovativeness} = \beta_1 D + \beta_2 D^2 + \beta_3 M + \beta_4 M^2 + \gamma X \]

H1 predicts \( \beta_1 \) to be positive and \( \beta_2 \) to be negative, while H2 predicts \( \beta_4 \) to be negative. We have no prediction for \( \beta_3 \); although overall innovativeness among all business groups increases as market development advances, other factors might explain the innovativeness of any focal group at a point in time. We can calculate the point at which density generates the maximum impact on innovation (\( D_{\text{max}} \)) in equation [1] by calculating the partial derivative of *Innovativeness* with respect to D. This produces

\[ D_{\text{max}} = \frac{\beta_1}{-2(\beta_2 + \beta_4 M)} \]

Equation [2] has the nice property that, given predicted signs (\( \beta_1 > 0, \beta_2 < 0 \) and \( \beta_4 < 0 \)), \( D_{\text{max}} \) increases in \( \beta_1 \) (Combinatorial Opportunity) while decreasing in \( \beta_2 \) (main effect of Combinatorial Exhaustion) and in \( \beta_4 \) (market-varying Combinatorial Exhaustion). Moreover, \( D_{\text{max}} \) becomes smaller as M increases.

One question is the degree to which market development or buyer-supplier density might arise endogenously as a result of a group’s innovative activities. Market development undoubtedly reflects the maturation of business activities, including group activities, but growth in labor markets, intermediaries, capital markets, legal protection, and other elements of innovation infrastructure is beyond the control of any one group. For buyer-supplier ties, meanwhile, higher density associates with lesser diversification; the analysis will assess the effects of diversification.

**Control variables**

Several time-varying measures address other influences on patenting. Two variables assess other elements of intra-group structure. *Group equity density* denotes the proportion of affiliates with cross-shareholdings. Equity ties may facilitate innovative activity by supporting internal capital markets (Chang and Hong, 2000; Belenzon and Berkovitz, 2010), but might also constrain innovation if minority shareholders such as controlling families use cross-shareholding to extract resources or if equity ties keep inefficient group members from acquisitions that would enhance innovativeness under new ownership (Morck and Yeung, 2004). *Group director density* might enhance information flow (e.g., Useem, 1984; Keister, 1998), but it might also reduce innovativeness by focusing a group’s efforts on current activities (Morck and Yeung, 2004). We also measured aggregate tie density (equity, investment, and buyer-supplier ties), which produced insignificant results in sensitivity analysis.

Other variables assess group-level factors that might affect innovativeness. *Group assets*, in billions of New Taiwanese Dollars, measured group size. *International linkages* is a factor loading based on the number of links that affiliates of each group had formed with actors outside Taiwan (using the BGT as source), including international joint ventures, licensing, acquisitions, and foreign direct investment outside Taiwan; the linkages might act as substitutes for internal buyer-supplier ties as sources
of innovative ideas. Group industry concentration records the industry-weighted average of the five-firm concentration ratio, which assesses exposure to competitive pressures. Group diversification uses an entropy calculation (Palepu, 1985) based on 2- and 4-digit Taiwan SIC codes. Group pre-sample patents controls for idiosyncratic innovative capability by recording the number of patents that a group received prior to 1981 (Blundell, Griffith, and van Reenen, 1999). Electronics is a 0-1 variable that denotes groups for which the largest firm was a member of the electronics sector (16% of the groups, which produced 89% of the patents in the sample). Group industry R&D reports the industry-average R&D intensity of the group’s affiliates. Group industry patenting propensity measures the degree to which the industries in which a group’s affiliates operate tend to use patents as a way of protecting intellectual property, using industry-specific measures in a U.S. survey by Cohen, Nelson, and Walsh (2004). Internal sales records the degree to which a group relied on vertically integrated sales to affiliated firms, as an alternative factor that might drive local search and consequent resource depletion. Change in sales denotes group sales growth over time, to control the possibility that growing firms tend to be more innovative. Group age records years since the founding of the first group affiliate; older groups might either have more resources for innovation or exhibit inertia that constrains innovative activity. Group buyer-supplier tie age is the mean age in years of the ties within the group, which helps assess whether redundancy simply reflects the passage of time rather than increased market development. Year dummy variables records each year of the panel, which we used to control temporal effects other than market development. We considered other controls but found high correlations with variables that we included in the analysis; these included family share of directors (0.63 correlation with director density), number of affiliates (0.49 correlation with group assets), period of first group entry (0.60 correlation with market development), and buyer-supplier centralization (0.65 correlation with buyer-supplier density).

Table 2 reports summary statistics. Market development has negative correlations with buyer-supplier density (r = -0.31) and industry concentration (r = -0.48), while diversification has negative correlation with buyer-supplier density (r = -0.34). Group industry R&D correlates with the electronics sector (r=0.39) and group industry patenting propensity (r = 0.31). Group buyer-supplier tie age has moderate correlations with market development (r=0.23), assets (r=0.26), and age (r=0.27). We found similar core results when we dropped correlated variables. Buyer-supplier density is largely independent of the other two measures of tie density (r = 0.14 with equity density; r = 0.16 with director density).

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

Method

The count nature of our dependent variable (number of patents), together with over-dispersion of values of the variable, suggests using negative binomial regression (Hausman, Hall, and Griliches, 1984). Because the dependent variable includes many zeros (only a quarter of groups patented during the period), we adopted Zero-Inflated Negative Binomial (ZINB) regression. ZINB separates two regimes. In regime 1 (“inflation”), the patent outcome is always zero, for groups that never patent. In regime 2
(“count”), the usual negative binomial process applies, for groups that generate positive counts in some years. An alternative approach of examining only groups that patented would risk sample selection bias. Greene (2003: 779-780) shows that ZINB outperforms standard negative binomial when regime-splitting is needed, which a significant Vuong statistic indicates arises with our data. As we discuss later, we tested for robustness to alternative approaches.

