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Technological Diversification and Market Performance — Evidence from Taiwan's Electronics Industry

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Abstract: *This paper examines the relationship between technological diversification and market performance by analysing patent data from listed Taiwanese electronics companies from 1990-2008. We fit each patent into a 35-field technology classification to calculate a newly constructed diversity index for the firm. After controlling for effects of firm size and firm age, we confirm a positive role of technological diversification on the firm's market performance as measured by sales, gross profit, and the ratio between sales and employment. This paper suggests technological diversification rather than technological specification as the innovation strategy. By combining related and unrelated knowledge fields, firms could be inspired with new ideas in product innovation or process innovation.*

Keywords: Innovation, technological diversification, market performance, electronics industry, Taiwan
JEL Classification: D22, O31, O32

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1. Introduction

Innovation has long been considered a primary instrument and powerful weapon to battle competitors in an imperfect competition market. With rapid and continuous changes in technology, firms are eager to innovate to survive and grow, especially in high-tech industries (Baumol, 2002). Granstrand and Sjölander (1990) found that firms are increasingly multi-technological. The innovation strategy of technological diversification is currently highly emphasised.

The concept of diversification can be traced to product or market diversification. Firms could expand into a broader range of product field

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and/or manage more than one business line to diversify their production and reach economic scope. Since the complexity and interdependence of technology have grown continuously, some studies have questioned whether product diversification is a good measurement of technological diversification (Granstrand, 1998; Fai & von Tunzelmann, 2001). Other studies argued that technological diversification is usually higher and more stable than product diversification, and originates in different stages of the value chain (Cantwell & Andersen, 1996; Gambardella & Torrisi, 1998; Heeley & Matusik, 2004). One complex product could contain more than one technology, but the range of product diversification remains relatively narrow. Therefore, firms might be multi-technological even if they manage only one core business line. Based upon such indications, firms' technological diversification strategy is worthy of attention.

There are multiple reasons for technological diversification. First, firms might obtain higher cross-fertilisation between different but related technological fields by spanning their innovative activities over more than one technology (Gransrand, 1998; Suzuki & Kodama, 2004). Second, firms with broader technological knowledge might obtain synergies among related and unrelated technologies, and create a new product or service through technological fusion (Kodama, 1992). Third, concentrated innovation in a specific technological field might be too risky. Managers may want to spread the risk of innovation instead of putting all eggs into one basket. Instead of trying hard to develop one core technology, firms might be more likely to diversify their research resources into different but related technological fields. However, to develop new technology is costly and time-consuming, so not all firms can afford many different fields of research. Furthermore, a specific technology could lead to more innovation through the learning effect and delving deeper into a specific field could be easier due to accumulative experience.

Our aim in this paper is to analyse whether technological diversification has a positive impact on market performance. First, we confirm the effect of patent stock is highly related to technological diversification. To this end, we should take the patent counts into consideration. Second, we construct a model to examine the role of technological diversification in market performance by adopting sales, profit, and sales contributed per employee as measurements of market performance.

2. Prior Research and Hypothesis

In order to sustain market position and grow in a competitive market, engaging in innovation has become indispensable to firms. One of the important issues they confront is how to innovate and whether to diversify their technology or to specialise. It sounds similar to the process of production; the specialisation brings economies of scale while the diversification brings the economies of scope. As the literature points out, there are at least two opposite effects to technological diversification. On the one hand, the research and development group may gain from different dimensions of the technological knowledge base. By integrating and coordinating related and unrelated technology, firms may inspire further innovation or create new products or processes (Grandstrand, 1998). On the other hand, economies of scale may occur in the process of technology development due to a learning effect. Development in a specific and definite technological field can centralise the firepower of a firm's innovation. (Kodama, 1992; Argyres, 1996; Hargadon & Sutton, 1997). Nevertheless, technological diversification is time-consuming and costly, and firms may not want to put all eggs in one basket.

