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

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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 intragroup 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 will set in at lower levels of density as the market environment becomes more developed because the opportunity costs of local search increase. The research introduces a dynamic argument to studies of business-group innovation.

Key words: strategy; effectiveness; generalized networks; research and development; innovation; business groups; market development
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1. Introduction

Business groups are key sources of innovation in emerging markets (Amsden and Hikino 1994, Amsden and Chu 2003, Chang et al. 2006, Kim 1997), which are now active centers of the world's economic activity, but we understand little about why innovativeness differs across groups and over time. Business groups are sets of independent firms that often operate in multiple industries; groups of firms are connected by structural linkages such as director interlocks, financial investments, and buyer–supplier ties (Granovetter 1995, Khanna and Thomas 2009). Several studies suggest that ties among group affiliates help firms gain access to resources when environments lack external institutions that would otherwise provide capital, legal protection, technology, human talent, and commercial supply chains (e.g., Keister 1998, Chacar and Vissa 2005, Carney et al. 2011). However, few studies have considered how variations in internal structural linkages affect group activity and performance; furthermore, no research has examined how variation in the structure of intragroup ties influences group innovativeness despite that ties might facilitate innovative activity by offering access to intragroup resources or inhibit innovation by inducing inertia (Lincoln et al. 1996, Khanna and Palepu 2000a). This study argues that the density of intragroup buyer–supplier ties both facilitates and constrains group innovativeness, with the constraints increasing over time as the group's home environment adopts more extensive market-based institutions.

The study draws insights about intragroup ties and innovativeness from studies of business groups while building on ideas from the technology and social networks literatures. The business-group literature argues that early in the development of a market environment, intragroup buyer–supplier ties offer alternatives to external supply chains (Leff 1978, Keister 2001), filling what Khanna and Palepu (2010) refer to as institutional voids and potentially contributing to innovative activity (we will also assess equity and director ties, which also address institutional voids). Technology studies research implies that stable operating linkages such as ongoing buyer–supplier ties can help groups combine resources from different affiliates (Nelson 1959, Monteiro et al. 2008) but also suggests that linkages create tendencies toward local search (Nelson and Winter 1982, Helfat 1994). The concept of network density (the proportion of potential ties that members of a network actually form (Freeman 1977)) helps assess when the benefits of buyer–supplier ties will outweigh the constraints.

We refer to the benefits of using ties to share resources across firms as combinatorial opportunities that arise from knowledge and trust in sharing resources and to the constraints as combinatorial exhaustion that arises from resource redundancy, depletion, and organizational saturation. We expect the density of intragroup buyer–supplier ties to have an inverted-U impact on the innovative activity of a group's affiliates, with initial increases in combinatorial opportunities that are countered by growing 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 more prevalent, causing the opportunity costs of local search to increase. We test the argument with 263 Taiwanese business groups from 1981 to 1998, when groups helped Taiwan become an innovation powerhouse (Amsden and Chu 2003, Einhorn 2005). Our study contributes to the business-group literature by demonstrating that differences in groups' internal structure and the changing nature of external environments jointly shape groups' roles as innovators.

2. Background on Business Groups and Innovation

2.1. The Role of Business Groups in Emerging Markets

Business groups have long been common in emerging economies, from the 19th century in the United States 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 (Granovetter 2005, Khanna and Yafeh 2007). Exchange within groups involves interfirm linkages, including financial, director, and buyer–supplier ties. Intragroup ties help coordinate group-wide strategies (Khanna and Thomas 2009) and act as conduits for sharing resources (Keister 1998), where resources include financial assets and physical goods as well as intangible assets such as knowledge and information. Financial ties arise when affiliates hold equity shareholdings or lend each other money (Gerlach 1992). Director ties arise when individuals sit on the boards of affiliates (Keister 2001). Buyer–supplier ties are operating linkages that arise when groups create or acquire affiliates that produce components and/or distribute goods (Lincoln et al. 1996, Chang et al. 2006).

Intragroup ties address gaps in market infrastructure. Intragroup buyer–supplier ties, which we focus on in this research, help fill institutional voids when suitable external vendors are not available and/or firms face concerns about protecting the value of external exchanges. Leff (1978) and Khanna and Palepu (2000b) argue that institutional voids arise when there is limited market-oriented infrastructure, which includes scarcity of commercial value chains in the form of independent suppliers. The scarcity of independent suppliers in turn arises from limits in institutions such as capital markets, labor markets, and legal infrastructure. Creating buyer–supplier relationships within groups helps fill the commercial void in two ways. First, groups often create suppliers and/or distributors that are not available externally. Second, even when external vendors do exist, intragroup buyer–supplier ties provide greater protection for exchanges than would be available with external vendors that do exist, owing to weakness in legal infrastructure; such protection is particularly important for exchanging specialized components and other resources that face proprietary concerns. As we discuss later, when market institutions are limited, proprietary protection, via intragroup ownership and family ties that often arise in parallel with business supplier ties as well as any expectation of risk sharing across affiliates, will encourage greater resource sharing than would occur among independent firms. By bridging institutional gaps, linkages such as buyer-supplier ties may influence multiple aspects of group performance, including innovative activity.

Studies of group innovativeness and other aspects of performance typically consider groups' economic impact and/or compare groups to other firms. A few country-level studies suggest that groups may help newly industrialized countries increase their innovative ability (Kim 1997, Chang et al. 2006). Scholars studying knowledge diffusion and industrialization argue that groups offer reputations and government ties that attract foreign technology providers (Amsden and Hikino 1994, Hobday 1995). Claessens et al. (2000) suggest that family ownership in East Asian groups provides long-term perspectives and willingness to undertake research and development (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 firm-level innovation benefits when a country has limited market institutions. At the group level, meanwhile, Chang and Hong (2000) show that group affiliation in Korea helps affiliates pool resources that contribute to financial performance. Khanna and Palepu (2000a, b) demonstrate that groups in Chile and India create value for their members through product, labor, and capital market intermediation.

In the most detailed study of group innovativeness to date, although in a developed market setting, Belenzon and Berkovitz (2010) examine innovative activity of business groups based in Western Europe from 1995 to 2004. They argue that group affiliates enjoy innovation investment incentives because internal capital markets avoid asymmetric information. The study does not examine intragroup linkages but instead compares innovation by groups to that of other firms while assessing contingencies based on sectoral financial intensity. They find that affiliates tend to be more innovative than nongroup firms, particularly in financially intense settings, while finding little evidence of intragroup knowledge flows based on patent cross-citations. The null result for intragroup knowledge sharing in developed markets is consistent with the argument we develop in §3. No studies have examined whether intragroup relationships such as buyer–supplier ties influence group-level innovative activity.

2.2. Intragroup Buyer–Supplier Ties: Combinatorial Opportunities and Exhaustion

Ongoing intragroup buyer–supplier relationships can both constrain and benefit group innovativeness. The 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 gaining 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 for 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. Mahmood et al. (2011), meanwhile, find that buyer–supplier ties associate with greater innovative capabilities of more central affiliates.