5. RESULTS  

Hypothesis tests

Table 3 reports the results. Model 1 contains the control variables, while subsequent models add variables that test the hypotheses. The Change in $\text{LLR}$ (log-likelihood ratio) $\chi^2$ statistic demonstrates improved explanatory power versus nested models.

*********** Table 3 about here ***********

Panel B of the models estimates influences on whether a group will undertake patent applications during the study period. We included buyer-supplier density and market development to ensure that any “count” effects associated with our focal concepts did not arise from tendencies to be a patentee (“inflation” effects). We also included inflation covariates that reflect the technological emphasis of a group’s businesses (group industry R&D, group industry patenting propensity, electronics sector, group pre-sample patents), competitive conditions (group industry concentration), other intra-group structural linkages (director density, equity density), and group characteristics that might affect the likelihood that a firm would have resources needed for patenting (group assets, international linkages, internal sales share, group age, group diversification, sales growth, and buyer-supplier tie age). The likelihood of being a patentee (negative coefficient) increased with market development, group assets, international linkages, pre-sample patents, sales growth, and industry patenting.

Panel A reports influences on how many patents groups filed in a two-year window. The panel adds year dummies and includes the other two measures of intra-group density, as well as variables from the inflation matrix that had significant impact on patent incidence and variables that we use in subsequent checks of causal mechanisms. This approach preserves degrees of freedom in Panel A; we found robust results when we varied the control variables. Model 1 shows that patent incidence increases with pre-sample patents and electronics sector, while decreasing with director density, industry concentration, and buyer-supplier tie age. The results are similar in subsequent models.

The results in Models 2 and 3 of Panel A of Table 3 support both hypotheses. Consistent with H1, Model 2 shows that buyer-supplier density has a significant positive impact on patenting ($\beta=2.819$, $p<0.05$), while density-squared has a significant negative impact ($\beta=-9.551$, $p < 0.05$). Consistent with H2, Model 3 shows that the interaction of buyer-supplier density and market development has a significant negative impact ($\beta= -1.034$, $p < 0.01$); density ($\beta=8.589$, $p < 0.01$) and density-squared ($\beta= -9.111$, $p < 0.05$) remain significant. The main effect of market development is insignificant in both models, showing that the impact of market development on any group depends on its characteristics (e.g., buyer-supplier
density) rather than affecting all groups homogeneously.

Figure 1 uses the results from Model 3 to depict the magnitude of the effect of buyer-supplier density on patenting. The figure shows combinations that involve the full range of market development (values from 1.0 to 13.2), together with values of density from 0 to 0.6 (about two standard deviations above the mean density of 0.19). The figure shows that patenting has a strong inverted-U relationship with density, with lower benefits at higher levels of market development. Low market development (value=1.0) is at the rear of the figure, where the benefits peak with density = 0.42. At the front of the figure, where market development is much higher (value =13.2), the maximum benefit comes much earlier, with density = 0.19. Higher values of density produce a rapidly declining impact on patenting when market development is high. The results have meaningful magnitude: With market development =1.0 (13.2), the difference between the maximum and minimum impact on patenting tendency within the range of density from one standard deviation below mean density to one standard deviation above mean density is 42% (27%) of the overall mean patenting rate.

******** Figure 1 about here ********

Sensitivity analyses
The core results were robust to multiple sensitivity analyses. First, we found consistent results with alternative measures of the market development variable, including linear time and a less pronounced non-linear operationalization of the four sub-dimensions. Second, similar results held when Panel A dropped control variables, as well as when we distinguished between related and unrelated diversification, added number of affiliates, or added period of first group entry. Third, we found similar results in a more parsimonious analysis when we analyzed a subsample that included only groups that were in the data at the beginning of the study period (about half the group-years in the sample). Fourth, the results held when we added dummies for groups that emphasized the “traditional” and “non-manufacturing” sectors, which had low patenting tendencies while sitting near the extremes of low buyer-supplier density (non-manufacturing) and high density (traditional), and also when we omitted the two largest patentees, UMC and TSMC. Fifth, probit regression found that density had a significant non-monotonic impact on the likelihood that a group would be a patentee in a given period.

Although the results are robust, it is possible that the relationship between network density and innovation is bi-directional. We argue that density generates combinatorial opportunities and exhaustion that influence innovativeness; conversely, a group’s innovativeness could influence the level of interdependence within the group by causing reconfiguration across multiple businesses within a group. Rajan and Zingales (1998: 560) suggest that one way to assess causality is to “focus on the details of theoretical mechanisms through which [one variable affects another], and then document their working”. We investigated seven factors that reflect mechanisms that underlie combinatorial opportunity and exhaustion; we summarize the results here and report the analysis in Appendix 2a.

Four mechanisms enhance combinatorial opportunities from greater density: Buyer-supplier tie
age, tie industry heterogeneity, group age, and external linkages. First, buyer-supplier tie age indicates how long people in a group have had the opportunity to actively work together. Although the main effect of tie age leads to increased redundancy (as Table 3 showed), we also found that tie age has a countervailing positive influence in combination with density (p<0.01), possibly by increasing knowledge and trust and so extending the point of maximum density before redundancy sets in. Second, tie industry heterogeneity (based on an entropy measure) indicates the range of industries in which a group’s buyer-supplier partners operate, which will increase knowledge variety and reduce tie redundancy (see, e.g., Rodan and Galunic, 2004), thereby generating combinatorial opportunities; we found that density imposed fewer constraints on groups with buyers and suppliers in heterogeneous industries (p<0.01). Third, older groups will tend to accumulate stocks of knowledge and may also allow trust to form across affiliates, thereby increasing the benefits of operating density; we found that density imposed fewer constraints on older groups (p<0.01). Fourth, external linkages provide access to external knowledge, reducing the impact of resource depletion; we found that density provided greater benefits for groups with international linkages (p<0.05).

