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Technological diversification, complementary assets, and performance

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Abstract

Most research on technological diversification or complementary assets has been carried out in isolation when assessing their effects on performance. In this study, we posit that technological diversification and performance are positively linked and that specialized complementary assets have a moderating effect on this relationship. This study also finds that different specialized complementary assets have distinctive moderating effects on the relationship between technological diversification and performance. We conclude that maintaining a coherent relationship between technological diversification and specialized complementary assets give firms generates competitive advantage.

Keywords: Technological scope; Technological diversification; Complementary assets

1. Introduction

Diversification has a critical role in business growth, especially in competitive environments full of uncertainties and risks. Inspired by the work of Chandler [1] and Ansoff [2], numerous studies have demonstrated the significance of diversification in strategy management theories [3–7]. However,

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previous diversification research used the degree of product or market diversification as the measurement for calculating diversification. These approaches, in fact, neglected to consider the resources and competence required to produce this product as well as the market diversification required to sell it [8,9].

Indeed, product or market diversification are based on the expansion of a firm's core competence and resources [10–12], by which static and dynamic synergies of competence are attained [13,14]. Technological development is a prerequisite in the process of expanding competences, and for creating additional opportunities for market and/or product diversification [15]. It also allows firms to cultivate competitive advantage in specific areas [16]. Especially when the industry structure is imperfect, quality improvement and innovation can generate competitive advantage for firms, [17]. These improvements in quality and innovation require firms to diversify their technological base; that is, firms need to "span their innovative activities over more than one technology" [12]. Thus, analyzing technological diversification — the essence of diversification — rather than merely product or market diversification is important.

Although the importance of technological diversification for performance has been recognized in existing research, they demonstrate the inconsistent results. Some studies empirically proved that a positive relationship exists between technological diversification and performance [4,11,18,19]; others argue that increased technological specialization is linked to performance [20,21]. Other studies demonstrated that has no direct impact upon performance [7]. One crucial reason for these inconclusive results is the fact that the moderating effect of complementary assets has been neglected in most of these studies.

Entering a new technological area or so-called technological diversification taxes a firm's resources and capital, and adequate internal support becomes critical to success. Additionally, technological diversification usually increases risks and adds uncertainties. Support for complementary assets, such as capital, distribution and marketing can mitigate these inherent risks and uncertainties. Therefore, as the degree of technological diversification increases, the importance of complementary assets increases. That is, the relationship between technological diversification and performance is moderated by supports for complementary assets.

One rationale explaining why some firms fail in their innovation is that the inevitable risks and uncertainties prevent initial innovation investments from being successfully converted into a final product [22]. Nevertheless, even though some firms successfully commercialized their innovations, they still lost their lead position. For instance, Electrical Music Industries (EMI) Ltd., the innovator of the computed tomography scanner (CT scanner), lack sufficient experience in the hospital channel and were replaced by the follower—General Electric Company which had strong support from its hospital channels. Thus, even if an innovative firm has technological capabilities, it may lack the required complementary assets. Complementary assets are specialized support assets required for successful commercialization of a core technology [23]. While certain complementary assets are specialized and not readily available, owners of such complementary assets can easily replace an original innovator and emerge as winners because they are able to acquire the technology, in some cases, through learning or technology transfer when the appropriability regime is lost [22,24–28]. Thus, from this perspective we assume that technological capabilities alone cannot ensure a firm's performance. The simultaneous cooperation of complementary assets and technological capabilities is critical for success [22,29,30].

The motivation for this study was the prevailing ignorance regarding complementary assets in technological diversification research. Therefore, the study focuses on the inclusion of complementary assets and the exploration of its moderating effects on technological diversification and performance in order to fill the void in the literature. This study also follows Taylor and Lowe [31] and characterizes complementary assets by their functional classifications into three categories: marketing resources, production resources, and human capital. Thus we investigate the moderating effects of these three specialized complementary assets (SCAs) on technological diversification and performance.

Thus, this study contributes to existing literature in three ways. First, the study addresses the need for a more thorough testing of the moderating effect of the SCAs on the relationship between technological diversification and performance [9,25–27]. Second, by drawing the SCAs, the study develops and contributes theoretically proximal and fine-grained measures of those assets. Third, the study carries out an empirical examination which builds on an original dataset of 582 Taiwanese high-technology (high-tech) firms during 1997–2005.

This paper is organized as follows. Section 2 reviews relevant literature. A set of hypotheses is then developed that is related the moderating effects of the SCAs on the relationship between technological diversification and performance. The research methodology is then depicted, highlighting sample selection, data collection, variable definitions and measures, and the calculation process. Next, the results and conclusions are elucidated. Finally, this paper is concluded by offering a series of implications and suggestions for future research.

2. Theory and hypotheses development

This study examines the relationship between technological diversification, complementary assets, and performance. Relevant literature on technological diversification is reviewed to identify the relationship between technological diversification and performance. Then the moderating effects of complementary assets on technological diversification and performance are then discussed.

2.1. Technological diversification

“Technology” is an attractive resource firms need to continue growing and protect profitability [32,33]. Thus, firms must consider how and where to use their superior technological competences to extend their activities to other product or business domains [34–36]. That is, how should they spread the technological base of their firms and acquire new technological assets, or sources of competitive advantage [37].

Technological diversification is defined as a “corporation’s expansion of its technological competence in to a broader range of technological areas” [21]. Technological diversification can be hypothesized as leading to increased profit from economies of scale and scope. Thus, technological diversification is derived from the breadth of a body of knowledge, and from how far and in what direction a firm pursues links in a knowledge network [19].

First and perhaps the most important issue a firm faces in developing their technological strategy is selection of technological scope. Firms can either choose to enter familiar areas using a technological specialization strategy or enter unfamiliar areas using a technological diversification strategy. Indeed, technological diversification or specialization is a decision regarding business technology strategy that, given limited resources, poses a dilemma. Pursue both strategies simultaneously is very difficult for firms. The benefits of specialization are based on economies of scale as firms can easily accumulate technological competence with lower unit cost in familiar areas. Moreover, economies of specialization due to the effects of learning and knowledge transfer among similar technological areas enable firms to establish their core competence [36,38]. Although a certain degree of specialization is required to achieve the needed expertise for improving current complex techniques, firms that more technologically diversified have particular advantages in competitive markets [17].

