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CORPORATE VENTURE CAPITAL INVESTMENT OF NETWORK CHARACTERISTICS AND INNOVATION: TAIWAN SEMICONDUCTOR INDUSTRY

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Abstract

This work focuses on network linkages among high-tech firms with the intention of strategic growth and innovation by intra-industry corporate venture capital (CVC) investment network analysis. A strategic investment model is also developed based on the case of Taiwan semiconductor industry. Additionally, this exploratory study of the 55 listed Taiwan semiconductor firms empirically analyzed network effects of intra-industry CVC investment activities. The examined indictors of network effects were reachability, degree centrality, constraint and betweenness centrality with corresponding network characteristics of visibility degree, active degree, strategic position and degree of information control. The network characteristics of the firm itself were examined for associations with firm innovation capability (i.e., number of output patents) by Pearson correlation analysis. Finally, the findings derived from the empirical results provide four implications and strategic directions for the semiconductor intra-industry CVC investment activities.

Key Words: Corporate Venture Capital (CVC), Network Analysis, Network Characteristics, Innovation, Semiconductor Industry, Taiwan

Introduction

In this era of globalization, large corporations have begun investing in external start-ups. Identifying promising start-ups is often difficult in fast-paced environments. However, what gives these corporations' investors or top managers their confidence? More generally, why do some corporate forays into venture capital (VC) successfully generate significant growth for their own businesses? To answer these questions, Chesbrough (2002) proposed a framework for analyzing corporate venture capital (CVC), which can help a company decide whether it should invest in a particular start-up by first understanding what kind of benefit might be realized from the four types and purposes of CVC investments such as driving, enabling, emergent and passive investments. A driving investment strategy mainly advances current business. Enabling investment lies in the notion of complementarity strategy of current business. Emergent investment allows exploration of potential new opportunities and businesses. Passive investment provides financial returns only. Therefore, a framework for mapping CVC investments can indeed help corporations evaluate their existing and potential VC investments and help determine when and how to use CVC as an instrument of strategic growth. Additionally, MacMillan et al. (2008) pointed out that a CVC generally has a strategic mission to help grow the business of the parent company. It does this by helping the company identify new directions, provide new technologies, develop new products or improve manufacturing processes, and enter new markets or enhance existing businesses.

Technological innovation is the new currency of competition in the promotion of industrial development and economic growth. Large corporations have begun to realize that they cannot compete globally if they rely only on in-house research and development. A robust innovation strategy includes both internal initiatives and mechanisms to access external innovation, including collaborations, partnerships, acquisitions, joint ventures, licensing and investments in emerging venture-backed companies. The CVC is a vital component in the innovation strategies of corporations around the globe (Ernst & Young 2008).

CVCs have become a significant part of overall VC activities. In 2000, at the peak of the most recent VC cycle, more than US$100 billion in VC was invested. About 16 percent of that investment was from CVCs. After 2002, total VC investment stabilized at around US$20 to US$25 billion annually, and CVC investment stabilized at around 6 to 8 percent of total VC investment. According to National Venture Capital Association, the top five industry sectors for CVCs investment in 2006 were biotechnology (22.0%), software (13.4%), telecommunications (12.0%), semiconductors (10.5%) and media/ entertainment (10.1%). This indicates that the semiconductor industry, a key high-tech industry, still has high-potential opportunities for developing CVCs investment activities. In 2008, the Taiwan IC industry outperformed the overall global IC industry because of its strength in manufacturing consumer electronics such as Laptop Computer, 3G Mobile Phone, PND, Digital Camera, LCD TV plus the growing market of Gigabit Ethernet, Set-Top-Box and digital frame. The projected revenue of the Taiwan semiconductor industry for 2009 is US$ 52.95 billion with an annual growth rate of 18.9%, which surpasses the global rate of 8.27%. In terms of the output value, Taiwan's IC industries take up one-fourth of global market share from 20.9% in 2007 to 23% in 2008, according to Ministry of Economic Affairs, Taiwan. During the past three decades, the Taiwan government has regarded the semiconductor industry as a strategically important high-tech industry; moreover, not only is it now the leading industry in the Hsinchu Science-based Industrial Park, revenues generated by the semiconductor industry is the fourth highest in the world. Therefore, enhancing intra-industry CVC investment activity is the key to remaining competitive in the global high-tech industry.

This study applies the Chesbrough CVC investment framework to analyze network relationships among high-tech firms with the intention of strategic growth and innovation by intra-industry CVC investment activities; moreover, the framework is applied to the Taiwan semiconductor industry to obtain a specific strategic investment model that gives firm investors or top managers insight into network relationships in the industry. This empirical study investigated intra-industry CVC investment activities (i.e., stocks exchange) network analysis among the 55 listed Taiwan semiconductor firms, which offers four network indicators of reachability, degree centrality, constraint and betweenness centrality with corresponding four network characteristics of visibility degree, active degree, strategic position and degree of information control, and further analyzing a firm itself network characteristics interacts with its firm innovation capability (i.e., number of output patents) by Pearson correlation analysis. The analytical results have several main practice implications for the strategic direction in the semiconductor intra-industry CVC investment activities.