Our purpose is to analyse the effect of technological diversification on market performance. Most empirical studies have confirmed the positive impact of technological diversification on performance. For example, Gambardella and Torrisi (1998) analysed the largest 32 U.S. and European electronics firms from 1984 to 1992 and found that better performance is associated with greater technological diversification. Also, by analysing the diversification dynamics of Japanese industry during the 1980s and 1990s, Gemba and Kodama (2001) concluded that an R&D diversification strategy into downstream activities contributes to increased profitability. Miller (2006) adopted a large sample of firms to show the contribution of diversification based on technological diversity and market-based measures of performance and reached the same conclusion. In recent research, Lin and Chang (2015) used 165 S&P manufacturing firms to show that large firms can benefit from a diversified technological portfolio with regard to both financial and innovation performances. Kim, Lee, and Cho (2016) confirmed the relationship between technological diversification and firm growth is inverted U-shaped, implying that both insufficient and excessive technological diversifications are harmful to firm growth.

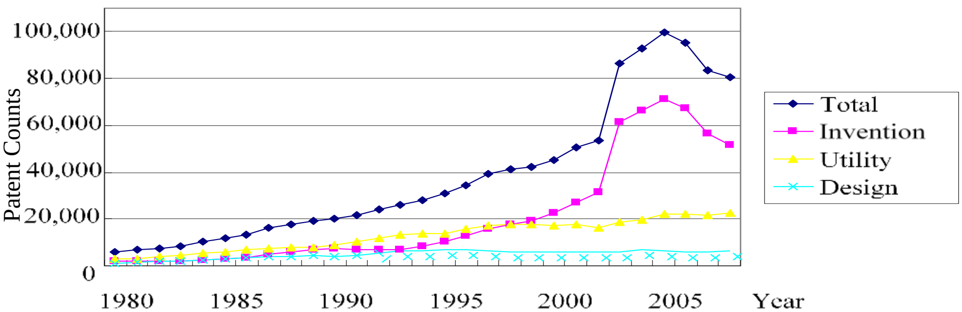
However, Granstrand and Oskarsson (1994) found evidence to the contrary. They analysed the relationship between technological diversification and the growth of sales and showed that the technological diversification does not automatically lead to the growth of sales and claim that the management of technology is all-important. These arguments lead to the following hypothesis.

Hypothesis: *Technological diversification has a positive impact on market performance.*

3. Data and Model

Intellectual property rights have been a key area of focus since 1990, and the number of patents granted has grown rapidly since then. The trend in the total number of Taiwanese patents granted is shown in Figure 1. The patents can be classified into invention, utility, and design. The former two categories are based on the International Patent Classification (IPC), while the design category is based on the design Locarno Agreement Establishing an International Classification for Industrial Designs. In this paper, we stress only invention and utility. In order to examine the impact of technological diversification, we use 630[1] electronics firms listed on the Taiwan Stock Exchange (TSE), Over-the-Counter (OTC), and Emerging Stock (ES) markets during 1990-2008[2]. We collected the necessary information of these firms including financial condition (such as annual sales, gross profit, R&D expense, number of employees, etc.) from the Market Observation Post System.

Figure 1: Trends in Number of Taiwan Patent Counts (1980-2008)



Referring to the "Standard Industrial Classification of ROC" published by the Directorate General of Budget, Accounting and Statistics of Executive Yuan; TSE Corporation classified the listed companies into 29 industrial categories including eight electronics industries[3]. Rather than conducting study across several industries, we adopt a single sector to avoid the potential industry-specific influences. Electronics is one of the most representative sectors where innovation is extremely active. The firms' annual patent counts statistics in these eight electronics industries are presented in Table 1. On average, those firms involved in semiconductor, computer and peripheral equipment, and in the optoelectronics industry, have at least ten patents every year.

In order to measure firms' innovation activities[4], we adopt patent statistic as an indicator of a firm's portfolio of technological competency. The patent data is based on the Taiwan Intellectual Property Office (TIPO) database.

