Review of Quantitative Finance and Accounting, 26: 67–84, 2006

Patent Citation, R&D Spillover, and Tobin's Q: Evidence from Taiwan Semiconductor Industry

CHEN-LUNG CHIN
Department of Accounting, National Chengchi University, No. 64, Sec 2, Jhihnan Rd., Taipei City, 116, Taiwan
E-mail: kim@nccu.edu.tw

PICHENG LEE*
Department of Accounting, Lubin School of Business, Pace University, New York, NY 10038, USA
E-mail: plee@pace.edu

HSIN-YI CHI
Department of Accounting, National Taichung Institute of Technology, No. 129, Sec. 3, Sanmin Rd., Taichung City, Taiwan
E-mail:syjsj6273@mail.ntit.edu.tw

ASOKAN ANANDARAJAN
School of Management, New Jersey Institute of Technology, Newark, NJ 07102-1982, USA
E-mail:anandarajan@adm.njit.edu

Abstract. Although prior research has examined the effect of patent citations on Tobin's Q in a variety of environments, in this study we examine whether the parameters are affected by stage of a company in the value chain. Unlike other national semiconductor firms, Taiwanese semiconductor firms typically specialize in one of the value-added activities, namely, either design or manufacturing or packaging and testing. Our finding is that the effect of patent citation on Tobin's Q is accentuated when the firm is at the front end of the value chain and diminishes as we proceed to the back end. This finding is novel in the literature. We also find that frequency of patent citations and R&D spillover are positive and significant in relation to Tobin's Q. In addition, the effect of R&D spillover on Tobin's Q is more pronounced for firms in the design sector relative to other sectors.

Key words: patent citation, R&D spillover, Tobin's Q

JEL Classification: M41, O3

1. Introduction

In the accounting literature a widely accepted paradigm proposes that financial-statement information is useful to potential investors. However, researchers have observed that the value relevance of financial statement information has gradually declined[1]. Subsequent research, therefore, examined the value relevance of non-financial information. Most of the research that focuses on non-financial information examines how firm valuation

*Corresponding author. Authors are grateful for insightful comments and suggestions from an anonymous reviewer. Picheng Lee also gratefully acknowledges a research grant from Lubin School of Business at Pace University.

is impacted by extent of R&D activity[2]; advertising activity (Hall, 1993); trademarks (Bosworth and Mahdian, 1999); and brand (Kallapur and Kwan, 2004). Patenting activity, the focus of this study, deserves further investigation.

The first objective of this paper is to explore whether citations of patents cross-filed and granted in the United States for Taiwanese semiconductor firms (measured by number of patent citations) are associated with Tobin's Q. Patent citations refer to the citing of patents by a company in its respective patent application (Shane and Klock, 1997 among others). Watanabe et al. (2001) note that patent applications to foreign countries, especially from the United States, provides a better demonstration of innovational ability. In addition, they indicate that patents granted by the United States Patent and Trademark Office (USPTO) enhances a firm's visibility and exposure.

Early U.S. studies conclude an association between patent count and market value (e.g., Connolly and Hirschey, 1988; Griliches, 1990). For example, Trajtenberg (1990) observes that patent count is a "noisy" measure of innovative activity.[3] To address this criticism, we follow Hall et al.'s (2001a) methodology to examine association of patent activities and Tobin's Q by using patent citations as a proxy for the importance of knowledge contained in a patent.

Patent citations are sound surrogates of technological competence because they are objective, and not quoted at the whim of the inventor[4] (De Carolis, 2003). Therefore, it provides a good indication of the relevant state of the art (Campbell and Nieves, 1979; Trajtenberg, 1990). Secondly, patent citations signal valuable technological knowledge (De Carolis, 2003). The number of times a patent document cited is a measure of its technological significance (OTFA, 1976, p.167), hence citations may be a more pronounced indicator of the "importance" of the cited patent (Jaffe, Trajtenberg and Fogarty, 2000). Empirical studies establish the validity of patent citation analysis as indicators of technological competence[5]. Shane and Klock (1997) recognize that citations contain information above and beyond simple patent counts in firm valuation for the semiconductor industry. Likewise, Hirschey et al. (2001) conclude that patent citations are value relevant. In this paper, we propose that citations of patents cross-filed and granted in the U.S. for Taiwanese firms are positively related to Tobin's Q.

The second objective of this study is to enhance and to present a fresh perspective to the extant literature by examining how different stages in the value-added-chain in the semiconductor industry affect the relationship between patent citations and Tobin's Q. The semiconductor industry is selected for the current study because of the strategic importance of intangible capital such as patents in this segment of the electronics industry[6]. Currently there are two types of semiconductor systems. The first type is the integrated device manufacturing (IDM) system which includes IC design, fabrication, and packaging and testing that are all performed by a single company. The IDM system is followed in the U.S. (e.g. Intel, Texas Instruments and Motorola), Japan (e.g., NEC and Toshiba) and Korea (e.g., Samsung). The second type is characterized solely by the Taiwanese semiconductor industry in which firms specialize in merely one of the above mentioned value added activities (Hung and Yang, 2003). The Taiwanese semiconductor industry is unique in that each firm specializes in one of the following value-added activities: namely, design, manufacturing or packaging and testing, unlike the industries in the United States, South Korea and Japan industries where one company conducts all the activities.

Prior studies focused primarily on the relationship between patents and firm performance. Our study provides a refreshing opportunity to examine how the stage of the industry value chain affects the relationship between patenting citation and Tobin's Q. While the different stages of the manufacturing process have been discussed, design is the only stage that is knowledge intensive (e.g. Tung 2001). The other stages are relatively capital and labor intensive. This is currently accentuated by further specialization in the design sector that has resulted in miniaturization of electric circuitry which requires more skilled labor (e.g. Macher, Mowery and Simcoe 2002). We examine whether the impact of patent citations (i.e. citations *received*) on Tobin's Q is affected by different stages in the semiconductor value chain. Due to inherent uncertainty and greater complexity inherent in the designing stage, we argue that the association between patent citation and Tobin's Q is more pronounced for firms in the stage of design, than in the manufacturing or packaging and testing stages.

The examination of the effect of R&D spillover on Tobin's Q is the third objective of this paper. Spillover is defined as excess R&D spending by other firms which overflow and in turn enhances knowledge-flow among firms. This spillover effect increases firm productivity and is positively associated with Tobin's Q. Tobin's Q was selected in this study as the dependent variable by proxy for firm value because it has been used extensively in the literature (e.g., Jaffe, 1986; Shane and Klock, 1997; Bharadwaj et al., 1999). The relationship between R&D spillover and Tobin's Q is expected to be more pronounced for firms in the stage of design sector relative to other sectors.

Our paper contributes to the literature in two significant ways. First, it marks the first attempt to examine if the relationship found in the U.S. holds true in a different environment such as Taiwan. Specifically, we explore the relationship between citation of the cross-filed patent in US and Tobin's Q. We find that frequency of patent citation for patents cross-filed in US and spillover are significantly and positively related to Tobin's Q. Second, this paper also investigates whether the effect of patent citations on firm value is affected by the industry value chain. In contrast to the U.S., Taiwanese semiconductor firms typically specialize in one of the value-added activities. This provides a unique setting to address this issue.

