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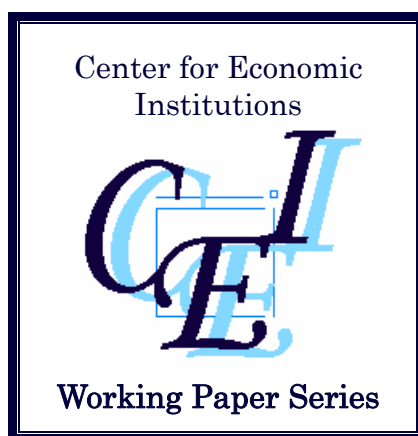
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THE STRUCTURE OF INTRA-GROUP TIES: INNOVATION IN TAIWANESE BUSINESS GROUPS

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ABSTRACT

Business groups are a network form of multi-business firm that play central economic and technological roles in many emerging economies. We draw from the technology studies literature, complemented by concepts from studies of organizational networks, to investigate how equity, director, and operating ties between firms within groups shape their innovation opportunities. Technology studies suggest that such ties create both opportunities and constraints that influence innovative activity by affiliates and, in aggregate, by a group as a whole – opportunities that arise from access to information, people, money, and other resources, but also constraints that arise from entrenched relationships among different actors. The network literature, in turn, suggests that centrality and density of ties between firms within a group will shape the benefits and constraints. We find that the overall density and individual centrality of the three types of ties affects affiliate and group innovativeness among about 2,000 firms within 263 business groups in Taiwan between 1982 and 2000. Groups that offer affiliates focused access to financial resources and operating knowledge, coupled with autonomy from intra-group competition and strategic interference, often generate fertile opportunities for innovative activity by some of their members. The results also offer implications for multi-business firm innovativeness.

Business groups are a common type of multi-business firm in developing economies, frequently dominating a substantial fraction of a country's productive assets and strongly influencing technological development in their countries. Business groups were common in Europe, North America, and Japan during the 19th and much of the 20th centuries (Caves and Uekusa 1976; Encoua and Jacquemin 1982). Groups are now ubiquitous in contemporary developing economies, where they take names such as grupos economicos in Latin America, business houses in India, chaebols in South Korea, family holdings in Turkey, and mining houses in South Africa (Amsden and Hikino 1994; Ghemawat and Khanna 1998; Kock and Guillen 2001). Although groups vary across countries, the common definition is that business groups are sets of legally independent companies, with activities in multiple industries, that are linked as affiliates through persistent informal links and formal relationships such as equity, director, and operating ties (Hamilton and Biggart 1988; Khanna and Rivkin 2001). In turn, several scholars have defined groups as a form of network organization, with variation in overall group density and affiliate centrality based on ties among firms within a group (Powell and Smith-Doerr 1994; Granovetter 1995). Business groups have several features that help them thrive in emerging economies, including their role in marshalling and sharing commercial resources when market infrastructures are weak (Khanna and Palepu 1997), as well as their ability to use political connections to support commercial activity (Fisman 2001; Siegel 2005).

Although we are beginning to understand why business groups exist, we have only limited understanding of how groups affect technological dynamism in emerging economies. Business groups have an ambiguous place in theories of technological development, with the potential to either facilitate or hinder innovation. On the one hand, groups provide scale and scope that may contribute to innovative activity by their affiliated firms (Chang and Hong 2000). Economic theory suggests that developing countries can grow by acquiring technologies from more advanced countries (Gerschenkron 1962; Abramovitz 1986). Groups potentially play important roles in such borrowing, because their ability to share externally acquired technology among affiliates that operate in multiple industries may facilitate technological catch-up (Amsden and Hikino 1994). On the other hand, group control of important commercial and political resources throughout an economy can induce political stagnation, create entry

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barriers for innovative new firms, and may impede technological dynamism (Morck and Yeung 2004; Mahmood and Mitchell 2004). A paradox of economic growth, moreover, is that the faster a developing country catches up with those it borrows technologies from, the sooner the developing country needs to shift from being primarily a technology importer to becoming a technology creator (Lucas 1988).

The role of business groups as technology importers and creators in many emerging market economies implies that whether the countries can sustain economic dynamism depends on whether their groups facilitate or inhibit innovative activity of their member firms (Kim 1997). In turn, because of the importance of innovation to economic and social development, it is critical to understand the forces that shape the innovative activities within groups. This question is particularly salient because there is wide variation in innovativeness across different groups and among group affiliates, even in similar industrial and institutional contexts. Patent and R&D investment statistics reveal high variation in innovative activity across different groups (e.g., Samsung vs. Hyundai in Korea, Hon Hai vs. Kinpo in Taiwan), as well as across firms within groups (e.g., Samsung Display Devices vs. Samsung Electro-Mechanics).

The technology studies literature offers a base for examining mechanisms by which groups might affect innovative activity of member firms, complemented by concepts from studies of organizational networks. The literature on multi-business firm innovation identifies potential advantages for group affiliates stemming from access to shared resources that might contribute to innovative activity, but has found mixed results when examining the innovativeness of diversified firms in established market economies. In turn, though, implications of the network studies literature suggest that group density and affiliate centrality of resource ties, rather than simply the potential availability of shared resources, will influence the incentives and the abilities of individual affiliates to innovate and, in aggregate, the overall innovativeness of a group. Although network studies typically examine activities and performance of actors within single networks, the centrality and density concepts are relevant for examining activities across multiple networks as we do here.

Three types of formal inter-firm ties, involving different types of resources, are key features of business groups (Gerlach 1992; Keister 2001): equity, director, and operating ties. Equity ties are

financial investment linkages that arise when affiliates hold ownership stakes in each other through cross-shareholdings. Director ties are strategic linkages that arise when an individual sits on the board of multiple affiliates. Operating ties are functional linkages that arise when affiliates within a group engage in buyer-supplier relations. The business group literature suggests that the ties sometimes act as conduits for sharing financial, strategic, and operating resources that lead to superior financial performance in group affiliates (Keister 1998; Chang and Hong 2000), but is silent regarding the effects of ties on affiliates' innovative activity. We will assess how the content and structure of these three types of ties influences business group innovative activity, by examining affiliate-level and aggregate group patenting within 263 business groups in Taiwan between 1981 and 2000. The proliferation and heterogeneity of equity, operating, and director ties within business groups in Taiwan, coupled with highly varied innovativeness of the groups and their affiliates, makes this setting particularly interesting.

The business group, technology studies, and network literatures each provides insights, but no single body of work explains why some affiliates and some groups are more innovative than others. Because existing theory generates conflicting arguments, particularly in the context of multiple types of ties that involve differing resources, we will treat this as an exploratory investigation rather than state formal hypotheses. The results highlight the innovative impact of different configurations of different types of ties within business groups and, more generally, within multi-business firms.

