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多重研發合作、技術探索與開發、以及廠商績效之研究

Multiple-Source R&D Collaboration, Exploration and Exploitation, and Firm Performance

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摘要

廠商的創新能力可以透過內部的研發投資與外部的研發合作來累積，本研究試圖探討廠商多重研發合作在不同的創新階段中，對廠商績效之影響。透過問卷調查台灣 165 家資訊通訊科技廠商，本研究發現，在技術探索階段中，廠商與大學以及同業間的研發合作，或從政府部門取得技術授權，會增加該廠商的創新能力，且接受政府部門的技術移轉可以強化內部研發能耐與創新能力之正向效果。在產品開發階段中，廠商的外部研發資源對市場績效並無直接效果，但與大學的研發合作、以及接受政府單位的技術移轉，對廠商創新能力與市場績效之正向關係有正向的調節效果，而與同業間的研發合作對此關係有負向之調節效果。

【關鍵字】研發合作、研發聯盟、技術移轉

Abstract

A firm's innovation can be fostered either from the firm's internal research and development (R&D) efforts or from the external collaborative R&D activities. This paper attempts to examine the impact of multiple-source R&D collaborations on firm performance in different stages of the innovation process. The research employed a questionnaire survey of 165 Taiwanese firms in the information and communication technology sector and secondary industrial data were also collected. The results showed that in the technology exploration stage, R&D collaborations with universities and competitors and technology licensing from the government may increase a firm's repertoire of innovation directly, while technology licensing has a positive moderate effect on the relationship between internal innovation capability and repertoire of innovation. In the product exploitation stage, external R&D collaborations do not have a direct impact but rather have an indirect impact on market performance. R&D collaborations with universities as well as acquisition of licensed technologies from the government have a positive moderate effect on the relationship between a firm's repertoire of innovation and market performance whereas collaborations with competitors have a negative moderate effect.

【Keywords】R&D collaborations, alliances, technology transfer

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1. Introduction

A firm's innovation capability can be fostered either by a firm's internal research and development (R&D) efforts or by its external collaborative R&D activities. Firms lacking sufficient internal R&D resources are suggested to improve their innovation capability via external R&D collaborations (Lin, 2003), such as research joint ventures, strategic alliances, and licensing agreements with universities, research institutions, or other partner firms.

Previous R&D collaboration research focuses on issues of the innovation process of R&D collaborations, such as exploration and exploitation (Levinthal & March, 1993; Rothaermel & Deeds, 2004). An increasing number of works have investigated the impact of different types of R&D collaborations on firm performance in different datasets, but few works have been conducted using the same dataset. Thus, the first objective of this paper is to attempt to examine the impact of the various sources of R&D collaborations on firm performance in the same dataset.

Second, previous R&D collaboration studies mainly evaluate the performance for a single-source R&D collaboration, such as with universities (Bayona, Garcia-Marco, & Huerta, 2002; Lockett, Wright, & Franklin, 2003; Power, 2003; Zucker, Darby, & Armstrong, 2002), research institutions (Kassicieh, Kirchhoff, Walsh, & McWhorter, 2002; Sakakibara & Dodgson, 2003), or partner firms (Branzei, 2005; Hagedoorn, 1993; Hemmert, 2003; Yeheskel, Shenkar, Fiegenbaum, Cohen, & Geffen, 2001). However, in business practice, firms adopt more than one source of R&D collaborations simultaneously in different stages of the innovation process. Little effort has been made to investigate whether firm performance is influenced by the multiple sources of R&D collaborations in different stages of the innovation process. Thus, another objective of this paper is to explore whether firm performance is influenced by multiple sources of R&D collaborations in the exploration and exploitation stage of the innovation process.

Finally, while traditional research of R&D collaborations examines the effect of different R&D collaborations on firm performance separately, it neglects the possible interaction effect of multiple external R&D collaborations. Therefore, this paper also attempts to examine the moderating effect of different R&D collaborations on firm performance.

To meet the above research objectives, a number of hypotheses were then developed in the context of the Taiwanese high-technology firms in the information and communication technology (ICT) sector. Five widely-applied external sources of R&D collaborations, including collaborative R&D projects with universities, research institutions, and

competitors, as well as received subsidies and technology licensing from the government, were examined in this paper. To empirically examine the developed research hypotheses, a questionnaire survey of 165 firms within the Taiwan's ICT industry was conducted and a range of secondary data was also collected from various databases.

The results show that different types of external R&D collaborations or resources may influence firm performance directly or indirectly in the different stages of the innovation process. In the exploration stage, R&D collaborations with universities and competitors and technology licensing from the government have a direct positive impact on a firm's repertoire of innovation while technology licensing can further strengthen the contribution of internal innovation capability to the repertoire of innovation. In the exploitation stage, R&D collaborations with universities and acquisition of licensed technologies from the government have a positive moderating effect on the positive relationship between repertoire of innovation and market performance whereas collaborations with competitors have a negative moderating effect on that relationship.