In conducting this research, we examined public information and spoke with executives, industry professionals, and scholars with knowledge of business groups in Taiwan. The Formosa Plastics Group (FPG) offers an example of the benefits of buyer–supplier ties. The 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 intragroup 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 intragroup relationships, as do buyer–supplier relationships among subsidiaries of multibusiness 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. The 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 intragroup 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 generate constraints of combinatorial exhaustion. Exhaustion, which is the point at which combinatorial opportunities reach their limits, can arise from three sources: resource redundancy, resource depletion, and organizational saturation. Redundancy occurs when new ties connect to resources that are already available via existing ties (Dosi 1988). Depletion occurs when firms use up the innovative potential of internal resources and yet are constrained by existing routines from searching for new external insights (Rosenkopf and Nerkar 2001, Rosenkopf and Almeida 2003, Fleming and Sorenson 2004). Organizational saturation occurs when firms reach the limit of managerial capacity to use resources for new activity (Portes 1998, Hansen 1999). Combinatorial exhaustion from redundancy, depletion, and/or saturation can reduce both investment incentives and innovative productivity.

Combinatorial exhaustion is common in practice. In the FPG case, VIA's founder established Xander International in 1997 as a supplier of electronic components. FIC, VIA, and Xander shared staff who spent extensive time coordinating purchasing and technical activities within the FPG affiliates. This organizational saturation left limited time to look for innovative external opportunities, depleting internal resources. Interviews with executives of the Fabgarm Group (disguised name) highlight combinatorial exhaustion arising from the three mechanisms. Fabgarm has many textile affiliates with multiple garment brands, with a dense set of buyer–supplier ties. Redundancy of ties arose because much of the affiliates' knowledge was homogeneous and so generated diminishing marginal returns to recombination. Depletion arose because exchanges among affiliates tended to use up novel knowledge, such as how to increase yarn counts in textiles, and the emphasis on internal sourcing inhibited affiliates' ability to look for new external ideas. Saturation arose owing to limited time to seek ideas; one respondent said the groups with fewer intragroup 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.

The social network concept of network density helps assess how the balance of combinatorial opportunities and exhaustion will affect business-group innovativeness. The density of structural ties 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 example, the density of a four-member group with two ties would be $2/6$ possible ties $= 0.33$. Sociologists suggest that density can both facilitate and constrain network performance. The literature on cohesion (Coleman 1988) suggests that greater density creates direct and indirect paths by which actors can share resources, whereas structural holes arguments (Burt 1992) expect greater benefits from sparseness in which brokers between diverse networks facilitate innovative activity. The few studies that even indirectly examine how density affects network innovativeness (e.g., Hargadon and Sutton 1997, Hansen 2002, Reagans et al. 2004, Burt 2004, Obstfeld 2005, Mahmood and Zheng 2009) find varied results. A study by Uzzi and Spiro (2005) that is most relevant to our argument finds that networks with short paths between members, which Watts (1999) called small-world networks, initially lead to greater artistic creativity in collaborating teams but ultimately result in lower creativity.

The hypotheses below consider how buyer–supplier density affects business-group innovativeness. We first develop the base logic concerning the trade-off of combinatorial opportunities and exhaustion and then turn to market evolution.

3. Hypotheses

3.1. Variation Across Groups: Impact of Buyer–Supplier Tie Density on Group Innovativeness

Operating density creates combinatorial opportunities that arise from two related sources. First, dense ties create widespread knowledge of resources distributed throughout a group. Second, trust about exchanging resources within groups will tend to be greater than in exchanges with independent suppliers.

Resources that can contribute to innovation often reside in different affiliates. Access to affiliates will create combinatorial opportunities if there is variety in knowledge that resides at different points within the group. Rodan and Galunic (2004) find that heterogeneous knowledge within a firm enhances individual performance. Moreover, it is not enough that knowledge simply exists within a group, because any firm with the potential to conduct innovative activities may not know that resources exist and where they are located. Ties help create channels for identifying information (Granovetter 1985), which is particularly important for gaining a fine-grained understanding of tacit knowledge (Uzzi 1997), and ongoing relationships also help avoid degradation of information over time (Moody and White 2003) as well as help solve problems that arise during exchange (Uzzi 1996). Within a business group, ongoing buyer–supplier ties create an information channel that facilitates knowledge search and subsequent opportunities to combine knowledge across affiliates and create new goods and services.

Initially, increasing density of buyer–supplier ties will generate 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, buyer–supplier density creates resource opportunities that would not necessarily occur with high vertical integration (high internal sales), which may involve only a few suppliers with limited variety of resources.

As well as creating knowledge of opportunities, dense ties encourage affiliates to share knowledge by building trust that reduces concerns about who will appropriate the value of any innovative activity. 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) and developing sanctions for deviant behavior (Coleman 1988). In turn, trust encourages people to share information that will allow units to generate innovations from a given investment while also creating incentives to invest in more innovative activity because there is less need to safeguard assets (Williamson 1985, Lincoln et al. 1996). Hence, operating density creates knowledge and trust that generate combinatorial opportunities.

When a group faces institutional voids, particularly limits to legal protection, intragroup ties will provide greater combinatorial benefits than will linkages with any external suppliers that may be present. External suppliers that arise despite the institutional voids might provide valuable knowledge of resources. Nonetheless, concerns about knowledge appropriation will often remain high even in ongoing ties with independent actors, particularly in emerging economies where formal protection of contracts is weak.

Intragroup exchanges benefit from several protection mechanisms that independent ties lack, including cross-equity investments, family-based ownership, and expectations of risk sharing among affiliates. Cross-equity ownership helps groups attenuate appropriation concerns about how partner firms will share benefits of exchanging resources; any direct or indirect ownership ties of the buyers and suppliers within the group help align incentives that protect the value of the resource exchange. Repeated interactions since childhood among family members working in different affiliates can also generate trust that protects the value of exchanges. Equity holdings and family ownership usually do not exist among independent firms, so group membership helps fill the institutional void of legal protection mechanisms. In addition, to the extent that affiliates expect to share risks and support each other over time, where such willingness to provide mutual insurance may arise because of equity holdings and family-based ownership, individual affiliates will worry less than independent firms will about who benefits from sharing a particular resource.[1] Hence, relative to ties with external actors, intragroup affiliation generates greater willingness to share resources that create combinatorial opportunities.

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 of knowledge learned by all parties, the affiliates expect

[1] The groups literature has argued that affiliation offers mutual insurance (e.g., Aoki 1984), although the evidence is mixed. Khanna and Yafeh (2005) find patterns consistent with risk sharing in prewar Japan as well as during the 1990s in 4 of 12 markets they study, including less volatility of profits among group affiliates in Taiwan.

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 generates constraints that arise from the three elements of combinatorial exhaustion: redundancy, depletion, and saturation. Redundancy of duplicated resources means 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. For business groups, overemphasizing local search means focusing on knowledge within affiliates rather than seeking ideas beyond group boundaries. Greater density of buyer–supplier ties will induce affiliates to focus attention on intragroup activities. 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 eventually creates negative marginal innovativeness as groups use up internal resources and do not replace them. Moreover, if intragroup ties tend to last longer than ties with independent vendors, because of family relationships, financial ties, and/or risk sharing, then resource depletion will be more extreme for affiliates, which will exacerbate combinatorial exhaustion.