Three other mechanisms exacerbate combinatorial exhaustion, particularly through resource depletion arising from local search: Electronics sector, group R&D-intensity, and internal sales. The electronics sector and other industries with high R&D have extensive external knowledge and so groups will pay a high price from internal resource depletion if density creates local search tendencies. Dense groups with high internal sales share also will be at risk of local search, owing to organizational saturation. We found that density provided fewer benefits for groups in the electronics sector (p<0.01), with high share of internal sales (p<0.01), or in R&D-intensive settings (p<0.01). The results of the mechanism tests help demonstrate the causal logic that underlies the predications.

We also undertook sensitivity analysis for patent activity at the firm and patent levels of analysis. First, we regressed buyer-supplier centrality on firm-level patenting, with the expectation that central firms are better able to gather and use knowledge for their innovative activity (Ahuja, 2000). We found the expected positive impact of buyer-supplier centrality on firm patenting (p<0.05; Appendix 2b). Second, we sought to undertake patent citation analysis to determine whether citations reflect buyer-supplier relationships, which would be consistent with the idea that the ties facilitate knowledge flows. We attempted to use citations involving Taiwanese patents, but the Taiwan Intellectual Property Office (TIPO) informed us that citation reporting in their database did not begin until 2008, well after our study period. We then sought citation information in U.S. patent applications by the Taiwanese companies in our sample. However, very few Taiwanese firms filing in the U.S. cite patents of their affiliates because the citations reference U.S.-granted patents and typically only the core member of a group files patents in the U.S. (in a very few cases, two members). Hence, few firms have U.S. patents that their affiliates can cite, so most citations to a firm’s group are self-citations. In total, we identified only 483 citations in which firms cited their own group members’ patents (all 483 citations involved United Integrated Circuits
and United Microelectronics citing each other (UMC Group) or Vanguard International Semiconductor and Taiwan Semiconductor Manufacturing citing each other (TSMC Group)). Intriguingly, all 483 citations involved affiliates with which the citing firms had buyer-supplier ties, although this incidence is too low to draw conclusions about knowledge flows.

Finally, we investigated whether greater buyer-supplier density increased incentives to invest in innovative activity and/or the productivity of a given level of investment. The analysis uses R&D data from publically listed affiliates (693 firms in 188 groups). We assessed how group-level buyer-supplier density affected (1) affiliate R&D/Sales intensity, as measure of investment incentives; and (2) affiliate R&D capability, measured using stochastic frontier estimation, which captures the level of efficiency by which a firm turns inputs (R&D expenditures) into outputs (patents). The estimates use fixed effects identification to control time-invariant industry and group effects (the results are robust to including time varying group variables). Table 4 reports both influences. Affiliates of groups with higher buyer-supplier density tended to have both higher R&D intensity and higher R&D productivity (both p<0.05).

********** Table 4 about here **********

6. DISCUSSION AND CONCLUSION
We started by asking how intra-group buyer-supplier ties affect business group innovativeness as markets evolve. The analysis supports our argument that the density of buyer-supplier ties creates both combinatorial opportunities that contribute to innovativeness and combinatorial exhaustion that deflates innovativeness, with the constraints increasing as a group’s home environment increasingly adopts market-oriented institutions. Group innovativeness first increases and then decreases with buyer-supplier tie density, with the peak of maximum benefit occurring earlier as the environment adopts legal, capital, labor, and commercial institutions. The results vary consistently when we examine factors that reflect the underlying elements of combinatorial opportunity and exhaustion, including tie industry heterogeneity, business age, external linkages, industry R&D intensity, electronics sector, and internal sales share. We show that buyer-supplier density both creates incentives to invest in R&D and creates greater innovative output from a given level of investment. Thus, the results are consistent with the core argument.

The research draws attention to three under-studied elements of business group studies: Groups’ roles as innovators, differences in internal structure across groups, and the changing nature of external environments. Research about business groups has only begun to examine differences in groups’ innovative activity, whether at one point or over time. This lack of attention stems from a prior focus on comparing groups to independent firms, as well as from data limitations about internal group structure and about changes over time. We demonstrate that buyer-supplier ties, which are key elements of group structure, have substantial impact on group innovativeness, with the impact changing as the home environment changes. The conclusions about the important of the development of the market environment complements Belenzon and Berkovitz’s (2010) study of innovation by European-based groups: They found only limited internal knowledge transfer in this developed market setting, reinforcing the point that
the incentives for internal knowledge sourcing decline as markets gain external innovation infrastructure.

The results provide insights about the mechanisms that underlie combinatorial opportunities and exhaustion. The mechanism tests found influences from factors that increase access to varied knowledge, potentially increase trust, reduce tie redundancy, either attenuate or exacerbate resource depletion, and/or generate organizational saturation. The cases reinforced the importance of these mechanisms.

The study has limits that suggest future research. First, we focus on one country that has undergone only a partial transition to market orientation; studies of countries at different points of market transition in which groups may play somewhat different roles would be useful. Second, the data limit the degree to which we can assess endogeneity; studies that use different data such as R&D investments will help assess robustness. Third, one could consider how other aspects of group structure, such as equity and director density, affect group innovativeness as markets evolve. Fourth, it would be useful to incorporate informal aspects of intra-group structure such as relational ties, in addition to formal linkages. Fifth, studies that examined other measures of innovativeness, such as new product introduction, would be valuable. One intriguing issue is that group structure might affect incentives to use patents as opposed to other forms of protecting new technology. A group with more linkages will have greater transactional complexity, for example, and may rely more on contracts and/or relationships with its affiliates rather than patents.

The study also points to research avenues for the more general technology studies and social network literatures. Technology research has long been puzzled by why multi-business firms are sometimes more and other times less innovative than independent firms (Nelson, 1959; Link and Long, 1981). An extrapolation of our argument is that intra-unit operating density within multi-business firms initially may create innovative benefits but ultimately generates constraints; moreover, the constraints will
set in at lower points of density in advanced market economies, where most technology studies research has focused. The social networks literature, meanwhile, has begun to consider how differences in network structure affect network performance, including innovativeness, and how changes in the environments within which networks are embedded will affect key elements of performance (Granovetter, 2005; Provan, Fish, and Sydow, 2007). Our study of business groups could be extended to study how network structure and changes in external environments may jointly affect network innovativeness.