Our paper is presented in the following format; in section two we discuss the semiconductor industry, in section three we develop our hypotheses. Our sample selection and variables are discussed in section four. We discuss our methodology and models in section five. Our conclusions are presented in section six.

2. Semiconductor industry

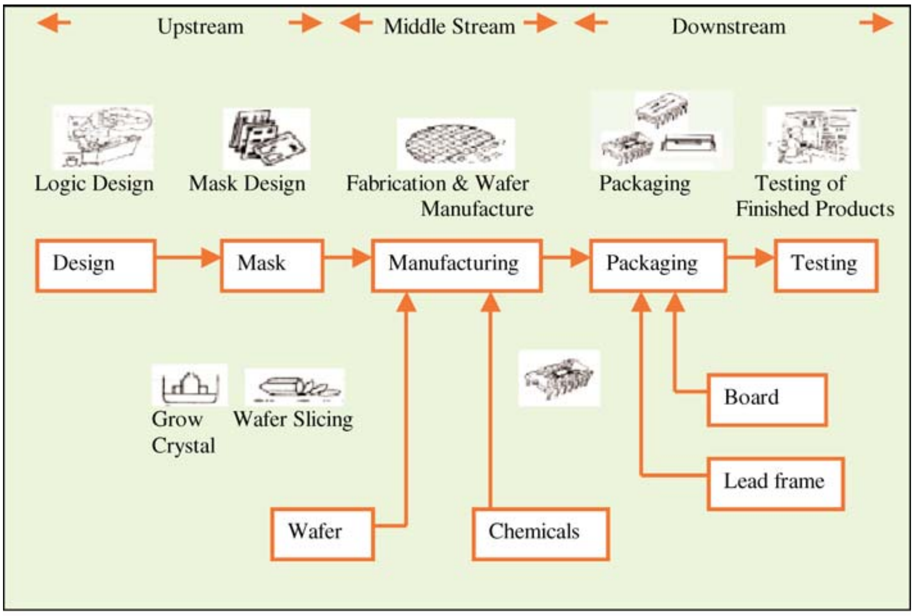
Semiconductor products include discrete devices, optoelectronics, and integrated circuits. Integrated circuits account for the bulk of all semiconductors. Hall and Ziedonis (2001) indicate that the semiconductor industry provides an excellent setting within which to examine the relationship of patent activity and a firm's "rapidly advancing and cumulative technology" (page 102). In the United States, products of firms in the semiconductor industry go through several stages, namely, design, manufacturing and packaging. In Taiwan, semiconductor firms specialize in one of the above value-added activities, namely, either design or manufacturing or packaging and testing. Overall, the semiconductor industry is characterized by continuous innovation and has advanced exponentially since its inception in the middle of the twentieth century. The share of semiconductors in global electronics production rose from 2–3 percent in the 1960s to just fewer than 10 percent in the 1980s and is expected to increase from 25 to 30 percent currently.

The electronics industry is composed of "upstream" and "downstream" sectors. Semiconductors, and other components, are included in upstream sectors; while consumer electronics, telecommunications, and information-technology products are categorized by downstream sectors. The semiconductor industry can also be divided into four core businesses based on production stages (design, manufacturing/fabrication, packaging, and testing). The four core businesses have different characteristics. The design business is knowledge intensive and requires little capital fabrication technology. Fabrication is capital intensive, while packaging and testing are both labor intensive in nature. Each sector, nevertheless, adds value to the final products that are fed into the downstream sector.

2.1. The industry in Taiwan

In the last two decades the electronics industry has become the most dynamic sector in East Asia. The region as a whole has exported large quantities of PCs, disk drives, semiconductors, televisions and telephones. The commencement of semiconductor production in Taiwan dates back to the 1960s. In 1966, General Instruments of the USA established the first semiconductor plant in Taiwan. Other firms quickly followed suit. In the 1970s, the government decided to stimulate indigenous production capacity in semiconductors with the intention of upgrading the overall technological level. Chen (2002) in an overview notes that the development of the semiconductor industry in Taiwan is the result of a vertical disintegration strategy which, in turn, facilitated the formation of local and cross-border linkages in pursuit of industrial expansion. Hung and Yang (2003) also indicate that Taiwanese semiconductor firms specialize in one of the value-added activities, namely, either design or manufacturing or packaging and testing, while in the United States or Japan products of firms in the semiconductor industry go through several stages. Figure 1 presents the vertical specialization in Taiwan semiconductor firms at the different stages of industry value chain.

Taiwan has become the world's fourth largest semiconductor producer, trailing the U.S., Japan, and South Korea respectively. Electronic News (2000) reported that Taiwan's semiconductor fabrication industry grew by a total of $8 billion in 1999 with an overall growth of 57.6 percent. The backend of the business also benefited from strong growth in the fabrication front end. Testing grew by 49.7 percent and packaging by 63.3 percent. In 1999 Taiwan's semiconductor industry generated total revenues of $12.5 billion for a growth of 48.1 percent over the previous year. Due to the prominence and importance of the semiconductor industry in Taiwan, we recognize that this is a suitable environment for examining the influence of innovation on firm value. For a detailed overview of the semiconductor industry in Taiwan please refer to Mathews (1997), Chang and Tsai (2000), Tung (2001), Chen (2002) and Hung and Yang (2003).



***Source: Industry Economics & Knowledge Center of Industrial Technology Research Institute project, March 2002. (p. 6, *An overview on Taiwan Semiconductor Industry*)**

Figure 1. The disintegrated taiwan semiconductor industry.

3. Hypothesis development

Patent citations are indicators of valuable technological knowledge (De Carolis, 2003). Patent citations reflect patent quality since a higher frequency of citations by other firms in their respective patent applications imply that the research of a particular firm has contributed significantly to advances in knowledge. Empirical studies establish the validity of patent citation analysis as indicators of technological competence (Carpenter and Narin, 1983; Narin et al., 1988; and Trajtenberg, 1990). Prior studies document that in the United States, patent citations are associated with firm value (Shane and Klock, 1997; Hall, 2000; Hirschey et al., 2001).

The United States is the biggest export destination of Taiwan semiconductor products[7]. Patent applications to foreign countries, in particular the United States, provide a better demonstration of innovational ability (Watanabe et al., 2001), and increases the protection of legal and intellectual property rights internationally. In addition, they mention that patents granted by the USPTO enhance a firm's visibility and exposure. Therefore, we expect that citation of patent cross-filed and granted in the U.S. for foreign firms are positively correlated with foreign firm' market value. Hence our first hypothesis is stated as follows:

H1: *Citations by other firms in their respective patent applications for Taiwanese semiconductor firms successfully filing in the U.S. has a positive relationship with Tobin's Q.*

The different stages of production are design, manufacturing/fabrication, testing and packaging. Design involves a greater degree of sophistication and expertise. Tung (2001) notes that this is the only stage which is knowledge intensive. The other stages are relatively capital and labor intensive. While capital and labor are readily available and can be accumulated in the course of business, the skills and creativity required by scarce, highly specialized people to create new knowledge (as is required in the design sector) is a valuable commodity that cannot be easily acquired or accumulated. The Report on Information Industry Research (2001) by Industrial Technology Intelligence Services in Taiwan also indicates that the entry barrier for the design sector market is higher because the design sector is more sophisticated and therefore the possibility of imitation is lower. Hence, patents granted in the design sector should have a greater effect on firm performance relative to other sectors. Since we use patent citations rather than simple patent count, our hypothesis is stated as follows:

H2: *Citations by other firms in their respective patent applications for Taiwanese semiconductor firms successfully filing in the U.S. are more pronounced for firms in the design sector relative to other sectors.*

Outside sources of knowledge are often critical to the innovation progress (e.g. Cohen and Levinthal, 1990). An important strand of work deals with knowledge spillover across countries. Jaffe (1986) examined the relationship of R&D activity with patents and profit and found a positive estimated coefficient on an interaction term between R&D and a measure of the "technology spillover." He concludes that other firms' R&D activity has a significant effect on firms' profits. In the economic literature it has been noted that diffusion in the form of R&D creates benefits to a company that percolates to other firms in the industry. We have developed a model showing the relationship between R&D spillover and Tobin's Q. Please refer figure 2.

