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Profitability decided by patent quality? An empirical study of the U.S. semiconductor industry

Yin-Hui Cheng · Fu-Yung Kuan · Shih-Chieh Chuang · Yun Ken

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Abstract The investment in research and development (R&D) for semiconductor industry is never small as the technology cycle time (TCT) is relatively short comparing to other industries, thus a semiconductor company requires lots of technological innovations and capital offerings to maintain. The semiconductor industry contributes primarily part of the micro-electronic industries. Advancing technology and patent application are the centre of attention within the semiconductor sector. This research examines the relationship between patent quality and the profits a patent creates for a company in this selected field. This study distinguishes itself from prior research by including cross-sectional data, time series data to simultaneously collect and analyze. The study result shows that some indicators of patent quality are statistically significant to return on assets.

Keywords Patent · Patent citation · Patent quality · Profitability

Introduction

Along with the continuous development of the industry, the management of intangible assets and corporate knowledge is becoming high valuable; the evaluation of a company's R&D capabilities is of equal importance. During the innovating process, the study uses patenting to protect and consolidate the invented technologies. A patent features three criteria: novel, useful and not obvious, and a patent allows a company to create incentives

Y.-H. Cheng
National Taichung University, Taichung City, Taiwan

F.-Y. Kuan
National Kaohsiung First University of Science and Technology, Kaohsiung City, Taiwan

S.-C. Chuang (✉)
National Chung Cheng University, Chiayi County, Minsyong, Taiwan
e-mail: bmascc@ccu.edu.tw

Y. Ken
National Yunlin University of Science and Technology, Yunlin, Taiwan

during a fixed period of time and serves as indicator for a company to evaluate its R&D capability.

From the economic point of view, increasing R&D expenditures and patent counts cause constructional and technological changes in the industry and lead to economic development. Therefore an empirical research into the correlation between patent count, R&D expenditures and economic performance is necessary. Prior research is no certain method for a company to evaluate its intangible assets when patent comes into the place as a more practical indicator. The research topic of this study explores how patents can be as an indicator to effectively evaluate a company's value with an attempt to further distinguish the relationship between patent and a company's profitability.

In order to verify the relationship between patent quality and profitability, the study employs multiple indicators to measure the concept of patent quality in this research. Previous researches in this field have proven the significance of the study on patent quality. Deng et al. (1999) and Thomas et al. (2001) use patent quality to predict stock returns and market-to book (M/B) ratios and gain remarkable result. This study uses ROA as standard variable making a contribution to the research finding for the relationship between patent quality and a company's economic performance. In particular, we have chosen the semiconductor industry as our research target because it is a concentrated technological and capital industry that requires an enormous amount of investment in technological development and has a short TCT, which makes it a key industry.

The industries upstream and downstream of the semiconductor industry include IC package, IC design, IC testing, IC manufacturing, discrete devices, transparent media adapters, electro-optical semiconductors, design appliances, and wafer materials. In addition to the immense investment required and the short technology cycle, the technological aspect of the semiconductor industry is highly complicated, with many different kinds of components involved. Semiconductors are a key component in electronic products, which grant the industry a quantitative advantage over other related industries in patenting key technologies. Hence, it is crucial to be able to interpret the technologies and protection procured in the semiconductor industry, which is why this industry, and more specifically U.S. semiconductor companies, which have a greater volume of patents, was selected as the study target.

Literature review

Patent quality

Patent quality is a term given for assessing patent; instead of using patent number as the sole evaluation basis, various indicators include to evaluate a patent's advantages. For example, cites per patent (CPP) indicates the citation intensity of a company's patent; the study consider patent of greater importance when its CPP value is larger. Current Impact Index (CII) is taken as another index of a patent's citation frequency within the most recent 5 years; it reflects the popularity of the patent. Out of the existing literature on the methods of evaluating patent quality, the study selects two representative articles to be the ground of this study and compiles the patent quality indicators as shown in Table 1.

