Technological Network and Firm Performance: An Empirical Study of the Semiconductor Industry

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ABSTRACT

This study examines whether or not the positions of the network affect firm performance. A sample set involves 35 firms in the semiconductor industry, including four main subsidiary industries: fables, IC manufacturing, packaging and testing. Different from previous research, this study tests relational measurement and firm performance. We collected patent citation data to represent diverse organizations and provided evidence that positions within networks, as defined in terms of contact and controlled positions within networks are related to firm performance. As hypothesized, firm performance was positively related to degree centrality and betweenness centrality in networks, and was negatively related to constraints in networks. Results show that betweenness centrality was significantly and positively related to firm performance.
Key words: technological network, network position, patent citation, firm performance

INTRODUCTION

Although a growing body of management theory and research focuses on the innovative performance of companies, the management and applied economics literature on innovation and related topics have a long history of struggling in regards to the measurement of the innovative performance of companies. Basically, available measures such as R&D expenditures (Duysters and Hagedoorn, 2001; Henderson and Cockburn, 1994), patents counts (Meyer, 2000; Stuart, 2000; De Carolis, 2003), patent citations (De Carolis, 2003), or counts of new product announcements (Hitt, Hoskisson, Johnson, and Moesel, 1996) have been used in capturing innovative performance and firm performance.

Though the patents measuring the use of raw patent counts are subject to a long-standing debate with regard to its bias and deficiencies (Archibugi, 1992; Griliches, 1990), it appears that raw patent counts were generally accepted as one of the most appropriate indicators that enabled researchers to compare the inventive or innovative performance of companies in terms of new technologies, new processes and new products (Patel and Pavitt, 1991; Pavitt, 1988). Furthermore, De Carolis (2003) argued that developing and sustaining technological capabilities is crucial to continuous innovation in high-tech companies, and he used a total number of patents to measure technological capabilities that was positively related to firm performance (measured by return on assets). Therefore, in this study, we focused on why patent citations are important to firms and how they affect them.

Gradually, more and more researchers will be using patent citations as an indicator of inventive performance of companies. Compared to raw counts of patents, patent citations also include a measure of the quality of patents. The fundamental assumption using this indicator was positively related with the importance of patent and the degree to which a patent is cited in later patents (Meyer, 2000). This information on earlier patents can be traced in each patent application as it is required that each patent cites earlier patents with somewhat similar or related technical claims. The number of patent citations for a particular patent showed its importance or impact. Evidence of the validity of patent citations as an indicator of the quality of innovations, regarding the correlation between the inter-subjective assessment of the importance of patents by technical specialists and the number of citations, was found in several studies (Albert et al., 1991; Narin et al., 1987; Pavitt, 1988). In addition, Meyer (2000) showed that an increasingly science-based technology might convey the impression that there was direct knowledge-transfer going on, which was reflected in citations to scientific research papers in patents.

Therefore, the distinctive attributes of this study emphasizes on how the structural properties of social networks explains a firm's outcomes. Centrality, the extent to which a given firm was connected to others in a network, is the structural measurement most often related with instrumental outcomes. While occupied on the central position within a network, firms get more resources and control more information. Therefore, we collected patent citation data to build relational network data to examine the relationship between network positions and firm performance.

LITERATURE REIVEW AND HYPOTHESES

One research stream regarding the social network can be seen as a source of social capital, and there is a growing body of studies focusing on the relationships between network features, configurations, structures and their benefits, including better performance (Zaheer and Bell, 2005), technical and administrative innovation (Ibarra, 1993), technological exchange (Stuart, 1998), individual and group performance (Sparrowe et al., 2001), managerial performance (Moran, 2005), and knowledge transfer (Reagans, and McEvily, 2003).

These critical findings are in multiple-levels of analyses, which include individuals, groups, and inter-firms. Tichy, Tushman, and Fombrun (1979) provided a systematic social network analysis for organizations, which include transactional context, nature of the links, and structural characteristics. Kenis and Knoke (2002) also introduced a complete and detailed set of network variables such as density, reciprocity, connectivity, multiplicity, cohesion and hierarchy to subsequent nonlinear change in inter-organizational change.