Understanding CVC Investment Activity

The CVC programs in established corporations face both inward and outward. They face outward to build relationships with the entrepreneurial venture community, to learn about new technology and business directions, and to make strategic investments for the corporation. They face inward to interact with R&D and business operating units within the firm in order to identify the interests and priorities of operating units. The CVCs support existing business of the corporation by introducing new technologies and partnerships to its operating groups. The CVCs can also help identify technologies and opportunities that fall within or beyond the existing businesses of the corporation (MacMillan et al. 2008).

Differences between CVCs and Traditional VCs

The CVCs differ from traditional VCs in several ways. One is their different organizational structure. A CVC is normally either a somewhat autonomous unit of a parent corporation or a functional unit serving as part of the parent corporation’s research and development group. Unlike traditional VCs, which are usually limited partners, CVCs are an important influence on the performance of portfolio firms. A second difference is investment lifespan. Corporate venture programs are considerably shorter than traditional VC investments are (Gompers & Lerner 2002). A typical corporate venture program terminates in four years while a traditional VC investment lasts up to fifteen years (Gompers & Lerner 2001, 2004). The third and most important difference is investment motive. The CVCs invest in portfolio firms for strategic reasons rather than for financial reasons. Additionally, the CVCs, especially ones from research and development groups of the parent corporation, strive to exploit industry knowledge to develop products or services that can potentially provide competitive advantage for the parent corporation. The portfolio firm may be a prospective supplier of the CVC parent, or it may be a cash-hungry start-up that can potentially penetrate new markets for the parent. Conversely, the primary investment motive of traditional VCs is financial return.

Seeking Strategic Growth and Innovation

The established corporations of today recognize the growing need to innovate. While some corporations grow through external acquisitions, many recognize the ultimate importance of generating "organic growth" through innovation. Corporations are searching for new innovation strategies. The various approaches to innovation include internal R&D, incubation of new businesses, and strategic investments and alliances. Many firms emphasize an "open innovation" strategy to bring external sources of innovation into the firm. Given the success of VC in creating new entrepreneurial companies and technologies, corporations have also looked to that model as yet another approach to innovation (MacMillan et al. 2008). Additionally, Chesbrough (2002) argued that a framework for mapping CVC investments, including driving, enabling, emergent and passive investments, can clarify why some CVC investments proliferate only when financial returns are high, why others proliferate in both good times and in bad, and why still others make little sense in any phase of the business cycle. Such a framework can help companies to evaluate their existing and potential VC investments and determine when and how to use CVC as an instrument of strategic growth. Further, Dushnitsky and Lenox (2005) proposed that new ideas are coming from "innovation networks" loose collections of individuals and organizations outside a company that can form an extension of the company and that can be called upon to help solve problems and find new ideas for growth. A CVC unit is a proven method of accessing innovation and can provide an anchor for an innovation network.

Network Analysis on CVC Investment

Zheng (2004) proposed that highly developed social network analysis on CVC syndication. It attempts to explain this co-investment pattern using social network analysis. This analysis explores four attributes of social networks: prominence, range, brokerage, and cohesion. The findings of the CVC network provide a number of implications for the theory of social capital. Junichi (2008) recently suggested that social network analysis on IT investment and firm performance. He finds out network analysis based on business connection shows profit, IT expenditure and IT ROI are positively related between the main firm and other firms in each 2-clique networks.

This suggests that the formation of network characteristics can certainly express the types and purposes of intra-industry CVC investment activities, with the ultimate goal of strategic growth and innovation within the networks. The objective of this paper is to employ a highly developed analytical model of social network analysis and to develop a strategic investment model for the Taiwan semiconductor industry for the high-tech industrial insight. It aims to contribute on the broad-sense CVCs knowledge to existing literature, specifically in the area of the semiconductor intra-industry CVC investment activities. Based on the analytical results for intra-industry CVC investment activities, four findings are derived, which provide practical implications and strategic directions for semiconductor intra-industry CVC investment activities.