Technological diversification can obtain synergies among related and unrelated technologies [17,39]. Suzuki and Kodama [40] traced two Japanese firms with their patents, technology development, and sales over a 30-year period. They identified that obvious synergies evolved among multiple technologies that generated competitive advantage for the firm. In addition to achieving synergies, technological diversification can also improve performance directly through risk reduction. On average, only about half of technological projects undertaken are successful [41]. Investments in R&D entail risks and uncertainties. Ever increasing competition and rapid technological change can cause a firm's technology to become obsolete rapidly. In such a situation, a firm with a higher level of diversification associated with technology can generate a richer R&D portfolio, thereby balancing the risks inherent to each project. Consequently, a firm can decrease variance associated with returns from investments [17]. A richer R&D portfolio also prevents firms from being hold-up in some particular technologies, and provides it with more strategic flexibilities.

Gambardella and Torrisi [11] empirically found that a positive relationship existed between technological diversification and performance. Investigating R&D activities and performance of Japanese firms, Gemba and Kodama [42] recognized the positive influence of technological diversification on firm performance. The most recent empirical research has confirmed this influence [19]. In summary, arguments regarding the positive impacts of technological diversification suggest the following hypothesis:

Hypothesis 1. An increase in technological diversification has a positive effect on performance.

2.2. Complementary assets

According to Teece [23], complementary assets are the specialized supporting assets required for successful commercialization of a core technology. Whether innovative technology is independent or indigenous successful commercialization of innovation requires that core technology be utilized in combination with other capabilities or assets. Therefore, profiting from innovation requires both a core technology and relevant complementary assets. Teece suggested that to commercialize the design of new product in a profitable manner, a firm must have access to complementary manufacturing technology, distribution channel and etc.

Complementary assets can be *generic,* meaning not tailored in any way, they can be *specialized* which involves unilateral dependence with a core technology, or *co-specialized* which means in nature being bilaterally dependent on a core technology. Generally, generic complementary assets offer little or no competitive advantage to a firm, as such asses are readily available in the marketplace or easily developed by the firm itself. Conversely, specialized and co-specialized complementary assets are difficult to access in the marketplace due to transaction cost issues associated with asset specificity and small numbers bargaining. It is these specialized or co-specialized complementary assets that generate competitive advantage for firms. When innovation depends on specialized complementary assets[2] for successful

[2] Since Teece's distinction is not crucial to this study, the term "specialized" is used to refer both specialized and co-specialized complementary assets [26].

commercialization, a firm with proprietary access to such assets will outperform competitors who do not have access to such assets. Thus, to maintain competitiveness and reduce cost and time required to achieve those assets, firms typically develop these SCAs on their own.

Complementary assets are very important in the paradigmatic stage [23]. Soon after a new dominant design shows up in the marketplace, there are common platforms or standards in the marketplace, competitors or followers can easily enter the same market because technological barriers are easily overcome. During this stage of increased rivalry, firms can avoid competition by technologically leapfrogging into a new or next-generation product and new market segments, or enhancing their competitive advantage by leveraging SCAs. However, entering new segments entails a much higher level of technology as well as market uncertainties and risks. Technological leapfrogging is a difficult task for any firm. Alternatively, a firm can enhance their process innovation by reducing cost and focusing on marketing capabilities for customer preference to achieve cost leadership or focus advantage [43]. Consequently, SCAs for production and marketing are prerequisite.

This literature review indicates that technological diversification positively impacts performance. However, support by SCAs markedly increases the influence. Specialized complementary assets play the moderating role in the relationship between technological diversification and performance. These arguments lead to the following hypothesis:

Hypothesis 2. As technological diversification is positively related to performance (as proposed in Hypothesis 1), this relationship is stronger when there are more SCAs available than when there are few available.

Traditionally, any asset that assists in commercialization of an innovation, such as financial assets, complementary technology, intangible assets, management capabilities, or market knowledge, can be considered a complementary asset. Taylor and Lowe [31] differentiated complementary assets using a functional perspective into marketing resources, production resources, human capital and others.

Specialized marketing complementary assets comprise availability of channels, marketing systems, logistics, branding loyalty and others that are germane to the successful commercialization of an innovation [44]. Rothaermel [45], who conducted an empirical study of pharmaceutical firms, demonstrated that testing and examining of new products, channels, and logistic system are necessary complementary assets for performance. Technological diversification strategies typically expose firms to unfamiliar markets. Therefore, appropriate and adequate market knowledge or marketing capabilities can reduce risks and uncertainties.

Another issue related to successful commercialization is production capability, as manufacturing skills for a prototype and those for final mass products are extremely different. Mass production favors quality, cost, speed, and reliability [30], whereas creating a prototype requires only a few specific skills. Hence, developing the necessary production skills and facilities for manufacturing a prototype though to the final product are essential. Additionally, pursuing a technological diversification strategy allows a firm to have many diversified product and market configurations [10–12]. To establish a higher level of product variety and market configuration, firms must have flexible production capabilities achieved via modularization [46,47].

Conversely, innovation originates from creativity, and this talent is much more difficult to access in the marketplace. Thus, developing and maintaining appropriate human capital promotes innovation. Additionally, technological diversification requires that a firm has a wider technological scope which in turn demands that a wide range of ideas are generated. However, people's habitual domains generally limit their drive to generate ideas. Thus, a sufficient pool of human capital is required to generate diversity ideas for technological diversification.

This discussion indicates the moderating effects of SCAs on the relationships between technological diversification and performance, as proposed in hypothesis 2. However, following Taylor and Lowe [31] suggestion, we further classified SCAs into marketing resources, production resources, and human capital for analyzing the distinctive moderating effects of various SCAs.