Each patent is classified by the IPC system from World Intellectual Property Organization (WIPO). The measurement of technological diversification deserves attention. Since the IPC contains more than 600 fields, the calculation of index based on IPC may be overestimated. Following Garcia-Vega (2006), we fit the over 600 subclasses of IPC into a 35-field technology-oriented classification developed by Fraunhofer ISI, the Observatoire des Sciences et des Technologies, and the French patent office (INPI). They developed a systematic technology classification based on the codes of the IPC. The first version was published in 1992 and comprised 28 technology classes. The version we adopt is shown in Table 2.[5]

Table 1: Patent Counts and Diversification Index Statistics of Electronic Industry

Industry	No. of Firms	Patent		Div. Index	
		Mean	S. D.	Mean	S. D.
Semiconductor	116	18.01	76.59	0.362	0.304
Computer and peripheral equipment	108	12.75	51.71	0.506	0.328
Optoelectronic	77	11.63	63.08	0.366	0.325
Communications and internet	68	3.98	14.77	0.392	0.335
Electronic parts and components	149	4.30	22.65	0.315	0.315
Electronic products distribution	21	0.73	2.19	0.335	0.355
Information service	26	1.18	3.37	0.267	0.302
Other electronic industry	65	10.11	52.70	0.449	0.336
Total	630	9.39	48.60	0.392	0.330

Table 2: Technology Classification (35 fields) Based on the IPC

1. Electrical machinery, apparatus, energy	19. Basic materials chemistry
2. Audio-visual technology	20. Materials, metallurgy
3. Telecommunications	21. Surface technology, coating
4. Digital communication	22. Micro-structure and nano-technology
5. Basic communication processes	23. Chemical engineering
6. Computer technology	24. Environmental technology
7. IT methods for management	25. Handling
8. Semiconductors	26. Machine tools
9. Optics	27. Engines, pumps, turbines
10. Measurement	28 Textile and paper machines
11. Analysis of biological materials	29. Other special machines
12. Control	30. Thermal processes and apparatus
13. Medical technology	31. Mechanical elements
14. Organic fine chemistry	32. Transport
15. Biotechnology	33. Furniture, games
16. Pharmaceuticals	34. Other consumer goods
17. Macromolecular chemistry, polymers	35. Civil engineering
18. Food chemistry	

Technology diversification is calculated by the following equation. The concept is similar to the Herfindahl Index of market concentration.

$$diversity = 1 - \sum_{j=1}^{35} \left(\frac{N_{ij}}{N_i} \right)^2 \tag{1}$$

where N_i is the total patents applied for by firm i in the current year; N_{ij} is the number of patents applied for by firm i in technology field j=1 to 35. Therefore, the sum of 35 N_{ij} should be equal to the total number of patents, N_i. If the firm's patent applications are all in a single field, this means it specialises its technology, and $\sum_{j=1}^{35} \left(\frac{N_{ij}}{N_i} \right)^2$ will approach 1, then the index of diversity will come near zero. Otherwise, the index diversity will approach one for diversified technology firms.

In order to examine the relationship of patent and technological diversification, we adopt annual data on employment, age, debt ratio as well as industrial dummies to control the specific industrial characteristic for each firm. All of the financial data are deflated by the 1990 consumer price index from the Taiwan Economic Journal (TEJ) Databank which is one of most reliable data banks for Taiwanese listed companies.

Since the effect of technological diversification might be due to the patent stock, we first consider the following model to check the relationship between diversity and patent.

$$\begin{aligned} diversity_{it} &= \alpha_0 + \alpha_1 \ln(patent_{it}) + \alpha_2 age_{it} + \alpha_3 age^2{}_{it} + \alpha_4 \ln(emp_{it}) \\ &\quad + \alpha_5 debt_{it} + \delta_i + \varepsilon_{it} \end{aligned} \tag{2}$$

We adopt patent counts to measure innovation activity.