Organizational saturation arises from limits on managerial time and attention. 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 groups, organizational saturation means that affiliates run out of capacity to seize ideas that arise from additional ties. Saturation can occur in dense groups if managers spend so much effort managing operating relationships that they lack time to follow up innovative opportunities at their partners. Moreover, organizational saturation arising from density will reinforce 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.

Together, redundancy, depletion, and saturation reflect two aspects of combinatorial exhaustion. First, redundancy and depletion reduce the stock of novel knowledge within a group (and depletion, at least, may be more pronounced for ties within groups than with independent firms, if group-based ties tend to be longer lasting), whereas saturation reduces a group's ability to take advantage of its stock of knowledge. Second, redundancy creates diminishing marginal innovative returns to density, whereas 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 will have an inverted-U impact on group innovativeness. Greater density initially provides knowledge about resources and generates trust about sharing resources among affiliates, generating combinatorial opportunities. At some point of buyer–supplier density, though, combinatorial exhaustion arises from tie redundancy, resource depletion, and organizational saturation, producing decreasing returns. Ultimately, the constraints that arise from combinatorial exhaustion become so strong that buyer–supplier density produces negative marginal returns on group innovativeness.

Hypothesis 1 (H1). *Group innovativeness first increases with the density of intragroup buyer–supplier ties and then declines after density crosses a threshold.*

3.2. Variation in Innovation Thresholds as the Institutional Environment Evolves

Business-group buyer–supplier relationships in emerging economies are embedded in dynamic contexts, including changes in market infrastructure, deregulation of industries and public enterprises, and inflow of foreign capital (Khanna and Palepu 2000b). 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, Entwisle et al. 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 exacerbates the impact of combinatorial exhaustion.

The market development of the institutional environment is the degree to which a country possesses market institutions that businesses need for commercial activity (North 1990, Khanna and Palepu 1997). At least four aspects of the institutional environment support firms' innovative activity. Capital markets offer financial support (Hoshi et al. 1991, Lundvall 1992, Almeida and Wolfenzon 2006). Labor markets facilitate access to people needed to develop and commercialize ideas (Saxenian 1994, Khanna and Palepu 1997). Commercial intermediaries such as suppliers, complementary firms, and distributors help firms identify and take advantage of 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, La Porta et al. 1999). Gaps in any of these dimensions generate institutional voids that can constrain innovative activity.

The growth of market institutions in a country will reduce the marginal innovative benefits of sharing resources via intragroup buyer–supplier ties. Firms that emphasize internal sources for innovation will miss opportunities to use resources that are increasingly available externally. Hence, the opportunity costs of local search increase as an environment becomes more market oriented, reducing both the benefits of internal knowledge and the tendency to draw on it. Belenzon and Berkovitz (2010), for instance, find few cross-citations among group affiliates 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 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; indeed, such path dependencies may be more pronounced for intragroup ties than for ties with independent firms, if family-based ownership and other forms of stickiness lead to longer lasting ties.

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. If reliance on intragroup buyer–supplier ties causes inward focus, then a group will incur innovation constraints relative to groups that have less internal focus when external opportunities increase. 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 (H2). *The greater the market development of the institutional environment in which a group operates, the lesser the net innovative benefits of intragroup buyer–supplier density.*

Samsung and Daewoo illustrate 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 take advantage of external market and technical opportunities.

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, whereas combinatorial exhaustion becomes increasingly salient as markets develop.

4. Data, Measures, and Statistical Method

4.1. Business Groups in Taiwan

Business groups are important economic actors in Taiwan and played key roles as innovators as Taiwan became an important global source of technical advance in several industries (Hobday 1995, Ernst 1998). Chung and Mahmood (2006) report that the top 100 groups accounted for as much as 85% of the country's gross domestic product (GDP) in 2002, up from 28% in 1980. Business activity in Taiwan involves multiple industries, including electronic devices, industrial equipment, chemicals, plastics, construction, wholesale trade, data processing, food manufacturing, financial services, real estate, and life sciences (Chung 2001). 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; 8 of the top 10 recipients were business-group affiliates (Taiwan Semiconductor Manufacturing Company (TSMC), United Microelectronics Corporation (UMC), Hon Hai, Walsin Lihua, Acer, Advanced

Semiconductor, Umax, and Giant). Many 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 was substantial group-level patenting variation within industries.

Taiwan offers a rich context in which to examine how intragroup operating linkages affect group innovativeness at different levels of market development. The groups have extensive variety in the structure of buyer–supplier ties. Moreover, Taiwan offers clear definitions of group membership for identifying ties.[2] 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 market infrastructure that occurred between the 1970s and the late 1990s.

4.2. Data Sources

The Business Groups in Taiwan (BGT) directory, compiled by the China Credit Information Service (CCIS) in Tapei, provided our core data. The CCIS, an affiliate of Standard & Poor's, is the most prestigious credit-checking agency in Taiwan, and the BGT offers the most comprehensive source of reliable business-group data. The 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 with principal firms registered in Taiwan, reporting that the top 100 groups contributed 42% of national GDP in the 1990s. BGT records supply links, interlocking directorates, and cross-shareholdings. Several studies use BGT data (Claessens et al. 2000, Luo and Chung 2005), although none has translated intragroup ties.[3]

BGT provides information for five years: 1981, 1986, 1990, 1994, and 1998. Our initial sample included 592 group-year cases (267 groups, with 3,500 unique affiliates). Manufacturing affiliates account for about three-quarters of total group revenue, with the balance from the service sector. We included service firms in the measures of ties because service activities can contribute knowledge for innovation, such as information about customer preferences. After excluding cases with missing data, the final sample included 578 group-year observations (263 groups).

4.3. Variables and Methods

4.3.1. Dependent Variable. We use Taiwan patent data to measure innovative activity. Scholars commonly use patents to compare innovative activity across firms while recognizing that patents are imperfect measures (Griliches 1990, Schilling and Phelps 2007). Patents record innovative activity as much as or more than they do innovative success. Moreover, patents record only portions of firms' innovative activities and do not suit some types of innovative activity, whether in different technological conditions or because of differences in strategy across firms, industries, countries, and time. Patents 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 controls for key sources of heterogeneity 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 patent applications. Because patenting and operating abroad is more expensive than is domestic patenting, focusing on U.S. or other foreign patents would bias the analyses toward larger firms.[4]

We collected information about patenting by business-group affiliates from online databases of the Intellectual Property Office (http://www.patent.org.tw), which cover all patents applications that were granted in Taiwan since 1950 (i.e., we identified the application dates of subsequently granted patents). 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

[2] Khanna and Rivkin (2006) suggest that group boundaries are ambiguous in some countries, such as Chile, and Saxonhouse (1993) notes that governmental encouragement of intergroup activities plus a lack of family solidarity obscures *keiretsu* boundaries in Japan. In Taiwan, by contrast, regional kinship and patrilineal family connections delineate group boundaries (Numazaki 1986). Groups in Taiwan lie at a midpoint of Granovetter's (1995) continuum of power centralization, exerting less hierarchical control than Korean *chaebol* but more than Japanese *keiretsu* (Orru et al. 1991). Coordination mechanisms inside Taiwanese groups tend to involve relationships among leaders rather than strong control by a group president (Chang and Hong 2000).