The major contribution of this study shows the necessity of examining the effects of multiple-source R&D collaborations on the different stages of the innovation process. This research enriches our understanding of how external R&D collaborations interact differently with a firm's internal innovation in the exploration and exploitation stages. Moreover, this study also shows the necessity for researchers to examine different sources of external R&D collaborations in the same study since firms conduct multiple R&D collaborations simultaneously.

2. Background and Hypotheses

2.1 Types of R&D Collaborations and Firm Performance

The importance of technology innovation as a source of a firm's core competence has been discussed by an increasing number of researchers (Barney, 1991; Dedrick & Kraemer, 1998; Hamel & Prahalad, 1994; Kogut & Zander, 1992; Porter, 1985; Schumpeter, 1934). A firm's innovation capability can be fostered either from a firm's internal R&D efforts or from its external R&D collaborations. Firms with abundant research resources can possibly increase their innovation capabilities internally whereas firms lacking sufficient internal resources can improve innovation capabilities via external R&D collaborations or alliances (Lin, 2003). Inkpen (1996) also asserts that start-up firms can use collaborative technology innovation projects to acquire knowledge and experience from other partner firms. Thus, external R&D collaborations can be complementary to internal R&D accumulation for

improving a firm's innovation capability.

A number of studies have focused on the collaborative projects between universities and entrepreneurial companies (Bayona et al., 2002; Liu & Jiang, 2001; Perez & Sanchez, 2003; Steffensen, Rogers, & Speakman, 2000; Shane, 2002). The results of previous empirical research suggest that firms with collaborative research projects with universities outperform firms without such projects in terms of number of patents (Lockett et al., 2003; Power, 2003; Zucker et al., 2002), financial performance (Lockett et al., 2003; Niosi & Banik, 2005), as well as firm growth (Lindelof & Lofsten, 2004; Niosi & Banik, 2005).

In addition to university-industry collaborations, external R&D collaborations can be also conducted via collaborations with research institutions (Kassicieh et al., 2002; Sakakibara & Dodgson, 2003). The difference between collaborations with universities and those with research institutions is that the latter ones mainly focus on applied technologies or product development while the former ones emphasize basic research. Existing empirical studies suggest that firms conducting collaborative R&D projects with research institutions have better innovation performance (Blau, 1999; Fusfeld, 1995; Kennedy & Holmfeld, 1989).

Horizontal alliances with competitors and vertical alliances with suppliers or customers are very important technology sources for firm innovation. However, firms conducting vertical alliances may have important incentives other than technological collaborations, such as securing sources of critical components as well as channels. Thus, to focus on the effect of innovation collaboration, we only consider collaborations with competitors in this study. Alliances with competitors are possible sources of external R&D collaborations (Yeheskel et al., 2001). A R&D alliance with competitors is formed because none of the firms has sufficient resources necessary to achieve the target specification within the limited schedule. A R&D alliance is possible if heterogeneous and complimentary resources possessed by different firms are combined in supplemental manners (Mothe & Quelin, 2001). The results of previous studies suggest that firms with inter-firm R&D collaborations can have better innovation performance (Harding, 2001; Hemmert, 2003; Furukawa, Teramoto, & Kanda, 1990; Peters & Becker, 1998; Walker, 1995), financial performance (Branzei, 2005; Hemmert, 2003; Walker, 1995; Yeheskel et al., 2001), and market performance (Branzei, 2005).

In addition to collaborative R&D projects with universities, research institutions, and competitors, technology transfer is another possible source of external R&D resources. "Technology transfer is any process by which basic understanding, information, and

innovations move from a university, an institute, or a government laboratory to individuals or firms in the private and quasi-private sectors" (Parker & Zilberman, 1993). Particularly, technology licensing from the government is also an important source of external R&D resources. In this study, we use the term of technology licensing from the government, which refers to the acquisition of technologies via the government sector without any technology exploration process. Firms conducting collaborative projects with governmental laboratories have been categorized into the type of collaboration with research institutions in this study. Previous studies suggest that firms with collaborative R&D projects with the government, including technology transfer, may have better innovation performance (Cohen, Nelson, & Walsh, 2002; Jang & Huang, 2005) or financial performance (Mowery, 1998).

Moreover, the sources of external R&D collaborations can also be enhanced by governmental financial subsidies (Klette, Moen, & Griliches, 2000). Such subsides can be used to initiate a technology exploration project or a product exploitation project. Previous empirical studies conclude a variety of findings, suggesting that governmental subsidies can help to improve a firm's financial performance (Grupp, 1997; Liu & Shieh, 2005; Poznanski, 1994; Yi & Shin, 2000), market performance (Grupp, 1997; Lackman, 2005; Lerner, 1999), and innovation performance (Lackman, 2005). Lee and Park (2006) also conclude that financial support from the government in the early stage of R&D activities can improve the success of a firm's innovativeness.