Hypothesis 2-1. As technological diversification is positively related to the performance (as proposed in Hypothesis 1), this relationship is stronger when there are more marketing SCAs available than when few are available.

Hypothesis 2-2. As technological diversification is positively related to the performance (as proposed in Hypothesis 1), this relationship is stronger when there are more production SCAs are available than when few are available.

Hypothesis 2-3. As technological diversification is positively related to the performance (as proposed in Hypothesis 1), this relationship is stronger when there are more human capital SCAs are available than when few are available.

3. Methods and measures

3.1. Data and sample

To examine the proposed arguments, this study applied a panel data set containing patents, and operating and financial information collected during 1997–2005 from the firms listed in the Electronic and Information Technology category of Taiwan's two stock markets (the Taiwan Stock Exchange (TSE) and Taiwan Over-the-Counter Securities Exchange). Study data were obtained from two sources. A proprietary dataset of patent was obtained from the Intellectual Property Office, Ministry of Economic Affairs. This dataset contains detailed registered patent information for each Taiwanese firm financial and operating data for each firm sampled was retrieved from the *Taiwan Economic Journal,* a database containing all financial information from companies listed on the TSE and ROSE.

The reasons for choosing Taiwanese high-tech companies are as fellows. First, compared with other Taiwanese industries, high-tech industries are more focused on technological development, and their core competences rely primarily on technological developments. Second, pressure from ever-increasing global competition forces these companies to diversify their technologies. High-tech firms have experienced rapid growth during the last years, and many have performed extremely well [48]. Total output of high-tech firms makes Taiwan the fourth largest producer of electronic and information hardware products worldwide. Therefore, Taiwanese high-tech firms comprise a relatively significant sample for the target industry in this study. Finally, choosing from the population of Taiwanese high-tech companies is extremely representative as the products of the sample population cover nearly the entire industry value chain from software to hardware, both upstream and downstream.

As this study focuses on the technological diversification strategies of each sample firm, electronics distributors are excluded from the sample because their technological density is much lower than electric firms. Thus, 582 companies of the 638 listed companies comprise the study sample.

3.2. Variables and measures

3.2.1. Technological diversification

Existing studies have attempt to capture the total output of R&D using measures of technological diversification such as number of patents [49] and number of new products launched [12,39]. However, these measures only identify the results of R&D departments, not the degree of technological diversification of a company. Another widely accepted measure is the Herfindahl index [11,17,18,50].

In this study the variable 'technological diversification' was constructed based on the Herfindahl index of concentration. The technological portfolio for each firm is calculated as fellows. With 364 technological fields classified by 3-digital International Patent Classification (IPC) codes indexed by $j=1,\ldots, 364$, if the ith firm has Ni patents in the analyzed period, then each patent can be assigned to a technological field. Let Nij denote the number of patents that the ith firm holds in category j, such that $\sum_{j=1}^{364} Nij = Ni$. The Herfindahl index of concentration can therefore be acquired for each firm and year. Subtracting this value from 1, the technological diversification variable is obtained as follows:

$$\text{Technological Diversification} = 1 - \sum_{j=1}^{364} \left(\frac{Nij}{Ni}\right)^2.$$

A higher value implies that a firm invests more resources into technological diversification whereas a low value suggests that the scope of technology is relatively narrow.

3.2.2. Complementary assets

No consistent measures for complementary assets exist in previous studies. This lack is due to the fact that measuring SCAs across different ranges of technological diversification and a diverse set of companies is extremely difficult. Firms typically do not reveal their SCAs for individual technologies. Consequently, any attempt to measure it will be ambiguous.

Mitchell [24] utilized three measures as industry-specialized assets: distribution, industry experience, and market share after a survey of the US diagnostic imaging instrument industry. His empirical study confirmed that these three measures are specialized assets that promote performance and restrict competitors from entering a market. Christmann [30] surveyed 88 chemical firms using a questionnaire[3] to investigate a firm's process innovation capabilities as a proxy of SCAs. He observed that SCAs for production are significant determinants of firm performance. Some researchers have argued subjectively that human capital is the most important specialized complementary assets [27,51]. Consequently, they adopted "the number of employees" as a measure of SCAs. Some studies adopted a different perspective and pointed out that after an idea has been converted into a product, the most essential assets are customer relationships and market knowledge [24,26,52,53].

Therefore, as no consistent or widely accepted measures exist for SCAs, one goal of this study was to develop and contribute a theoretically proximal and fine-grained measure of specialized complementary

[3] Questionaire items for complementary assets of capabilities for process innovation were as follows: 1. being the first in the industry to try new methods and technologies; 2. using the least technology in production; 3. capital investment in new equipment and machinery.

assets. We propose a measure to assess specialized complementary assets. The following formula presents the measure for approximating firm SCAs.

$$\text{SCAs} = \frac{\text{Selling expense} + \text{Manufacturing overhead} + \text{Payroll expense}}{\text{Sales}} \times \text{VAD Ratio.}$$

This study follows the work by Taylor and Lowe [31] and classifies complementary assets into marketing resources, production, and human capital based on their functional classifications. Therefore, the sum of Selling expense, Manufacturing overhead, and Payroll expense account for the complementary assets associated with marketing resources, production resources, and human capital. To eliminate the effects of firm size, the sales of each firm are considered in the proposed measure. To emphasize the importance of these assets and capacities, this study introduces the value-added (VAD) ratio [54] to represent the degree of specialization. The VAD ratio is widely adopted for measuring the extent of vertical integration. Hung et al. [54] proposed that the value of VAD accounts for the willingness to possess technology or assets. When the VAD value increases, a firm typically has a higher willingness to make or own SCAs. Thus, the study applied the VAD ratio to measure the degree of specialized assets. The following equation is utilized to calculate the VAD ratio: Value-added = Net operating income − Consumption of raw material − Purchase in the year − Work-in-process goods purchased − Manufacturing expense; VAD ratio = value-added / Net sales of a firm. The other three specialized complementary assets are measured as follow:

$$\text{Marketing SCAs} = \frac{\text{Selling expense}}{\text{Sales}} \times \text{VAD Ratio;}$$

$$\text{Production SCAs} = \frac{\text{Manufacturing overhead}}{\text{Sales}} \times \text{VAD Ratio;}$$

$$\text{Human capital SCAs} = \frac{\text{Payroll expense}}{\text{Sales}} \times \text{VAD Ratio.}$$