Breitzman and Narin (2001) use the patent indicator that CHI Research, Inc (CHI) provides in their study. CHI is an institution which offers information on technology, scientific and financial index, and CHI has its own Tech-Line database. Ernst (1998) uses patent activity and patent quality to analyze a company's patent portfolio and propose three

Table 1 Summary of patent quality indicators

Indicator	Explanation	Function
Number of patent	A company's patent number as published by USPTO	To evaluate the degree of a company's R&D activity
Cited per patent, CPP	The citation frequency of a company's patent in future patens	The higher represent the cited patent is more essential and important
Current Impact Index, CII	It reflects the total number of forward citations in a given year to the company's patents issued in the most recent 5 years	CII = 1.0 means the patent's citation rate is the same as before within 5 years CII > 1.0 means the company's patents are more frequently cited within 5 years than before and the patented technology is important to the development of the industry
Technological strength, TS	The product of patent number and CII	To represent a company's total value
Science linkage, SL	The number of scientific and research paper cited in one patent application	The higher represents a stronger connection to basic science
Technology cycle time, TCT	The TCT is the median age of the patents cited on the front page of a patent	It measures the pace of technological progress in an industry; a smaller TCT value means it takes less time to replace a technology

indicators which are respectively for the relative patent position, technology attractiveness, and the importance of a technological field.

Base on literature, the study evaluates a company's patents by its patent quality. With different industrial background and technological attributes, the value of patent quality also means differently. By using multiple indicators, a company will be able to mark degrees of importance to its patents and find a new way to evaluate its economic performance.

The correlation between patent quality and a company's profitability

Table 2 displays the correlation between patent quality and a company's profitability. The measure of patent quality is mostly in a quantitative way by looking at the patent numbers and the citation intensity. On the assessment of a company's profitability usually uses public data such as trend of stock returns and MTB ratios for reference. The study aims to explore the correlation between patent quality and profitability by evaluating multiple patent quality indicators. The study also uses ROA as dependent variables in order to investigate the impact on a company's profitability caused by patent quality.

Methodology

Testing model

As Table 2 illustrates, in literature that relates to the research of the correlation between patent quality and profitability as well as the study on the use of cross-sectional/longitudinal data, a company, of single or cross industry, uses various variables to represent its R&D capabilities. This is to do with a company's stock and market price and it also reveals that patent related measurement variables have certain degree of impact on a company.

Table 2 A summary of the relation between patent quality and companies' profitability

Researchers	Sample/periodical	Independents	Dependents
Deng et al. (1999)	388 companies of chemical, pharmaceutical, electronics and several other industries (1985–1995)	Patent number Current impact index Science linkage Technology cycle time	Stock return Market-to-book ratio (M/B ratio)
Ramanathan (1999)	Pharmaceutical	Patent related issues	Stock prices
Thomas et al. (2001)	308 U.S. listed companies (1990–1997)	Patent number Patent growth rate Current impact index Science linkage Technology cycle time	Stock market performance
Hagedoorn and Cloodt (2003)	1,200 high-tech companies from four industries (1997–1998) Aerospace and defense Computers and office machinery Pharmaceuticals Electronics and communications	R&D expenditures Patent number Patent citation rate New product announcement	Innovation performance
Markman et al. (2004)	85 U.S. pharmaceutical companies (1995–1999)	Patent citation rate Patent application numbers	Profitability New product introduction

The independent variables use in this study retrieve from the patent database: the patent count, CPP, technological strength (TS), CII, science linkage (SL), TCT as the independent variables. The dependant variables associate with the company's profitability: the return on assets (ROA) obtains from the company's financial data. Meanwhile with the cross-sectional and longitudinal information provided, the study runs the following regressions:

$$ROA_{i\tau} = \beta_1 P_{i\tau} + \beta_2 CPP_{i\tau} + \beta_3 TS_{i\tau} + \beta_4 CII_{i\tau} + \beta_5 SL_{i\tau} + \beta_6 TCT_{i\tau} + \varepsilon_{i\tau} \quad (1)$$

where (β_1, …, β_6) are the regression coefficients to be estimated and $\varepsilon_{i\tau} \sim N(0, \sigma^2)$. $ROA_{i\tau}$: the ROA "i" company creates within a given τ time; $P_{i\tau}$: the patent numbers "i" company has during a period of τ time; $TS_{i\tau}$: the technological strength "i" company achieved within a given τ time; $CII_{i\tau}$: the Current Impact Index "i" company has during the given period of τ time; $SL_{i\tau}$: the science linkage "i" company has during the given period of τ time; $TCT_{i\tau}$: the technology cycle time a company "i" requires given a period of τ time. The definition of patent indicators showed as in Table 1 (Breitzman and Narin 2001).

Sampling

The study derive samples and relevant company background information from Standard & Poor's Compustat Research Insight's files, which provide financial, statistical, and marketing information on approximately 10,000 active U.S. companies, 10,400 inactive (Research) U.S. companies, 1,000 Canadian companies, 450 ADRs and 350 types of annual data, 230 types quarterly data, 300 financial ratios. It also includes 600 indices of S&P, Dow Jones and Russell. The Compustat database provides the most also comprehensive company financial data, growth rate, extensive balance sheet, income statement and detailed footnotes; annual and quarterly data is also available for a maximum of

20 years and 48 quarters. The Compustat files also contain information on aggregates, industry segments, banks, market prices, dividends, earnings as well as the financial trends.