BUSINESS GROUPS AND INNOVATIVE ACTIVITY

Business groups are a type of multi-business firm that combines elements of conglomerate holding companies and multidivisional corporations, creating what some theorists view as a network form of organization (Nohria and Eccles 1992; Podolny and Page 1998). Group affiliates coordinate their activities with each other, but also are responsible to their own governance bodies of shareholders, directors, and auditors. Like conglomerates, groups provide corporate financial structures for businesses in multiple industries (Williamson 1985). Like multidivisional corporations, meanwhile, businesses within groups operate with a substantial degree of interdependence (Chandler 1997). Yet groups also differ from conglomerate and multidivisional corporations. Groups are more stable and coordinated than

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conglomerates, with founding families commonly exerting strong influence on affiliates (Hamilton and Biggart 1988), while remaining less centralized than most multidivisional firms (Granovetter 1995). Thus, business groups in developing economies function as networks of loosely coupled firms (Powell and Smith-Doerr 1994), linked by formal economic arrangements such as equity cross-holdings, director interlocks, and buyer-suppler relationships, as well as informal ties based on family, friendship, religion, language, and ethnicity (Khanna and Rivkin 2001).

Scholars argue that the business groups can substitute for weak market institutions in emerging economies (Caves and Uekusa 1976; Leff 1978; Khanna and Palepu 1997). Chang and Hong (2000) demonstrated that group affiliation often assists individual firm financial performance in Korea by allowing resource sharing among affiliates. Other studies demonstrate that groups in Chile and India can create value through product, labor, and capital market intermediation (Khanna and Palepu 2000a, 2000b).

A few studies have addressed business group innovation, often discussing potential rather than measuring outcomes. Scholars studying the diffusion of industrialization argue that groups offer business reputations and government ties that attract foreign technology providers, potentially contributing to technological advance in their countries (Amsden and Hikino 1994; Hobday 1995). Claessens, Djankov, and Lang (2000) suggest that concentrated family ownership provides long term perspectives, potentially creating a willingness to undertake R&D investments, although Morck, Stangeland, and Yeung (2000) find that Canadian firms controlled by heirs are significantly less active in R&D than comparable firms of the same age, size, and industry categories. Mahmood and Mitchell (2004) examine how group market share affects industry innovativeness in Korea and Taiwan from 1981 to 1995, showing that when groups have an intermediate market share in an industry, the mix of groups and independent firms provides both infrastructure needed to carry out innovation and access to new ideas. Chang, Chung, and Mahmood (2006) find that group affiliation in Korea and Taiwan offers greatest firm-level innovation benefits when a country has weak market-based institutional infrastructure, such as restricted capital markets and limited supply and distribution base. Even in similar institutional settings, however, groups and the firms within them differ in terms of innovative activity. Why the differences exist remains a puzzle.

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Shared resources and business group innovative activity

The literature on multi-business firm innovation, combined with studies on business group activity, offers a logical starting point to assemble the puzzle. We will consider influences that shape the innovative activities of individual firms within a group. The analysis will examine both affiliate-level and aggregate group-level innovative activity.

Critics of diversification suggest that multi-business firms often erect entry barriers through predatory pricing, reciprocal purchasing, and mutual forbearance that reduces innovation incentives for their units, as well as their competitors (Bernheim and Whinston 1990; Berger and Ofek 1995). More fine-grained arguments, though, focus on benefits and constraints that arise from shared resources.

Arguments in the technology studies, business group, and related literatures suggest ways that ties involving financial, strategic, and operating resources that are common in groups might facilitate or constrain innovative activity within multi-business firms generally and within business groups in particular. First, equity ties among affiliates may facilitate innovative activity within groups. In emerging markets, many of the institutions that underpin a robust capital market exist only in relatively weak form. Equity ties among businesses support internal capital markets (Servaes 1996; Teece 1996; Chang and Hong 2000), while helping to reduce R&D uncertainty (Nelson 1959), share costs across projects (Cohen and Klepper 1996), and nurture new ventures (Gompers and Lerner 2001). Moreover, equity ties may insulate group members from short-term profit pressures, allowing managers to undertake R&D risks (Claessens et al. 2000). Hence, shared financial resources might allow multi-business firms such as business groups to support investments by units with innovative opportunities.

Conversely, though, equity ties might constrain innovation. Minority shareholders such as controlling families may use cross-shareholding to extract resources from other shareholders, while equity ties might protect inefficient group members from acquisitions that would lead to greater innovativeness under new ownership (Morck and Yeung 2004). Such negative effects may be strong for business groups because of the absence of robust markets for corporate governance in developing economies.

Second, director ties may enhance information flow and innovative activity. Useem's (1984) work

on the inner-circle of directors in the U.S. and Britain emphasizes that interlocks facilitate environmental scanning. In turn, Davis (1991) outlines how interlocks create catalysts for organizational innovation in the adoption of poison pills. Evidence from developing economies suggests that director interlocks sometimes assist performance by providing information that is not available in the market (Keister 1998). Moreover, director ties may help create shared goals for business development, which may create greater willingness to reinforce innovative activities across units within the firm.

Conversely, though, innovative activity by affiliates and their groups might suffer when directors hold positions in multiple companies. Information overload may inhibit ability to share useful information. Moreover, when interlocks arise from a central family's desire to control multiple companies, interlocking may lead to crony capitalism whereby a small number of people, often family members or friends, sit on the boards of multiple affiliates with little consideration of the board members' governance skills (Morck and Yeung 2004). Such crony capitalism may inhibit innovative activity if top managers focus on reinforcing family control and maximizing family objectives such as rent seeking rather than developing new goods and services that would require outside professionals who might dilute family control.

Third, operating ties based on buyer-supplier links may facilitate innovative activity by creating opportunities to recombine resources that arise in disparate lines of business (Leff 1978; Kodama 1986; Porter and Stern 2002). Within business groups, operating ties potentially provide channels that would allow firms to take advantage of ideas from customers (von Hippel 1988) and suppliers (Teece 1989; Cusumano and Takeshi 1991), as well as providing opportunities to leverage partners' complementary resources (Shan, Walker, & Kogut 1994; Koza & Lewin 1998). These advantages will be particularly valuable in developing economies, which have limited external supply markets (Amsden 1989).

Conversely, again, buyer-supplier relationships can also constrain innovative activity. Group firms may force members to buy from other group members at inferior prices and quality, and otherwise support weaker firms. For example, *keiretsu* sometimes tax high performing buyers and suppliers in order to help low performing affiliates (Lincoln, Gerlach and Ahmadjian 1996), thereby reducing incentives for firms to take innovative risks. Moreover, access to buyer-supplier links within a group may also lead to

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local search that precludes member firms from searching for new ideas beyond the boundaries of their

own groups and so deflate innovative activity (Nelson and Winter 1982; Rosenkopf and Nerkar 2001).