The age of a firm is also related. The squared term reveals the marginal effect of firm age on diversity. Meanwhile, employment may partially represent the power of doing technological diversification. Following Garcia-Vega (2006), we also consider the financial constraints, debt ratio (*debt*), and expect the negative sign which represents the more debt would cause less expenditure on research and development. The variable δ_i represents the industrial dummies as control variables. As demonstrated by Stephan (2002), technological diversification may be industry-specific.

Our main hypothesis examining the role of technological diversification on market performance is tested by the following model.

$$performance_{it} = \beta_0 + \beta_1 diversity_{it} + \beta_2 \ln(patent_{it}) + \beta_3 rd_{it} + \beta_4 age_{it} + \beta_5 \ln(emp_{it}) + \beta_6 debt_{it} + \delta_i + e_{it} \quad (3)$$

In this paper, we adopt three proxies consisting of annual sales, gross profit, and the ratio of annual sales over employment, to measure market performance.

4. Empirical Results

Tables 3 and 4 show the summary statistics and the correlation matrix to this study respectively. In order to examine whether the technological diversification contributes to market performance, we first test the effect of patents on diversification, and we find a quite robust empirical result. Since the dependent variable, diversity, is a variable between zero and one, we adopt Fractional Probit and Logit model to regress.

Table 3: Summary Statistics

Variable	Mean	Std. Dev.	Min	Max
Diversity	0.36	0.33	0.00	1.00
Patent	22.14	100.00	0.00	2,260.00
Age	12.38	8.50	1.00	58.00
Employment	578.37	1,732.13	1.00	35,077.00
Debt ratio	41.92	21.51	0.00	936.40
Sales	5,791,263.00	32,200,000.00	-64,376.56	1,400,000,000.00
RD ratio	19.96	665.09	0.00	58,897.89
Gross profit	891,529.90	5,042,484.00	-38,100,000.00	150,000,000.00
Sales/Employment	10,875.34	19,090.84	0.00	535,570.70

Table 4: Correlation Matrix

Variables	1.	2.	3.	4.	5.	6.	7	8.	9.
1. Diversity	1.00								
2. Patent	0.17	1.00							
3. Age	0.09	0.12	1.00						
4. Employment	0.18	0.34	0.12	1.00					
5. Debt ratio	0.04	0.02	0.07	0.02	1.00				
6 Sales	0.17	0.68	0.10	0.45	0.08	1.00			
7. RD ratio	-0.02	-0.01	-0.05	-0.01	-0.06	-0.01	1.00		
8. Gross profit	0.13	0.45	0.00	0.76	-0.07	0.60	-0.01	1.00	
9. Sales/Employment	0.10	0.31	0.06	0.03	0.14	0.52	-0.02	0.18	1.00

Table 5 presents the empirical results of the relationship of patent stock and technological diversification of Eq. (2). In both models, the innovation-related variable (patent) has the expected positive sign and relates significantly to technological diversification after controlling the effect of age, employment, financial constraints and other industrial specifications. This result indicates that the effect of patent stock is positively related to technological diversification. Those firms that diversify their technological fields have more patents. Therefore, if we want to analyse the impact of diversity on market performance, the effect of patent stock should be considered.

Table 5: Estimations of Technological Diversification Determinants

	(1) **div**	**(2)** **div**
ln(patent)	0.5207***	0.3178***
	(26.09)	(26.90)
Age	0.0177*	0.0104*
	(2.31)	(2.29)
Age2	-0.0002	-0.0001
	(-1.02)	(-1.01)
ln (emp)	0.0347	0.0195
	(1.59)	(1.48)
Debt ratio	0.0003	0.0003
	(0.23)	(0.33)
Industry 2	0.3790***	0.2377***
	(5.61)	(5.81)
Industry 3	-0.0134	-0.0010
	(-0.18)	(-0.02)
Industry 4	0.1356	0.0857
	(1.67)	(1.74)
Industry 5	0.2171**	0.1408**
	(2.93)	(3.14)
Industry 6	0.0555	0.0328
	(0.31)	(0.30)
Industry 7	-0.1206	-0.0726
	(-0.90)	(-0.90)
Industry 8	0.2051*	0.1227*
	(2.51)	(2.46)
_cons	-2.0028***	-1.2257***
	(-15.85)	(-16.17)
N	3986	3986
pseudo R^2	0.0981	0.0989