As shown in the , Romer (1990) notes a relationship between firm productivity and R&D spending. Bernstein and Nadiri (1988) indicate that R&D spending by other firms

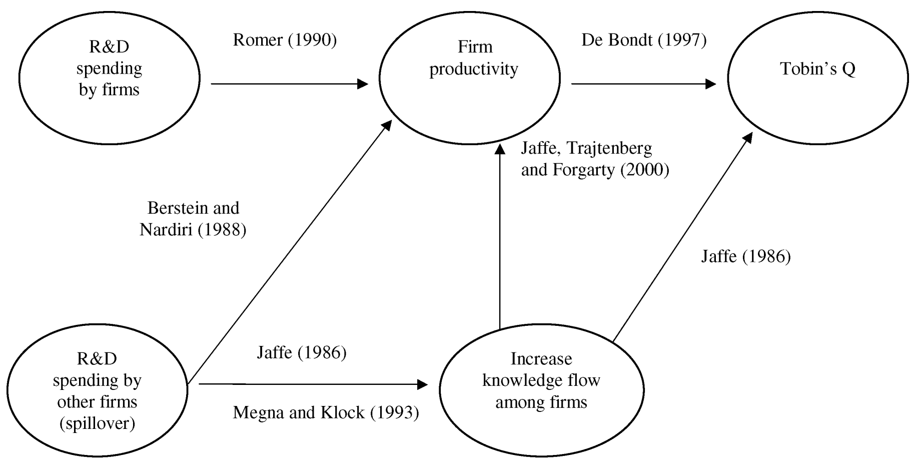


Figure 2. Empirical model relating Spillover to Tobins Q.

(referred to as spillover) also influences firm productivity. DeBondt et al. (1997) state that more spillovers lead to larger cost reductions, stimulate investments, and expand output and profitability and consumer surplus to add value. The explanation is also presented by Jaffe (1986) who argues that spillover is characterized by increased knowledge flow among firms. Jaffe, Trajtenberg and Fogarty (2000) established a link showing that increased knowledge flow, otherwise referred to as knowledge diffusion, influences firm value. As mentioned previously, only the design stage is knowledge intensive relative to the manufacturing, packaging and testing stages which rely more on capital and labor. Highly specialized knowledge is a commodity that, unlike capital and labor, cannot be easily obtained and collected. This results in the design sector being more sophisticated and not easily emulated. Therefore, we conclude that the effect of R&D spillover is more pronounced for the design stage firms. Hence, our third hypothesis is stated as follows:

H3: *The association of R&D spillover and Tobin's Q is greatest for those firms in the design stage and lowest for those firms in the packaging and testing stage.*

4. Sample and variables

4.1. Sample selection

The study is based on the publicly listed semiconductor firms in the Taiwan Stock Exchange. We reviewed a thirteen-year period from 1990 to 2002[8]. The Taiwan Economic Journal (TEJ) database was used to identify all semiconductor firms with complete equity returns and accounting data needed for this study. United States patents data were collected from the National Bureau of Economic Research (NBER) website and United States Patent and Trademark Office (USPTO)[9]. We identified 279 firm-year observations. Table 1 summarizes our data.

As shown in panel A we have a total of 279 firm years of which 82 are in the design end, 82 in the manufacturing end, and 115 in the packing and testing end of the value

Table 1. Sample distribution

Year	1990–1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
Panel A: Firm-year distribution in the semiconductor industry value chain											
All	16	7	13	14	21	28	32	40	50	58	279
Design	3	1	1	2	5	7	8	11	19	24	82
Manufacture	8	3	6	6	7	9	11	11	11	11	82
Packaging & Testing	5	3	6	6	9	12	13	18	20	23	115
Panel B: Patent citation statistics											
Year	1990-1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Total
All	555	975	2,761	3,713	2,838	4,660	4,434	4,779	3,230	1,070	29,015
%	1.9	3.4	9.5	12.8	9.8	16.1	15.2	16.5	11.1	3.7	100.0
Design	0	0	0	0	0	35	62	58	43	21	219
%	0.0	0.0	0.0	0.0	0.0	15.9	28.4	26.5	19.6	9.6	100.0
Manufacture	555	975	2,693	3,701	2,826	4,561	4,282	4,680	3,046	974	28,293
%	1.9	3.5	9.6	13.2	9.9	16.1	15.1	16.5	10.8	3.4	100.0
Packaging & Testing	0	0	68	12	12	64	90	41	141	75	503
%	0.0	0.0	13.5	2.4	2.4	12.7	17.9	8.2	28.0	14.9	100.0

chain of the semiconductor industry. Panel B of Table 1 shows that the number of total patent citations in our study period is 29,015 of which 219 are in the design end, 28,293 in the manufacturing sector and 503 in the packaging and testing sector. Table 1 shows that the manufacturing sector accounts for most of citations received compared to the design and packaging and testing sectors.

4.2. Operational definition of variables

Dependent variable. The dependent variable is a Tobin's Q score. Tobin's Q is widely used to measure firm value and/or market performance (e.g. Morck, Shleifer, Vishny, 1988; McConell and Servaes, 1990; Cho, 1998; Doidge et al., 2004). In the current study, Tobin's Q is calculated using the book value of total assets plus market value of equity minus the book value of equity as the numerator and book value of total assets as the denominator[10], consistent with Doidge et al. (2004).

Independent variables

Patent citation. Patent citations (CITED) are measured in terms of the number of citations made by other firms in their respective patent applications. Following Gu and Lev (2002), we define *CITED* as patent citation, i.e., the number of citations in subsequent patents cited by the other firm's patents, scaled by the industry firm-year average of citation[11]. Our formula is as follows:

$$CITED_{it} = \sum_{t=-5}^{t=-1} \frac{Citation_{it}}{M\_Citation_{jt}}$$

In the above formula, $Citation_{it}$ is the number of citations made by other firms in their respective patent applications by each firm year; $M_Citation_{jt}$is a mean citation number in the specific sector j (e.g. design, manufacturing, and packaging and testing) of semiconductor industry at year t. Following Gu and Lev (2002), $CITED_{it}$ is a 5-year summation of firm i's citation frequency after industry effect is removed.