Methodology

Data

Investment data for the 55 listed Taiwan semiconductor firms were obtained from *Company Financial Quarterly Reports*, and intra-industry CVC investment activities were analyzed by coding intra-industry CVC investment activities that occurred from April to December, 2007 and from January to September, 2008. This study applied equity method to search for a subsidiary or external investment unit; moreover, any subsidiary or external investment units whose voting shares are fifty percent or more owned directly by the firm. Accordingly, the intra-industry CVC investment activities between the 55 listed semiconductor firms in Taiwan are coded as inward or outward investment (i.e., stocks exchange) and recorded in a Microsoft Office Excel spreadsheet. Binary data are applied to the measurement in the value matrix. A firm CVC investment activity between the 55 listed Taiwan semiconductor firms is indicated by a 1, and absence of CVC investment activity is indicated by 0. Therefore, the binary-matrix is intended to enable network analysis of the 55 listed Taiwan semiconductor firms.

In terms of firm innovation capability, it can be evaluated by the number of patents held by the 55 listed Taiwan semiconductor firms according to the United States Patent and Trademark Office (USPTO) and Taiwan Intellectual Property Office (TIPO) databases. The USPTO examines whether other patents have been filed by the same Assignee when US applications and patents are filed. Multiple filings by the same Assignee are linked by a numeric code the USPTO appends to the filing. Inclusion of this code compensates for variations (and misspellings) in Assignee names. These codes can be searched separately in the Assignee field on Delphion Research Corporate Tree Analytical Tool.

Network Analysis

Network analysis is this study of the relations among the 55 listed Taiwan semiconductor firms in a network and is employed to find the patterns of the intra-industry CVC investment activities. Network analysis empirically derives the industrial structure based on linkages between firms in a network. A linkage is an industrial tie between firms in the whole network. The network linkages from the 55 listed Taiwan semiconductor firms intra-industry investment activities between the firms' inward and outward investments are coded a matrix using Microsoft Office Excel. Further, UCINET (Borgatti, Everett & Freeman 2002) software is used to compute various measurements of the intra-industry investment network. UCINET is chosen because of its user friendliness, data processing capabilities, and its ability to work with Excel data files. More importantly, it provides a highly specific strategic investment model that firm investors or top managers can use to obtain insight into CVC investment network relationships in the overall Taiwan semiconductor intra-industry.

To analyze intra-industry CVC investment networks, this study proposes four network indicators: reachability, degree centrality, constraint and betweenness centrality. The following four corresponding network characteristics are also proposed: visibility degree, active degree, strategic position and degree of information control. Reachability measures "visibility degree"; degree centrality estimates "active degree"; constraint represents "strategic position"; and betweenness centrality describes "degree of information control" in the whole network. The four indicators and four characteristics of the intra-industry CVC investment network are examined and discussed throughout the body of this paper. Pearson correlation analysis is also used to test the interaction of network characteristics with firm innovation capability. Finally some important findings and implications of the network are reported.

Reachability

Reachability can compute the network characteristic of visibility degree levels. In graph theory, reachability is the ability to move from one vertex in a directed graph to some other vertex. A node visibility degree shows whether the node can be recognized by or can be distinguished from other nodes. In the 55 listed Taiwan semiconductor firms intra-industry CVC investment network, reachability is the number connections established between two firms among the intra-industry direct or indirect firm's investment activity. The higher the reachability, the more visible the firm is in its network. This analysis assumes that, if the matrix data are asymmetric or directed, firm A can reach firm B, but firm B cannot reach firm A. Therefore, if the reachability indicates a connection is established between two firms, the number is 1; otherwise, the number is 0.

Degree Centrality

Degree centrality determines the network characteristic of active degree levels. Degree centrality is the number of direct connections an actor has with other actors in the network. The higher degree centrality, the more active degree an actor has in its network. Regarding the concept of degree centrality, a firm with high degree centrality maintains contacts with numerous other network firms. Firms have high centrality if they can gain access to more active investment activities and influence others, therefore, the higher the degree centrality, the more active degree a firm has. Additionally, degree centrality indexes are applicable to directed graphs if the number of the firm investment choices allowed is not fixed. In directed networks, degree centrality can distinguish between the in-degree and the out-degree of each actor to measure its in-degree and out-degree centrality, respectively (Knoke & Burt 1983). The in-degree centrality ($C_{D,in}(a_i)$) and out-degree centrality ($C_{D,out}(a_i)$) of a given node are formally defined as

$$C_{D,in}(a_i) = \sum_{j=1}^{k} r_{ij,in} \text{ ; } C_{D,out}(a_i) = \sum_{j=1}^{k} r_{ij,out}$$

where r_{in} and r_{out} denote inward and outward connections of actor *i*, respectively, and actor *k* indicates the number of actors in the network. Therefore, the indicators of in-degree and out-degree that correspond with the investigation of network characteristics as inward and outward connections of a firm represent the receipt and transmission of numerous investing directions, respectively. Comparing in-degree and out-degree measures of a given firm can reveal whether any of the 55 listed Taiwan semiconductor firms can play the role of a core firm, an inbound investment firm or an outbound investment firm.