[3] BGT includes figures that depict intragroup 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 coauthor read *Fan-ti-zi* fluently and led the translation; translators read the volumes, identified groups and affiliates, and transcribed financial information.

[4] Taiwan established its patent system in 1945. Taiwanese examiners follow standards for patentable inventions similar to the United States (Yang 2008). In accord with the agreement on Trade-Related Aspects of Intellectual Property Rights of the World Trade Organization, Taiwan restructured its patent system in 1994, extending patent life from 15 to 20 years.

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 10 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. We lagged the focal independent variables and control variables because patent applications typically correspond to activity preceding the application. 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 intragroup buyer–supplier density and market development. The later periods (especially 1998) include more groups because 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.

4.3.2. Focal Covariates: Buyer–Supplier Density and Market Development. The key covariates are buyer-supplier density and market development. *Buyer–supplier density* measures intragroup 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 predicted nonmonotonic impact on innovativeness.

Market development used four aspects of the national innovation infrastructure, based on the discussions of institutional voids that we cited earlier: capital markets, commercial intermediaries, labor markets, and legal protection. The four dimensions are relevant to intragroup buyer–supplier ties, whether by shaping the availability of external suppliers and/or a group's willingness to exchange with independent suppliers. We used the four elements to measure market development of the institutional environment in Taiwan, measuring each of the items in each period of the study. *Stock market trading volume* assessed capital

Table 1 **Business Groups in Taiwan, 1981–1998: Affiliates, Patent Applications, Buyer–Supplier Density, and Market Development**

Base year	Number of business groups	Number of affiliates (mean affiliates per group)	Patent applications by business groups: Two-year period after base year (mean applications per group)	Mean intragroup buyer-supplier density	Market development of the institutional environment: Relative magnitude[a]	Capital markets: Stock market trading volume, $US mln (multiplier)	Commercial intermediaries: Number of for-profit organizations (multiplier)	External labor market: Number of university graduates (multiplier)	Legal protection: Number of points in the *Global Competitiveness Report* (multiplier)[b]
1981	100	716 (7.2)	162 (1.6)	0.22	1.0	13.2 (1.0)	608,658 (1.0)	32,102 (1.0)	3.3 (1.0)
1986	97	749 (7.7)	143 (1.5)	0.17	1.7	39.0 (3.0)	741,887 (1.2)	39,065 (1.2)	4.3 (1.3)
1990	101	819 (8.1)	118 (1.2)	0.13	5.5	232.3 (17.6)	863,664 (1.4)	49,399 (1.5)	5.3 (1.6)
1994	115	1,116 (9.7)	780 (6.8)	0.09	8.1	351.2 (26.6)	975,549 (1.6)	68,274 (2.1)	6.4 (1.9)
1998	179	1,938 (10.8)	1,359 (7.6)	0.07	13.2	612.0 (46.4)	1,034,328 (1.7)	87,421 (2.7)	7.3 (2.2)
Total	592	5,339 (9.0)	2,562 (4.3)	0.19	7.0				

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

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 *Global Competitiveness Report* (World Economic Forum 1986, 1990, 1994, 1998) 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 element of the environment grew substantially during the period, resulting in a nonlinear increase in the market development measure.[5]

We created an interaction variable to test H2: *BSD-squared* × *Market* is buyer–supplier density times market development. This produces Equation (1):

$$\begin{aligned} &\mathit{Innovativeness}_{i,t} \\ &\quad = \beta_1 D_{i,t-1} + \beta_2 D^2_{i,t-1} + \beta_3 M_{t-1} + \beta_4 M_{t-1} * D^2_{i,t-1} \\ &\qquad + \gamma_1 X_{i,t-1} + \gamma_2 \mathit{Year}, \end{aligned} \tag{1}$$

where D denotes density, M denotes market development, X is a vector of other group-level influences, and *Year* is a set of time dummies. The subscript i denotes groups, and the subscript $t-1$ denotes a one-period lag relative to the patenting during the two-year period$_t$.

H1 predicts β_1 to be positive and β_2 to be negative, and H2 predicts β_4 to be negative. We have no prediction for β_3; although overall innovativeness among all business groups increases as market development advances, other factors might explain the innovativeness of any focal group in a given time. We can calculate the point at which density generates the maximum impact on innovation ($D_{\max}$) in Equation (1) by calculating the partial derivative of *Innovativeness* with respect to D. This produces

$$D_{\max} = \beta_1 / -2(\beta_2 + \beta_4 M). \tag{2}$$

Equation (2) has the nice property that, given predicted signs ($\beta_1 > 0$,β_2 and $\beta_4 < 0$), $D_{\max}$ increases in β_1 (combinatorial opportunity) while decreasing in β_2 (main effect of combinatorial exhaustion) and in β_4 (market-varying combinatorial exhaustion). Moreover, $D_{\max}$ 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 the activities of multiple groups, 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.

4.3.3. Control Variables. Several time-varying measures address other influences on patenting. Two variables assess elements of intragroup structure. *Group equity density* denotes the proportion of affiliates with cross-shareholdings, which might facilitate innovative activity by supporting internal capital markets (Chang and Hong 2000, Belenzon and Berkovitz 2010) or could constrain innovation if controlling families use cross-shareholding to extract resources or if equity ties protect inefficient affiliates (Morck and Yeung 2004). *Group director density* might enhance information flow (Useem 1984, Keister 1998) or reduce innovativeness by focusing efforts on current activities (Morck and Yeung 2004). We also measured aggregate tie density (mean of equity, investment, and buyer-supplier ties), finding insignificant results.

Other variables assess group-level influences on innovativeness. *Group assets* (billions of new Taiwanese dollars) measured size. *International linkages* is a factor loading based on the number of links that affiliates of each group had formed with actors outside Taiwan (BGT as source), including international joint ventures, licensing, acquisitions, and foreign direct investment outside Taiwan; the linkages might substitute for internal buyer–supplier ties as sources of innovative ideas. *Group industry concentration* records the industry-weighted average of the five-firm concentration ratio, to assess competitive pressures. *Group diversification* uses an entropy calculation (Palepu 1985) based on two- and four-digit Taiwan Standard Industrial Classification (SIC) codes.