Spillover effect. Spillover is defined as R&D spending by other firms which has an impact and enhances a firm's innovative ability. This is shown by the following equation:

$$\begin{aligned}\text{SPILLOVER}_{j-i,t} &= \{(\text{RD}_{j-i,t}/\text{Sales}_{j-i,t}) + (\text{RD}_{j-i,t-1}/\text{Sales}_{j-i,t-1}) \\ &\quad + (\text{RD}_{j-i,t-2}/\text{Sales}_{j-i,t-2})\}/3\end{aligned}$$

In the above formula, $\text{RD}_{j-i,t}$ refers to industry sector $j's$ R&D spending excluding firm i's R&D expenditure in year t; $\text{Sales}_{j-i,t}$refers to sales of the total industry sector represented by j and excluding firm i's sales in year t. The spillover effect is calculated by averaging three-year R&D intensity ratios after firm i's effect was removed.

Control variables. Control variables in our model generally follow prior studies on the determinants of Tobin's Q. Consistent with prior studies, we include R&D expense, advertising expense and leverage ratios as control variables. Cockburn and Griliches (1988) show a positive relationship between R&D expenditures and Tobin's Q. Hence, we expect the coefficient to be significant and positive. Similarly advertising expenditures have been asserted to have a positive relationship with Tobin's Q (Park et al., 1986; Aaker, 1991; Megna and Mueller, 1991; Morck and Yeung, 1991; Simon and Sullivan, 1993; Wu and Bjornson, 1996; Bharadwaj et al., 1999). In addition, we expect the coefficient of the advertising expense variable to be significant and positive. Finally, the leverage ratio is included as a control variable because leverage has been found to be negatively related to the profitability of the firm (Morck, Shleifer and Vishny, 1988). Therefore the coefficient of the leverage variable is expected to be significant but negative.

4.3. Descriptive statistics

Table 2 provides descriptive statistics of the variables used in our sample categorized by different stages in the semiconductor industry value chain. The mean of the Tobin's Q, is 1.273; this number is greater than one indicating that under current Generally Accepted Accounting Principles, innovation investments such as internally-developed patents are of substantial economic importance for many firms, though typically unrecognized in the balance sheet as accounting assets. Table 2 also reveals that the mean Tobin's Q for the designing stage is greater than those for manufacturing, and packaging and testing stages.

Table 2 indicates that the mean (median) spillover for the full sample and sub-samples (upper, middle, downstream respectively), are roughly similar. We also find that some of the variables used in our analyses are skewed to the right. This leads us to conduct further sensitivity analyses including Spearman rank correlations, Pearson product moment correlations, and rank regression. Further, plotting the independent variables against the dependent variables indicates a nonlinear relationship between them. In order to reduce the potential effects of outliers and to ensure a normal distribution of the error terms, we also transform the dependent and independent variables using rank transformation as done in prior research (Conover and Inman 1981). We then re-conduct our analyses (which we will discuss later) and verify that our results are not driven by outliers or nonlinear relationships.

Table 3 presents the Pearson and Spearman correlations among the variables included in the estimation equation. Consistent with our prediction, Tobin's Q is significantly correlated with CITED, SPILLOVER, R&D, and LEV. The results show that the coefficients of correlation have expected signs regardless of Pearson and Spearman correlations. Specifically, patent citation and spillover have a positive impact on Tobin's Q, whereas higher leverage has a negative impact. Thus, we conclude that right skewness does not influence our results.

5. Methodology and results

5.1. Patent citation and Tobin's Q in the context of value chain

To test the first two hypotheses, we initially ran four regression models. In the first model we examine the relationship of patent citations with Tobin's Q. We include R&D

Table 2. Descriptive statistics

Variables	Mean	Std. dev.	Quartile 0.25	Quartile 0.5	Quartile 0.75
Total					
Q	1.273	1.156	0.523	0.917	1.582
Citation	103.990	340.930	0.000	0.000	18.000
CITED	5.394	4.091	0.000	0.000	4.901
SPILLOVER	3.058	1.054	2.981	3.042	3.061
AD	$7.272*10^{-7}$	$2.310*10^{-6}$	0.000	0.000	$3.447*10^{-7}$
RD	0.011	0.020	0.000	0.003	0.014
LEV	0.335	0.143	0.236	0.322	0.444
Design					
Q	1.707	1.170	0.804	1.444	2.473
CITED	5.414	14.559	0.000	0.000	0.000
SPILLOVER	3.061	1.062	2.994	3.055	3.068
AD	$6.563*10^{-7}$	$2.298*10^{-6}$	0.000	0.000	0.000
RD	0.013	0.025	0.005	0.009	0.026
LEV	0.261	0.152	0.137	0.241	0.335
Manufacture					
Q	1.205	1.276	0.511	0.838	1.326
CITED	5.265	3.719	0.561	0.967	5.018
SPILLOVER	3.056	1.055	2.972	3.049	3.060
AD	$1.574*10^{-6}$	$3.401*10^{-6}$	0.000	$1.168*10^{-8}$	$1.902*10^{-6}$
RD	0.015	0.029	0.005	0.008	0.023
LEV	0.371	0.113	0.285	0.372	0.464
Packaging and testing					
Q	0.935	0.783	0.411	0.717	1.230
CITED	5.135	17.955	0.000	0.000	0.000
SPILLOVER	3.056	1.055	2.972	3.049	3.060
AD	$1.735*10^{-7}$	$4.594*10^{-7}$	0.000	0.000	0.000
RD	0.006	0.013	0.000	0.001	0.009
LEV	0.363	0.137	0.257	0.365	0.458

Q denotes Tobin's q, is calculated using book value of total assets plus market value of equity minus the book value of equity as the numerator and book value of total assets as the denominator. *CITED* is defined as five-year average patent citation, the number of citations in subsequent patents received by the firm's patents, scaled by the industry-year average of citation. SPILLOVER is defined as average three-year R&D spending by other firms deflated by total other firms' sales. AD is advertising expense divided by sale; RD is research and development expense divided by sale; LEV is equal to liability divided by total assets.

expenditure, advertising expenditure, and leverage as control variables. In the other three regression models dummy variables are included to represent the stage of the firm in the industry value chain. The four regression models are shown below.

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4 LEV_{it} + \varepsilon_{it} \quad (1)$$

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 (D_{12} * \text{CITED}_{it}) + \varepsilon_{it} \quad (2)$$

Table 3. Spearman (Pearson) correlations in upper (lower) triangle ($N = 279$)

Variables	Q	CITED	RD	AD	LEV	SPILLOVER
Q		0.417**	0.453***	0.225	−0.462*	0.561***
		(0.031)	(0.000)	(0.501)	(0.089)	(0.000)
CITED	0.424**		0.242	0..301	−0.345	0.397
	(0.023)		(0.110)	(0.438)	(0.269)	(0.138)
RD	0.462***	0.237		0.466	−0.363	0.251
	(0.000)	(0.103)		(0.095)*	(0.389)	(0.474)
AD	0.217	0..283	0.482		−0.358	0.261
	(0.483)	(0.415)	(0.087)*		(0.449)	(0.584)
LEV	−0.478*	−0.334	−0.345	−0.342		0.357
	(0.075)	(0.289)	(0.364)	(0.438)		(0.438)
SPILLOVER	0.558***	0.386	0.264	0.253	0.347	
	(0.000)	(0.124)	(0.453)	(0.572)	(0.424)	

Q denotes Tobin's q, is calculated using book value of total assets plus market value of equity minus the book value of equity as the numerator and book value of total assets as the denominator. *CITED* is defined as five-year average patent citation, the number of citations in subsequent patents received by the firm's patents, scaled by the industry-year average of citation. SPILLOVER is defined as average three-year R&D spending by other firms deflated by total other firms' sales. AD is advertising expense divided by sale; RD is research and development expense divided by sale; LEV is equal to liability divided by total assets.