Besides, one strategic management theory of the firm based on resource-based view argues that the firm possessing a bundle of unique, valuable, rare and inimitable capabilities will determine better firm performance and competitive advantage in the long term (Barney, 1991). If firms can hold and control specific capabilities, they will perform better than those firms which cannot. Furthermore, De Carolis (2003), basing these on core competencies and resource-based view, addressed that technological capabilities make a difference in firm performance by developing and exploiting these inimitable capabilities. Therefore, in this study, we emphasized on an individual firm’s structural attributes, primarily on centrality and firm performance, because we were interested in how a prominent firm can perform better in the semiconductor industry with its distinctive network position.

There are many debates going on regarding the structural approach within the social sciences, and these have resulted in new controversies; however, the most central debate concerns the fundamental nature of intercorporate relations in advanced capitalist societies and the lines which have been drawn are between the resource dependence and social class perspectives. Pfeffer (1987) made an attempt to sort out the proponents of the two perspectives: resources dependence and social class, and searched for issues on which these two models diverged. Resource dependence perspective views companies as the primary actors in a business community, where corporate leaders serve mainly as agents of organizations in which they are affiliated with. Social class, however, view corporations as tools of a dominant social class whose interests both embody and transcend those of any particular organization. Therefore, the debate between the two perspectives focused around divergent interpretations of the same data.

Pfeffer and Salancik (1978) took the external perspective to discuss organizational behavior and outcome. For survival, they noted the problem of the acquisition of resources by social organizations. However, the most critical argument about the resource dependence perspective is that they heavily stress the context of the organization and ignore other important factors. Pfeffer and Salancik (1978) was able to relate inter-corporate relations to patterns of resource dependence. (1) Symbiotic dependence means that the output of one organization is the input of another. Vertical relations, such as supplier and manufacturer, could be an example of symbiotic dependence. Therefore, if the proportion of transactions is larger, the level of dependence will be higher. (2) Commensalistic dependence means that the organizations compete in the same niche. This kind of relation could be analogous to the competitors in the same industry. This kind of dependence is greater and most problematic at intermediate levels of market concentration.

Besides, inter-firm relations will be pursued to reduce constraints on profit (Burt, 1983). Burt also identified the “autonomy” to measure the extent of dependence. By managing resource interdependencies through mergers to reduce uncertainty, firms attempt to restructure their relationship with their environment (Pfeffer, 1972). Therefore, we can argue that firms that control the specific interdependent resource will manage the firms’ uncertainty.

In brief, researches that are based on social network perspective have contributed a number of important insights to social power. Perhaps, most importantly, the network approach that addresses that power is inherently relational. All sociologists would agree that power is a fundamental characteristic of social structures. In this study, we captured the power view of social structure to measure the linkage of the firms in the semiconductor industry. An individual firm does not have power in the abstract, but they have power because they can dominate others (Hanneman and Riddle, 2005). Because power is a consequence of patterns of relations, the amount of power in social structures can be different. Besides, network analysts often described the way an actor was embedded in a relational network as striking constraints on the actor, and offering the actor opportunities.

Therefore, inter-firm research can argue that firms that faced fewer constraints and had more opportunities than others were in advantageous structural positions. Having a favored position represents that firms may extract better bargains in exchanges, have greater influence, and that firms will perform better than those in less favored positions. In addition, network analysts were more likely to describe their approaches as descriptions of centrality than of power. Hanneman and Riddle (2005) proposed three approaches (degree, closeness, and betweenness) to describe the positions of individuals in terms of how close they are to the center of the action in a network. Therefore, we focused on in-degree centrality, out-degree centrality, and betweenness centrality to demonstrate how central positions affect.

Contact Positions within Network and Firm Performance

We used density centrality as an indicator to measure a firm's contact position within a network. There are two indicators for measuring degree centrality, which are in-degree and out-degree, to distinguish the relationship of resource sending from resource receiving. Degree centrality measures a firm's capacity to develop communication within a network. In addition, firms who have more ties to other actors may occupy advantaged positions. Because firms have many ties, they may have alternative ways to satisfy needs, and hence rely less on other firms. Because firms have many ties, they may have access to, and be able to, control more of the resources of the network as a whole. Because firms have many ties, they are often third-parties and deal makers in exchanges, among others, and are able to benefit from this brokerage. Because of this, the effective measure of an actor's centrality and power potential is their degree. Hence, we chose degree centrality because it measures a firm's capacity to develop communication within a network. It shows that firms who are tied to very central positions should have higher centrality than those who are not. Therefore, if firms are more central in the industry network, they will have more opportunities to develop communication with other actors and will have more opportunities to perform better than other firms, which are less central. The following hypothesis can be reasonably established:

Hypothesis 1: Firms that occupy higher-level contact positions within networks will have positive relationship with firm performance.