3.2.3. Performance

Financial results represent a more immediate assessment of a firm's ability to generate profit for shareholders. Similar to research on technological diversification [19,30,55], each firm's financial results were measured using its annual return on equity (ROE). However, financial results do not fully represent firm overall performance. Therefore, some studies applied annual sales as a performance index [11,17,21,32]. Thus, this study applied both ROE and annual sales as performance measures to fully determine the performance of sample firms.

3.2.4. Control variable

The study employed a diverse set of control variables to account for other potential effects on firm technological diversification, SCAs, and performance, to reduce the possibility of a potential specification bias due to unobserved heterogeneity.

Industry level: The external competitive environment impacts a firm's technology strategy. Therefore this study selected *environmental munificence* and *environmental dynamism* as control variables both have been widely adopted in previous studies [56–58]. Environmental munificence refers to the richness

Table 1
Pearson correlation matrix

Variables	Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11
1. Sales	6.1432	.6840	1.00										
2. ROE	.0858	.4332	.060**	1.00									
3. Firm size	6.2626	.6591	.892**	−.013	1.00								
4. Firm age	13.8476	8.5118	.260**	−.002	.250**	1.00							
5. Munificence	.1783	.0460	.017	.061**	.020	.219**	1.00						
6. Dynamism	.0506	.0223	.007	.035*	.013	.151**	.441**	1.00					
7. Technological diversification (TD)	.1867	.2968	.442**	.052**	.433**	.068**	.085**	.022	1.00				
8. SCAs	.0407	.7281	.155**	.039	.026	.062**	−.015	.015	.013	1.00			
9. Marketing SCAs	.0181	.0681	−.028	−.021	−.083**	.003	−.173**	−.090**	−.014	.732**	1.00		
10. Production SCAs	.0249	.2029	.190**	.081**	.057**	.079**	.015	.055**	.019	.778**	.459**	1.00	
11. Human capital SCAs	−.0031	.5273	.131**	.014	.014	.058**	.007	.010	.015	.969**	.537**	.613**	1.00−

**p<0.01; *p<0.05 (two-tailed test).

Table 2
Multiple regression model

Variables	Log sales						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constants	.0051/†	.6031	.2678**	.2622**	.4449**	.3675**	.4598**
Control variable							
Firm size	.9572**	.8789**	.9245**	.9252**	.9033**	.9109**	.9048**
Firm age	.0051**	.0036**	.0012†	.0013†	.0025**	.0013*	.0021**
Munificence	−.2998	−.1915†	−.0143	−.0049	−.1319	−.0304	−.1458
Dynamism	−.0893	−.2375	.4425	.4321	−.2377	.1620	−.3094
Dependent variables							
Technological diversification (TD)		.1620**	.1581**	.1466**	.1956**	.1817**	.1379**
SCAs			.1136**	.1095†			
TD × SCAs				.2621**			
Marketing SCAs					.5443**		
TD × Marketing SCAs					−2.4937		
Production SCAs						.5221**	
TD × Production SCAs						−.6303**	
Human capital SCAs							.1340**
TD × Human capital SCAs							.0409**
Adjusted R^2	.7974	.8020	.8187	.8189	.7958	.8221	.8071
Mean VIF	1.18	1.25	1.22	1.25	1.25	1.38	1.17

**$p<0.01$; *$p<0.05$; †$p<0.1$ (two-tailed test); values are unstandardized regression coefficients.

of external resources for future growth and is measured as the regression slope coefficient divided by the mean value for the regression of time against the value of shipments in the firm's industry. Environmental dynamism is the changes in an environment and is measured as the standard error of the regression slope divided by the mean value of shipments using the same regression models.

Firm-level: Research suggests that older firms generally introduce more innovation, albeit incremental innovations, than young firms [59]. Over time, established firms also have a relatively larger degree of technological diversification and required complementary assets. Consequently, this study calculated *firm age* as the difference between the current year and the firm's founding date for each year during the study period. Additionally, *firm size* is used to control economies and diseconomies of scale, as measured by the natural logarithm of total assets.

3.3. Analysis

The data used in this study are longitudinal, and thus represent a panel dataset. Panel data follow a given set of companies over time, thereby providing multiple observations for each firm. In this sample, 582 firms were followed over 9 years, equaling 5238 firm years.

To investigate the relationship between technological diversification, complementary assets and performance, this study employed a generalized least square (GLS) regression to test hypotheses. The regression model is as follows:

$$Y_{it} = b_0 + b_1X_{1t} + b_2X_{2t} + b_3X_{1t}X_{2t} + control\ variables + e_{it}$$

			ROE			
Model 8	Model 9	Model 10	Model 11	Model 12	Model 13	Model 14
−.0250	.1052	.0448	.0254	.0652	.1463	.0508
−.0035	−.0212†	−.0103	−.0076	−.0155	−.0233	−.0136
−.0022*	−.0001	−.0005	−.0003	−.0010	−.0009	−.0011
.5850**	.4834**	.2189	.2323	.4811**	.2348	.4897**
.2956	.2277	.8502†	.8282*	.4641	.5085	.4636
	.0995**	.1121**	.0909**	.0865**	.1231**	.0972*
		.0371**	.0290*			
			.2160*			
				−.1182		
				.8823†		
					.1966**	
					−.2046	
						.0089
						.0017
.0036	.0075	.0147	.0168	.0107	.0155	.0105
1.18	1.25	1.22	1.25	1.25	1.38	1.17

Where Y_{it} is the dependent variable: Sales and ROE in (t) period. The X_{1t} and $X_{2t,}$ represent the degree of technological diversification and specialized complementary assets in t period respectively. The $X_{1t}\,X_{2t}$ are the interaction term of technological diversification and SCAs, respectively, which are used to test hypotheses. The control variables include environmental munificence, environmental dynamism, firm size, and firm age.