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 (D_{13} * \text{CITED}_{it}) + \varepsilon_{it} \quad (3)$$

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4 LEV_{it} + \alpha_5 (D_{23} * \text{CITED}_{it}) + \varepsilon_{it} \quad (4)$$

where,

$\text{CITED}_{it} = a$ 5-year summation of firm i's citation frequency after industry effect is removed.

RD_{it} = Research and development expenses/Sales for firm i in year t

AD_{it} = Advertising expense/Sales for firm i in year t

LEV_{it} = Leverage as measured by total debt divided by total assets for firm i in year t

D is indicative of design firms, M is indicative of manufacture firms, and PT is indicative of packaging and testing firms. D_{12}, D_{13}, and D_{23} are dummy variables. In the D-M state, $D_{12} = 1$ if a firm is classified as a design firm, else 0 if a firm is classified as a manufacturing firm. In the D-PT state, D_{13}=1 if a firm is classified as a design firm, else 0 if a firm is classified as a packaging and testing firm. In the M-PT state, D_{23}=1 if a firm is classified as a manufacture firm, else 0 if a firm is classified as a packaging and testing firm. To be consistent with our hypotheses, we expect α_1 and α_5 to be positive.

In our first regression we regress Tobin's Q on patent citations, R&D expense, advertising expense and leverage. The results are shown in Table 4. In order to minimize problems related to heteroskedasticity in all our regressions, we report white-adjusted t-statistics (White 1980) for all the coefficients in this paper.

As shown in the column (1) of Table 4, patent citations (CITED) are significantly positive at the 5 percent level, which means that patent citations have a significant

Table 4. A regression analysis of Tobin's Q on patent citation across industry value chain

Variables	SIGN	(1) All	(2) D-M	(3) D-PT	(4) M-PT
α_0		0.0020 (1.528)*	0.0010 (0.528)	0.0019 (0.358)	0.0014 (0.463)
CITED_{it}	+	0.0013 (1.978)**	0.0012 (2.012)**	0.0012 (1.983)**	0.0011 (2.033)**
RD_{it}	+	0.0052 (2.896)***	0.0053 (2.875)***	0.0055 (2.527)***	0.0048 (2.887)***
AD_{it}	+	0.0601 (1.329)	0.0581 (1.329)	0.0599 (1.358)	0.0602 (1.333)
LEV_{it}	−	–0.0232 (1.559)*	−0.0232 (1.559)*	−0.0228 (1.477)*	−0.0248 (1.321)
D_{12} *CITED_{it}	+		0.0059 (1.851)**		
D_{13} * CITED_{it}	+			0.0053 (1.726)**	
D_{23} * CITED_{it}	+				0.0053 (1.885)**
N		279	164	197	197
F-value		18.945	18.975	17.321	16.993
Adj. R^2		0.485	0.485	0.475	0.463

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4\text{LEV}_{it} + \varepsilon_{it} \quad (1)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4\text{LEV}_{it} + \alpha_5(D_{12} * \text{CITED}_{it}) + \varepsilon_{it} \quad (2)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4\text{LEV}_{it} + \alpha_5(D_{13} * \text{CITED}_{it}) + \varepsilon_{it} \quad (3)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3 AD_{it} + \alpha_4\text{LEV}_{it} + \alpha_5(D_{23} * \text{CITED}_{it}) + \varepsilon_{it} \quad (4)$$

***1 Significance level, **5 Significance level, *10 Significance level, on basis of one-tailed tests.
Q denotes Tobin's q, is calculated using book value of total assets plus market value of equity minus the book value of equity as the numerator and book value of total assets as the denominator. *CITED* is defined as five-year average patent citation, the number of citations in subsequent patents received by the firm's patents, scaled by the industry-year average of citation. SPILLOVER is defined as average three-year R&D spending by other firms deflated by total other firms' sales. AD is advertising expense divided by sale; RD is research and development expense divided by sale; LEV is equal to liability divided by total assets.
D is indicative of design firms, M is indicative of manufacture firms, and PT is indicative of packaging and testing firms. D_{12}, D_{13}, and D_{23} are dummy variables. In the D-M state, $D_{12} = 1$ if a firm is classified as a design firm, else 0 if a firm is classified as a manufacturing firm. In the D-PT state, $D_{13} = 1$ if a firm is classified as a design firm, else 0 if a firm is classified as a packaging and testing firm. In the M-PT state, $D_{23} = 1$ if a firm is classified as a manufacture firm, else 0 if a firm is classified as a packaging and testing firm.

influence on Tobin's Q. These results provide evidence to support hypothesis H1 that citations of patents cross-filed and granted in the U.S. for Taiwanese firms have a positive association with Tobin's Q. We also note that R&D is highly significant at the 1 percent level. This corroborates the findings of prior research in the U.S. which conclude that R&D activity significantly influences firm performance and value.

In our second regression (shown in the column (2) of Table 4 as D-M), we incorporate a dummy variable (D_{12}) representing 1 if the firm is in the design stage and 0 if the firm is in manufacturing. The interaction between industry stage and patent citation (D_{12}*CITED_{it}) is significantly positive at the 5 percent level. This indicates that citations of patent cross-filed and granted in U.S. for Taiwanese firms in the design stage have a more positive association with Tobin's Q relative to those firms in the manufacturing stage.

The column (3) as D-PT of Table 4 shows the results of our third regression. We incorporate a dummy variable (D_{13}), representing 1, if firm is in design and 0 if the firm is in packaging and testing segment of the value chain. As predicted, the coefficient of the interaction between patent citation and the dummy variable (D_{13}*$CITED_{it}$) is significant at the 5 percent level. This indicates that patent citation for those firms in the design stage has a more positive relationship with Tobin's Q relative to those firms in the packaging and testing stage.

In the final column (4) M-PT showing the results for our fourth regression, we include a dummy variable (D_{23}) representing 1 if the firm is in the manufacturing stage and 0 if in the packaging and testing stage. The results show that the coefficient of the interaction between the dummy variable and patent citation (D_{23}*$CITED_{it}$) is significant at the 5 percent level. This indicates that patent citation has a stronger association with Tobin's Q for those firms in the manufacture stage of the value chain relative to those firms in the packaging and testing stage. This finding supports hypothesis H2. Overall, based on these findings, we conclude that the stage of the firm in the industry value chain affects the association between patent citation and Tobin's Q. The relationship is strongest for those firms in the design stage followed by manufacturing; the relationship is weakest for those firms in packaging and testing[12,13].