Constraint

Constraint is another possible measure of structural holes (Burt 1992), which is the extent to which an actor is directly and indirectly dependent on other actors through its interconnectedness and the absence of structural holes. The value of constraint CTi is given by

$$CT_i = \sum_j \left(p_{ij} + \sum_q p_{iq} p_{qj} \right)^2, \quad q \neq i, j$$

If CTi=0, the actor has many disconnected and easily replaceable links whereas if CTi=1, the actor has only one effective link. This indeed applies when attempting to identify potential opportunities and strategic positions among the 55 listed Taiwan semiconductor firms by measuring structural holes. Numerous structural holes in a firm indicate numerous opportunities to broker the investment flows with other firms and also indicate that the firm is located in an essential and non-substitutable position. A firm with advantageous structural holes, which is generally the overlapping firm between subgroups, also has high capacity to control the investment position that brings together firms from opposite sides of the focal firm.

Betweenness Centrality

The betweenness-based measure of actor centrality was developed independently by Anthonisse (1971) and Freeman (1977). Overall centrality of an actor is determined by summing the partial betweenness values for all unordered pairs of points as follows

$$C_B(a_k) = \sum_{j}^{n} \sum_{<\, i}^{n} b_{ij}(a_k)$$

where $i \neq j \neq k$, and n is the number of actors in the graph. The sum $C_B(a_K)$ is an index of the overall partial betweenness of actor a_k. Whenever a_k falls on the only geodesic connecting a pair of actors, $C_B(a_K)$ is increased by 1. When alternative geodesics $C_B(a_K)$ grow in proportion to the frequency of occurrence of a_k among those alternatives, applying this indicator to the network characteristics of the 55 listed Taiwan semiconductor firms' intra-industry CVC investment activities indicates whether the central firm can more or less completely control information or communication between pairs of other firms. However, when several geodesics connect a pair of firms, the situation becomes more complicated. Therefore, high betweenness centrality in a firm indicates that the firm is a highly critical intermediary between pairs of other firms since most investing activities remain in the firm when investments involve various other firms.

Pearson Correlation Analysis

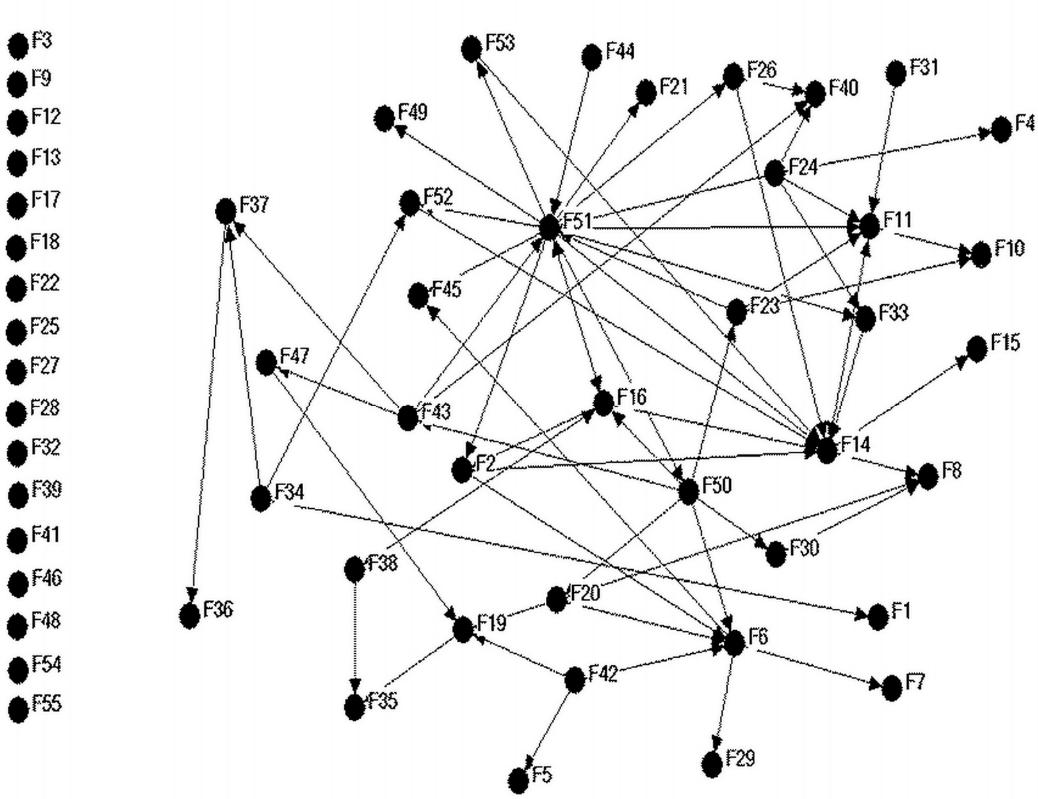
In this study, number of output patents was considered an indicator of firm innovation capability. Patent data as an indicator of innovation has a long tradition. Kung and Lin (2003) reviewed the number of patents obtained by Taiwan between 1998 and 2002 to study the innovative potential of the country and to project trends. Additionally, Chen et al. (2005) argued that patent, which represents innovative capability of a country, is also viewed as a factor in evaluating a country's leading position. To develop a suitable global patent strategy and to maximize both intellectual property rights and returns on R&D investment in the global marketplace of today, the patent databases is based on USPTO and TIPO in an example of the 55 listed Taiwan semiconductor firms.