Together, these discussions suggest that ties involving financial, strategic, and operating

resources will shape business group innovative activity, but do not provide conclusions about the

direction of the effects. Indeed, studies of multi-business firm innovation offer mixed results. Such studies

typically examine whether firm innovativeness increases or falls with product market diversification,

using measures of innovativeness such as R&D expenditure and patenting. Although some studies find

that innovativeness rises with diversification, many analyses find that multi-business firms are no more

innovative than independent competitors and may be less inventive (Scherer 1980; Link and Long 1981;

Hoskisson and Hitt 1988; Baysinger and Hoskisson 1989; Stimpert and Duhaime 1997).

The one consensus of research on multi-business firm innovation is that any potential advantages

of business groups for their members are not guaranteed. Instead, equity, operating, and director ties

create both benefits and constraints on innovation, quite possibly with different influences arising from

different ties. A missing piece to this puzzle lies in assessing how the structure of inter-affiliate ties

involving different types of resources might facilitate or constrain innovative activity by group members.

Impact of tie structure on affiliate innovative activity: Centrality and density

The network literature implies that the structure of the ties among firms will influence the balance

of benefits and constraints. Network research typically compares activities of actors at different points

within a single network. This study differs because it both compares activities of individual firms across

multiple networks and compares the aggregate activities of different networks. Moreover, networks of

affiliates within business groups differ somewhat from other corporate networks, such as sets of alliances,

which often have fuzzier boundaries and may be more fluid than business groups (Khanna and Rivkin,

2001). Nonetheless, two tie structure concepts from the network literature are relevant here, centrality and

density. Indeed, the greater clarity and stability of business group boundaries means that tie structures

such as density and centrality are likely to have substantial influence on group activities and performance.

Affiliate centrality. Network research suggests that benefits for individual actors may vary

according to an organization's location within a network. The network literature uses the term centrality to describe organizations with ties to many other organizations. Central organizations can draw on more sources of information and complementary resources, which may facilitate innovative activity (Ahuja 2000). Nonetheless, centrality also may constrain innovativeness by forcing organizations to focus on existing patterns of activity and making it difficult for them to seek new opportunities (Uzzi 1996). We define three types of affiliate centrality, based on equity, operating, and director ties.

Equity tie centrality is the degree to which an affiliate shares financial cross-shareholdings with other firms within a group. Group affiliates with greater equity centrality will have greater access to internal capital markets and will have greater credibility within the group, making it easier for an affiliate to access complementary resources from other affiliates. Conversely, though, affiliates with extensive cross-equity holdings might need to transfer resources to their partners, which would leave them with fewer resources to apply to innovative activity.

Director centrality is the degree to which an affiliate shares directors with other affiliates within a group. Affiliates with greater director centrality may have greater knowledge of opportunities that arise across units and greater ability to share resources to pursue the opportunities. At the same time, though, a wide span of director control might instead drain a firm's managerial capacity, constraining innovative activity if the control creates myopia that favors short-term financial targets rather than long term R&D.

Operating centrality is the degree to which a group affiliate has buyer-supplier linkages to other members of the group. Affiliates with greater operating centrality may have greater access to fine-grained information and resources that they can use for innovative activities, thereby providing scale and scope to recoup investments in innovative activity. In contrast, though, operating centrality might cause a firm to focus on current activities and reduce the unit's incentives to search for new ideas and partners. In each type of tie, therefore, centrality offers both benefits and constraints on affiliate innovative activity.

Group density. Sociologists argue that the overall density of ties influences activities within a network. Network studies define density as the ratio of actual ties within a given network to the total number of potential ties that organizations could forge within that network. While some scholars expect

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high density to contribute to superior performance by increasing the ability for actors to share resources with each other (Coleman 1990), others argue that a dense set of relationships can increase incentives for actors to hoard resources rather than facilitate resource flow (Burt 1992, 2000).

The discussion of the benefits and constraints of equity, director, and operating centrality applies to the three types of density. High equity density creates opportunities for sharing financial resources among affiliates, but also may lead to competing demands for financial resources that could interfere with innovative activities. High director density provides shared knowledge and may promote strategic coordination, but also can lead to conflicting priorities among senior leaders that cause firms to focus on current activities rather than seek innovative opportunities. Finally, high operating density might provide widely shared knowledge of recombination opportunities, but also may lead firms in a group to focus on current activities rather than search for innovative opportunities.

Overall, then, network research offers useful insights about how centrality and density of the three types of resource ties create potential benefits and constraints on innovative activity, without generating definitive predictions about the impact of different tie structures involving different types of resources. We now turn to an empirical context in which to examine the innovative impact of tie structure.

TAIWANESE BUSINESS GROUPS: INNOVATION AND INTRA-GROUP TIES

Taiwanese 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.

Of particular interest to our study, groups played key roles as innovators during a period in which Taiwan moved from being primarily a technology importer to becoming an important source of technical advance in many industries during the 1980s and 1990s (Hobday 1995; Ernst 1998). Between 1990 and 1999, business group affiliates received about 40% of the US patents awarded in Taiwan. Moreover, between 1970 and 1999, the U.S. Patent and Trademark Office reports that seven of the top ten

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Taiwan-based recipients of U.S. patents were business group affiliates. These affiliates included United Microelectronics Corporation (UMC Group), Taiwan Semiconductor Manufacturing Company and Vanguard International Semiconductor (TSMC Group), Winbond Electronics (Walsin Lihua Group), Hon Hai Precision Industry Company (Hon Hai Group), Mosel Vitelic (Mosel Pacific Group), and Acer Peripherals (Acer Group). Many of the top patenters operate in the semiconductor, electronics, and industrial equipment sectors, although affiliates of some of the groups are leaders in sectors such as metals (China Steel Group), bicycles (Giant Group), and chemicals (Formosa Plastics Group). There is substantial variation in patenting between and within groups, which this study seeks to explain.

Governance of groups in Taiwan involves substantial variety in the structure of equity, director, and operating ties, which offers a rich context in which to examine variation in innovativeness. Moreover, Taiwan offers clear definitions of group membership for identifying ties. Group boundaries are ambiguous in some countries. In Japan, for instance, governmental encouragement of inter-group activities plus a lack of family solidarity obscures *keiretsu* boundaries (Saxonhouse 1993; Weinstein and Yafeh 1995). In Taiwan, by contrast, strong cultural foundations such as regional kinship and patrilineal family connections delineate group boundaries (Numazaki 1986).