The patent quality indices we use in this study are from the Smart KMS-ICM database. In light of the size of the U.S. market, the US Census Bureau creates Standard Industrial Classification (SIC) to distinguish the nature of different industries. The type of industry selected for this study is categorized under SIC 3674: Semiconductor Related Device.

The research targets we select from the Compustat files are 163 listed U.S. semiconductor companies under SIC 3674. The study examines their ROA during a 7-year period of time from 1996 to 2002; those without complete financial data are dropped out and only 80 companies were left to be further screened. Out of the 80 companies, only 43 are qualified to be used in this study; those failed to present complete patent quality data, and those without patent application record over 3 years have been discarded.

Testing tool

The samples used in this study have to include cross-sectional information on a company's patents and financial data as well as longitudinal time-series information. Panel Data sets offer two-dimensional data which can deal with both cross-sectional data and time series information at the same time. It analyzes annual time information from each research unit in the cross-sectional data. In this study we use Panel Data to carry out a cross-sectional research on a company's ROA value, which represents profitability, and to examine the correlation of the longitudinal time-series data.

Panel Data has four model types including basic model, individual-effect model, fixed-effects model and random-effects model. Both fixed-effects and random-effects models can be further divided into one-way and two-way types of models (Hausman 1978). The difference between ordinary least squares (OLS), fixed-effects model and random-effects model is that OLS calculation can only be analyzed either cross-sectional or time-series data at a time. Therefore, when a combination data appears, using OLS may overlook the differences embedded in the cross-sectional data thus generates unreliable estimate results. Whereas fixed-effects model and random-effects model can deal with the two data types simultaneously; given special consideration to the differences within cross-sectional data, we can eliminated discrepancies among samples. The estimation result gained will also be more efficient and consistent.

Analysis and discussion

Panel Data model selection analysis

The study uses ROA as dependent variables to decide which model will be selected for analysis of the impact of panel on a company's profitability in the semiconductor industry. We showed the results in Table 3 with F test, suggesting that one way fixed-effects model was appropriately and significantly than ordinary least squares model and two way fixed-effects model for panel quality on prediction for ROA. Therefore, the study selects one way fixed-effects model for analysis in first step. In LM test, one-way random-effects (12.46) model and two-way random-effects model (16.43) were significantly than ordinary least squares model (6.63). Thus, one-way random-effects model and two-way random-effects model are recommended. Finally, the study we compares one way fixed-effects model, one-way random-effects model, and two-way random-effects model to decide

Table 3 ROA samples and Panel Data models

	H_0: OLS ≻ OWF	H_0: OWF ≻ TWF
	H_1: OWF ≻ OLS	H_1: TWF ≻ OWF
Samples	F(39,115) = 1.853*	F(6,109) = 1.28
	H_0: OLS ≻ OWR	H_0: OLS ≻ TWR
	H_1: OWR ≻ OLS	H_1: TWR ≻ OLS
Samples	LM(1) = 12.46*	LM(2) = 16.43*
	H_0: OWR ≻ OWF	H_0: TWR ≻ TWF
	H_1: OWF ≻ OWR	H_1: TWF ≻ TWR
Samples	Hausman(6) = 1.61	Hausman (6) = 2.12
Suitable model	Two-way random	

* $p < 0.1$. The value within () is the degree of freedom; the value above () within the cell is the test statistics; *OLS* means ordinary least s quares model, *OWF* means one way fixed-effects model, *TWF* means two-way fixed-effects model, *OWR* means one-way random-effects model, *TWR* means two-way random-effects

which one is most suitable for the prediction of panel quality on ROA. Firstly, we compare one-way random-effects model and one-way fixed-effects model. In Hausman test, the results indicate that one-way random-effects model is chosen instead of one-way fixed-effects model. Second, two-way random-effects and two-way fixed-effects are tested to compare, and the results show that two-way random-effects model is more suitable than two-way fixed-effects model. Finally, we found that a significant value in two-way random-effects model (2.12) is more suitable than one-way random-effects model (1.61), so we chose two-way random-effects model for panel quality on prediction for ROA.