Controlled Positions within Networks and Firm Performance

We used betweenness centrality as an indicator to measure a firm's contact position within a network. Betweenness centrality emphasizes on how many relationships that are involved, and how much an actor can access, control, and negotiate within the networks. It also measures a firm's capacity to control communication in a network, while information centrality concerns the relationship between information quality and the length of geodesic. Moreover, betweenness centrality regards a firm as being in a favored position to the extent that the actor falls on the geodesic paths between other pairs of actors in the network. In other words, the more firms depend on specific firms to make linkages with other firms, the more power the specific firms have. In this study, we also used constraints to measure positional advantages or disadvantages of firms that result from their embeddedness in networks. Burt (1992) developed a number of measures (including a computer program structure that provides these measures and other tools) to evaluate the term 'structural hole' of firms within networks. Also, he facilitated a great deal of further thinking about how and why firms connect and how they affect their constraints and opportunities, and hence the outcome of their behavior. Therefore, firms that occupied the central position (higher betweenness centrality) or less constraining to others will be positively related to firm performance. Therefore, we can establish the following hypothesis:

Hypothesis 2: Firms that occupy higher-level controlled positions within networks will have positive relationship with firm performance.

METHODS

Sample and Procedures

Our initial sample set contains 53 semiconductor industry companies listed in Taiwan. These 53 firms collectively make up a total of 56,932 citations to 11,089 patents. After excluding patents that do not apply, but including only patent citations themselves, our final sample set contains 35 companies, including 19 Fabless companies, 9 IC manufacturing companies, 4 packaging and testing companies, and 3 others, which remain. We also gathered the profiles and financial data of these companies from the Taiwan Economic Journal Data Bank (TEJ) from 1999 to 2005, and patent data from the United

States Patent and Trademark Office (USPTO) from 1990 to 2005. We used patent citation data to build 7 35 × 35 symmetric and asymmetric matrixes, in which the row actor sent a citation to the column actor.

Measures

Independent variables consist of contact positions and controlled positions that represented degree centrality and betweenness centrality of firms within a network. Degree centrality, including in-degree centrality and out-degree centrality, is calculated by the number of ties to others, and we used degree centrality to measure the extent of contact within networks. In-degree centrality (NrmInD) and out-degree centrality (NrmOut) represent directed ties. We measured the extent of contact within network using two variables, in-degree and out-degree (Wasserman & Faust, 1994). We computed normalized in-degree centrality scores for each actor to allow for comparisons across actors. In-degree centrality is a form of degree centrality that counts only those relations with a focal company cited by other companies, and thus it does not suffer from the limitations of self-reports, and neither does out-degree centrality. Degree centrality was computed following Freeman's (1979) definition in the UCINET IV software package (Borgatti, Everett, & Freeman, 1992).

Bonacich (1987) proposed a modification of the degree centrality approach that has been widely accepted as superior to the original measure. Bonacich's idea, like most good ones, is pretty simple. The original eigenvector centrality approach argues that actors who have more connections are likely to be more powerful because they can directly affect more actors. This makes sense, but having the same degree does not necessarily make actors equally important.

We measured the extent of control within networks using betweenness centrality (nBetwee). Betweenness centrality measures the position of a given actor that represents geodesic paths between other actors in the graph. It is defined as the number of times any given actor *i* needs actor *k* (the subject of the measurement) to reach any other given node, *j*, in a geodesic path. If g_{ij} is defined as the number of geodesic paths between *i* and *j*, and g_{ikj} is the number of these geodesics that pass through *k*, *k*'s betweenness centrality is defined as (Freeman, 1979): $\sum_i \sum_j \frac{g_{ikj}}{g_{ij}}, \quad i \neq j \neq k$. If the boundaries of the graph are assumed to mediate flows of any kind (information, for example), the elimination of actors with high betweenness centrality will most dramatically restrict these flows. Therefore, betweenness centrality is generally defined in terms of an undirected graph. We computed betweenness centrality based on Freeman's (1979) definition in the UCINET IV software package (Borgatti, Everett, & Freeman, 1992).