It is useful to compare governance of Taiwanese groups to governance of groups in other countries. Granovetter (1995:114) suggested a continuum of power centralization among group affiliates. At one end is a consolidated hierarchical management system, led by an individual or small senior management team. Many Korean *chaebol* lie near this end of Granovetter's continuum. Biggart (1990) suggests that affiliates of most *chaebol* are under tight control of the group president, *haejang;* Biggart describes the president as a patriarch and the management system as patrimonialism. Chang and Hong (2000), meanwhile, indicate that *chaebol* operate much like multidivisional firms due to sophisticated coordination and control among affiliates. At the other end of Granovetter's continuum is a loosely coordinated governance body composed of more equal partners who reach decisions through communication and mutual consensus. Members of many Japanese *keiretsu*, for instance, commonly participate in group-wide affairs via a presidents' council, in which each firm retains its own privileges

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and interests. Biggart (1990) calls this system communitarianism. Orrù et al. (1991) also refer to the *keiretsu* as communities of firms, similarly contrasting *chaebol* as examples of corporate patrimonialism.

Taiwanese business groups lie near the mid-point of Granovetter's continuum. Hamilton and Kao (1990) and Orrù, et al. (1991) note that Taiwanese groups exert less hierarchical control than *chaebol*, but more coordination than *keiretsu*. The major coordination mechanisms inside many Taiwanese groups involve a moderate degree of control by socially-related leaders, rather than strong control by a single group president or looser coordination via a president's council (Hamilton 1997:265). The shared equity, interlocking directorates, and operating ties that we described earlier facilitate the coordination and are likely to influence innovative activities within Taiwanese business groups, as well as groups in many other emerging markets. The following examples, which draw from public sources and interviews in Taiwan and elsewhere, illustrate the ties (the appendix provides additional examples).

Hon Hai Precision Industry Co. (Hon Hai Group). Hon Hai Precision Industry Co. (HHPIC), a member of the Hon Hai Group, is an example of highly-innovative group affiliate in Taiwan. HHPIC was number seven in Taiwan-based recipients of U.S. patents between 1970 and 1999. It was also seventh in domestic patents from 1991 to 1999. Founded in 1974, the Hon Hai Group has grown from a single firm with less than 20 people working in a small factory to a business group with a staff of over 100,000 people located around the globe. During this time, HHPIC has expanded from making plastic switches for televisions to become one of the world's largest electronic contract manufacturers of computers, consumer electronics, and communications products such as connectors, cable assemblies, enclosures, flat-panel displays, game consoles, motherboards, and servers. The company produces PC and consumer electronics goods for OEM customers such as Apple, Cisco, Dell, Nokia, Sony, and HP-Compaq, often using the trade name Foxconn. HHPIC also provides design engineering and mechanical tooling services. In 2004, continuing to move up the technology ladder, HHPIC initiated a three-year plan to create a nanotechnology R&D center in Taiwan.

HHPIC maintains operating ties with several other members of the group. For instance, Foxconn Electronics focuses on handset and wireless communication development, Innolux Display supplies 40%

of the LCD panel demand, and Foxconn Technology supplies aluminum alloy cases and thermal

components. Other members of the Hon Hai Group also produce electronic components, including Hong

Fu Jin Precision (electronic components), Foxconn Advanced Technology (flexible printed circuit boards),

Foxconn International Holdings (handsets), and Cheng Uei Precision (cell phone components).

The business model for the Hon Hai Group combines centralization and autonomy. The group

locates R&D and design, production process testing, and sample production facilities within business

units close to its key customers, while also retaining a central development facility within HHPIC. The

group uses a global ERP production management system to connect manufacturing facilities across its

major market regions in Asia, North America, and Europe. At the same time, executives in the group note

that each subsidiary has a particular mission, such as making specific components, and that achieving its

mission is the primary focus of a subsidiary. Figure 1 depicts Hon Hai's supply and equity ties in 2000.

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

Formosa Plastics Group. The Formosa Plastics Group (FPG) further illustrates benefits and

constraints on innovative activity within groups. Mr. Wang Yung-ching, who founded FPG in 1958, has

two daughters, Shirleen and Cher Wang. Shirleen Wang and her husband, Dr. Ming J. Chien, established

First International Computer, Inc. (FIC) in 1980; FIC was the world's largest computer motherboard

producer in 1997. In turn, Cher Wang helped establish the chipset maker, VIA Technologies, Inc., in 1987.

FIC and VIA share equity, director, and operating ties within FPG. When VIA began to produce

central processing units (CPUs), most motherboard manufacturers in Taiwan were reluctant to use its

CPUs because they feared being punished by Intel, their major CPU provider. FIC used VIA's CPUs in its

LEO computers, however, which helped VIA become established while FIC gained high quality, lower

cost CPUs. The ties between FIC and VIA have contributed to ongoing innovation at the two firms, as the

companies have co-developed a series of motherboards for the Intel Pentium 4 platform. For instance,

FIC introduced the P4-800T ATX motherboard in 2003, based on the VIA PT800 chipset.

Nonetheless, the same ties that facilitate innovation sometimes also create constraints. In 1997,

for example, Cher Wang and her husband established Xander Inc., as another affiliate of FPG. Since Cher

Wang sat on the boards of both FIC and Xander, as well as her own VIA affiliate, she was able to use her interlocking directorships to transfer customers from FIC to Xander. This hurt the profitability of FIC and its ability to fund innovative activities, fuelling wide spread resentment. In order to avoid conflict with her sister, Shirleen Wang let Cher Wang take charge of FIC's LEO Computer subsidiary, while also moving some marketing staff from FIC to LEO, which created further short-term constraints at FIC. An additional constraint emerged in 1999, when Intel sued both FIC and VIA, claiming that VIA had violated Intel's chipset technology intellectual property. Intel included FIC in the suit because of its group ties to VIA, while ignoring other companies that used VIA's chipsets. The suit diverted time and money that would otherwise have been available for development activities at FIC. The core point is that intra-group ties can create both benefits and constraints on innovative activity.

DATA, MEASURES, AND STATISTICAL METHOD

Our major data source is the *Business Groups in Taiwan* (BGT) directory, compiled by the China Credit Information Service (CCIS) in Taipei. CCIS is an affiliate of Standard & Poor's and is the oldest and most prestigious credit-checking agency in Taiwan. BGT offers the most comprehensive and reliable source of business group data. BGT reports data on the top 100 or more groups (sales), assessing groups whose principal firms are registered in Taiwan. CCIS defines a business group as *a coherent business organization including several independent enterprises*. According to BGT, the top 100 groups contributed 42% of national GDP in the 1990s. Tthe BGT records ties such as supply links, cross-shareholding, and interlocking directorates. Several previous studies rely on the BGT (Hamilton and Biggart 1988; Claessens et al. 2000; Chung 2001; Khanna and Rivkin 2001; Feenstra 1997), although none has translated and coded the intra-group ties.