[5] We focused on two issues when considering measures of market development: first, we wanted a multidimensional measure reflecting aspects of the institutional environment that prior work suggests are relevant for innovative activity; second, we needed items that were available during the study period. Several multidimensional approaches are available only for recent years, such as measures using the Economist Intelligence Unit (e.g., Chakrabarti et al. 2011), Standard & Poor's (e.g., Khanna et al. 2004), the World Governance Indicators project, and the World Bank's "Doing Business" data. The items we selected were both conceptually appropriate and available in relevant time series. We found high correlations (ranging from 0.95 to 0.99) when we compared the market development measure to commercial and technical development (number of retailers in Taiwan and number of firms in Hsinchu Science Industrial Park); political risk (POLCONIII: Henisz 2007); economic development (total and per capita GDP); and legal protection (counterfeiting disposition and number of counterfeit cases). The stock market trading volume item within our market development measure had strong correlations (from 0.85 to 0.98) with measures of capital market development in the *Global Competitiveness Report*, including venture capital availability, cost of capital, credit flow, and local capital market access.

Group presample patents controls for endogeneity from innovative capability, recording the number of patents that a group received prior to 1981 (Blundell et al. 1999). *Electronics* is a 0-1 variable that denotes groups in which the largest firm was an electronics company (16% of the groups, which produced 89% of the patents in the sample). *Group industry R&D* reports the industry-mean R&D intensity of the group's affiliates. *Group industry patenting propensity* measures the degree to which affiliates' industries use patents to protect intellectual property, using industry-specific measures in a U.S. survey by Cohen et al. (2004). *Internal sales* records the degree to which a group relied on vertically integrated sales to affiliated firms, which might drive resource depletion. *Change in sales* denotes sales growth, to assess whether growing groups are more innovative. *Group age* records years since founding of the first affiliate; older groups might 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 assesses whether redundancy reflects depletion as buyer–supplier relationships age and exhaust novel opportunities. Finally, *Year* dummies denote each panel to address temporal effects other than market development.

We examined correlations to assess independence among covariates. Market development has negative correlations with buyer–supplier density ($r = -0.31$) and industry concentration ($r = -0.48$), and diversification has a 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). 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 of the variables in the reported analysis.

4.3.4. Qualitative Assessment of the Mechanisms and Measures. We interviewed 10 business-group executives and 6 innovation scholars to assess whether the mechanisms concerning combinatorial opportunities, combinatorial exhaustion, and market development that underlie our logic tend to occur widely in groups. We used our social networks and contacts to obtain interviews with senior executives from business groups of mixed age and size in traditional (chemicals, plastics, retail, and textiles) and high-tech (semiconductor and electronics) sectors. In addition, we interviewed innovation scholars with experience in Taiwan to assess the quality of our market development measure and the representativeness of the examples. The following quote from an interview with an innovation scholar highlights issues about knowledge sharing, trust, and the role of internal networks.

Table 2 Summary Statistics

Variables	Mean	SD	Min	Max
1 *Group patent applications*	4.4	40.8	0	850
2 *BSD*: *Buyer–supplier density*	0.19	0.23	0	1
3 *Market*: *Market development*	7.0	4.8	1	13.2
4 *Group director density*	0.37	0.3	0	1
5 *Group equity density*	0.25	0.2	0	1
6 *Group assets*	35.6	90.9	0.24	1,008
7 *Group international linkages*	0.15	0.24	0	1.67
8 *Group industry concentration*	0.21	0.15	0.002	0.83
9 *Group diversification*	0.3	0.2	0	0.85
10 *Group presample patents*	0.31	1.95	0	19.8
11 *Group electronics sector*	0.16	0.37	0	1
12 *Group industry R&D*	1.95	1.7	0	6.94
13 *Group internal sales share*	5.28	3.36	0	32.5
14 *Group change in sales*	−16.8	583	−100	246.8
15 *Group age*	29	11.2	4	80
16 *Group industry patenting*	15.1	8.6	0	31.6
17 *Group buyer–supplier tie age*	2.35	0.98	0	9.25
18 *Tie industry heterogeneity*	0.76	0.15	0	1

Note. $n = 578$.

> [T]raditionally Taiwan SMEs [small and medium enterprises] tend not to share knowledge for companies outside a subset of its strategic network [group] due to their limited resources/capabilities and the tacitness of the source of competitive advantage. [...] Trust has been a concern for knowledge sharing among Taiwan SMEs. Again, the limited resources/capabilities prohibit trust among SMEs. That is why sometimes institutional intermediaries [such as their internal supply networks] play an important role in facilitating knowledge sharing among them.

The interviews gave us confidence in the mechanisms and measures. The executives noted that combining resources via intragroup buyer–supplier ties is a source of innovative activity for many groups in Taiwan, complementing other sources for innovation such as international ties and operations, links with external suppliers and research institutes, and relationships with customers. They noted that intragroup ties helped create trust and provide knowledge about tacit information while they also highlighted limits to these mechanisms that arose if groups overemphasized internal activities. The respondents stressed the growing availability of external sources of innovation as the Taiwanese environment becomes increasingly market oriented, mentioning more robust commercial infrastructure within the country and across the world, availability of skilled technical personnel and research institutes, access to domestic and international sources of capital, and reliability of the legal system. We believe that intragroup combinatorial opportunity and exhaustion are relevant mechanisms for shaping groups' innovative activity at different stages of market development, though not the only factors that influence innovation.

4.3.5. Zero-Inflated Negative Binomial Regression. The count nature of our dependent variable (number of patents) together with overdispersion of values of the variable suggests negative binomial regression (Hausman et al. 1984). Because the dependent variable includes many zeros (a quarter of groups patented during the period), we used zero-inflated negative binomial (ZINB) regression. ZINB separates two regimes. In regime 1 ("inflation"), the outcome is always zero (groups that never patent). In regime 2 ("count"), the negative binomial process applies (groups with positive counts in some years). Examining only groups that patented would risk sample selection bias. Greene (2003, pp. 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

5.1. Hypothesis Tests

Table 3 reports the results. Model 1 contains the controls; subsequent models test the hypotheses. The *change in LLR* X^2 statistics show improved explanatory power versus nested models.

Panel B reports 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 included inflation covariates that reflect the technological emphasis of a group's businesses (group industry R&D, group industry patenting propensity, electronics sector, group presample patents); competitive conditions (group industry concentration); other intragroup structural linkages (director density, equity density); and group characteristics that might affect whether groups 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, presample patents, sales growth, and industry patenting. The results were similar with alternative specifications.

Panel A reports influences on how many patents groups filed in a two-year window. The panel adds year dummies to ensure that any market development effects do not simply reflect the passage of time and includes the other two measures of intragroup density as well as most variables from the inflation matrix, including variables that we use in subsequent checks of causal mechanisms. The econometric literature on ZINB models is still evolving, but some econometricians suggest that the count panel should omit some of the controls that appear in the inflation panel, similar to the practice in two-stage selection models. Panel A omitted four variables that appeared in Panel B: group change in sales, assets, industry patenting, and diversification. The first three controls had significant impact in the inflation panel but little or no impact when we added them to the count analysis (any influence appears to have been picked up by correlated controls such as group tie age and group presample patents), but diversification was not significant in either panel (we included diversification to ensure that variety in groups' industries was not driving the results). This approach also preserves degrees of freedom in Panel A, which had fewer cases than Panel B after eliminating those with zero patents. Model 1 shows that patent incidence increases with presample patents and electronics sector while decreasing with director density, industry concentration, and buyer–supplier tie age; the results are similar in subsequent models. We found robust results of the predicted effects when we varied the control variables.