Business groups have been key actors in emerging market economies for more than a century. Understanding how groups’ roles as innovators vary across groups and over time is central to understanding trajectories of technological growth within and across nations. In parallel, the forces that affect group innovativeness arise within corporations and organizational networks in many contexts. Most generally, this study seeks to shed light on organizational innovativeness in dynamic environments.
References


Figure 1 uses the results from Model 3 of Table 3 to depict the effect of buyer-supplier density on patenting at different levels of market development. The figure shows that patenting has a strong inverted-U relationship with density, with declining benefits as market development advances. Low market development (value=1.0) is at the rear of the figure, where the benefits peak with density = 0.42. At the front of the figure, where market development is much higher (value =13.2), the maximum benefit comes much earlier, with density = 0.19. Higher values of density produce a rapidly declining impact on patenting when market development is high.
<table>
<thead>
<tr>
<th>Base year</th>
<th>Number of business groups</th>
<th>Number of affiliates (mean per group)</th>
<th>Patent applications by business groups: Two-year period after base year (mean applications per group)</th>
<th>Mean intra-group buyer-supplier density</th>
<th>Market development of the institutional environment: Relative magnitude *</th>
<th>Capital markets:</th>
<th>Stock market trading volume, US$ bln (multiplier)</th>
<th>Commercial intermediaries: Number of for-profit organizations (multiplier)</th>
<th>External labor market: Number of university graduates (multiplier)</th>
<th>Legal protection: Number of points in world competitiveness report (multiplier) **</th>
</tr>
</thead>
<tbody>
<tr>
<td>1981</td>
<td>100</td>
<td>716 (7.2)</td>
<td>162 (1.6)</td>
<td>0.22</td>
<td>1.0</td>
<td>13.2 (1.0)</td>
<td>608,658 (1.0)</td>
<td>32,102 (1.0)</td>
<td>3.3 (1.0)</td>
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<td>1986</td>
<td>97</td>
<td>749 (7.7)</td>
<td>143 (1.5)</td>
<td>0.17</td>
<td>1.7</td>
<td>39.0 (3.0)</td>
<td>741,887 (1.2)</td>
<td>39,065 (1.2)</td>
<td>4.3 (1.3)</td>
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</tr>
<tr>
<td>1990</td>
<td>101</td>
<td>819 (8.1)</td>
<td>118 (1.2)</td>
<td>0.13</td>
<td>5.5</td>
<td>232.3 (17.6)</td>
<td>865,664 (1.4)</td>
<td>49,399 (1.5)</td>
<td>5.3 (1.6)</td>
<td></td>
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<tr>
<td>1994</td>
<td>115</td>
<td>1,116 (9.7)</td>
<td>780 (6.8)</td>
<td>0.09</td>
<td>8.1</td>
<td>351.2 (26.6)</td>
<td>975,549 (1.6)</td>
<td>68,274 (2.1)</td>
<td>6.4 (1.9)</td>
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<tr>
<td>1998</td>
<td>179</td>
<td>1,938 (1.8)</td>
<td>1,359 (7.6)</td>
<td>0.07</td>
<td>13.2</td>
<td>612.0 (46.4)</td>
<td>1,034,328 (1.7)</td>
<td>87,421 (2.7)</td>
<td>7.3 (2.2)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>592</td>
<td>5,339 (9.0)</td>
<td>2,562 (4.3)</td>
<td>0.19</td>
<td>7.0</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* Market development is the mean value of the multipliers of each of the four dimensions, using 1981 as the base year; the results are robust to other combinations of the four dimensions.

** The 1981 and 1986 values of the legal protection score are estimates (the market development measure is robust to alternative estimates).

Table 2. Descriptive statistics (product moment correlations and summary statistics; n=578)

| a | Product moment correlations | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  |
|---|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | Group patent applications  | 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 2 | BSD: Buyer-supplier density| -0.06| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 3 | Mkt: Market development   | 0.07| -0.31| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 4 | Group director density    | -0.03| 0.16| -0.11| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 5 | Group equity density      | -0.01| 0.14| 0.12| 0.20| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 6 | Group assets              | 0.10| -0.21| 0.28| -0.19| -0.14| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |     |
| 7 | Group international linkages| 0.01| 0.03| -0.13| 0.01| 0.09| -0.08| 1.00|     |     |     |     |     |     |     |     |     |     |     |     |
| 8 | Group industry concentration| -0.06| 0.17| -0.48| 0.03| -0.01| -0.14| 0.17| 1.00|     |     |     |     |     |     |     |     |     |     |     |
| 9 | Group diversification     | -0.10| -0.34| -0.07| -0.07| -0.14| 0.21| -0.10| 0.05| 1.00|     |     |     |     |     |     |     |     |     |     |
| 10| Group pre-sample patents  | 0.05| -0.05| -0.04| -0.01| -0.07| 0.20| -0.01| 0.04| 0.08| 1.00|     |     |     |     |     |     |     |     |     |
| 11| Group electronics sector  | 0.22| -0.08| 0.15| 0.01| -0.03| -0.01| 0.17| -0.16| -0.19| 0.05| 1.00|     |     |     |     |     |     |     |     |
| 12| Group industry R&D        | 0.10| -0.04| 0.02| 0.07| -0.01| -0.08| 0.07| -0.16| -0.06| 0.06| 0.39| 1.00|     |     |     |     |     |     |     |
| 13| Group internal sales share| 0.00| 0.05| 0.04| 0.00| 0.03| 0.00| 0.09| -0.01| 0.04| -0.06| 0.04| 1.00|     |     |     |     |     |     |     |
| 14| Group change in sales     | 0.01| 0.02| 0.00| -0.02| 0.01| 0.03| 0.03| 0.01| 0.01| -0.05| -0.03| 0.00| 1.00|     |     |     |     |     |     |
| 15| Group age                 | -0.07| -0.15| 0.22| -0.16| -0.09| 0.20| -0.02| -0.07| 0.25| 0.11| -0.10| -0.09| 0.05| 0.10| 1.00|     |     |     |     |
| 16| Group industry patenting  | 0.04| 0.15| -0.23| 0.07| 0.08| -0.25| 0.09| 0.10| -0.13| 0.10| 0.12| 0.31| 0.08| 0.02| 0.00| 1.00|     |     |     |
| 17| Group buyer-supplier tie age| -0.04| -0.09| 0.23| -0.07| 0.01| 0.26| -0.02| -0.06| -0.01| 0.19| 0.05| 0.02| 0.06| 0.27| 0.03| 1.00|     |     |     |
| 18| Tie industry heterogeneity| -0.11| -0.05| -0.04| 0.05| 0.03| 0.09| -0.02| 0.06| 0.12| 0.13| -0.08| -0.05| -0.01| 0.01| 0.16| -0.12| 0.07| 1.00|     |