The dependent variables were firm performance indicators that were assessed by return on assets (ROA) and return on equity (ROE). Return on assets was computed as the income (or loss) before extraordinary items and other adjustments, was annualized and then divided by average total assets. Return on equity was computed as the income (or loss) before extraordinary items and other adjustments, was annualized and then divided by average total equity. Both financial measures were obtained from the TEJ data base.

In this study, we included several control variables in the model. These control variables included the firm size as measured by the log of number of employees (logem), lagged one year firm sales (lagsa1), lagged one year log of R&D expenditures (lagRD1), lagged two year log of R&D expenditures (lagRD2), and number of patent (Nopatent). The reason for lag sales and R&D expenditures is because these input resources for new invention of patents will not be carried out in the same year. Aside from this, we want to control the firm size effect, so we use number of employees and patents as controlled variables. In addition, we also infer that firms founded earlier will have more accumulated and sophisticated knowledge of the industry than the younger firms. We then measured firm age (firmyear) as 2005 minus the founding year, and held it as the control variable.

RESULTS

We analyzed random-effects GLS regression on ROE and ROA by using Stata 8.0. Correlations among study variables are reported in Tables 1 and 3. We analyzed general correlations for each variable of this research in Table 1. We found that all control and independent variables were almost positively related to other control and independent variables (except constrain). We also found that the firm year was significantly negatively related to both dependent variables (ROE and ROA). The same correlation was also found in out degree centrality.

Table 1: Correlation

	ROE	ROA	lagsa1	lagRD1	lagRD2	Nopatent	firmyear	logem	NrmOut	NrmInD	nBetwee	Constr
ROE	1.0000											
ROA	0.8628**	1.0000										
lagsa1	-0.0307	-0.0102	1.0000									
lagRD1	0.0412	0.0787	0.8398**	1.0000								
lagRD2	-0.0443	-0.0747	0.8075**	0.8822**	1.0000							
Nopatent	-0.0088	0.0371	0.5252**	0.4214**	0.4018**	1.0000						
firmyear	-0.2246**	-0.2696**	0.4206**	0.2914**	0.3070**	0.2691**	1.0000					
logem	-0.1106	-0.1464*	0.8865**	0.7280**	0.6525**	0.5268**	0.5121**	1.0000				
NrmOut	-0.1327*	-0.1354*	0.6374**	0.5310**	0.5423**	0.7392**	0.2958**	0.6092**	1.0000			
NrmInD	-0.0663	-0.0513	0.6224**	0.5090**	0.5215**	0.7367**	0.3374**	0.6023**	0.7842**	1.0000		
nBetwee	-0.0077	0.0220	0.4667**	0.3722**	0.3872**	0.7170**	0.3001**	0.4559**	0.6586**	0.7483**	1.0000	
Constr	0.0402	-0.0174	0.1741*	0.1373*	0.1644*	0.0425	0.0570	0.1354*	0.1721*	0.1102	-0.0278	1.0000

** p<0.01, * p<0.05

Table 2 presents the results of the regression analyses testing the hypothesized relationships between network structural variables and firm performance. We controlled for organizational differences by entering the organization attribute variables in Model 1, followed by the density centrality, betweenness centrality, and constraint measures in Model 2 for both dependent variables.