Patent quality and ROA analysis

The study use ROA as an index to evaluate a semiconductor company's profitability. We study a company's ROA to explore the relationship between ROA and patent quality. A two-way random-effects model is applied to test 43 semiconductor companies' data during 1996 and 2002, as Table 3 shows. From Table 4 we learn that CPP has a significant and positive relation to ROA, $\beta = 1.114$ ($t = 2.095$, $p < 0.05$). The result also shows that a frequently cited patent will improve developing a company's ROA and has a direct and positive impact on the company's profitability. Similarly, in a two-way random-effects model, we learn that the TS has a significant negative effect on ROA, $\beta = -6.82$ ($t = 2.737$, $p < 0.05$). The result also shows that a patent of high TS will lower the ROA performance and has a negative impact on the company's profitability.

Conclusion

The research results indicate that the relationship between CPP (which indicates the citation intensity of a company's patents, where a patent is of greater importance when its CPP value is larger) and ROA is positively significant. This shows that a higher patent quality as measured by CPP is of greater benefit in augmenting a company's ROA. Patents with a high CPP value are often related to inventions of importance, which has a direct and positive impact on a company's profit-earning ability.

Table 4 The impact of research samples to ROA when adopted alternative analysis approaches

	OLS		One-way fixed		One-way random		Two-way fixed		Two-way random	
	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio	Coeff.	t-ratio
P	−0.0207	−0.379	−0.0005	−0.06	−0.0178	−0.319	−0.0569	−0.638	−0.0282	−0.460
CPP	0.9825	2.760***	1.0202	2.75***	1.0136	3.045***	1.4640	1.667*	1.1143	2.095**
TS	−6.3115	−2.59***	−7.6414	−2.84***	−6.5767	−2.773***	−8.8846	−2.170**	−6.8249	−2.373**
CII	0.0216	0.801	0.0061	0.138	0.0189	0.668	0.0196	0.444	0.0216	0.694
SL	1.8751	1.002	−0.3768	−0.129	1.2798	0.645	−1.1983	−0.414	0.6109	0.283
TCT	0.8256	0.918	0.1858	0.167	0.4659	0.513	−0.0418	−0.038	0.2610	0.276
R^2	0.8925E−01		0.4407				0.4952			
Adjusted R^2	0.5376E−01		0.2219				0.2590			

Note: All figures are the t-value

* <0.1, ** <0.05, *** <0.01

However, the relationship between P and ROA is not significant, which indicates that companies need to emphasize the quality rather than the quantity of their patents. As patents in the semiconductor industry predominately originate from fabrication refinements, any perceptible improvements may be patented, which makes patent procuring fairly simple and results in the amassing of a large quantity of patents. However, the possession of these patents does not literally improve performance, because patents of substantial importance may be limited in number.

It is apparent from the analysis results that the negative relationship between TS and ROA deserves attention. If we recall the results displayed in Table 4 and evaluate other less significant coefficients, we can draw the conclusion that TS is the product of P and CII. In all of the testing models, the coefficient P appears to be slightly negative but is not significant, and statistically there is no significant connection between P and ROA. The CII coefficients are slightly positive in all pf the test models, but are not significant. Statistically, there is no significant relationship between CII and ROA, but their product TS has a significant negative relation with ROA. This indicates that there is an interaction effect between P and CII on ROA, which is an interesting result. The effect of P on ROA is determined by CII (the total number of forward citations in a given year of the company's patents issued in the most recent 5 years). A lower CII indicates that the possible effects within the past 5 years are less important, despite the quantity of patents, and that P is likely to have a weaker, or even negative, effect on ROA in the next 5 years. Investment is required to expand the quantity of P, but the influential effect of P may not be directly proportional to its quantity, which may in fact reduce ROA. However, when CII is high, P positively influences ROA. Consequently, the major discovery of this study is that CII determines the direct effect of the quantity of P on ROA in the semiconductor industry.

Future studies could focus on three directions. First, this study used ROA as the index of a company's profitability, but future research could use other performance measurements, such as the company's ROE or market value. Second, this study conducted empirical research in the U.S. semiconductor industry by combining time-series and cross-sectional data. Future studies could utilize different models to investigate this area. Finally, this study only considered the semiconductor industry as categorized by the U.S. Census Bureau's Standard Industrial Classification (SIC 3674), but different company samples would be obtained if other industry category standards were adopted, such as the United Nations' International Standard Industrial Classification (ISIC), the North American Industry Classification System (NAICS), or the Global Industry Classification Standard (GICS). Furthermore, different industries altogether could be adopted as study subjects in similar research, which would give a comparative industrial viewpoint and highlight the influence of other industry characteristics.

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