**Summary statistics**

- **Mean**: 4.40 0.19 7.0 0.37 0.25 35.6 0.15 0.21 0.30 0.31 0.16 1.95 5.28 -16.8 29.0 15.1 2.35 0.76
- **Standard deviation**: 40.8 0.23 4.8 0.30 0.20 90.9 0.24 0.15 0.20 1.95 0.37 1.70 3.36 583.0 11.2 8.6 0.98 0.15
- **Minimum**: 0 0 1 0 0 0 0 0 0 0 0 0 0 -100.0 4 0 0 0
- **Maximum**: 850 1 13.2 1 1 1 1008 1.67 0.83 0.85 19.80 1 6.94 32.50 246.8 80 31.60 9.25 1
Table 3. Zero inflated negative binomial (ZINB) estimates of influences on business group innovativeness (n=578 group-years, 106 non-zero patent observations; robust s.e.)

<table>
<thead>
<tr>
<th>Panel A: No. of patent applications (positive coefficient = more patent applications by a group in a given period)</th>
<th>1. Coef.</th>
<th>s.e.</th>
<th>2. Coef.</th>
<th>s.e.</th>
<th>3. Coef.</th>
<th>s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSD: Buyer-supplier density (H1 +)</td>
<td>6.063</td>
<td>2.819</td>
<td>**</td>
<td>8.589</td>
<td>3.218</td>
<td>***</td>
</tr>
<tr>
<td>BSD-squared (H1 -)</td>
<td>-9.551</td>
<td>4.657</td>
<td>**</td>
<td>-9.111</td>
<td>5.322</td>
<td>**</td>
</tr>
<tr>
<td>Mkt*BSD-squared (H2 -)</td>
<td>-1.034</td>
<td>0.342</td>
<td>***</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mkt: Market development</td>
<td>-0.025</td>
<td>0.052</td>
<td></td>
<td>-0.014</td>
<td>0.057</td>
<td>0.010</td>
</tr>
<tr>
<td>Group director density</td>
<td>-1.380</td>
<td>0.699</td>
<td>**</td>
<td>-1.306</td>
<td>0.819</td>
<td>**</td>
</tr>
<tr>
<td>Group equity density</td>
<td>0.523</td>
<td>1.152</td>
<td></td>
<td>0.477</td>
<td>1.160</td>
<td>0.373</td>
</tr>
<tr>
<td>Group international linkages</td>
<td>-0.717</td>
<td>0.559</td>
<td></td>
<td>-0.663</td>
<td>0.574</td>
<td>-0.784</td>
</tr>
<tr>
<td>Group industry concentration</td>
<td>-2.357</td>
<td>1.240</td>
<td></td>
<td>-2.316</td>
<td>1.313</td>
<td></td>
</tr>
<tr>
<td>Group pre-sample patents</td>
<td>0.175</td>
<td>0.032</td>
<td>***</td>
<td>0.177</td>
<td>0.035</td>
<td>***</td>
</tr>
<tr>
<td>Group electronics sector</td>
<td>3.161</td>
<td>0.470</td>
<td>***</td>
<td>3.613</td>
<td>0.667</td>
<td>***</td>
</tr>
<tr>
<td>Group industry R&amp;D</td>
<td>0.117</td>
<td>0.134</td>
<td></td>
<td>0.113</td>
<td>0.143</td>
<td>0.089</td>
</tr>
<tr>
<td>Group internal sales share</td>
<td>0.012</td>
<td>0.039</td>
<td></td>
<td>0.026</td>
<td>0.038</td>
<td>0.029</td>
</tr>
<tr>
<td>Group age</td>
<td>-0.018</td>
<td>0.020</td>
<td></td>
<td>-0.005</td>
<td>0.024</td>
<td>-0.006</td>
</tr>
<tr>
<td>Group buyer-supplier tie age</td>
<td>-0.436</td>
<td>0.146</td>
<td>***</td>
<td>-0.445</td>
<td>0.148</td>
<td>***</td>
</tr>
<tr>
<td>Year: 1990 (v. 1981 &amp; 1986)</td>
<td>0.989</td>
<td>0.701</td>
<td></td>
<td>0.995</td>
<td>0.797</td>
<td>0.888</td>
</tr>
<tr>
<td>Year: 1994 (v. 1981 &amp; 1986)</td>
<td>0.731</td>
<td>0.472</td>
<td></td>
<td>0.751</td>
<td>0.513</td>
<td>0.890</td>
</tr>
<tr>
<td>Year: 1998 (v. 1981 &amp; 1986)</td>
<td>1.010</td>
<td>0.476</td>
<td>**</td>
<td>0.927</td>
<td>0.487</td>
<td>*</td>
</tr>
<tr>
<td>Constant</td>
<td>2.005</td>
<td>1.018</td>
<td>**</td>
<td>0.957</td>
<td>1.311</td>
<td>0.709</td>
</tr>
</tbody>
</table>