The results in Models 2 and 3 of Panel A 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. Because the model fit improves significantly from Model 2 to Model 3, as indicated by the significance of the *change in LLR* X^2 statistic, indicates that the interaction has a meaningful influence on patenting activity; the impact varies based on levels of market development, as Figure 1 depicts.[6] The

[6] Recent econometric practice highlights sensitivities to interpreting the coefficients on interactions in nonlinear models (Zelner 2009), recommending graphical analysis to assess interactions at different levels of variables. Formal graphical tests are not available for ZINB. Therefore, we approximated our core analysis by adapting Zelner and Blanchette's (2009) "intgph" software for Stata (http://ideas.repec.org/c/boc/bocode/s457049.html, accessed February 15, 2011) to undertake basic negative binomial analysis of the nonzero patent counts in Panel A of our data. We

Table 3 **Zero Inflated Negative Binomial (ZINB) Estimates of Influences on Business-Group Innovativeness**

	1. Coef.	s.e.	2. Coef.	s.e.	3. Coef.	s.e.
Panel A (count): No. of patent applications (positive coefficient = more patent applications by a group in a given period)						
BSD: *Buyer–supplier density* (H1+)			6.063	2.819**	8.589	3.218***
BSD-squared (H1−)			−9.551	4.657**	−9.111	5.322**
Market × *BSD-squared* (H2−)					−1.034	0.342***
Market: *Market development*	−0.025	0.052	−0.014	0.057	0.010	0.067
Group director density	−1.380	0.699**	−1.306	0.819	−1.318	0.871
Group equity density	0.523	1.152	0.477	1.160	0.373	1.246
Group international linkages	−0.717	0.559	−0.663	0.574	−0.784	0.538
Group industry concentration	−2.357	1.240*	−2.316	1.313*	−2.419	1.425*
Group presample patents	0.175	0.032***	0.177	0.035***	0.176	0.035***
Group electronics sector	3.161	0.470***	3.613	0.667***	3.717	0.629***
Group industry R&D	0.117	0.134	0.113	0.143	0.089	0.140
Group internal sales share	0.012	0.039	0.026	0.038	0.029	0.037
Group age	−0.018	0.020	−0.005	0.024	−0.006	0.023
Group buyer–supplier tie age	−0.436	0.146***	−0.445	0.148***	−0.443	0.145***
Year: *1990* (vs. 1981 and 1986)	0.989	0.701	0.995	0.797	0.888	0.899
Year: *1994* (vs. 1981 and 1986)	0.731	0.472	0.751	0.513	0.890	0.591
Year: *1998* (vs. 1981 and 1986)	1.010	0.476**	0.927	0.487*	0.983	0.538*
Constant	2.005	1.018**	0.957	1.311	0.709	1.381
Panel B (inflation): 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
Market: *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 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 presample 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 age	0.024	0.028	0.029	0.031	0.029	0.032
Group buyer–supplier tie age	0.066	0.346	0.078	0.347	0.084	0.352
Group assets	−0.075	0.021***	−0.076	0.023***	−0.077	0.024***
Group change in sales	−0.014	0.007**	−0.013	0.007**	−0.013	0.007**
Group industry patenting	−0.125	0.053**	−0.118	0.055**	−0.119	0.056**
Group diversification	−1.656	1.436	−1.083	1.604	−1.201	1.621
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)**

Notes. $n = 578$ group-years (263 groups), 106 nonzero patent observations; robust standard errors (s.e.). ZINB estimates with simple s.e. had highly significant Vuoung statistics (ZINB with robust s.e. does not calculate a Vuong statistic), suggesting that standard negative binomial analysis is not appropriate. The year dummies omitted two periods because the *market development* variable is ordinal in time.

Sensitivity analyses: The H1 and H2 results in Model 3 are robust to including dropping or adding control variables and year dummies in Panels A and B; dropping large patentees, varying patent windows, restricting the sample to 100 groups per period, and omitting entrants to the sample.

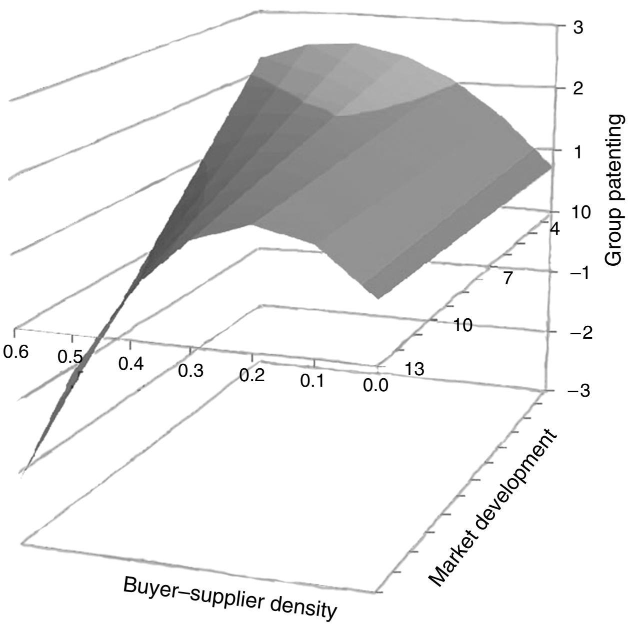
$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$ (one-tailed tests for hypotheses; two-tailed tests for control variables).

main effect of market development is insignificant in both models, showing that its impact depends on a group's characteristics rather than affecting all groups homogeneously.

found the expected decreasing marginal benefit of density as market development increased, with significantly positive (negative) impact at low (high) levels of market development ($p < 0.05$). Overall, the combination of improved statistical fit when adding the interaction term, the relevant shape of the three-dimensional surface in Figure 1, and the significant decrease in the marginal benefit of density as market development increases provides confidence in the estimated relationship.

Figure 1 uses the results from Model 3 to depict the effect of buyer–supplier density on patenting as market development varies. The figure uses the full range of market development (from 1.0 to 13.2), together with values of density from 0 to 0.60 (about two standard deviations above mean density of 0.19). Patenting has a strong inverted-U relationship with density, with lower benefits at higher levels of market development. Low market development (1.0) is at the rear of the figure; the benefits peak with density equal to 0.42. At the front of the figure, where market development is high (13.2), maximum benefit comes much

Figure 1 Combined Impact of Buyer–Supplier Density and Market Development on Group Patenting



Notes. This figure 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 equal to 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 equal to 0.19. Higher values of density produce a rapidly declining impact on patenting when market development is high.

earlier (density equal to 0.19). Higher values of density produce a rapidly declining impact on patenting when market development is high. The magnitude is meaningful: With market development equal to 1.0 (13.2), the difference between maximum and minimum impact on patenting for density with range from one standard deviation above and below mean density is 42% (27%) of the overall mean patenting rate.