The BGT database provides information about business groups in Taiwan for five calendar years: 1981, 1986, 1990, 1994, and 1998. Because the composition of the top 100 list changes from year to year, our initial sample included 592 group-year observations (267 unique groups) and 5,339 affiliate-years (3,500 unique firms). Activities by 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

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of ties because service activities can contribute knowledge needed for innovation, but we included only affiliates with manufacturing sector industry classifications (2,500 unique firms in the initial sample) in the analyses of innovative activity because service firms rarely apply for patents.

The BGT directory reports its information in traditional Chinese script ("*Fan-ti-zi*"). Taiwan uses the traditional script, which pre-dates the Communist revolution, while mainland China has since adopted a simplified form of Mandarin script ("*Jian-ti-zi*"). One of the co-authors, who reads the traditional Chinese script fluently, led the translation of the source documents. The coding required translators to read each of the five volumes, identify groups and affiliates, and manually transcribe financial information about each affiliate. The volumes included figures for each group that depicted intra-group buyer-supplier relationships, shared directorships, and equity cross-holdings, which we used to code operating, director, and equity ties between affiliates.

We use Taiwan patent data for the primary measure of innovative activity. Patents are imperfect measures because they record only portions of firms' innovative activities, but provide a useful and common means of comparing activity of multiple 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. Patenting is common across multiple industry sectors in Taiwan; Yu's (1998) study of Taiwanese firms located the Hsinchu Science Park found effectiveness across a wider variety of industries than in the U.S., where patents are most common in chemical-based industries (Levin, et al. 1987; Cohen, Nelson, and Walsh 2000).

We focus on local patents because we are interested in overall innovative activity rather than activity only by Taiwanese firms registered in the U.S. Since patenting abroad is more expensive than patenting domestically, focusing on U.S. patents might bias the analyses toward larger firms or firms that export heavily to the U.S., although we examine U.S. patents in sensitivity analysis.

We collected information about patenting by business group affiliates from online databases of

the Taiwanese government's 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", as classified by the Intellectual Property Office, which tend to be more substantial innovations than "Process Patents".

The dependent variable is patent application counts by affiliate i of group j over a two-year period following each of the five years for which the BGT directory provided data. Thus, we identified new invention patent applications for 10 years (1982-1983, 1987-1988, 1991-1992, 1995-1996, and 1999-2000). We lagged the independent variables because patents applications typically correspond to activity preceding the application. For explanatory variables in 1981, for instance, the dependent variable includes the total number of patent applications for 1982 and 1983. In total, the study uses 2,562 new invention patent applications by business group affiliates during the 10 years.

We use within-group equity, director, and operating ties to measure group density and affiliate centrality. Group density is the ratio of actual ties to the number of potential ties among affiliates (*Group Operating Density, Group Director Density, Group Equity Density*). The affiliate centrality measures use degree centrality, which gauges the number of direct partners for the focal affiliate. We did not use centrality measures that include indirect ties, such as closeness and betweenness centrality (Freeman 1977), due to the small size of our networks. The mean number of affiliated businesses (network size) in our data ranges from 7.2 to 10.8. In small networks, centrality measures that include indirect contacts are not as efficient as degree centrality. We created a degree centrality measure for each type of tie (*Affiliate Operating Centrality, Affiliate Director Centrality, Affiliate Equity Centrality).*

The analyses use non-directional measures of ties, such that a tie from affiliate A to affiliate B is equivalent to a tie from B to A. Direction of ties among affiliates does not apply to density measures, where the unit of analysis is the group. We do not believe that tie direction is relevant for affiliate director or operating centrality. Because firms can receive valuable information from both buyers and suppliers, we do not distinguish between buyer relations (out-degree) versus supplier relations (in-degree). Similarly,

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to the extent that group structure encourages firms to share information with each other, distinguishing between in-degree versus out-degree centrality for director ties is not relevant. By contrast, sensitivity analyses compare the effects of in-degree and out-degree equity centrality, because equity ownership rights might matter for deciding which affiliates receive priority in the flow of financial resources.

Table 1 summarizes the sample. The mean number of affiliates increased over time, while operating tie density dropped substantially, director density declined slightly, and equity density increased slightly. Operating ties between affiliates fell as the Taiwanese groups became more diversified (Amsden and Chu 2003), while equity ties helped finance expansion (Luo and Chung 2005).

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

Several time-varying affiliate-level variables assessed other influences on innovative activity. *Affiliate Assets* records firm assets (billions of New Taiwanese Dollars). *Affiliate Age* records years since founding. *Affiliate Family Ownership Share* denotes the share of ownership held by the founding family. *Affiliate Industry R&D* records the mean R&D/sales intensity of each affiliate's main industry (2-digit SIC), to assess technological opportunity. A dummy variable denoting the *Affiliate Electronics Sector* also addressed variation in technological opportunity and propensity to patent across industries (*Group Industry R&D* and the *Group Industry Concentration* variables that we describe below also address sector-specific influences).[1] We recorded the cumulative number of patents that each firm had applied for prior to the time period of the dependent variable, creating a *Prior Stock of Patents* variable to address unobservable firm-specific effects that arise from knowledge that firms possess when they enter the sample and that might correlate with both innovative activity and tie structure.[2]

Several time-varying measures address group level influences on patenting. We recorded total *Group Assets*, in billions of New Taiwanese Dollars (subtracting the assets of the focal firm for the affiliate-level analyses). *Group Industry Concentration* records the industry-weighted average of the five-firm concentration ratio to assess exposure to competitive pressures. *Group Diversification* is an entropy index (Palepu 1985) based on 2-digit Taiwan SIC codes. *Group Industry R&D* reports the weighted average of industry-average R&D by all the affiliates within a group. A dummy variable

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denoted the UMC and TSMC groups, the most active patenters in Taiwan during the past three decades, in order to pick up any idiosyncratic influences for these groups. Finally, *Year of Panel* assessed time trends. We also recorded the number of firms in each group but found that this correlated highly with group assets and group diversification, so that the measure did not provide additional information.

Table 2 reports summary affiliate-level statistics. The final sample, after dropping service firms and cases with missing data (mainly cases that lacked firm size information), included 3,119 affiliate-year observations (1,991 unique firms) and 582 group-year observations (263 unique groups). The table reports substantial correlations between the centrality and density measures, indicating need for care in conducting analysis with both sets of measures. Correlations among centrality and density across the three types of ties are low or moderate (r=0.14 to r=0.35), however, showing that equity, director, and operating ties involve distinct types of relationships and resources. The table shows large variation in patenting, ranging from zero to 832 (the number of "New Invention Patent" applications filed in 1999 and 2000 by United Microelectronics Corporation, an affiliate of the UMC group). Average centrality and density across affiliates was highest for the director measures, followed by the equity and operating ties. The high levels of director centrality and density arise because many Taiwanese groups use interlocking directorates to retain founding family control as they diversify (Chung and Mahmood 2004).