Panel B: Likelihood that group is a patentee (negative coefficient=more likely to be a patentee in at least one period)

| BSD: Buyer-supplier density                       | 1.430 | 1.770 | 1.384 | 1.887 |
| Mkt: Market development                           | -0.186 | 0.077 | **     | -0.165 | 0.083 | **   | -0.177 | 0.082 | ** |
| Group director density                             | -1.572 | 1.055 |       | -1.623 | 1.213 |       | -1.579 | 1.210 |       |
| Group equity density                               | 1.585 | 1.541 |       | 1.592 | 1.665 |       | 1.432 | 1.724 |       |
| Group assets                                       | -0.075 | 0.021 | ***    | -0.076 | 0.023 | ***   | -0.077 | 0.024 | *** |
| Group international linkages                       | -3.263 | 1.151 | ***    | -3.472 | 1.237 | ***   | -3.461 | 1.201 | *** |
| Group industry concentration                       | -0.155 | 1.819 |       | 0.153 | 2.000 | 0.124 | 1.993 |
| Group diversification                              | -1.656 | 1.436 |       | -1.083 | 1.604 |       | -1.201 | 1.621 |       |
| Group pre-sample patents                           | -1.161 | 0.399 | ***    | -1.133 | 0.356 | ***   | -1.114 | 0.331 | *** |
| Group electronics sector                           | 1.178 | 0.926 |       | 1.499 | 1.022 |       | 1.529 | 1.011 |       |
| Group industry R&D                                 | -0.265 | 0.224 |       | -0.281 | 0.232 |       | -0.288 | 0.228 |       |
| Group internal sales share                         | 0.099 | 0.065 |       | 0.111 | 0.066 | *     | 0.114 | 0.066 | * |
| Group change in sales                              | -0.014 | 0.007 | **     | -0.013 | 0.007 | **   | -0.013 | 0.007 | ** |
| Group age                                          | 0.024 | 0.028 |       | 0.029 | 0.031 | 0.029 | 0.032 |
| Group industry patenting                           | -0.125 | 0.053 | **     | -0.118 | 0.055 | **   | -0.119 | 0.056 | ** |
| Group buyer-supplier tie age                       | 0.066 | 0.346 |       | 0.078 | 0.347 | 0.084 | 0.352 |
| Constant                                           | 5.968 | 1.859 | ***    | 4.946 | 2.080 | **   | 5.113 | 2.060 | ** |
| Ln(a) dispersion                                   | 1.07  | 0.10  | ***    | 1.064 | 0.102 | ***   | 1.028 | 0.101 | *** |
| Log-likelihood(df)                                 | -495.1 | (14) |       | -491.9 | (16) |       | -489.9 | (17) |       |
| Change in LLR $X^2$(df)                            | 6.5   | (2)   | **     | 4.0   | (1)   | **    |       |       |     |

*** p < 0.01, ** p < 0.05, * p < 0.10 (one-tailed tests for hypotheses; two-tailed tests for control variables)

Notes
1. ZINB estimates with simple s.e. had highly significant Vuong statistics (ZINB with robust standard errors does not calculate a Vuong statistic), suggesting that standard negative binomial analysis is not appropriate.
2. The year dummies needed to omit two periods because the market development variable is ordinal in time.
3. Sensitivity analyses: The H1 and H2 results in Model 3 are robust to including dropping or adding control variables and year dummies in Panel A; dropping large patentees; varying the patent windows; restricting the sample to 100 groups per period; and omitting entrants to the sample.
Table 4. Fixed effect estimates of impact of buyer-supplier density on affiliate-level R&D intensity and R&D productivity (n=693 firms, 188 groups)

<table>
<thead>
<tr>
<th></th>
<th>1. R&amp;D intensity</th>
<th>s.e.</th>
<th>2. R&amp;D productivity</th>
<th>s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buyer-supplier density</td>
<td>0.0043</td>
<td>0.0021**</td>
<td>0.0388</td>
<td>0.0021**</td>
</tr>
<tr>
<td>Group director density</td>
<td>-0.0019</td>
<td>0.0010*</td>
<td>-0.0283</td>
<td>0.0010***</td>
</tr>
<tr>
<td>Group equity density</td>
<td>0.0000</td>
<td>0.0010</td>
<td>-0.0272</td>
<td>0.0010***</td>
</tr>
<tr>
<td>Firm centrality</td>
<td>0.0023</td>
<td>0.0010**</td>
<td>0.0322</td>
<td>0.0010***</td>
</tr>
<tr>
<td>Ln firm assets</td>
<td>-0.0004</td>
<td>0.0003</td>
<td>0.0021</td>
<td>0.0003</td>
</tr>
<tr>
<td>Firm age</td>
<td>0.0000</td>
<td>0.0001</td>
<td>-0.0066</td>
<td>0.0001***</td>
</tr>
<tr>
<td>ROA</td>
<td>-0.0001</td>
<td>0.0001**</td>
<td>0.0012</td>
<td>0.0001**</td>
</tr>
<tr>
<td>Diversification: Unrelated</td>
<td>0.0002</td>
<td>0.0011</td>
<td>-0.0040</td>
<td>0.0011</td>
</tr>
<tr>
<td>Diversification: Related</td>
<td>-0.0003</td>
<td>0.0017</td>
<td>-0.0125</td>
<td>0.0017</td>
</tr>
<tr>
<td>Constant</td>
<td>0.0153</td>
<td>0.0066**</td>
<td>0.9467</td>
<td>0.066***</td>
</tr>
<tr>
<td>σ_u, σ_e (ρ)</td>
<td>0.018, 0.006 (0.897)</td>
<td></td>
<td>0.096, 0.054 (0.760)</td>
<td></td>
</tr>
<tr>
<td>F(9,496)</td>
<td>2.62***</td>
<td>30.88***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*** p < 0.01, ** p < 0.05, * p < 0.10 (two-tailed tests)

(1) R&D intensity (investment incentives) = Affiliate R&D/Sales (public affiliates)
(2) R&D productivity (investment productivity): Affiliate R&D capability, using stochastic frontier estimation, which captures the level of efficiency by which a firm turns inputs (R&D expenditures) into outputs (patents)
Appendix 1. Examples: Eternal Chemical Group (identified) and Fabgarm Group (anonymous)

We used published reports and conversations with people involved in the groups’ internal operations to prepare examples of recombination benefits and constraints of two business groups in Taiwan.