5.2. Sensitivity Analysis

The core results were robust to multiple sensitivity analyses. First, we found consistent results with alternative measures of market development, including omitting the capital markets item (which had the largest multiplier) and using only the capital market item as the variable for market development. Second, similar results held when Panel A distinguished between related and unrelated diversification, added number of affiliates, or added period of first group entry. Third, more parsimonious analysis found similar results with a subsample that included only groups that were in the data at the beginning of the study period (about half the group-years). Fourth, the results were similar when we omitted the two most frequent patentees (UMC and TSMC). Fifth, we found no evidence of serial autocorrelation, based on the Woolridge test for autocorrelation in panel data. Sixth, probit regression found that buyer-supplier density had a significant inverted-U impact on the likelihood that a group would be a patentee.

We assessed two sets of descriptive patterns in the data. First, we examined the patenting/employee ratio (PER) in high- and low-density groups in the different periods to see whether lower density groups appeared to gain innovative productivity advantages as market development increased; we found that the PER in high-density groups started at a somewhat higher level than the PER in low-density groups during the 1980s but remained flat over time, even as technological opportunities increased in Taiwan, whereas the PER in low-density groups increased sharply over time, substantially surpassing the PER of high-density groups during the 1990s. Second, we plotted density versus patents using localized linear regression (lowess in Stata), which is a form of nonparametric regression where each point along the regression curve is produced by a weighted least squares regression of nearby points, thereby allowing the data to determine the functional shape of a relationship (Robinson 1988, Altman 1992). The Lowess curves showed inverted-U relationships between buyer–supplier density and patenting in four panels (1981, 1986, 1990, 1998), plus declining benefits of density after an initial high plateau in 1994. As expected, the point of maximum benefit from density tended to shift toward smaller values as market development increased.

A question concerns the patent inflation process, which might be uniform or nonuniform across groups and/or time. If patent inflation is uniform across groups, then the year dummies in the analysis will address nonuniformity across time. If patent inflation varies across both time and groups, however, then nonstationary trends (unit root processes) exist. In our setting, nonstationarity could arise if groups' knowledge and patenting capabilities unrelated to technological factors differ across groups and also accumulate over time within groups. We considered six unit root tests for panel data but the options faced limits in our context: four tests (Levin–Lin–Chu, Harris–Tzavalis, Breitung, and Hadri Lagrange multiplier) require balanced panel data, but the underlying data in our context are unbalanced; the Im–Pesaran–Shin test requires no gaps in individual panel series, unlike our sample; Fisher-type tests assume T tends to infinity, which failed because of the limited number of time series in our study (five periods) and because of the panel-constant value for market development (i.e., one observation for each period). As an approach that was consistent with our data structure, therefore, we estimated regressions accounting for nonstationarity by using generalized estimating equations (GEE) population-averaged models for panel data with unstructured and nonstationary error structures for dependent variables with a count distribution (xtreg using GEE for Poisson in Stata 11); the GEE analysis was consistent with the hypotheses.

Although the results are robust, the relationship between network density and innovation could be bidirectional. 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, p. 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." Table 4 reports tests with eight factors that reflect mechanisms that underlie combinatorial opportunity and exhaustion.

Five mechanisms enhance combinatorial opportunities from greater density. First, buyer–supplier tie age indicates how long people have opportunities to work together. Although the main effect of tie age leads to increased redundancy (Table 3), tie age had a countervailing positive influence in combination with density ($p < 0.01$), potentially by increasing knowledge and trust and so extending the point of maximum density before redundancy sets in. Second, tie industry heterogeneity (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 (Rodan and Galunic 2004) and so generate combinatorial opportunities; density imposed fewer constraints on groups with buyers and suppliers in heterogeneous industries ($p < 0.01$). Third, older groups will accumulate stocks of knowledge and trust across affiliates, thereby increasing the benefits of operating density; density imposed fewer constraints on older groups ($p < 0.01$). Fourth, external linkages offer access to knowledge, reducing the impact of resource depletion; density provided greater benefits for groups with international linkages ($p < 0.05$). Fifth, cross-equity tie density generates somewhat greater protection for mutual exchanges; the interaction of buyer–supplier density and equity density had a moderately significant positive impact on innovativeness ($p < 0.10$).

Three other mechanisms exacerbate combinatorial exhaustion through resource depletion arising from local search. First, the electronics sector as an industry with high R&D needs requires extensive external knowledge, so groups will pay a high price from internal resource depletion if density creates local search tendencies; density provided fewer benefits

Table 4 **ZINB Estimates of How Combinatorial Opportunity (CO) and Combinatorial Exhaustion (CE) Mechanisms Shape the Impact of Density**

	1. *Buyer–supplier age*	2. *Tie industry heterogeneity*	3. *Group age*	4. *International linkages*	5. *Equity density*	6. *Electronics*	7. *Group industry R&D*	8. *Internal sales share*
	Panel A: No. of patent applications (positive coefficient = more patent applications by a group in a given period)[a]							
Buyer–supplier density (BSD)	3.91*	5.07**	5.65**	7.34***	7.35***	5.53**	−3.99	3.41*
BSD-squared	−37.89***	−27.52***	−26.80***	−18.59***	−19.73***	−8.42**	41.94**	17.53**
BSD-squared × *Mechanism*	11.79***	28.28***	0.66***	11.25**	16.30*	−13.51***	−7.70***	−4.50***
Mechanisms								
1. *Group buyer–supplier tie age*	−0.47***	−0.47***	−0.49***	−0.48***	−0.48***	−0.49***	−0.48***	−0.49***
2. *Tie industry heterogeneity*	−2.67*	−2.76*	−2.71*	−2.59*	−2.52	−2.95**	−2.23	−2.18
3. *Group age*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
4. *Group international linkages*	−0.64	−0.77	−0.78*	−0.84*	−0.75	−0.80*	−0.79*	−0.51
5. *Group equity density*	1.16	0.99	0.69	0.75	−0.01	1.38	2.11**	1.36
6. *Group electronics sector*	3.37***	3.47***	3.53***	3.40***	3.47***	3.45***	3.17***	3.40***
7. *Group industry R&D*	−0.02	−0.03	−0.04	−0.02	−0.06	−0.02	0.13	0.04
8. *Group internal sales share*	0.05	0.04	0.04	0.03	0.04	0.04	0.03	0.07*
Market development	−0.10	−0.04	−0.06	−0.07	−0.06	−0.04	−0.09	−0.03
Group director density	−1.39*	−1.49*	−1.15	−1.52**	−1.37*	−1.57**	−1.36*	−1.12
Group industry concentration	−2.43	−2.46*	−2.23	−2.52	−2.35	−2.29	−2.13*	−1.70
Group presample patents	0.19***	0.20***	0.20***	0.20***	0.20***	0.20***	0.19***	0.19***
Year: 1986 (*vs. 1998*)	−0.19	0.49	0.39	0.50	0.41	0.49	−0.07	0.66
Year: 1990 (*vs. 1998*)	0.05	0.62	0.46	0.45	0.63	0.50	−0.04	0.30
Year: 1994 (*vs. 1998*)	0.31	0.66	0.51	0.67	0.69	0.64	0.33	0.63
Constant	4.34**	3.56*	3.80**	3.85*	1.03*	3.75*	3.57*	2.47
Ln(a) *dispersion*	0.94***	0.95***	0.96***	0.99***		0.94***	0.86***	0.93***

[a]The analysis includes an inflation panel, equivalent to Panel B in Table 3 (variables: *market development, group buyer–supplier density, director density, equity density, assets, international linkages, industry concentration, diversification, presample patents, electronics sector, industry R&D, internal sales share, change in sales, age, industry patenting, buyer–supplier tie age, tie industry heterogeneity*, and a constant).