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

The count nature of our dependent variable (number of patents), together with over-dispersion of values of the variable, suggests using negative binomial regression for the analysis (Hausman, Hall & Griliches 1984; Gurmu & Trivedi 1994). At the same time, the dependent variable is characterized by "many zeros". Indeed, only 24% of business groups patented during the study period, involving a minority of individual firms. Therefore, we adopt Zero-Inflated Negative Binomial (ZINB) regression to handle the preponderance of zeros (Mullahy 1986; Lambert 1992).

ZINB regression separates two regimes that may generate zero outcomes. In regime 1, the patent outcome is always zero (some firms never patent). In regime 2, the usual negative binomial process applies (some firms generate no patents in some years and positive counts in other years).[3] Greene (2003:

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779-80) demonstrates that ZINB outperforms standard negative binomial when regime-splitting is needed, which the Vuong (1989) statistic suggests arises with our data. We also cluster by groups within the firm-level ZINB models to address the possibility that affiliates share group-specific attributes.

RESULTS

Table 3 reports the results. [4] Model 1 includes controls and centrality variables for the firm-level analysis. Equity centrality contributes to affiliate patenting, while director centrality detracts.

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

Model 2 adds group equity density. We omitted director and operating density from the model because their correlations with the corresponding centrality measures were high enough that they did not offer independent information. Although equity density also had substantial correlation with equity density (r=0.63), there was sufficient independent variation to create additional influence, as indicated by the log-likelihood ratio comparing model 1 to model 2. The centrality results remain stable, while greater equity density leads to lower innovative activity.

Figure 2 uses non-parametric kernel regression, which estimates the functional relation between a univariate response variable Y and a d-dimensional explanatory variable X (Hardle 1991), to depict the combined effects of equity centrality and equity density. The vertical axis reports patent applications as a function of centrality and density (on the horizontal axes). The figure shows greatest combined benefits for affiliates with high equity centrality in groups with low overall density of equity ties (left rear), and greatest constraints for peripheral firms in high density groups (right front).

********** **Figure 2 about here** **********

Model 3 adds the square of operating centrality, to investigate a possible non-monotonic impact on patenting. Affiliates with a moderate degree of operating centrality have a significantly higher level of patenting, while firms at the low and high ends of operating centrality have lower patenting activity.

Thus, the most innovative affiliates tend to have high equity centrality in relatively sparse equity networks that provides access to financial resources with little competition from other members of the group, moderate operating centrality that provides access to ideas from other affiliates, and limited

director inter-linkages or over-embedded supply relationships that would create strategic constraints by other members of their groups. We discuss the implications later in the paper.

We now turn to aggregate group patenting. Even if particular tie structures offer advantages for some affiliates, we need to determine whether the group as a whole is innovative relative to groups with different patterns of ties. It is possible that a configuration that assists one firm might divert resources from other members to such an extent that the group as a whole is less innovative than groups in which the cumulative activities of several moderately innovative firms lead to greater aggregate patenting.

Model 4 in Table 3 reports the group-level results. Director density and operating density deflate overall group innovative activity, reinforcing the negative affiliate-level influences of high centrality. Thus, the firm-level influences aggregate such that the most innovative groups provide substantial autonomy to their member firms in terms of both inter-locking directorships and operating ties.

Several control variables in Table 3 influence patenting. Aggregate group patenting declines with diversification and industry concentration. Affiliate patenting increases with affiliate industry R&D intensity and prior patent stock, while declining with group diversification and family ownership share.

The negative impact of family ownership share on innovativeness is intriguing. The result is consistent with recent literature that discusses negative consequences when families are controlling owners (Morck and Yeung 2004). Such arguments focus on the risk that high family ownership will constrain a group's willingness to invest in risky activities such as research and development in order to protect a family's investment in the group, which often represents most of the family's wealth.

We carried out several sensitivity analyses. First, we estimated models with standard negative binomial analyses, using generalized estimating equations (GEE) for panel data; the results were at least as strong as those with ZINB. Second, we checked for generality by dropping affiliates of the UMC and TSMC groups, finding similar results. Third, for the group-level analysis, we also used information from the BGT directories (1981-1998) to identify how many joint ventures, licenses, and acquisitions that members of the group had completed with foreign firms, in order to determine whether such foreign ties offer alternatives to intra-group ties for obtaining innovative ideas. The variable was insignificant.

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Fourth, we examined group-level innovative activity in terms of U.S. patenting rather than local patents. Firms sometimes patent as a way to create entry barriers. If groups can use other types of entry barriers, they may not need to patent locally. This is not true for U.S. patents, however, because even large Taiwanese groups are not large enough to erect global entry barriers. Thus, while U.S. patenting might over-represent innovations by larger groups, local patents might over-represent innovations by smaller groups. Nonetheless, the results for U.S. patenting were similar to those using local patents.

Fifth, we distinguished between in-degree and out-degree equity centrality. Both directions have positive impact on patenting, but the strongest influence arises from out-degree equity centrality, that is, centrality that reflects a firm's equity holdings in other affiliates. This suggests that financial ownership provides particularly useful access to information and resources in other affiliates that a central firm can apply to its own innovative activity.

DISCUSSION

We started by asking why some business group affiliates and business groups are more innovative than others in similar contexts. How do the results help solve this puzzle?

Most directly, the analyses show that ties within a business group strongly influence innovative activity, sometimes facilitating and sometimes constraining patenting. The central implication is that affiliates have fertile opportunities for innovative activity if they have broad access to financial resources within otherwise sparse equity networks, access to a moderate degree of operating knowledge from other members of the group, and autonomy from inter-affiliate director interlocks and over-embedded buyer-supplier ties that would impose strategic constraints. By contrast, groups with dense networks of inter-locking directorships and operating ties often constrain innovative activity.

Thus, innovation influences are strongest when a group with limited financial and strategic interconnections can focus financial and operating resources on the innovative activities of their central businesses, which can draw on the knowledge and resources of other affiliates. This structure combines the benefits of strong ties and loose connections. Affiliates with central financial positions and moderate operating positions have ties to other affiliates that allow them to gather knowledge and spread costs. At

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the same time, the overall group is loosely enough connected that it does not constrain its individual members to focus so strongly on current activities that they do not devote resources to innovation.

Conceptually, this pattern is similar to Burt's (1992) notion of structural holes, coupled with ideas from evolutionary economics (Nelson and Winter 1982). In structural holes theory, individuals or organizations that tie together otherwise unconnected actors can use those positions to draw on the resources of their disparate partners. In evolutionary economics, meanwhile, organizations have opportunities to search for differentiated knowledge and then innovate by combining that knowledge in novel ways. Central units within loosely-connected multi-business firms fill such structural holes and can act as innovation integrators of ideas that arise in peripheral unit.