Table 2: Random-effects GLS regression on ROE and ROA

	ROE		ROA	
	Model 1	Model 2	Model 1	Model 2
_cons	-0.2687	-0.1001	4.7332	-3.8610
	(0.4581)	(0.5269)	(19.8947)	(26.5377)
lagrd1	-0.0240	-0.0411	-4.4582	-0.1520
	(0.0943)	(0.1247)	(3.9013)	(5.5848)
lagrd2	-0.0543	-0.1710	-2.2439	-8.5806
	(0.0480)	(0.1292)	(1.8507)	(5.7942)
logem	-0.0257	-0.1883*	-1.0867	-7.7779
	(0.1105)	(0.1014)	(4.7707)	(5.3974)
lagsa1	0.1454	0.3243**	8.3909	13.8609**
	(0.1359)	(0.1290)	(5.5855)	(6.1375)
nopatent	-0.0002	0.0001	-0.0065	-0.0069
	(0.0004)	(0.0004)	(0.0176)	(0.0183)
firmyear	-0.0133**	-0.0055	-0.6287**	-0.2087
	(0.0065)	(0.0055)	(0.2976)	(0.3164)
nrmout		-0.0153**		-0.5588**
		(0.0060)		(0.2861)
nrmind		0.0000		0.2699
		(0.0055)		(0.2942)
nbetwee		0.0417**		1.7628*
		(0.0203)		(0.9797)
constr		-0.3078		-4.5108
		(0.3847)		(17.7260)

* p<0.1, **p<0.05, ***p<0.01 N=245 Standard errors in parentheses.

We found that the firm year was negatively related to both ROE and ROA. This might be the observation of relatively specialized firms, which were founded in recent years and had advanced technology and capabilities to carry out higher performance.

With regard to independent variables, we found that out degree centrality had negative influences on both ROE and ROA and it was not significant to above dependent variables in degree centrality. Results show that Hypothesis 1 was not supported, and reversed our prediction that the more connections a firm had, the higher the performance it will achieve. The significantly negative correlation between out degree centrality and performance might be that the more citations from other firms there is, the more loyalty these firms should pay to and become more resource-dependent. This finding may respond to the resource dependency approach, that the more citations from focal firms there are, the more firms will depend on them, which in turn will generate more power and influences.

Concerning Hypothesis 2, we found that betweenness centrality had positive influences on both ROE and ROA; however, the constraint did not. This was consistent with our prediction that the more between positions one has, the more its control and innovation abilities it possesses. However, we found that one firm, which possesses a structural holes position, could not perform better than the others. We found that Hypothesis 2 was supported.

DISCUSSION

Technological Network Positions and Firm Performance

The results of this study offer support for the hypothesized relationships between the extent of control within network and firm performance. Firms who were central in their industrial networks had higher levels of firm performance than firms who were not central players in such network. We found that firms with high betweenness centrality within network carried out higher levels of firm performance. These results are important because they reveal that firms who are central to other firms within networks are rated more positively on firm performance. As a result, they can perform better than those who do not occupy the vital control positions within networks. Additionally, firm performance traditionally has been evaluated on the basis of capabilities and resources that firms have. Therefore, our results showed that firms that occupied the central control position within networks had more power to manage information and resources, results different from previous researches. Although these points of views are certainly important, we want to emphasize that firms engaged on the central control position definitely affect firm performance, especially firms that have high betweenness centrality.

However, the results of this study did not offer support for the hypothesized relationships between the extent of contact within network and firm performance. We found that the out-degree centrality has negative significant relationship with firm performance, both in ROA and in ROE. The results show that, compared with central controlled networks of firms engaged in managing important information and resources, there are also a higher level of contact networks of firms that engage in blocking contacts with other firms in the network. From resource dependency perspective, firms that have more patent citations on other firms may depend more on other firm's technology know-how and may need to pay more loyalty to the cited firms. Hence, firms that occupy contact positions within networks have worse firm performance. Furthermore, future research should examine the moderated effect or mediated effect of firm performance in which firms are in a central contact position within networks based on the resource dependency approach.

This study proposed the dynamic notion to capture more the proper evolution of a firm within the industry, but results showed that the dynamic measurements were not related with firm performance. Future research may develop more appropriate indicators to mapping the trajectory of firms.