The GLS procedure produces more efficient estimates than a general linear regression model, because it minimizes a weighted sum of squared residuals. The GLS estimates are corrected for autocorrelation and cross-section heteroscedasticity, while estimating the weighted averages of effects within and between firm effects. This study applied a more conservative approach by estimating the GLS regression models using White heteroscedasticity—consistent standard errors and covariances. This estimation procedure generates covariances that are robust in terms of general heteroscedasticity, because variances within a cross-section are allowed to differ across time.

Testing moderated regression models requires that direct effects and interaction effects are included. This approach is a relatively conservative method for examining interaction effects because the statistical significance of the interaction terms are evaluated after all lower-order effects have been controlled.

4. Results

Table 1 presents the descriptive statistics and correlations for all variables in the citation sample of firms. To assess the threat of multicollinearity, the variance inflation factors (VIFs) for each coefficient were calculated. The estimated VIFs for the proposed model are between 1.17–1.38; the average mean is 1.24, which is well below the recommended ceiling of 10. This indicates that the multicollinearity problems are not significant in this study.

Table 2 shows the result from regressions designed to illuminate the relationships between degree of technological diversification and performance. Two indicators are employed for measuring firm performance. Models 1–7 show the effect of technological diversification on sales. Models 8–14 show the relationship between technological diversification and ROE.

In Table 2, Models 1 and 8 represent the base model, which includes the control variables and the independent variables. We included only the control variables in order to have a point of reference against which can be compared with other equations. Models 2 and 9 add technological diversification to the control variables as a test of the hypotheses regarding the direct effects of technological diversification on performance. The results suggest that higher technological diversification result in higher performance (Model 2: $R^2=0.8020$, $p<0.01$; Model 9: $R^2=0.0075$, $p<0.01$). Hypothesis 1 posits that the relationship between technological diversification and firm performance will be positive. Thus these analytical results support Hypothesis 1 meaning that the greater degree of technological diversification, the better the firm performance.

Hypothesis 2 posits that specialized complementary assets will moderate the relationship between technological diversification and firm performance. As shown in Table 2, we found that the interaction between technological diversification and SCAs in Model 4 was significant ($R^2=0.8189$, $p<0.01$). This finding supports the assumption that as SCAs increase; the positive relationship between technological diversification and sales becomes much stronger. Thus, for Model 11, the result shows that SCAs will moderate the relationship between technological diversification and ROE. Consequently, Hypothesis 2 is supported.

The results of the regression analyses as shown in Model 5 in Table 2 provide information related to Hypothesis 2-1, which posits a positive effect of technological diversification and performance. The results do not support this hypothesis. The interaction effect is not significant. Conversely, in Model 12, it is partially supported ($R^2=0.107$, $p<0.1$), indicating that as specialized marketing complementary assets increase, the relationship between technological diversification and ROE will positively be stronger. Thus, the result shows that Hypothesis 2-1 is partially supported.

Hypothesis 2-2 posits that firms with high levels of specialized production complementary assets have a better performance when increasing the degree of technological diversification. However, Hypothesis 2-2 is not supported for sales (Model 6) or for ROE (Model 12). Although Model 6 indicates that production complementary assets moderate technological diversification and performance ($R^2=0.8221$, $p<0.01$), the effect is negative, and is contrary to the hypothesis. As the moderating effect is not significant in Model 13, the hypothesis on ROE cannot be proved either. Therefore, Hypothesis 2-2 does not hold.

Hypothesis 2-3 states that specialized human capital complementary assets moderate the relationships between technological diversification and performance. This hypothesis is supported at $p<0.01$ (Model 7). This means that when firms own more human capital assets, it will promote innovation, thereby increasing firm sales. However, in Model 14, the moderating effect does not exist, and thus, no evidence exists that emphasizes that human capital has a significant moderating effect on technological and ROE. Consequently, Hypothesis 2-3 is only partially supported.

The results demonstrate that sales are associated with technological diversification (Hypothesis 1). The relationship between technological diversification and sales is moderated by total SCAs (Hypothesis 2)

Table 3
Results of testing hypotheses

	Sale	ROE
	T value	*T* value
Technological diversification	0.1620**	0.0995**
SCAs moderating effect	0.2621**	0.2160*
Marketing SCAs moderating effect	−2.4937	0.8823†
Production SCAs moderating effect	−0.6303**	−0.2046
Human capital SCAs moderating effect	0.0409**	0.0017

**$p<0.01$; *$p<0.05$; †$p<0.1$ (two-tailed test); values are unstandardized regression coefficients.

and by specialized human capital assets (positive; Hypothesis 2-3), whereas production assets have a negative effect on this relationship (Hypothesis 2-2). Similar to sales, ROE is associated with technological diversification (Hypothesis 1). However, only marketing assets moderate the effects between technological diversification and ROE (Hypothesis 2-1). The effect of production and human capital assets are not significant for ROE.

In summary, Hypotheses 1 and 2 are supported because support for technological diversification is positively related to performance and has a moderating role for SCAs. However, Hypothesis 2-1, 2-2 and 2-3 are only partially supported for ROE and Sales. The different SCAs have different and unequal moderating effects on technological diversification and performance. In order to make that easier to see, we provide Table 3 to classify our empirical results.

5. Discussion

This study empirically examined the effects of technological diversification on firm performance. An econometric analysis based on panel data of 582 Taiwanese firms between 1997 and 2005 indicates a statistically significant positive relationship exists between technological diversification and Sales or ROE. Although the results are based on Taiwanese high-tech companies, they support the hypothesis that technological diversification promotes performance. As such, technological diversification not only stabilizes returns, it also enhances performance due to the competitive advantages obtained. An increase in firm technological diversification can promote cross-fertilization between different technological areas, and reduces the lock-in effect of technologies with low profitability [17].