Notes: *t* statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: OLS Estimations of Market Performance Determinants

Dep. Variable	ln(sales)		ln(gross profit)		ln(sales/employment)	
Model	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
div(t-1)	0.1055**		0.1362**		0.0656	
	(2.93)		(3.07)		(1.79)	
div(t-2)		0.1448***		0.1275**		0.1085**
		(3.94)		(2.68)		(2.85)
patent(t-1)	0.1263***		0.1645***		0.0956***	
	(13.03)		(14.08)		(10.15)	
patent(t-2)		0.1108***		0.1608***		0.0864***
		(11.10)		(12.67)		(8.60)
rd_r	-0.0052***	-0.0120***	-0.0254***	-0.0090***	-0.0049***	-0.0111***
	(-13.26)	(-11.75)	(-13.64)	(-8.03)	(-12.24)	(-10.68)
age	0.0638***	0.0703***	0.0160***	0.0199***	0.0567***	0.0585***
	(23.78)	(23.32)	(5.49)	(6.01)	(21.43)	(19.82)
ln(emp)	0.7927***	0.7704***	0.7572***	0.7646***		
	(39.16)	(35.82)	(34.11)	(32.35)		
debt ratio	0.0034***	0.0027**	-0.0114***	-0.0104***	0.0032***	0.0023*
	(3.78)	(2.77)	(-10.39)	(-8.33)	(3.44)	(2.26)
industry 2	0.6380***	0.7799***	0.3345**	0.4707***	0.5463***	0.6383***
	(4.44)	(5.18)	(2.64)	(3.72)	(3.72)	(4.27)

Table 6: (Continue)

Dep. Variable	**ln(sales)**		**ln(gross profit)**		**ln(sales/employment)**	
Model	**(1)**	**(2)**	**(3)**	**Model**	**(1)**	**(2)**
industry 3	0.6034***	0.6556***	0.1387	0.2855*	0.5367***	0.5557***
	(4.20)	(4.35)	(1.11)	(2.29)	(3.65)	(3.72)
industry 4	0.1559	0.3632*	-0.2679	0.0039	0.0302	0.1557
	(0.98)	(2.09)	(-1.90)	(0.03)	(0.19)	(0.90)
industry 5	0.5520***	0.5908***	0.2443	0.3660*	0.4549**	0.4402*
	(3.39)	(3.39)	(1.71)	(2.51)	(2.73)	(2.55)
industry 6	-0.0563	-0.0699	-0.2618*	-0.0949	-0.0494	-0.0669
	(-0.41)	(-0.48)	(-2.15)	(-0.78)	(-0.35)	(-0.46)
industry 7	0.5772	0.3587	0.4242	0.4662	0.4933	0.3031
	(1.87)	(1.02)	(1.55)	(1.46)	(1.57)	(0.86)
industry 8	-0.3652	-0.2764	0.3289	0.2388	-0.3773	-0.2715
	(-1.45)	(-0.98)	(1.49)	(1.01)	(-1.47)	(-0.97)
_cons	8.4647***	8.5541***	8.6145***	8.2977***	7.4954***	7.5241***
	(53.22)	(51.29)	(53.52)	(50.42)	(57.28)	(55.84)
N	2369	1783	2309	1733	2369	1783
R^2	0.7732	0.7904	0.7478	0.7713	0.2634	0.2732

Notes: *t* statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

In the empirical results presented in Table 6, we confirm the positive role of technological diversification in market performance. To test the hypothesis, we adopt three dependent variables, ln(sales) for models (1) and (2), and ln(gross profit) for models (3) and (4), and ln(sales/employment) for models (5) and (6) to measure market performance. Since the effect of technological diversification might not be revealed in the current year, the lag terms of patent stock and the lag terms of technological diversification are also taken into consideration. The empirical results suggest that a higher level of technological diversification leads to better market performance. The results are quite robust except for model (5). This means that firms that develop in related and unrelated research fields tend to have better market performance.