Eternal Chemical: Benefits from combinatorial opportunities (knowledge and trust)

Eternal Chemical Group illustrates the recombination benefits that buyer-supplier ties can create, along with mechanisms that underlie the benefits. Eternal Chemical Company, the core firm in the group, was founded in 1964 in Kaohsiung, Taiwan, as a producer of commodity resins. Over the past five decades, Eternal has become one of the top 100 groups in Taiwan, evolving into a specialized electronic chemical and optical-electronic innovator that is one of the world’s leading supplier of dry film photo-resistant materials for printed circuit boards, ahead of firms such DuPont and Hitachi. Eternal had 21 affiliates in 2010, producing polyester resin, coating, laminates, and other chemical products, which they use in the intra-group value chain. For example, the largest and most central member firm, Eternal Chemical Corporation, produces polyester resin. Some affiliates use the resin to make coating and paint, while others use resin to make synthetic adhesives. Further downstream, affiliates provide lamination services. Affiliates have independent governance structures, accounting systems, purchasing departments, and R&D departments, and seek to maximize their own profits. As Taiwan’s economy has expanded, affiliates increasingly also sell products to external buyers, including companies that compete with Eternal’s members.

Eternal’s affiliates commonly have specialized knowledge at different points of the value chain, which creates combinatorial opportunities via the intra-group buyer-supplier relationships. Upstream affiliates such as Eternal Chemical provide raw materials and knowledge that downstream affiliates can use for new product development. Feedback from external customers also channels back to the upstream members via the buyer-supplier ties. The feedback loop creates an ongoing flow of know-how and innovation in multiple product areas. As an illustration of the structural importance of buyer-supplier activity within the core affiliate, Eternal Chemical’s purchasing and R&D departments both report to the President, on the same level as the Corporate Planning Execution department.

Eternal’s development of alternative materials for radio-frequency identification device (RFID) antennas illustrates the recombination benefits. In the early 2000s, a specialized materials affiliate saw an opportunity for an alternative to costly metal RFID antennas by combining its materials knowledge with coating and lamination technologies of affiliates within the group. The R&D team at the materials affiliate (RD1) created a prototype product (P1) with existing group technology, including resin (A1), adhesives (B1 & C1), production processes (D1), and laminating techniques (E1). The P1 prototype used raw materials and technology from the initiator’s own adhesives and production processes, plus resins and lamination from affiliates along the intra-group buyer-supplier chain, drawing on knowledge about where different skills resided that the materials affiliate had gained during its purchasing interactions with the firms in the supply chain. The R&D team and purchasing staff at a resin affiliate (RD2) next suggested a different kind of resin (A2) and production process (D2) that led to a second prototype (P2). The original team (RD1) then designed a new adhesive (B2) and production process (D3), and worked with staff from a lamination affiliate to produce a new laminating technique (E2) to make a marketable product (P3). The RD1 team also designed variants of P3 (P3a and P3b) using different adhesive technology and revised production processes based on conversations with external customers that had specialized needs. At this point, the only piece of prior art left from the original prototype was one of the adhesives (C1). The final products reflected extensions of Eternal’s original internal knowledge, along with external knowledge that the internal linkages had helped the RD1 team recognize they could use.

\[
\begin{align*}
P_3 &= \text{Resin (A2)} + \text{Adhesive (B2 & C1)} + \text{Production process (D3)} + \text{Laminating (E2)} \\
P_{3a} &= \text{Resin (A2)} + \text{Adhesive (B3 & C1)} + \text{Production process (D4)} + \text{Laminating (E2)} \\
P_{3b} &= \text{Resin (A2)} + \text{Adhesive (B2, C1, F1)} + \text{Production process (D5)} + \text{Laminating (E2)}
\end{align*}
\]

By 2006, the interactions among R&D personnel and purchasing staff at affiliates along Eternal’s buyer-supplier chain had successfully created alternative materials for RFID antennas, with substantial sales potential.

Our interviews highlighted several organizational processes involving buyer-supplier ties at the Eternal group that facilitate knowledge and trust needed for recombination activity. **Knowledge**: Respondents said that different affiliates can have an idea that initiates the innovation process, which leads to back-and-forth interactions that draw on and combine...
knowledge across affiliates. Personnel involved in knowledge transfer involve both technical and purchasing staff members, who work at the interface between affiliates. One respondent noted that this process leads to an outcome in which A+B does not only lead to C but also to A+ and B+, in the sense that companies A and B both learn something new (A+ and B+) about their base technologies in the process of creating the new product (C). **Trust:** The same respondent said that even though any one innovation sequence may not create equal rewards in the form of knowledge learned to all parties, the affiliates expect that they will benefit eventually, whether via revenue from the output of the sequence or from later innovation sequences; this expectation of long-term mutual benefit helps maintain trust necessary for knowledge sharing. The potential for unequal learning and reward in a given innovation sequence is much more possible within the group than with firms outside the group.

Eternal also attempts to exchange knowledge via a technology database, in the form of an internet site for sharing research papers. However, one respondent noted that the database is often not useful because it reports only the final output of an innovation process, but not the elements and combinations of knowledge – much of which is not codifiable – that are embedded within the process. Rather than the database, much more effective access to useful knowledge arises when purchasing staff, engineers, and other personnel from different affiliates interact during meetings and work activities; the interactions also generate trust.