Empirical findings also indicate that as a firm develops a technological diversification strategy, the SCAs play an important moderating role between technological diversification and firm performance. This observation implies that firms with a high degree of technological diversification can indeed take advantage of their internal resources. Specialized complementary assets [23] enable a firm to buffer the risks associated with unfamiliar environment and technologies [60].

Another contribution of this study is that it classifies SCAs into three categories namely marketing resources, production resources, and human capital. This study examined the respective moderating effects. Although the aggregate of SCAs (Hypothesis 2) has a moderating effect on technological diversification and performance, the different SCAs have different moderating effects.

The results suggest that specialized marketing complementary assets have a moderating effect on technological diversification and performance, especially for ROE. This means that possessing the required specialized marketing complementary assets enhance the positive effects of technological diversification on financial performance. Marketing resources can equip a firm with appropriate skills to examine and develop new projects that satisfy customer needs. Consequently, market knowledge and marketing capabilities are essential for firm pursuing innovation and extend the degree of technological diversification. Moreover, at the stage of commercialization, a firm has to promote its new product or service and identify existing and potential customers. This requires a lot of marketing resources to support. Thus, specialized marketing resources have a moderating effect on the relationship between technological diversification and performance.

It is worth noting that the results indicate that production assets have a negative moderating effect, implying that when a firm establishes more specialized production resources, the impact of technological diversification on performance may be reduced. This may be because the investments in specialized production processes typically have a hold-up effect. Since production facilities and skills are tailored to specific innovations, these particular production facilities may not easily be transferred to another technology. This may become more significant the higher the degree of technological diversification.

Specialized human capital assets have a significant moderating effect on technological diversification and performance, especially on sales. Firms need human capital to take a product from an idea to market status. This is especially true when a firm has a widely diversified technological scope. In this case a firm needs more innovative ideas to establish and maintain its competitive advantages and thereby gain more profits. In this regard, having sufficient human capital plays a critical role in moderating between technological diversification and performance. Notably, the moderating effects of marketing and human capital on performance are different. The marketing assets have a stronger moderating effect on ROE than human capital, whereas human capital assets have a relatively stronger moderating effect on sales.

Overall, the findings that complementary assets have a moderating effect of the relationship between technological diversification and firm performance indicates that before deciding on technological diversification strategies, firms need to examine their existing resource and capabilities. Firms should adjust the degree of technological diversification to fit their existing resources and capabilities. In particular, since the different SCAs have different moderating effects on different performance indexes, maintaining a balance among the resource portfolio in technology management is important.

5.1. Limitations and future research

This study like most studies has several limitations, which in turn provide opportunities for future research. One limitation is the way in which this study proxies some measures. Although the results of technological diversification are multiple-faceted, this may be only partly appropriate for patents; that is, all inventions are patented or even patentable innovations must be novel, non-obvious, and have commercial application. Furthermore, a large variation exists between industries, and not all firms rely on patenting; some depend on other forms of intellectual property protection such as secrecy, trademarks and copyrights [61,62]. Therefore, in some industries, firm technological capabilities may not be completely convertible to patents. However, by selecting high-tech companies as the sample this study avoided this problem to a large extent as patents are regarded as critical tools in high-tech industries. Firms in this industry typically convert their technological capabilities into patents to protect their competitive advantage. However, more research can examine the effects of various measures of technological diversification on firm performance.

Second, to be objective, this study used secondary data to measure SCAs. This may not accurately represent the value of complementary assets. However, this study introduces the VAD ratio to represent the specific characteristics of complementary resources owned by a firm and to weigh the importance of these assets.

Third, this study had to rely on financial data (sales and ROE) as proxies for firm performance. Using other detailed measures of firm performance in future research may help validate the findings of this study. Additionally, more detailed measures of SCAs may contribute to existing knowledge of appropriate levels of holding complementary assets. They may be especially useful in identifying which assets should be maintained at high levels and which ones should be out-sourced.

Finally, while the sample in this study is representative of the population of high-tech firms in Taiwan, the theoretical model should be tested in other industrial settings to determine the generalization of findings. Furthermore, future research should examine time periods characterized by incremental and radical innovations, as the emergence of a new dominant design is likely to demand a more contingent approach for organizing SCAs. These efforts will strengthen the external validity of the theoretical model developed and tested in this study. The contributions of this study will encourage future research into this important phenomenon.

6. Conclusions

This study makes several contributions to technological diversification literature. Previous research focused primarily on technological diversification and performance. Consequently, these results obtained in previous research may have been an artifact of unobserved SCAs, unless the specialized complementary assets were controlled in analyses. Conversely, this study simultaneously investigates the effect of technological diversification on performance and the moderating role of SCAs. The new findings presented here provide broad support regarding the need for various SCAs. In particular, this study confirmed empirically the positive effects of technological diversification on performance.

Second, in existing literature regarding complementary assets, no consistent indicator exists for measuring complementary assets. The study developed a proximal measure of SCAs using the VAD ratio. This is radical approach and contributes to studies of complementary assets. In particular, this study also characterized the SCAs according to their functions. This additional step allows for distinguishing between distinctive effects of various SCAs. Empirical results indicate that the moderating effects of various SCAs are different, despite the fact that aggregate SCAs are found to be positive moderated.

This study also provides some important managerial implications. Empirical results sound a cautionary note indicating that pursuing a higher degree of technological diversification appears to be better for firms. In particular, a manager frequently needs to determine the degree of technological diversification to pursue. We suggest that this depends on how many required SCAs a firm possesses. This study found that technological diversification and having SCAs seem to be a valuable strategy in striving for superior performance.

When discussing SCAs, the study observed that various SCAs function differently with regards to technological diversification and performance. Thus, identifying the distinctive functions of various SCAs and their impacts on performance are equally important to R&D.