Depending on whether the network characteristics of the firm itself interact with its own innovation capability, we can evaluate and explore the correlation between four network characteristics (i.e. visibility degree, active degree, strategic position and degree of information control) and firm innovation capability (i.e., number of output patents) by Pearson correlation analysis in driving strategic directions of the firm in the strategy used by the firm to participate in intra-industry CVC investment activities.

Results Analysis

Whole Network Phenomena

The asymmetric matrix of intra-industry CVC investment activities can be constructed using a network graph in which the rows and columns are used to index firms. In the matrix, the cell (row i, column k) contains a one if i is directly linked to k and contains a zero otherwise. This matrix describes what network analysts call sociometric choices, which merely depict the presence or absence of a given relation (Degenne & Forse 1999). Therefore, binary data were applied to the measurement data in the value matrix. Firm investment activity among the 55 semiconductor firms was indicated by a "1", and absence of investment activity was indicated by "0". Consequently, the binary-matrix was intended to enable network analysis of the 55 listed Taiwan semiconductor firms. The visual evaluation of a network is first captured based on the network graph approach. Figure 1 shows network graph of the 55 listed Taiwan semiconductor firms , where a set of nodes represent the firms, and a set of arcs directed between pairs of nodes represent the directional CVC investments between firms. Table 1 shows four network indicators, reachability, degree centrality, constraint and



F1 (PTI)	F2 (ASE Inc.)	F3 (FST)	F4 (TMC)	F5 (MVI)
F6 (TSMC)	F7 (Ralink)	F8 (PPt)	F9 (Tong Hsing)	F10 (Orise Tech)
F11 (KYEC)	F12 (MXIO)	F13 (SONIX)	F14 (SPIL)	F15 (Sigurd)
F16 (SiS)	F17 (Sitronix)	F18 (PQI)	F19 (Nanya)	F20 (VIA)
F21 (SpringSoft)	F22 (IST)	F23 (SUNPLUS)	F24 (Weltrend)	F25 (PanJit)
F26 (HOLTEK)	F27 (MOSPEC)	F28 (Transcend)	F29 (GUC)	F30 (ALi)
F31 (ESMT)	F32 (KINSUS)	F33 (FARADAY)	F34 (Winbond)	F35 (Inotera)
F36 (Walton Chaintech)	F37 (Walton Advanced)	F38 (OSE)	F39 (LPI)	F40 (GREATEK)
F41 (SDI)	F42 (GTM)	F43 (Realtek)	F44 (ELAN)	F45 (Richtek)
F46 (Precision)	F47 (FATC)	F48 (GET)	F49 (DAVICOM)	F50 (MediaTek)
F51 (UMC)	F52 (NOVATEK)	F53 (ITE)	F54 (KB)	F55 (Rectron)

Figure 1. Network graph of the 55 listed Taiwan semiconductor firms

betweeenness centrality, and the corresponding four network characteristics of visibility degree, active degree, strategic position and degree of information control by the 55 listed Taiwan semiconductor firms , which are all calculated by UCINET (Borgatti et al. 2002) software. Additionally, Table 1 shows firm innovation capability (i.e., number of output patents) in the 55 listed Taiwan semiconductor firms.This exploratory study performed a network analysis of empirical data for intra-industry CVC investment (i.e. stocks exchange) among listed semiconductor firms in Taiwan. The examined network indicators were reachability, degree centrality, constraint and betweenness centrality with corresponding network characteristics of visibility degree, active degree, strategic position and degree of information control. The overall network analysis indicated that F51 (UMC) is the primary core firm, and the other is F14 (SPIL); moreover, F6 (TSMC) and F16 (SiS) also present more outstanding core firms. Nevertheless, seventeen firms are isolated, so no intra-industry CVC investment activity is occurring among the 55 listed semiconductor firms. As the whole network density is 2.22%, and degree centralization is 26.35%, which indicates that the network is characterized by low agglomeration and a pattern of highly concentrated structures and ties within the intra-industry investment network.