According to the above discussions, a firm's external R&D resources can be attained either by conducting collaborative R&D projects with universities, research institutions, and competitors or by receiving licensed technologies and financial subsidies from the government. As can be seen, most previous studies investigate the effect of a single type of external R&D collaboration on firm performance in each research. Few studies attempt to investigate multiple types of external R&D collaborations on firm performance in one study. One of the primary objectives of this research, therefore, is to attempt to fill this research gap.

2.2 Multiple R&D Collaborations, Exploration, and Exploitation

Levinthal and March (1993) suggest that there are two main stages of the innovation process: exploration and exploitation. Levinthal and March (1993) define exploration as 'the pursuit of knowledge, of things that might come to be known,' and exploitation as 'the use and development of things already known.' Modified from the studies of Levinthal and March (1993) and Rothaermel and Deeds (2004), Figure 1 shows the two stages of the

innovation process in this study: exploration for technology innovation and exploitation for new product development.

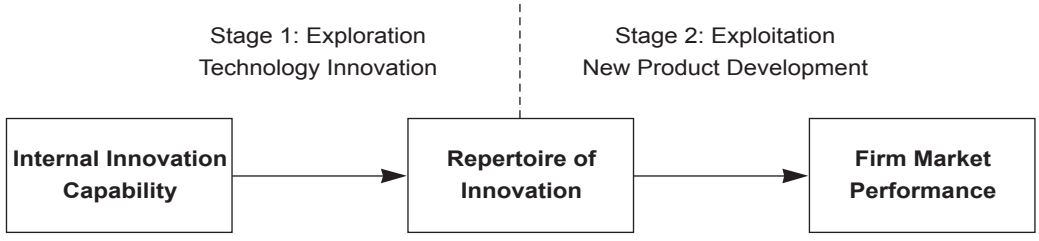

Figure 1 The innovation process: Exploration and exploitation

The exploration stage means the performance of R&D projects for the pursuit of technologies that might come to be known while the exploitation stage refers to the use and development of technologies already known for developing new products, both by utilizing firms' resources internally or by conducting collaborations with external partners. Engaging in R&D activities in the exploration stage may lead to innovative technologies and applications (e.g. technical process innovation), whereas undertaking R&D activities in the exploitation stage will using existing technologies for product development and commercialization.

In the exploration stage, since the technologies are relatively unknown and immature, firms are inclined to conduct collaborative R&D projects to share risks and costs of development. Since these immature technologies are mainly basic-research-oriented, firms are more likely to conduct the collaborative R&D projects with university and research institutions (Bozeman, 2000). Previous studies also suggest that collaborations with competitors are more likely to take place in the stage of exploration for the purpose of basic research or establishing technology standards (Bayona, Garcia-Marco, & Huerta, 2001). R&D collaborations in the exploration stage enable partners to share tacit knowledge and develop new knowledge (Rothaermel, 2001).

In the exploitation stage, since firms mainly employ technologies that are already known to develop new products, firms are inclined to access external R&D resources, such as applied technologies from universities or research institutions, to complement their internal innovation capability for developing new products, or to share risk of production development with competitors. R&D collaborations in the exploitation stage enable partners to leverage and integrate partners' existing resources or capabilities via exchanges of explicit

knowledge to develop new products (Rothaermel, 2001).

Technology licensing may have impacts on both the exploration and exploitation stages since such licensed technologies can be either applied in product commercialization or integrated into technology exploration. Similarly, the received subsidies from the government can be employed in both stages of technology exploration and product exploitation. The impact of technology licensing and financial subsides on firm performance in each stage can be direct or indirect. Thus, there is a need to further investigate how technology licensing and financial subsides from the government influence a firm's performance.

2.3 Multiple R&D Collaborations, Innovativeness, and Firm Performance

While previous studies have advanced our understanding of the R&D collaboration process by investigating a causal relationship between a firm's R&D collaborations and intermediate research outputs or performance indicators (Baum, Calabrese, & Silverman, 2000; Deeds & Hill, 1996; Kotabe & Swan, 1995; Lerner, Shane, & Tsai, 2003; Shan, Walker, & Kogut, 1994), the linking of different types of collaborations to each stage in the innovation process, beginning with technology exploration and culminating in product exploitation and commercialization, has not yet been undertaken (Rothaermel & Deeds, 2004). Rothaermel and Deeds (2004) suggest that there exists a system linking different types of collaborations to each stage in the innovation process.