As a whole, managers should strive to diversify technological cores to generate a richer R&D portfolio and identify the “optimum” level of required specialized complementary assets to generate maximal advantages for a firm. Since the various SCAs play dissimilar moderating roles, finding an appropriate balance among all assets can be difficult. Maintaining the right balance over time may prove to be extremely challenging because the competitive landscape is highly dynamic [63,64]. We therefore suggest that matching the appropriate level of technological diversification with a firm's complementary assets and industry environment can be considered a firm's dynamic capability, which has been described as a "firm's ability to integrate, build, and reconfigure internal and external competences to address rapidly changing environments" [65]. In conclusion, technological diversification is beneficial to performance, but must be matched with the required complementary assets. Additionally, a balance must exist and be maintained among the various complementary assets to optimize a firm's innovation and performance. Determining and maintaining this coherence among technological diversification and various SCAs is a critical and challenging, but also a potentially rewarding task for managers.

References

[1] A.D Chandler, Strategy and Structure, Harvard University Press, Boston, 1962.
[2] H. Ansoff, Corporate Strategy: An Analysis Approach to Business Policy for Growth and Expansion, McGraw-Hill, New York, MA, 1965.
[3] R.P. Rumelt, Diversification strategy and profitability, Strateg. Manage. J. 3 (9) (1982) 359–369.
[4] K. Palepu, Diversification strategy profit performance and the entropy measurement, Strateg. Manage. J. 6 (3) (1985) 239–255.
[5] C.A. Montgomery, B. Wernerfelt, Diversification, Ricardian rents and Tobin's q, Rand J. Econ. 19 (1988) 623–632.
[6] R.E. Hoskisson, M.A. Hill, R.A. Johnson, D.D. Moesel, Construct validity of an objective (entropy) categorical measure of diversification strategy, Strateg. Manage. J. 14 (3) (1993) 215–235.
[7] V. Ramanujam, P. Varadarajan, Research on corporate diversification: a synthesis, Strateg. Manage. J. 10 (6) (1989) 523–552.
[8] B. Wernerfelt, A resource-based view of the firm, Strateg. Manage. J. 5 (3) (1984) 171–180.
[9] C.K. Prahalad, G. Hamel, The core competence of the corporation, Harvard Bus. Rev. 68 (3) (1990) 79–91.
[10] O. Granstrand, P. Patel, K. Pavitt, Multi-technology corporations: why they have "distributed" rather than "distinctive core" competencies, Calif. Manage. Rev. 39 (4) (1997) 8–25.
[11] A. Gambardella, S. Torrisi, Does technological convergence imply convergence in markets? Evidence from the electronics industry, Res. Policy 27 (5) (1998) 445–463.
[12] S. Breschi, F. Lissoni, F. Malerba, Knowledge-relatedness in firm technological diversification, Res. Policy 32 (1) (2003) 69–87.
[13] J.F. Christensen, N.J. Foss, Dynamic Corporate Coherence and Competence-Based Competition: Theoretical Foundations and Strategic Implication, in: A. Heene, R. Sanchez (Eds.), Competence-Based Strategic Management, John Wiley & Sons Ltd, New York, NY, 1997, pp. 287–312.
[14] N. Foss, J.F. Christensen, A market-process approach to corporate coherence, Manag. Decis. Econ. 22 (2001) 213–226.
[15] E. Bigadikke, Corporate Diversification, Entry, Strategy and Performance, Harvard University Press, Boston, 1979.
[16] I.H. Ansoff, J.M. Stewart, Strategic for a technology-based business, Harvard Bus. Rev. 45 (6) (1967) 71–83.
[17] M. Garcia-Vega, Does technological diversification promote innovation? An empirical analysis for European firms, Res. Policy 35 (2) (2006) 230–246.
[18] H.K. Christensen, C.A. amd Montgomery, Corporate economic performance: diversification strategy verse market structure, Strateg. Manage. J. 2 (4) (1981) 327–343.
[19] D.J. Miller, Technological diversity, related diversification, and firm performance, Strateg. Manage. J. 27 (7) (2006) 601–619.
[20] N. Argyres, Capabilities, technological diversification and divisionalization, Strateg. Manage. J. 17 (5) (1996) 395–410.
[21] O. Granstrand, C. Oskarsson, Technology diversification in "MUL-TECH" corporations, IEEE Trans. Eng. Manage. 41 (4) (1994) 355–364.
[22] R. Cooper, A process model for industrial new product development, IEEE Trans. Eng. Manage. 30 (1983).
[23] D.J. Teece, Profiting from technological innovation: implications for integration, collaboration, licensing and public policy, Res. Policy 15 (1986) 285–305.
[24] W. Mitchell, Whether or when? Probability and timing of incumbents' entry into emerging industrial subfields, Adm. Sci. Q. 34 (2) (1989) 208–230.