**Fabgarm: Constraints from combinatorial exhaustion (redundancy, depletion, and saturation)**

Interviews with executives of the Fabgarm Group (this is a disguised name, because we promised anonymity in this set of interviews) also highlight combinatorial exhaustion arising from redundancy, depletion, and saturation. Fabgarm is a textile manufacturer that has many affiliates with multiple garment brands, with a dense set of buyer-supplier ties. **Redundancy** arose across buyer-supplier ties, respondents noted, because much of the affiliates’ knowledge of technology, products, and markets was homogeneous and so generated diminishing marginal returns to recombination. **Resource depletion** arose across Fabgarm’s affiliates because the exchanges tended to use up novel knowledge quickly, such as how to increase yarn counts in their textiles, while the emphasis in internal sourcing inhibited their ability to look for new external ideas from other suppliers and distributors. **Saturation** applied, one respondent noted, owing to limited time to seek ideas; at some point, meeting with people from affiliates just wasted time, particularly when the knowledge was largely redundant. One respondent said the groups with fewer intra-group ties found it easier to use external sources to identify new knowledge for their innovative activities because they did not have so many internal demands on their time and faced fewer pressures to use internal relationships whether or not they had useful knowledge.

**Market development**

The interviews highlighted the growth of opportunities as the socioeconomic environment has developed in Taiwan. Fabgarm now pushes itself to use external customers and suppliers to learn about production and design trends. The group identifies potential new partners in multiple ways: Because the group is well established, people commonly recommend new customers and suppliers; personal ties through sharing contacts create channels; and senior staff members spend extensive time overseas visiting customers and exhibitions at which potential new suppliers and customers participate.

The external buyer-supplier ties that arise from these sources sometimes create innovation opportunities. Fabgarm worked for several years to gain the opportunity to sell textiles to a British high-end garment manufacturer, which required both extensive discussions within the group about switching from internal affiliates and determined efforts to convince the external manufacturer that Fabgarm would be a credible supplier. After establishing the sales relationship, Fabgarm learned how to make a type of fine textile from the British firm, which allowed them to increase their yarn count from about 110 per square inch to the 170 count that is necessary for producing high-end clothing. The growth of the market base in Taiwan and its increasing international contact has created external buyer-supplier opportunities that in turn generate innovation opportunities.

Intriguingly, the interviews also highlighted the importance of intra-group buyer-supplier ties for building absorptive capacity within the group, even at Taiwan’s current stage of relatively advanced market development. Even now, groups operating in areas in which they have only limited initial knowledge bases often find it difficult to gain opportunities to learn from well-established firms. Even if other firms were willing to share, the newer firm may not know where to start asking questions and will not able to absorb external knowledge. At this stage, intra-group buyer-supplier ties are
valuable, because they provide more time to learn from each other before seeking more actively to learn from external sources. Thus, even when external sources of innovation exist in an advanced market economy, it is important to build a base of ongoing internal interactions in which affiliates learn from each other and generate ideas and innovations during the process of solving current problems. Eternal Chemical, for instance, did not create its first large-scale joint venture until 1988 (which led to creation of a special monomer polystyrene), after almost 25 years of internal experience.
Appendix 2a. ZINB estimates of how combinatorial opportunity (CO) & combinatorial exhaustion (CE) mechanisms shape the impact of density

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Buyer-supplier density (BSD)</td>
<td>3.91***</td>
<td>5.07*** 5.65** 7.34*** 5.53** -3.99**</td>
<td>3.41*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSD-squared</td>
<td>-37.89**</td>
<td>-27.52*** -26.80*** -18.59*** -8.42** 41.94**</td>
<td>17.53**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BSD-squared x Mechanism</td>
<td>11.79***</td>
<td>28.28*** 0.66*** 11.25** -13.51*** -7.70*** 4.50***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mechanisms**

1. Group buyer-supplier tie age  
   -0.47*** -0.47*** -0.49*** -0.48*** -0.49*** -0.48*** -0.49*** -0.49***

2. Tie industry heterogeneity  
   -2.67* -2.76* -2.71* -2.59* -2.95** -2.23 -2.18

3. Group age  
   0.00

4. Group international linkages  
   -0.64 -0.77 -0.78* -0.84* -0.80* -0.79* -0.51

5. Group electronics sector  
   3.37*** 3.47*** 3.53*** 3.40*** 3.45*** 3.17*** 3.40***

6. Group industry R&D  
   -0.02

7. Group internal sales share  
   0.05

Market development  
   -0.10 -0.04 -0.06 -0.07 -0.04 -0.09 -0.03

Group director density  
   -1.39* -1.49* -1.15 -1.52 -1.57 -1.36* -1.12

Group equity density  
   1.16

Group industry concentration  
   -2.43 -2.46* -2.23 -2.52 -2.29 -2.13 -1.70

Group pre-sample patents  
   0.19*** 0.20*** 0.20*** 0.20*** 0.20*** 0.19***

Year: 1986 (v. 1998)  
   -0.19 0.49 0.39 0.50 0.49 -0.07 0.66

Year: 1990 (v. 1998)  
   0.05 0.62 0.46 0.45 0.50 -0.04 0.30

Year: 1994 (v. 1998)  
   0.31 0.66 0.51 0.67 0.64 0.33 0.63

Constant  
   4.34 3.56 3.80 3.85 3.75 3.57 2.47

Panel B: Likelihood that group is a patentee (negative coefficient more likely to be a patentee in at least one period)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Buyer-supplier density</td>
<td>1.01**</td>
<td>2.00 1.06 0.56 0.37 2.57**</td>
<td>1.40</td>
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*** p < 0.01, ** p < 0.05, * p < 0.10 (one-tailed tests for BSD, BSD-squared, & BSD x Mechanism; two-tailed tests for control variables)
Appendix 2b. Negative binomial estimates of how firm-level buyer-supplier centrality affects firm-level patenting activity
(603 observations, standard errors adjusted for group clusters; positive coefficient=more patents)

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*** p < 0.01, ** p < 0.05, * p < 0.10 (two-tailed tests)