*$p < 0.10$; **$p < 0.05$; ***$p < 0.01$ (one-tailed tests for *BSD*, *BSD-squared*, and *BSD* × *Mechanism*; two-tailed tests for control variables).

Table 5 Fixed Effect Estimates of Impact of Buyer–Supplier Density on Affiliate-Level R&D Intensity and R&D Productivity

	1. Investment incentives: Affiliate R&D/sales intensity	s.e.	2. R&D capability: Affiliate R&D productivity[a]	s.e.
Buyer–supplier density	0.0043	0.0021**	0.0388	0.0021**
Group director density	−0.0019	0.0010*	−0.0283	0.0010***
Group equity density	0.0000	0.0010	−0.0272	0.0010***
Firm centrality	0.0023	0.0010**	0.0322	0.0010***
Ln *firm assets*	−0.0004	0.0003	0.0021	0.0003
Firm age	0.0000	0.0001	−0.0066	0.0001***
ROA	−0.0001	0.0001**	0.0012	0.0001**
Diversification: Unrelated	0.0002	0.0011	−0.0040	0.0011
Diversification: Related	−0.0003	0.0017	−0.0125	0.0017
Constant	0.0153	0.0066**	0.9467	0.0066***
σ_u, $\sigma_e(\rho)$	0.018, 0.006 (0.897)		0.096, 0.054 (0.760)	
$F(9{,}496)$	2.62***		30.88***	

Note. $n = 693$ public firms, 188 groups.
[a]Affiliate R&D productivity is based on stochastic frontier estimation of the efficiency by which a firm turns inputs (R&D expenditures) into outputs (patents).
$^{*}p < 0.10$; $^{**}p < 0.05$; $^{***}p < 0.01$ (two-tailed tests).

for electronics groups ($p < 0.01$).[7] Second, similarly, groups in R&D-intensive settings gained fewer benefits from density ($p < 0.01$). Third, dense groups with high internal sales share also will be at risk of local search, owing to organizational saturation; density had less benefit for groups with high shares of internal sales ($p < 0.01$). The results of the mechanism tests help demonstrate the causal logic that underlies the predications.

We undertook sensitivity analyses 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 ($p < 0.05$). 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 informed us that citation reporting in their database did not begin until 2008, well after the study period. We then sought citation information in U.S. patent applications by the Taiwanese companies in our sample. Very few Taiwanese firms filing in the U.S. cite patents of their affiliates, however, because the citations reference U.S.-granted patents and typically only the core member of a group files patents in the United States (in a very few cases, two members). Hence, most citations to a firm's group are self-citations because few group members have U.S. patents that their affiliates can cite. 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)). Although this incidence is too low to draw conclusions about knowledge flows, all 483 citations involved affiliates with which the citing firms had buyer–supplier ties, consistent with our logic.

Finally, we investigated whether buyer–supplier density increased incentives to invest in innovative activity and/or productivity of a given investment. Table 5 uses R&D data from public affiliates (693 firms in 188 groups). We assessed how group-level buyer-supplier density affected (1) investment incentives, based on affiliate R&D/Sales intensity; and (2) R&D capability, measured using stochastic frontier estimation of the efficiency by which an affiliate turns inputs (R&D expenditures) into outputs (patents). The fixed effects estimates control time-constant industry and group effects (the results were similar with time-varying group variables). Affiliates of groups with higher buyer–supplier density had higher R&D intensity and higher R&D productivity ($p < 0.05$).

6. Discussion and Conclusion

The study demonstrates how differences in business groups' internal structure and changes in external environments jointly shape groups' roles as innovators. The analysis reflects the argument that the density of buyer–supplier ties creates combinatorial

[7] Indeed, when we focus the base analysis only on groups in the electronics sector, initial buyer–supplier density does not contribute to patenting, again suggesting the high opportunity costs of local search in a sector where external technology—often technology beyond the home market—is important.

opportunities that contribute to innovativeness as well as combinatorial exhaustion that deflates innovativeness, with the constraints increasing as a group's home environment adopts market-oriented institutions. The results also provide insights about mechanisms that underlie combinatorial opportunities and exhaustion.

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 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 complement Belenzon and Berkovitz's (2010) study of innovation by Europe-based groups; they found few internal cross-citations in this developed market setting, reinforcing the point that incentives for internal knowledge sourcing may be low when markets offer external innovation infrastructure.

Nonetheless, the study could not measure recombination directly. Hence, other mechanisms might generate at least part of the observed patterns in innovative activity. One possibility is that frequent interactions within dense buyer–supplier ties lead to trust among actors, as we argue, but that the trust simply provides greater reliability in managing commercial relationships rather than encouraging actors to exchange and combine resources across the buyer–supplier boundaries. Such reliability in the commercial value chain could lead to greater willingness of any affiliate to invest in its own innovative activity, whether or not it relied on combining resources from other affiliates, because it would expect greater success of ultimate commercialization. In turn, at some point of density, reliability might breed complacency that locks affiliates into their current activities and reduces their innovative tendencies.

The study has other limits that suggest research. First, we focus on one country that has undergone only a partial transition to market orientation. Second, the data limit the degree to which we can assess endogeneity. Third, one could consider how other aspects of group structure (e.g., equity and director density) might affect group innovativeness via other mechanisms as markets evolve. Fourth, in addition to formal linkages, one could incorporate informal intragroup structures such as relational ties. Fifth, it would be valuable to examine other aspects of innovativeness, such as product introduction; group structure might affect incentives to use patents as opposed to other forms of protecting new technology, so a group with more linkages might have greater transactional complexity and rely more on contracts and/or relationships with its affiliates rather than patents. Sixth, studies could develop alternative measures of market development, which is an evolving concept within and across countries.

The work suggests two other extensions of business-group studies. First, research could explore the mechanisms that underlie combinatorial opportunities and exhaustion, such as comparing the role of redundancy and depletion in reducing internal opportunities to that of saturation in reducing the ability to take advantage of internal opportunities and/or search externally. Second, studies could consider how changes in different elements of the market environment of a business-group influence changes in buyer–supplier density and other elements of group structure. We would expect some groups to change their structure to reflect the changes in the environment by cutting existing ties and/or adding new affiliates that do not have ties, and other changes will happen via the entry of new groups that reflect the new environment.

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 multibusiness firms are sometimes more and other times less innovative than are independent firms (Nelson 1959, Link and Long 1981). An extrapolation of our argument is that intraunit operating density within multibusiness firms may initially create innovative benefits but ultimately generate 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 et al. 2007). Our study of business groups could be extended to examine how network structure and changes in external environments might 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.

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