[25] C.E. Helfat, Know-how and asset complementary and dynamic capability accumulation: the case of R&D, Strateg. Manage. J. 18 (5) (1997) 339–360.
[26] M. Tripas, Unraveling the process of creative destruction: complementary assets and incumbent survival in the typesetter industry, Strateg. Manage. J. 18 (1997) 119–142 (Special Issue).
[27] M.G. Colombo, L. Grilli, E. Piva, In search of complementary assets: the determinants of alliance formation of high-tech star-ups, Res. Policy 35 (8) (2006) 1166–1199.
[28] Z.L. He, K. Lim, P.K. Wong, Entry and competitive dynamics in the mobile telecommunications market, Res. Policy 35 (8) (2006) 1147–1165.
[29] C.E. Helfat, R.S. Raubitschek, Product sequencing: co-evolution of knowledge, capabilities and products, Strateg. Manage. J. 21 (10/11) (2000) 961–979.
[30] P. Christmann, Effects of "Best Practices" of environmental management on cost advantage: the role of complementary assets, Acad. Manage. J. 43 (4) (2000) 663–680.
[31] P. Taylor, J. Lowe, Are functional assets or knowledge assets the basis of new product performance? Technol. Anal. Strateg. Manag. 9 (4) (1997) 473–488.
[32] O. Granstrand, S. Sjolander, Managing innovation in multi-technology corporations, Res. Policy 19 (1) (1990) 35–60.
[33] R.M. Grant, Prospering in dynamically-competitive environments: organizational capability as knowledge integration, Organ. Sci. 7 (4) (1996) 375–387.
[34] J.B. Barney, Firm resources and sustained competitive advantage, J. Manage. 17 (1) (1991) 99–120.
[35] R. Amit, P. Shoemaker, Strategic assets and organizational rent, Strateg. Manage. J. 14 (1) (1993) 33–46.
[36] G. Hamel, C.K. Prahalad, Competing for the Future, Harvard Business School Press, Boston, 1994.
[37] J. Cantwell, L. Piscitello, Accumulating technological competence: its changing impact on corporate diversification and internationalization, Ind. Corp. Change 9 (1) (2000) 21–51.
[38] H. Rheem, Technology: core competence or diverse competencies? Harvard Bus. Rev. 73 (2) (1995) 11.
[39] O. Granstrand, Towards a theory of the technology-based firm, Res. Policy 27 (5) (1998) 465–489.
[40] J. Suzuki, F. Kodama, Technological diversity of persistent innovators in Japan: two case studies of large Japanese firms, Res. Policy 33 (3) (2004) 531–549.
[41] F. Scherer, New Perspectives on Economics Growth and Technological Innovation, Brookings Institution Press, Washington, D.C, 1999.
[42] K. Gemba, F. Kodama, Diversification dynamics of the Japanese industry, Res. Policy 30 (8) (2001) 1165–1184.
[43] M.E. Porter, Competitive Advantage, Free Press, New York, 1985.
[44] P. Almedia, Knowledge sourcing by foreign multinationals: patent citation analysis in the U.S. semiconductor industry, Strateg. Manage. J. 17 (1996) 155–165.
[45] F.T. Rothaermel, Complementary Assets, strategic alliances and the incumbent's advantage: an empirical study of industry and firm effects in the biopharmaceutical industry, Res. Policy 30 (8) (2001) 1235–1251.
[46] R. Sanchez, Strategic flexibility in product competition, Strateg. Manage. J. 16 (1995) 135–159 (Summer Special Issue).
[47] R. Sanchez, Demand uncertainty and asset flexibility: incorporating strategic options in the theory of the firm, in: N. Foss, V. Mahnke (Eds.), Competence, Governance, and Entrepreneurship, Oxford University Press, New York, NY, 2000, pp. 318–332, Chapter 15.
[48] S.H. Chen, Global production networks and information technology: the case of Taiwan, Ind. Innov. 9 (2) (2002) 249–265.
[49] M.A. Hitt, R.E. Hoskisson, R.D. Ireland, J.S. Harrison, The effects of acquisitions on R&D inputs and outputs, Acad. Manage. J. 34 (3) (1991) 693–706.
[50] C. Watanabe, K. Matsumoto, J.Y. Hur, Technological diversification and assimilation of spillover technology: Canon's scenario for sustainable growth, Technol. Forecast. Soc. Change 71 (9) (2004) 941–959.
[51] F.T. Rothaermel, C.W. Hill, Technological discontinuities and complementary assets: a longitudinal study of industry and firm performance, Organ. Sci. 16 (1) (2005) 52–70.
[52] W. Mitchell, Are more good things better: or will technical and market capabilities conflict when a firm expands? Ind. Corp. Change 1 (2) (1992) 327–346.
[53] R. Rosenbloom, C. Christensen, Technological discontinuities, organizational capabilities and strategic commitments, Ind. Corp. Change 3 (3) (1994) 655–686.
[54] S.C. Hung, N.C. Liu, J.B. Chang, The taxonomy and evolution of technology strategies: a study of Taiwan's high-technology-based firms, IEEE Trans. Eng. Manage. 50 (2) (2003) 219–227.

[55] D.J. Miller, Firms' technological resources and the performance effects of diversification: a longitudinal study, Strateg. Manage. J. 25 (11) (2004) 1097–1119.
[56] G.G. Dess, D.W. Beard, Dimension of organizational task environments, Adm. Sci. Q. 29 (1) (1984) 52–73.
[57] G.G. Dess, R.D. Ireland, M.A. Hitt, Industry effects and strategic management research, J. Manage. 16 (1) (1990) 7–27.
[58] Y. Mishina, T.G. Pollock, J.F. Porac, Are more resources always better for growth? Resource stickiness in market and product expansion, Strateg. Manage. J. 25 (12) (2004) 1179–1197.
[59] J.B. Sorensen, T.E. Stuart, Aging, obsolescence, and organizational innovation, Adm. Sci. Q. 45 (1) (2000) 81–112.
[60] J.D. Thompson, Organization in Action, McGraw-Hill, New York, 1967.
[61] R. Levit, A. Klevorick, R. Nelson, S. Winter, Appropriating the returns from industrial research and development, Brookings Pap. Econ. Act. 1987 (3) (1987) 783–831.
[62] W.M. Cohen, R.R. Nelson, J.P. Walsh, Protecting their intellectual assets: appropriability conditions and why U.S. manufacturing firms patent (or not), NBER Work. Pap. 7552 (2000).
[63] R.A. Bettis, M.A. Hitt, The new competitive landscape, Strateg. Manage. J. 16 (1995) 7–20 (Summer Special Issue).
[64] S.L. Brown, K.M. Eisenhardt, The art of continuous change: linking complexity theory and time-paced evolution in relentlessly shifting organizations, Adm. Sci. Q. 42 (1) (1997) 1–34.
[65] D.J. Teece, G. Pisano, A. Shuen, Dynamic capabilities and strategic management, Strateg. Manage. J. 18 (7) (1997) 509–533.

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