5.2. *Spillover effect and Tobin's Q.*

To test the third hypothesis, we run the following four regressions:

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 \text{AE}_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 \text{SPILLOVER}_{it} + \varepsilon_{it} \quad (5)$$

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 \text{AD}_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 \text{SPILLOVER}_{it} + \alpha_6 (D_{12} * \text{SPILLOVER}_{it}) + \varepsilon_{it} \quad (6)$$

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 \text{AD}_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 \text{SPILLOVER}_{it} + \alpha_6 (D_{13} * \text{SPILLOVER}_{it}) + \varepsilon_{it} \quad (7)$$

$$Q_{it} = \alpha_0 + \alpha_1 \text{CITED}_{it} + \alpha_2 \text{RD}_{it} + \alpha_3 \text{AD}_{it} + \alpha_4 \text{LEV}_{it} + \alpha_5 \text{SPILLOVER}_{it} + \alpha_6 (D_{23} * \text{SPILLOVER}_{it}) + \varepsilon_{it} \quad (8)$$

Additionally, we also include the construct of spillover in the above four regressions. Table 5 shows the results of all our regression equations.

The results in Table 5 show that, overall (regression 5) patent citations are significant at the 5 percent level and R&D investment at the 1 percent level. These results hold in regressions 6, 7, and 8. However, in regression 6, the interaction variable D_{12}*SPILLOVER is significant at the one percent level. This means R&D spillover for design firms are greater than for firms in the manufacturing stage. Similarly, in regression 7 the interaction term D_{13}*SPILLOVER is significant at the 5 percent level indicating that R&D spillover for firms in the design stage is greater relative to firms in packaging and testing. Finally, in regression 8, the interaction variable D_{23}*SPILLOVER is significant indicating R&D spillover is greater for firms in the manufacturing stage relative to those in packaging and testing. Overall, the results provide evidence to support hypothesis H3 which postulates that R&D spillover is more pronounced for firms in design and least pronounced for those in packaging and testing.

Table 5. A regression analysis of Tobin's Q on patent citation and R&D spillover across industry value chain

Variable	SIGN	(5) ALL	(6) D-M	(7) D-PT	(8) M-PT
α_0		0.0019 (1.464)*	0.0069 (1.121)	0.0056 (1.586)*	0.0033 (1.237)
CITED_{it}	+	0.0011 (2.038)**	0.0012 (2.062)**	0.0011 (1.976)**	0.0011 (1.987)**
RD_{it}	+	0.0047 (3.002)***	0.0052 (4.751)***	0.0059 (5.637)***	0.0063 (5.881)***
AD_{it}	+	0.0502 (1.527)*	0.0513 (1.219)	0.0667 (1.332)	0.0598 (1.208)
LEV_{it}	−	−0.0261 (1.616)*	−0.0305 (1.525)*	−0.0293 (1.525)*	−0.0333 (1.223)
SPILLOVER_{it}	+	0.0033 (2.674)***	0.0041 (2.981)***	0.0035 (2.811)***	0.0032 (2.245)***
$\text{D}_{12}*\text{SPILLOVER}_{it}$	+		0.0019 (2.031)**		
$\text{D}_{13}*\text{SPILLOVER}_{it}$	+			0.00012 (1.987)**	
$\text{D}_{23}*\text{SPILLOVER}_{it}$	+				0.00011 (2.083)**
N		279	164	197	197
F-value		19.651	18.413	18.378	17.547
Adj. R^2		0.483	0.476	0.451	0.438

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3\text{AE}_{\text{it}} + \alpha_4\text{LEV}_{it} + \alpha_5\text{SPILLOVER}_{it} + \varepsilon_{it} \quad (5)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3\text{AD}_{it} + \alpha_4\text{LEV}_{it} + \alpha_5\text{SPILLOVER}_{it} + \alpha_6(D_{12} * \text{SPILLOVER}_{it})\varepsilon_{it} \quad (6)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3\text{AD}_{it} + \alpha_4\text{LEV}_{it} + \alpha_5\text{SPILLOVER}_{it} + \alpha_6(D_{13} * \text{SPILLOVER}_{it}) + \varepsilon_{it} \quad (7)$$

$$Q_{it} = \alpha_0 + \alpha_1\text{CITED}_{it} + \alpha_2\text{RD}_{it} + \alpha_3\text{AD}_{it} + \alpha_4\text{LEV}_{it} + \alpha_5\text{SPILLOVER}_{it} + \alpha_6(D_{23} * \text{SPILLOVER}_{it}) + \varepsilon_{it} \quad (8)$$

***1 Significance level, **5 Significance level, *10 Significance level, on basis of one-tailed tests.
Q denotes Tobin's q, is calculated using book value of total assets plus market value of equity minus the book value of equity as the numerator and book value of total assets as the denominator. *CITED* is defined as five-year average patent citation, the number of citations in subsequent patents received by the firm's patents, scaled by the industry-year average of citation. SPILLOVER is defined as average three-year R&D spending by other firms deflated by total other firms' sales. AD is advertising expense divided by sale; RD is research and development expense divided by sale; LEV is equal to liability divided by total assets.
D is indicative of design firms, M is indicative of manufacture firms, and PT is indicative of packaging and testing firms. D_{12}, D_{13}, and D_{23} are dummy variables. In the D-M state, $\text{D}_{12} = 1$ if a firm is classified as a design firm, else 0 if a firm is classified as a manufacturing firm. In the D-PT state, $\text{D}_{13} = 1$ if a firm is classified as a design firm, else 0 if a firm is classified as a packaging and testing firm. In the M-PT state, $\text{D}_{23} = 1$ if a firm is classified as a manufacture firm, else 0 if a firm is classified as a packaging and testing firm.

5.3. Sensitivity analyses

As described above, we follow the Gu and Lev (2002) and define $CITED_{it}$ as the number of citations in subsequent patents cited by the firm's patents, scaled by the industry—year average of citation. CITED_{it} is a 5-year summation of firm i's citation frequency after the industry effect is removed. We also compute CITED_{it} by collecting all citations received since the patent filing date till the end of our study period divided by mean industry firm-year citations. Untabulated results reveal that the inferences drawn from prior empirical analyses remain unchanged. Thus, our results are robust using different proxies for patent citation.

6. Conclusions

The current study explores the relationship between citation of patents cross-filed and granted in the U.S. and Tobin's Q for Taiwanese semiconductor firms. In Taiwan, semiconductor firms typically specialize in one of the specific value-added activities, namely, either design or manufacturing or packaging and testing. We thus further examine whether the relationship is a function of semiconductor industry value chains.

We find that the frequency of citations of successfully filed patents in the U.S. is significantly and positively related to firm value as measured by Tobin's Q. Moreover, this relationship is affected by the stage of the firm in the value chain. The relationship is most pronounced for design companies and least pronounced for companies in packaging and testing. This paper also investigates the effect of knowledge diffusion (in terms of R&D spillover from other firms) on firm value. Our results indicate that Tobin's Q is higher as the amount of knowledge diffusion increases. In addition, the relationship between R&D spillover and Tobin's Q is more pronounced for firms in the design sector relative to those in the manufacturing, packaging and testing sectors. The potential areas of future interest include extending this study to other industrialized Asian countries such China, Japan and South Korea.