We are interested in how tie structures might influence innovation in other types of multi-business firms. As a first step, consider what the notions of operating, director, and equity ties mean when one moves beyond business groups. Operating ties generalize to the concept of operating interdependence, in which units buy and sell goods and services from each other and/or must coordinate their activities in shared markets. This allows units to influence others' short-term activities and also act as sources of knowledge for their partners. Director ties generalize to the notion of strategic interdependence arising from extensive senior management linkages across a firm, such as in corporations with divisional structures in which divisional vice-presidents and executive officers exercise extensive strategic authority over many business units. Equity ties generalize to the concept of financial interdependence, which arises from common financial systems within a multi-business firm, as well as from the corporate ability and willingness to use financial resources that one business generates to support the expansion of other units. Operating, strategic, and financial interdependence are common in many multi-business firms.

Viewing ties in terms of operating, strategic, and financial interdependence leads to propositions for assessing innovativeness of units within multi-business firms and of the firms as a whole. The results in this study suggest that multi-business firms that possess limited overall operating and strategic interdependence among their units will place few constraints on the innovative activities of their subsidiary units. In turn, rather than simply act as a conglomerate holding company, multi-business firms

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will facilitate innovation if they have a few central units that receive corporate financial support and maintain several operating linkages with other more peripheral units. The peripheral units can experiment with technologies and markets, and then pass ideas to the central units through their operating linkages.

In sum, this paper advances the business group literature, with broader contribution to technology research. This is the first study to examine how intra-group tie structure affects innovation in an emerging market. In turn, the study informs research on multi-business firm innovation, which typically emphasizes benefits that arise from presence in multiple product markets, rather than considering how inter-unit ties within the diversified firm facilitate the opportunities and/or create constraints.

Several limits of the study offer avenues for further research. First, multi-country analysis would test contextual robustness. Second, it would be useful to investigate tie structure tradeoffs between innovation and other performance outcomes such as profitability, growth, and survival. Such performance tradeoffs might explain why some groups retain tie structures that inhibit innovation. Third, formal and informal ties beyond those we used in this study – such as mutual debt guarantees, management rotations, and links based on friendship and ethnicity – may influence innovativeness. Fourth, combinations of different forms of density and centrality may affect innovation. Fifth, considering intensity as well as number of ties would provide a more complete picture of the innovation story. Sixth, considering how the influences vary across different types of multi-business firm warrants scrutiny. Such extensions would continue the task of unpacking the black box of organizational structure and innovation.

ENDNOTES

[1] *Electronics* includes computers, industrial and office equipment, appliances, radio, TV, & communications devices.

[2] Our data do not suit random or fixed effect techniques for controlling unobserved firm heterogeneity in panel data. Standard random effects estimators will be inconsistent because the unobserved firm heterogeneities correlate with the explanatory variables, η_i, i.e., $E(x_{it}\eta_i) \neq 0$. Fixed effects estimate would require at least one non-zero dependent variable observation for each firm (Green 2003: 747), but many Taiwanese firms did not apply for any patents during the study period.

[3] An alternative approach of examining only groups that patented would risk sample selection bias.

[4] Table 3 reports the second stage ZINB estimates, which estimate patenting influences for firms with at least one non-zero count. The ZINB first stage, which estimates the likelihood that patent counts will be non-zero (using the same predictor variables as the second stage), showed that larger firms and electronics firms were more likely to patent, as were larger groups and groups in R&D intensive industries.

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Table 1. Number of Affiliates and Mean Density of Ties in Taiwanese Business Groups, 1981-1998

Year	Number of groups	Number of affiliates	Mean no. of affiliates	Mean equity tie density	Mean director tie density	Mean operating tie density
1981	100	716	7.2	0.17	0.37	0.22
1986	97	749	7.7	0.19	0.37	0.17
1990	101	819	8.1	0.20	0.36	0.13
1994	115	1,116	9.7	0.21	0.30	0.09
1998	179	1,938	10.8	0.20	0.30	0.07
Total	592	5,339	9.0	0.19	0.34	0.14

Table 2. Affiliate-Level Correlations and Descriptive Statistics (3,119 cases)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	Patents	1																		
2	Affiliate Operating Centrality	0.02	1																	
3	Affiliate Director Centrality	0.02	0.15	1																
4	Affiliate Equity Centrality	0.08	0.35	0.23	1															
5	Group Operating Density	-0.01	0.77	0.14	0.18	1														
6	Group Director Density	0.00	0.15	0.77	0.20	0.17	1													
7	Group Equity Density	0.01	0.24	0.25	0.63	0.29	0.31	1												
8	Affiliate Electronics Sector	0.10	0.00	0.03	0.06	-0.03	0.04	0.02	1											
9	Affiliate Assets (NTD billions)	0.11	0.04	-0.02	0.16	-0.06	-0.07	-0.05	0.02	1										
10	Affiliate Industry R&D (% sales)	0.07	0.08	0.05	0.13	0.02	0.05	0.06	0.68	0.01	1									
11	Affiliate Family Ownership Share	-0.02	0.20	0.08	0.05	0.24	0.03	-0.02	-0.10	-0.07	-0.04	1								
12	Affiliate Age	0.00	0.29	0.00	0.31	0.10	-0.06	0.01	-0.04	0.21	0.09	0.17	1							
13	Affiliate Prior Stock of Patents	0.17	-0.10	-0.10	-0.06	-0.14	-0.12	-0.12	0.22	0.14	0.17	-0.14	0.03	1						
14	Group Assets (NTD billions) *	0.00	-0.21	-0.20	-0.21	-0.25	-0.24	-0.30	-0.06	0.17	-0.11	-0.20	0.06	0.30	1					
15	Group Diversification	-0.05	-0.27	-0.16	-0.15	-0.32	-0.21	-0.23	-0.20	0.07	-0.19	-0.06	0.04	-0.10	0.38	1				
16	Group Industry Concentration	-0.02	0.11	0.00	0.03	0.14	0.00	0.06	-0.09	-0.08	-0.03	0.12	0.03	-0.18	-0.17	0.10	1			
17	Group UMC-TSMC Dummy	0.26	-0.03	0.01	-0.01	-0.04	0.02	0.00	0.14	0.04	0.08	-0.05	-0.08	0.54	0.06	-0.18	-0.09	1		
18	Group Industry R&D (% sales)	0.04	-0.01	0.08	0.00	-0.02	0.12	-0.01	0.24	-0.04	0.24	-0.06	-0.06	0.29	-0.17	-0.20	-0.20	0.16	1	
19	Year of panel	0.02	-0.13	-0.04	0.01	-0.18	-0.04	0.00	0.04	0.10	0.00	-0.24	-0.04	0.17	0.29	-0.03	-0.60	0.08	0.05	1
	Mean	0.72	0.09	0.30	0.20	0.09	0.32	0.19	0.13	5.29	1.54	10.69	13.69	0.56	82.8	0.39	0.17	0.01	2.09	1997
	Standard deviation	17.15	0.18	0.32	0.24	0.15	0.25	0.15	0.34	18.66	2.21	20.55	11.71	1.08	135.2	0.21	0.15	0.10	1.71	3.19
	Minimum	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0.002	0	0	1992
	Maximum	832	1	1	1	1	1	1	1	580.9	7.27	100	80	6.89	832.4	0.82	0.83	1	6.94	2000