Technological Networks of IC Industry

After running symmetric and asymmetric network data using UCINET 6.0, we can draw the whole semiconductor industry and each subsector network both in graph and digraph (unidirectional and directional). Figures 1 present networks in the whole industry during 1999 to 2005. Figure 1 was a semiconductor industry network with 35 companies. We discovered that IC manufacturing companies in the center of a network hold the core positions within the network. Simultaneously, foundry, testing and packing companies occupied the peripheral positions within a network. In this study, we also found some interesting relationships between subsidiary industries in the IC Industry. Fabless companies constituted a nearly line network within a subsidiary industry network in Figure 2. IC manufacturing was highly connected with each other within the subsidiary industries network in Figure 3. In Figures 4 to 7, comparing two subsidiary industries separately, we still found that IC manufacturing companies block the central position within the network and foundry, while packing and testing firms remained in the border area of the network. Taiwan's IC industry has a distinctive infrastructure of vertical disintegration. Vertical disintegration means dividing an industry into several segments, from upstream to downstream, with each firm concentrating on certain functions of certain segments. Semiconductor manufacturing segments are marketing, designing, masking, manufacturing, testing and packaging. In this study, we control some attributes of firms, like firm size and firm age to show that the different positions of network affect firm performance. After drawing the networks of the IC industry, we may suggest future research to examine the diversity of the subsidiary industries network. We may analyze the structural equivalence of different position firms.