Visibility Degree

Reachability may indicate the level of visibility. The empirical results indicate that reachability ranges between 0 and 19. The mean reachability is 5.62, which means that each firm has an average of 5.62 connections in the intra-industry direct or indirect firm's investment activity. There are more than thirty firms over the mean on the reachability in the 55 listed Taiwan semiconductor firms CVC investment activities. The reachability value in orderly includes F8 (PPt), F10 (Orise Tech), F15 (Sigurd), F11 (KYEC), F14 (SPIL), F7 (Ralink), F29 (GUC), F35 (Inotera), F45 (Richtek), F6 (TSMC), F19 (Nanya), F36 (Walton Chaintech) and so on. The higher the reachability, the more visibility degree a firm is in the whole network. The F8 (PPt) consistently indicates outstanding visibility degree level by the highest reachability.

Active Degree

Degree centrality determines the characteristic of active degree levels. The empirical results indicated that degree centrality ranges from 0 to 17. The mean is 2.4, which means each firm has an average of 2.4 direct connections with other firms in the intra-industry CVC investment network. Analysis of CVC investment activities by the 55 listed Taiwan semiconductor firms indicated that more than twenty one firms exceeded the mean degree centrality. Firms can achieve high centrality if they can gain access to more active investment activities and influence others. The value of degree centrality in orderly includes F51 (UMC), F14 (SPIL), F6 (TSMC), F11 (KYEC) and F16 (SiS) to show Taiwan semiconductor mainly core investment listed firms. The higher the degree centrality, the more active the firm is in the network. Because it had the highest degree centrality, F51 (UMC) apparently had the highest active degree. Further, in directed networks, degree centrality can distinguish between the in-degree and the out-degree of each firm to measure its in-degree and out-degree centrality, respectively (Knoke & Burt 1983). Comparing in-degree and out-degree measures of a given firm can show whether the focal firm is an outbound or inbound firm among a group of firms. The initiative active degree firms were F51 (UMC), F50 (MediaTek), F24 (Weltrend), F43 (Weltrend), F34

Table 1. Network characteristics and innovation capability of the 55 listed Taiwan semiconductor firms.

No.	Firm abbreviation	Reachability (Visibility degree)	Degree centrality (Active degree)		Constraint (Strategic position)	Betweeness centrality (Degree of information control)	Innovation capability (Number of output patents)	
			Out-degree	In-degree			TIPO	USPTO
F1	PTI	1	0	1	1.00	181	181	47
F2	ASE Inc.	8	2	2	0.36	2,873	2,873	487
F3	FST	0	0	0	-	0	0	0
F4	TMC	1	0	1	1.00	0	0	0
F5	MVI	1	0	1	1.00	823	823	420
F6	TSMC	11	3	4	0.16	7,090	7,090	4,865
F7	Ralink	12	0	1	1.00	273	273	68
F8	PPt	19	0	3	0.33	740	740	75
F9	Tong Hsing	0	0	0	-	24	24	4
F10	Orise Tech	17	0	2	0.72	4	4	1
F11	KYEC	16	2	5	0.27	85	85	4
F12	MXIO	0	0	0	-	2,208	2,208	1,145
F13	SONIX	0	0	0	-	21	21	19
F14	SPIL	16	3	8	0.21	824	824	316
F15	Sigurd	17	0	1	1.00	24	24	3
F16	SiS	7	4	3	0.30	510	510	294
F17	Sitronix	0	0	0	-	39	39	2
F18	PQI	0	0	0	-	116	116	15
F19	Nanya	11	1	3	0.25	1,168	1,168	396
F20	VIA	8	3	1	0.29	2,881	2,881	946
F21	SpringSoft	8	0	1	1.00	17	17	15
F22	IST	0	0	0	-	106	106	0
F23	SUNPLUS	7	3	1	0.41	627	627	137
F24	Weltrend	0	5	0	0.26	99	99	9
F25	PanJit	0	0	0	-	23	23	2
F26	HOLTEK	8	2	1	0.37	180	180	88
F27	MOSPEC	0	0	0	-	0	0	0
F28	Transcend	0	0	0	-	36	36	1
F29	GUC	12	0	1	1.00	4	4	3
F30	ALi	8	1	1	0.50	224	224	38
F31	ESMT	0	1	0	1.00	72	72	39
F32	KINSUS	0	0	0	-	76	76	5
F33	FARADAY	8	1	2	0.43	418	418	204
F34	Winbond	0	3	0	0.33	1,458	1,458	983
F35	Inotera	12	0	2	0.50	1,226	1,226	0
F36	Walton Chaintech	10	0	1	1.00	0	0	0
F37	Walton Advanced	9	1	2	0.33	55	55	6
F38	OSE	7	2	1	0.56	73	73	17
F39	LPI	0	0	0	-	67	67	4
F40	GREATEK	9	0	3	0.33	3	3	1
F41	SDI	0	0	0	-	47	47	11
F42	GTM	0	3	0	0.33	4	4	0
F43	Realtek	7	4	1	0.22	1,132	1,132	275