Notes

1. See Brown, Lo and Lys (1999), Francis and Schipper (1999), Pownall and Schipper (1999).
2. See Griliches (1981), Megna and Klock (1993), Pegels and Thirumurthy (1996), Stoneman and Toivanen (1997), Toivanen, Stoneman and Bosworth (2002).
3. Besides, both Harhoff et al. (1999) and Trajtenberg (1990) note that some patents are "dead end" innovations while others lead to major developments in technology. They feel that the aggregating of different types of patents are not appropriate. Shane and Klock (1997) note that the main drawback of simple patent counts is that they are measured with error, and might not fully capture innovative activity or technological progress.
4. The patent examiner, together with the inventor and the inventor's attorney, arrive at a final list of citations for every patent and this list limits the scope of property rights of the patent owner and is protected by law. Hence, there is an incentive for all parties to cite the relevant state of the art (see De Carolis, 2003).
5. See Carpenter and Narin (1983), Narin et al. (1988), and Trajtenberg (1990).
6. The patents granted to Taiwan semiconductor industry account for 42% out of total patents in Taiwan. In addition, 56% out of all Taiwan patents granted by United States Patent and Trademark Office was granted to Taiwan semiconductor firms (see Chin et. al, 2004).
7. According to 2003 World Semiconductor Trade Statistics, United States is the biggest semiconductor market in the world and is also the primary market to Taiwan. Sixty-five percent of Taiwan semiconductor products are exported to North America market.
8. Taiwan semiconductor firms were not granted patents from United States until 1990.
9. Please see http://www.nber.org/patents/ for the NBER U.S. patent data files.
10. Typically, Tobin's Q is defined as the ratio of the market's valuation of the financial claims on a firm to the cost of replacing the firm's assets. However, our Tobin's Q estimate does not attempt to use a typical measure due to the lack of information regarding replacement cost and the market value of debt in Taiwan (please also refer Chung and Pruitt 1994).
11. Hall et al. (2001) also deflate the patent citation by the average of citation.
12. We identify influential observations using the DFFITS and R-Student statistics proposed by Belsley, Kuh, and Welsch (1980). The results still remain unchanged after our parameter estimates account for Belsley et al. (1980) influence diagnostics.

13. All variance inflation factors (VIF) are less than 3, which is evidence that our regression results are not affected by multicollinearity (Kennedy, 1992).

References

Aaker, D., *Managing Brand Equity: Capitalizing on the Value of a Brand Name*, Free Press, New York, 1991.

Balkin, D. B., G. D. Markman and L. R. Gomez-Mejia, "Is CEO Pay in High-Technology Firms Related to Innovation?" *Academy of Management Journal* 43, 1118–1129 (2000).

Belsley, D. A., E. Kuh and R. E. Welsch, *Regression Diagnostics: Identifying Influenctial Data and Sources of Collinearity*, Wiley, New York, 2000.

Bernstein, J. I. and M. I. Nadiri, "Interindustry, R&D Spillovers, Rates of Return, and Production in High-Tech Industries." *American Economic Review* 78, 429–434 (1988).

Bharadwaj, A. S., S. G. Bharadwaj and B. R. Konsynski, "Information Technology Effects on Firm Performance as Measured by Tobin's q." *Management Science* 45, 1008–1024 (1999).

Bosworth, D. L. and H. Mahdian, "Returns to Intellectual Property in the Pharmaceuticals Sector." *Economique Appliquee* 52, 69–93 (1999).

Brown, S., K. Lo and T. Lys, "Use of R^2 in Accounting Research: Measuring Changes in Value Relevance Over the Last Four Decades." *Journal of Accounting and Economics* 28, 83–115 (1999).

Campbell, R. S. and A. L. Nieves, "Technology Indicators Based on Patent Data: The Case of Catalytic Converters: Phase 1 report: Design and Demonstration. Pacific Northwest Laboratories" Battelle (1979).

Carpenter, M. C. and F. Narin, "Validation Study: Patent Citations as Indicators of Science and Foreign Dependence." *World Patent Information* 5, 180–185 (1983).

Chang, P. L. and C. T. Tsai, "Evolution of Technology Development Strategies for Taiwan's Semiconductor Industry: Formation of research consortia." *Industry and Innovation* 7, 185–197 (2000).

Chen, S. H, "Global Production Networks and Information Technology: The case of Taiwan." *Industry and Innovation* 9, 249–265 (2002).

Chin, C. C., H. W. Lin and C. Y. Chi, "Patent and Value-relevance in Taiwan." *Journal of Management Review* 21, 175–197 (2004).

Cho, M. H., "Ownership Structure, Investment and the Corporate Value: an Empirical Analysis." *Journal of Financial Economics* 47, 103–121 (1998).

Chung, K.H. and S.W. Pruitt, "A Simple Approximation of Tobin's q." *Financial Management* 23, 70–74 (1994).

Cockburn, I. and Z. Griliches, "Industry Effects and Appropriability Measures in the Stockmarket's Valuation of R&D and Patents." *American Economic Review* 78, 419–423 (1988).

Cohen, W. M. and D. A. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation." *Administrative Science Quarterly* 35, 128–152 (1990).

Cohen, W. M. and D. A. Levinthal, "Innovation and Learning: the Two Faces of R&D." *The Economic Journal* 99, 569–596 (1989).

Connolly, R. A. and M. Hirschey, "Market Value and Patents: A Bayesian Approach." *Economics Letters* 27, 83–87 (1988).

Conover, W.J. and R. L. Iman, "Rank Transformations as a Bridge Between Parametric and Nonparametric Statistics." *The American Statistician* 35, 124–133 (1981).

De Bondt, R, "Spillovers and Innovative Activities." *International Journal of Industrial Organization* 15, 1–28 (1997).

De Carolis, D. M., "Competencies and Imitability in the Pharmaceutical Industry: An Analysis of Their Relationship with Firm Performance." *Journal of Management* 29, 27–50 (2003).

Doidge, C., G. A. Karolyi and R. M. Stulz, "Why are Foreign Firms Listed in U.S. Worth More?" *Journal of Financial Economics* 71, 205–238 (2004).

Electronic News, Electronics shipments growth 1999 & 2000, published on January 1st, 2000.

Francis, J. and K. Schipper, "Have Financial Statements Lost Their Relevance?" *Journal of Accounting Research* 37, 319–352 (1999).

Griffith, R., S. Redding and J. V. Reenen, "R&D and Absorptive Capacity: Theory and Empirical Evidence." *Scandinavian Journal of Economics* 105, 99–118 (2003).

Griliches, Z., "Patent Statistics as Economic Indicators: A Survey." *Journal of Economic Literature* 28, 1661–1707 (1990).

Griliches, Z., "Market Value, R&D and Patents." *Economics letters* 7, 183–187 (1981).

Gu, F. and B. Lev, "On the Relevance and Reliability of R&D." Working paper, University of Boston, Boston (2002).

Hall, B., A. Jaffe and M. Trajtenberg, "Market Value and Patent Citations: A First Look." Working paper, University of California, Berkeley (2001a).

Hall, B., "Innovation and Market Value." In Barrell, G. Mason and M. O' Mahoney (Eds.), *Productivity, Innovation and Economic Performance*. Cambridge UK: Cambridge University Press, 2000 pp. 177–198.

Hall, B., "The Stock Market Valuation of R&D Investment During the 1980s." *American Economic Review* 83, 259–264 (1993).