Table 3. ZINB Estimates of Influences of Tie Structure on Firm and Group Patenting
(positive coefficient = greater patenting)

	1 Firm	s.e.		2 Firm	s.e.		3 Firm	s.e.		4 Group	s.e.	
Tie structure variables												
Affiliate Equity Centrality	1.980	0.852	**	3.476	0.836	***	3.519	0.887	***			
Affiliate Director Centrality	-1.445	0.569	**	-1.085	0.504	**	-1.244	0.497	**			
Affiliate Operating Centrality	-0.901	0.824		-0.732	0.692		2.858	1.403	**			
Operating Centrality squared							-5.001	1.557	***			
Group Equity Density				-5.640	1.221	***	-5.639	1.410	***	1.491	1.296	
Group Director Density										-3.876	1.579	**
Group Operating Density										-1.538	0.572	***
Affiliate-level variables												
Affiliate Assets (x 1000)	5.641	4.073		4.631	3.221		3.163	3.251				
Affiliate Industry R&D	0.882	0.238	***	0.932	0.202	***	0.938	0.214	***			
Affiliate Family Ownership Share	-0.040	0.022	*	-0.051	0.013	***	-0.049	0.014	***			
Affiliate Age	-0.002	0.034		-0.037	0.034		-0.044	0.034				
Affiliate Electronics Sector	-0.202	1.404		-0.722	0.786		-0.753	0.817				
Group-level variables												
Group Assets (x 1000) (a)	-0.680	1.342		-0.814	1.292		-0.395	1.428		1.980	1.849	
Group Industry R&D										-0.153	0.109	
Group Diversification	-1.107	0.813		-1.246	0.730	*	-1.589	0.758	**	-3.009	0.897	***
Group Industry Concentration	1.247	1.818		1.047	1.865		1.469	1.816		-3.274	1.352	**
Group UMC-TSMC Dummy	-0.525	0.686		-1.153	0.571	**	-1.141	0.551	**	-3.308	2.642	
Prior Stock of Patents	0.482	0.165	***	0.568	0.163	***	0.552	0.163	***	0.016	0.008	**
Year of panel	-0.141	0.081	*	-0.233	0.089	***	-0.200	0.086	**	-0.142	0.040	***
Constant	278.7	161.3	*	463.5	177.8	***	396.9	171.6	**	286.9	80.8	***
Cases	3,119			3,119			3,119			582		
Log (pseudo) likelihood	-657.5			-648.6			-646.1			-510.3		
Log-likelihood ratio (df)				17.8	(1)		5.0	(1)				

Note: The firm-level analyses cluster the observations by group

(a) "Group assets" excludes the focal firm for the firm-level analysis in models 1 to 3

*** p< .01, ** p<.05, * p<.10 (two-tailed tests)

Figure 1. Equity and Operating Ties among Hon Hai Group Affiliates (2000)
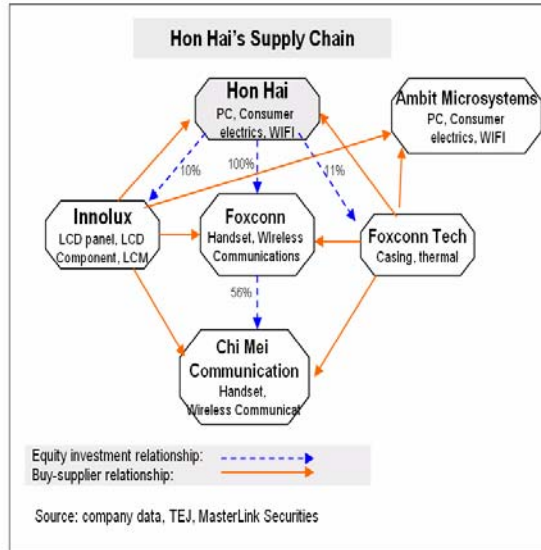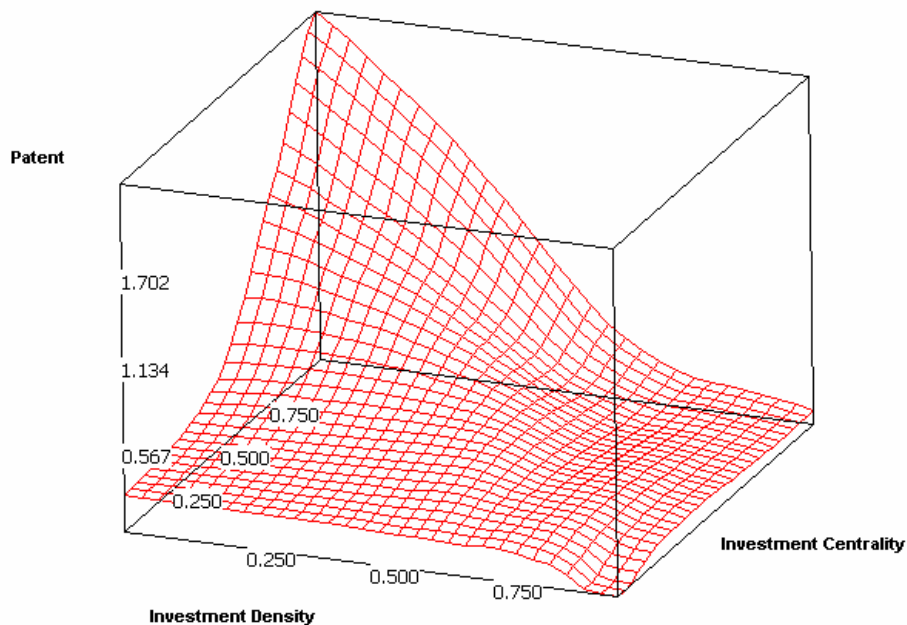

Figure 2. Firm-Level Innovation: Combined Effects of Affiliate Equity Centrality and Group Equity Density
The vertical axis denotes new invention patents: The figure depicts greatest patenting by affiliates with high equity centrality in groups with low overall density of equity ties, and lowest patenting by peripheral firms in high density groups.

Note: The figure excludes members of the UMC group, the most prolific patenter in the data, to reduce outlier effects; figures that include UMC have a similar shape, with different scaling.