F44	ELAN	0	1	0	1.00	321	321	30
F45	Richtek	12	0	2	0.50	20	20	13
F46	Precision	0	0	0	-	7	7	0
F47	FATC	8	1	1	0.50	1	1	1
F48	GET	0	0	0	-	1	1	1
F49	DAVICOM	8	0	1	1.00	3	3	2
F50	MediaTek	7	6	1	0.21	1,660	1,660	506
F51	UMC	7	12	5	0.14	5,259	5,259	3,010
F52	NOVATEK	9	1	2	0.37	512	512	95
F53	ITE	8	1	1	0.58	67	67	6
F54	KB	0	0	0	-	18	18	6
F55	Rectron	0	0	0	-	0	0	0
Mean		5.62	1.20	1.20	0.55	7.53	617.73	617.73

(Winbond) and F42 (GTM) to display Taiwan semiconductor outbound investment listed firms, since in-degree as relatively lower than out-degree in these firms. In contrast, the passive active degree firms were F14 (SPIL), F11 (KYEC), F8 (PPt) and F40 (GREATEK) to present Taiwan semiconductor inbound investment listed firms, since in-degree was relatively higher than out-degree in these firms.

Strategic Position

Constraint can be measured by structural holes, which is the extent to which a firm is directly and indirectly dependent on others, via crisscrossing connections and the absence of structural holes. The empirical data indicated that constraint ranged from 0.14 to and 1, and mean constraint was 0.55. Twenty-four firms were below the mean. In order of the firms below the mean were F51 (UMC), F6 (TSMC), F14 (SPIL), F50 (SPIL), F43 (Realtek), F19 (Nanya), F24 (Weltrend) and F11 (KYEC) to be mostly placed in a non-substitutable strategic position in the 55 listed Taiwan semiconductor firms. Notably, F51 (UMC) and F6 (TSMC) had advantageous strategic positions since they had the lowest constraints.

Degree of Information Control

Betweenness centrality ranged from 0 to 140.5, and mean betweenness centrality was 7.53. Ten firms that exceeded the mean were, in order of betweeness centrality score, F51 (UMC), F50 (MediaTek), F14 (SPIL), F16 (SiS), F6 (TSMC), F43 (Realtek), F11 (KYEC), F2 (ASE Inc.), F37 (ASE Inc.) and F20 (VIA) to more control degree of information or communication between pairs of other firms. A firm with high betweenness centrality is a critical intermediary between pairs of other firms since most investors stop at this firm when making investments involving various other firms. The semiconductor firm UMC had the highest degree of information control of the 55 listed Taiwan semiconductor firms with the highest betweenness centrality.

Network Characteristics and Innovation Capability

This study then examined the network characteristics of the firm itself, including visibility degree, active degree, strategic position and degree of information control, interacts with its firm innovation capability (i.e., number of output patents) by Pearson correlation analysis. The values in parenthesis show p value (*p<0.05, **p<0.01, ***p<0 001) by Pearson correlation analysis. Table 2 shows the correlation between network characteristics and firm innovation capability by Pearson correlation analysis in the 55 listed Taiwan semiconductor firms. (See Table 2. at the end of this article.)

Analysis of the correlation between visibility degree and innovation capability, the result is not a significant positive correlation with both USPTO and TIPO, consequently, a higher firm's visibility degree will not be better or worse correlation with its innovation capability. Additionally, the correlation between visibility degree and active degree is a highly significant positive correlation. However, the correlation between visibility degree and initiative active degree is not a significant positive correlation, but the correlation between visibility degree and passive active degree is a highly significant positive correlation. Further, the correlation between visibility degree, strategic position and degree of information control is also not a significant positive correlation.

Analysis of the correlation between active degree and innovation capability revealed that active degree is significantly and positively correlated with both USPTO and TIPO; therefore, a high active degree indicates strong innovation capability. Additionally, both initiative and passivity/activity are significantly and positively correlated with innovation capability. Further, the correlation between active degree, strategic position and degree of information control was significantly positive. Moreover, the correlation between initiative and passivity/activity and strategic position and degree of information control are also a highly significant positive correlation. And the correlation between initiative and passive active degree was significant and positive, which indicates that firms with high initiative active degree have high passive active degree.

Analysis of the correlation between strategic position and innovation capability, the result is a highly significant positive correlation with both USPTO and TIPO, so a higher firm's strategic position will be better correlation with its innovation capability. Additionally, strategic position and degree of information control were significantly and positively correlated; therefore, a good strategic position indicates better information control.