Hall, B., A. Jaffe and M. Trajtenberg, "The NBER Patent Citations Data File: Lessons, Insights and Methodlogical Tools." National Bureau of Economic Research, Working paper No. 3094 (2001b).

Hall, B. and R. H. Ziedonis, "The Patent Paradox Revisited: an Empirical Study of Patenting in the U.S. Semiconductor Industry, 1979–1995." *RAND Journal of Economics* 32, 101–128 (2001).

Harhoff, D., F. Narin, F. M. Scherer and K. Vopel, "Citation Frequency and the Value of Patented Innovation." *Review of Economics and Statistics* 81, 511–515 (1999).

Hirschey, M., V. J. Richardson and S. Scholz, "Value Relevance of Nonfinancial Information: The Case of Patent Data." *Review of Quantitative Finance and Accounting* 17, 223–226 (2001)

Hung, S. W. and C. Yang, "The IC fables industry in Taiwan: Current Status and Future Challenges." *Technology in Society* 25, 385–402 (2003).

Jaffe, A. B., "Technological Opportunity and Spillovers of R&D: Evidence from Firms' Patents, Profits and Market Value." *The American Economic Review* 76, 984–1001 (1986).

Jaffe, A. B., M. Trajtenberg and M. S. Fogarty, "Knowledge Spillovers and Patent Citations: Evidence from a Survey of Inventors." *American Economic Review* 90, 215–218 (2000).

Jaffe, A. B., M. Trajtenberg and R. Henderson, "Geographic Localization and Knowledge Spillovers as Evidence by Patent Citations." *Quarterly Journal of Economics* 108, 577–598 (1993).

Jaffe, A. B. and M. Trajtenberg, "Flows of Knowledge from Universities and Federal labs: Modeling the Flow of Patent Citations over Time and Across Institutional and Geographic Boundaries." National Bureau of Economic Research, Working paper No. 5712 (1996).

Kallapur, S. and Y. S. Sabrina, "The Value Relevance and Reliability of Brand Assets Recognized by U.K. Firms." *Accounting Review* 79, 151–173 (2004).

Kennedy, P. A., *Guide to Econometrics*, MIT Press, Cambridge, MA: 1992.

Macher, J. T., D. C. Mowery and T. S. Simcoe, "E-Business and Disintegration of The Semiconductor Industry Value Chain." *Industry and Innovation* 9, 155–181 (2002).

Mathews, J. A., "A Silicon Valley of the East: Creating Taiwan's Semiconductor Industry." *California Management Review* 39, 26–54 (1997).

McConnell, J. and H. Servaes, "Additional Evidence on Equity Ownership and Corporate Value." *Journal of Financial Economics* 27, 595–613 (1900).

Mcmillan, G. S., A. Mauri and R.D. Halmilton, "The Impact of Publishing and Patenting Activities on New Product Development and Firm Performance: The Case of the US Pharmachutical Industry." *International Journal of Innovation Management* 7, 213–221 (2003).

Megna, P. and D. C. Mueller, "Profit rates and Intangible Capital." *Review of Economics and Statististics* 73, 632–642 (1991).

Megna, P. and M. Klock, "The Impact of Intangible Capital on Tobin's q in the Semiconductor Industry." *American Economic Review* 83, 265–269 (1993).

Ministry of Economic Affairs. *Report on Information Industry Research*. http://mic.iii.org.tw/products/products4. asp. Industrial Technology Intelligence Services, Taipei, Taiwan, 2001.

Ministry of Economic Affairs. *Semiconductor Industry Yearbook*. Industrial Technology Intelligence Services, Taipei, Taiwan, 2003.

Morck, R. A. Shleifer and R.W. Vishny, "Management Ownership and Market Valuation: An Empirical Analysis." *Journal of Financial Economics* 20, 293–315 (1988).

Morck, R. and B. Yeung, "Why Investors Value Multinationality." *Journal of Business*, 64, 165–187 (1991).

Narin, F., M. Rose and D. Olivastro, "Patent Citation Analysis: New Validation Studies and Linkage Statistics." A. F. J. Van Raan (Ed.), In *Handbook of Quantitative Studies of Science and Technology* "North-Holland, Elsevier Science Publishers (1988).

Office of Technology Assessment and Forecast (OTAF). U.S. Department of Commerce, Patent and Trademark Office, Sixth Report. Washington, D.C., US Government Printing Office (1976).

Park, C. W., B. J. Jaworski and D. J. Macinnes, "Strategic Brand Concept-Image Management." *Journal of Marketing* 50, 135–145 (1986).

Pegels, C. C. and M.V. Thirumurthy, "The impact of Technology Strategy on Firm Performance." *IEEE Transactions on Engineering Management* 43, 246–249 (2000).

Pownall, G. and K. Schipper, "Implications of Accounting Research for the SEC's Consideration of International Accounting Standards for U.S. Securities Offerings." *Accounting Horizons* 13, 259–280 (1999).

Romer, P., "Endogenous Technological Change." *Journal of Political Economy* 71, 71–102 (1990).

Seethamraju, C. and B. Lev, "The Value-Relevance of Trademarks." Working paper. New York University, New York, NY (2000).

Shane, H. and M. Klock, " The Relation Between Patent Citations and Tobin's Q in the Semiconductor Industry." *Review of Quantitative Finance and Accounting* 9, 131–146 (1997).

Simon, C. J. and M. W. Sullivan, "The Measurement and Determinants of Brand Equity: A Financial Approach." *Marketing Science* 12, 28–52 (1993).

Stoneman, P. and O. Toivanen, "Innovation and Market Value in the UK." Working paper, Warwick Business School, University of Warwick, Coventry (1997).

Tabak, F. and S. H. Barr, "Innovation Attributes and Category Membership: Explaining Intention to Adopt Technological Innovations in Strategic Decision Making Contexts." *Journal of High Technology Management Research* 9, 17–33 (1998).

Taiwan Semiconductor Industry Association. *An Overview on Taiwan Semiconductor Industry.* http://www.tsia.org.tw/tsia_En/industry/seasonreport.asp, 2000.

Tobin, J., "Monetary Policies and the Economy: The Transmission Mechanism." *Southern Economic Journal* 37, 421–431 (1978).

Toivanen, O., P. Stoneman and D. Bosworth, "Innovation and the Market Value of UK firms, 1989–1995." *Oxford Bulletin of Economics and Statistics* 64, 39–61 (2002).

Trajtenberg, M., "A Penny for Your Quotes: Patent Citation and the Value of Innovations." *Rand Journal of Economics* 21, 172–187 (1990).

Tung, A., "Taiwan's Semiconductor Industry: What the State Did and Did not." *Review of Development Economics* 5, 266–288 (2001).

Watanabe, C., Y. S. Tsuji and C. Griffy-Brown, "Patent Statistics: Deciphering a 'Real' versus a 'Pseudo' Proxy of Innovation." *Technovation* 21, 783–790 (2001).

White, H., "A Heteroscedasticity-Consistent Covariance Matrix Estimator and Direct Test for Heteroscedasticity," *Econometrica* 48, 817–838 (1980).

Wu, W. and B. Bjornson, "Value of Advertising by Food Manufactures as Investment in Intangible Capital." *Agribusiness* 12, 147–156 (1996).