Additionally, the significantly negative effect of R&D intensity could be because R&D expenditure dilutes part of the profits. Firms may be willing to sacrifice some profit in exchange for growth in the future and devote more efforts into research and development to diversify their technology. The variables of age and employment are positively significant. However, the variable of debt ratio has different effects among the three performance measurements. A possible explanation is that those indexes represent different viewpoint on market performance. For the value of sales, it is the absolute value which firms may gain from the market, while the gross profit is the amount of net income returned.

5. Conclusion and Discussion

In this paper, we examined whether firms with active innovation tend to expand their technology, and analysed the role of technological diversification in market performance. By analysing 630 Taiwanese electronic listed firms during 1990-2008, the empirical results show that the innovation has a positive impact on technological diversification. The higher level of firms' age and the rate of employment lead to a greater level of technological diversification although the marginal effects decrease after a certain level. The impact of financing is not significant in this study. Also, technological diversification has a positively significant effect on market performance. These results are in line with Gemba and Kodama (2001) and Miller (2006).

With the rapid pace of change in technology, firms undoubtedly have to devote themselves to continuous innovation to compete with their rivals. Without continuously moving forward and doing advanced research and development, firms may be weeded out from the market. In this paper, we suggest technological diversification rather than technological specification as the innovation strategy. By combining related and unrelated knowledge fields, firms may be inspired with new ideas in product innovation or process innovation. Meanwhile, products might contain more than one technology nowadays as firms may need more than one technological field when they invent a new product. In addition, diversification into technology fields may benefit from synergy.

However, firms might not diversify their technology randomly. Since innovation is costly and time-consuming, firms have to allocate all resources efficiently. Other options could be considered such as cooperation with other firms to build up a technical alliance or even working through technology trading or licensing.

Previous studies (Suzuki & Kodama, 2004; Kim, Lee & Cho, 2016) employed the 23 two-digit subsections of the IPC. In this paper, we employed a more accurate 35 fields of Technology Classification based on the IPC. Therefore, our study provides better coverage and understanding of the relationship between diversification and performance of firms. This is our contribution to methodology.

We also consider the lag terms of patent and technological diversification since the effect of technological diversification might not be revealed in the current year. The empirical results confirm that the innovation may ferment in the future performance.

For policy implications, we suggest that governments should promote technological diversification by giving grants or providing tax incentives to firms to organise R&D consortiums of several firms from different industries so that they can combine their specialisation and explore innovation together. Meanwhile, too much diversification might be negative on performance. Governments should provide incentives only for firms to diversify to technologically 'related' industries. Those firms that qualified for incentives should have done something related to the new targeted products/sectors.

In this investigation, we explored the high-tech electronics industry. Further studies might extend this to different industries to identify the differences. Since the same electronic industry may cover different scenarios of innovation, other industries might have distinct technological paradigms. Moreover, we fit over 600 subclasses of IPC into a 35-field technology-oriented classification following Garcia-Vega (2006). To get a more robust result, further studies might use other technology-oriented classifications.

Notes

1. In order to analyse the technological diversification, firms having less than two patents are excluded.
2. The reason that we use the data only until 2008 is to avoid the impact of the Collapse of Lehman Brothers on firms' technological strategies. It is an external shock which had very significant impacts

on firms' diversification and business expansion strategies. It will make our analysis very difficult.

3. The classification of electronics industry is defined by TSE corporation. Since July 2007, the electronics industry has been rearranged, including semiconductor, computer and peripheral equipment, optoelectronics, communications and internet, electronic parts and components, electronic products distribution, information service, and other electronic industry.
4. Griliches (1991) analysed strength and weakness of adopting patent as an innovation measurement.
5. We thank Francesco Lissoni for kindly providing the concordance of IPC patent classes with the 35-field classification.

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