Analysis of the correlation between degree of information control and innovation capability revealed a highly significant positive correlation between information control and USPTO and TIPO. Therefore, a higher degree of information control can increase innovation capability.

Conclusion

This study examined network linkages among high-tech firms that increase the strategic growth and innovation resulting from intra-industry CVC investment by Taiwan semiconductor firms. This phenomenon was addressed by examining the network characteristics of the 55 listed Taiwan semiconductor firms' intra-industry CVC investment activities by network analysis, which offers network indicators of reachability, degree centrality, constraint and betweenness centrality with corresponding network characteristics of visibility degree, active degree, strategic position and degree of information control. Additionally, the focus on exploring the correlation between network characteristics and firm innovation capability we have suggested four findings for practically many implications and strategic directions among the semiconductor intra-industry CVC investment activities based on the empirical results. The findings of this study are summarized below.

First, a firm with a high degree of visibility may not have particularly high innovation capability. Therefore, a firm that invests in a high-visibility firm may reap only minimal innovation increases. However, the investment may significantly improve its active degree, especially passive active degree, in the semiconductor intra-industry CVC investment network. Therefore, firms with high visibility and high passivity-activity, such as F14 (SPIL), F11 (KYEC), F8 (PPt) or F40 (GREATEK), should passively invest in other firms. That is, a higher both visibility degree and passive active degree firm is always the focus of its original business activity; a few firms involve with the intra-industry upstream and downstream CVC investment activities.

Second, five core firms with high active degree and initiative and passivity/activity, namely F51 (UMC), F14 (SPIL), F6 (TSMC), F11 (KYEC) and F16 (SiS), have high innovation capability. For the purpose of increasing itself innovation capability, a firm can help itself look for new technology breakthrough and control intra-industry technology development trend. These core firms are attractive investments because they have superior innovation capability in the semiconductor intra-industry CVC investment network.

Third, in firms those are strategically positioned, including F51 (UMC), F6 (TSMC), F14 (SPIL), F50 (SPIL), F43 (Realtek), F19 (Nanya), F24 (Weltrend) or F11 (KYEC), can enhance their innovation capability in order to acquire developing technology that can be used to implement strategies for substituting or integrating technology in the semiconductor intra-industry CVC investment network. Therefore, these firms with diversified technology can seek new technology knowledge, the more opportunity it can identify the potential developing technology with its original unrelated or low related business and develop in technology substitution and technology integration for upgrading innovation capability.

Finally, the higher the degree of information control in firms such as F51 (UMC), F50 (MediaTek), F14 (SPIL), F16 (SiS), F6 (TSMC) or F43 (Realtek), the greater the importance of information handling. Therefore, according to a firm itself global patent strategy and beforehand developing innovation capability demand, it can handle in information and communication technology to influence the industry development directions and the leading mainstream technologies through the semiconductor intra-industry CVC investment activities. Investing in a firm with better information control, a firm can upgrade its own innovation capability by applying its R&D and patent strategy to catch up the leading mainstream technologies in the semiconductor industry.

In summary, this paper found that the core semiconductor firms with high active degree can enhance knowledge sharing and technology diffusion in the intra-industry CVC investment activities. Additionally, intra-industry CVC investment activities can help leading firms strategically position themselves to acquire knowledge needed to upgrade architecture, integrate new flat-top technology, etc.; further, the increased information control enables them to obtain new component information needed to enhance component innovation or incremental innovation etc. as the next step growth motivation. Therefore, a firm can upgrade its innovation capability by the intra-industry CVC investment activities; if a firm itself technology development direction is uncertain. A high-tech semiconductor firm can seek and find potential technology through extensive low-involvement and low-risk CVC investment (i.e. stocks exchange) activities.

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Table 2. Correlation between network characteristics and firm innovation capability.

Pearson Correlation (N=55)	Visibility degree (Reachability)	Active degree (Degree)	Initiative active degree (Out-degree)	Passive active degree (In-degree)	Strategic position (Constraint)	Degree of information control (Betweeness centrality)
Visibility degree (Reachability)	1					
Active degree (Degree)	0.439**	1				
Initiative active degree (Out-degree)	0.118	0.889**	1			
Passive active degree (In-degree)	0.710**	0.791**	0.422**	1		
Strategic position (Constraint)	-0.163	-0.685**	-0.607**	-0.476**	1	
Degree of information control (Betweeness centrality)	0.198	0.882**	0.873**	0.579**	-0.454**	1
Innovation capability (TIPO)	0.183	0.618**	0.596**	0.426**	-0.456**	0.604**
(USPTO)	0.119	0.561**	0.538**	0.392**	-0.376*	0.561**

Note: *p<0.05, **p<0.01, ***p<0 001