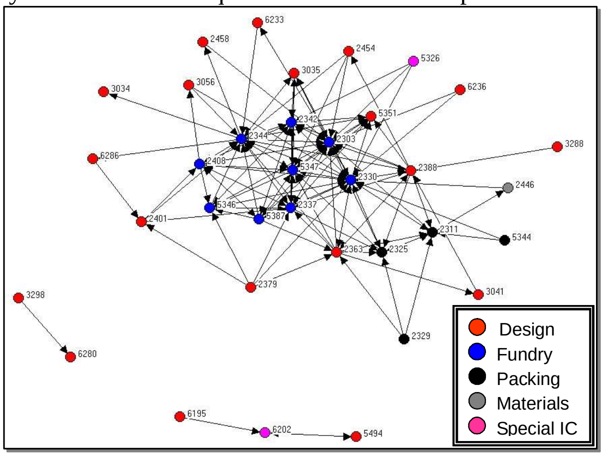

Figure 1: Semiconductor Industry Network

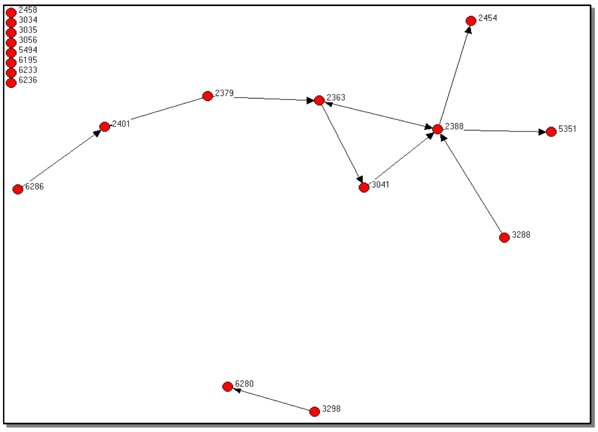

Figure 2: Fabless Network

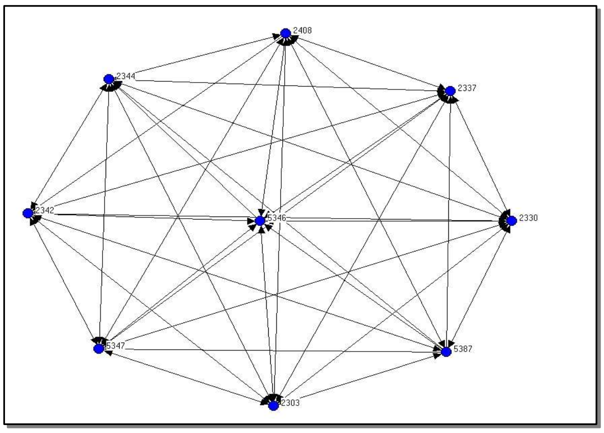

Figure 3: IC Manufacturing Network

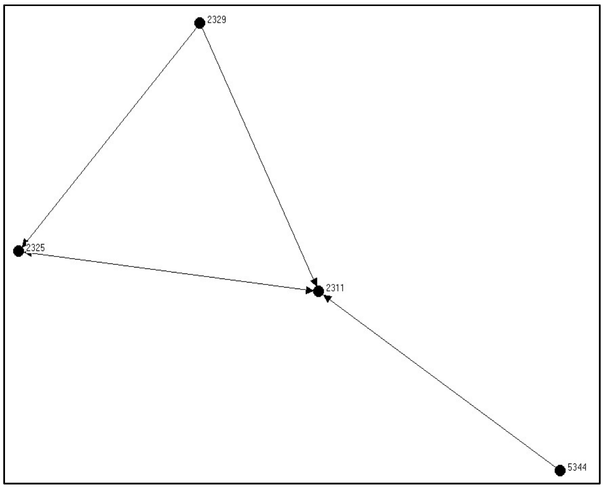

Figure 4: Packaging and Testing Network

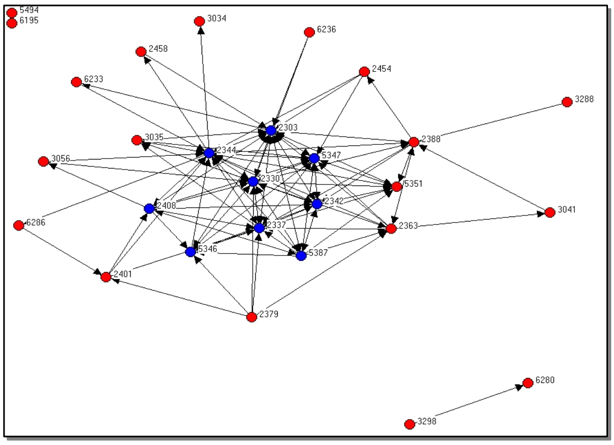

Figure 5: Fabless and IC Manufacturing Network

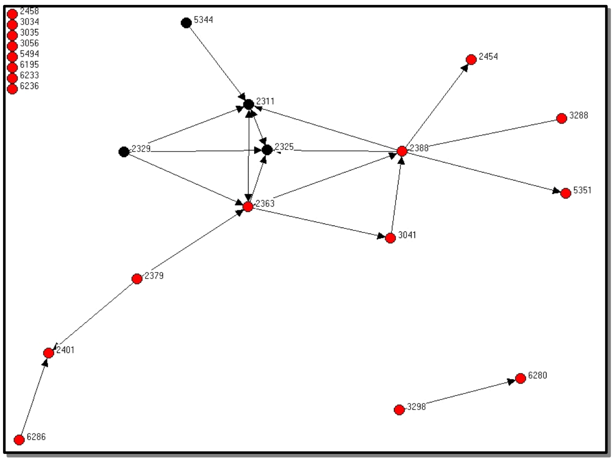

Figure 6: Fabless, Packaging and Testing Network

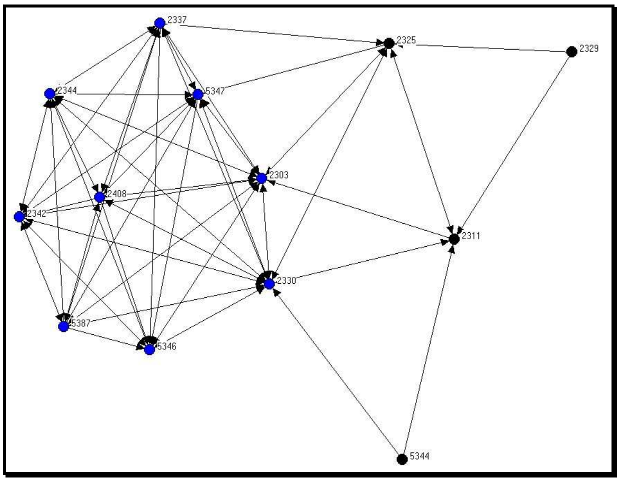

Figure 7: IC Manufacturing, Packaging and Testing Network

Limitations

In this research, we faced some limitations that we were not able to elaborate further. First is the limited number of firms, which is not enough. If the number of firms in each sector could be increased, we could give evidence to divide the industry hierarchy into more levels in terms of recognized positions. Second, we only focused on the semiconductor industry, which is not conclusive. Therefore, we could not compare the relative importance of patents in different industries.

CONCLUSION

In summary, this study contributes to several streams of research. First, it adds to the social network and firm performance literatures by demonstrating a relationship between network structure and firm performance in the semiconductor industry. In addition, these findings enhance the social network literature by revealing that rarely studied positions within networks are positively related to firm performance. Taken together, the results of the current study provide a strong rationale for the combination of modern social network analysis and technological capabilities research.

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