Moreover, how the synergic effect of simultaneous collaborations contributes to firm performance has not yet been fully investigated. Belderbos, Carree, and Lokshin (2006) examine the firm productivity of simultaneous engagement in R&D cooperation with different partners, such as competitors, clients, suppliers, and universities and research institutes. Nieto and Santamaria (2007) also suggest that collaborations with suppliers, clients, and research organizations (including universities and technology research institutions) have a positive impact on the innovation whereas collaborations with competitors have a negative impact. However, these studies do not include the sources of R&D collaborations from the government sector. Thus, there is a need to further investigate whether multiple R&D collaborations or resources, including technology licensing and financial subsidies from the government, have an impact on firm performance.

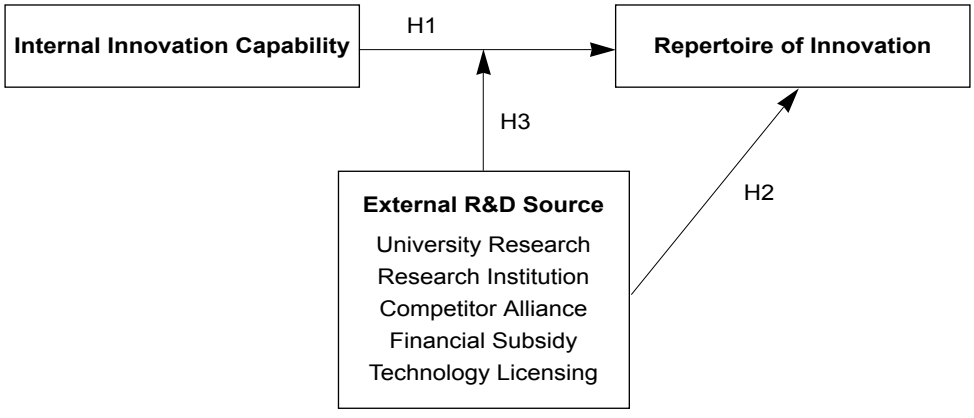

Figure 2 Exploration and firm repertoire of innovation

In the exploration stage of the innovation process (shown in Figure 2), the primary research question, therefore, is how external R&D collaborations or resources can complement a firm's internal innovation capability, which in turn improves a firm's innovation performance. A firm's internal endeavours on R&D activities are regarded as important sources for firm innovation. A number of studies suggest that a firm's innovativeness can be fostered via continuous R&D investment (Dosi, 1988; Freeman & Soete, 1997; Hagedoorn & Duysters, 2002; Hall & Bagchi-Sen, 2002). Gambardella (1992) also asserts that a higher level of R&D capacity improves a firm's ability to exploit sources of knowledge. Therefore, a firm's innovativeness, i.e. repertoire of innovation, is positively correlated to its internal innovation capability.

Hypothesis 1: A firm's internal innovation capability is positively associated with a firm's repertoire of innovation.

In the exploration stage of the innovation process, since the technologies are relatively unknown and basic-research-oriented, firms are more likely to conduct collaborative R&D projects with universities and research institutions (Bozeman, 2000). Previous empirical studies find that firms with collaborative research projects with universities outperform firms without such projects in terms of number of patents (Lockett et al., 2003; Power, 2003; Zucker et al., 2002). Both technology licensing and financial subsidies from the government may have impacts on the exploration stage of the innovation process since some licensed technologies can be used for developing applied technologies. Previous studies suggest that firms with collaborative R&D projects with the government, including technology transfer, may have better innovation performance (Cohen et al., 2002; Jang & Huang, 2005). Thus, a

firm's external R&D collaborations may affect its innovativeness and the following hypothesis can be posited:

Hypothesis 2: A firm's external R&D collaborations are positively associated with a firm's repertoire of innovation.

As discussed earlier, firms lacking sufficient internal R&D resources may seek external R&D collaborations to improve their innovation (Lin, 2003). Thus, external R&D collaborations and resources may affect a firm's repertoire of innovation either directly (as predicted by Hypothesis 2) or indirectly via the interaction with internal innovation capability. In the exploration stage, since the technologies are relatively unknown and immature, firms are inclined to conduct collaborative R&D projects to share risks of uncertainty and costs of development. Moreover, external R&D collaborations can increase the variety of a firm's R&D profiles and complement the firm's internal innovation capability, which in turn influences repertoire of innovation. Therefore, the following hypothesis can be posited:

Hypothesis 3: A firm's internal innovation capability is more strongly positively associated with a firm's repertoire of innovation when the firm accesses external R&D collaborations or resources.

While Figure 2 provides the effect of multiple external R&D collaborations in the exploration stage of the innovation process, Figure 3 depicts the possible effect of multiple external R&D collaborations in the exploitation stage of the innovation process. In the exploration stage, developed technologies are patented and accumulated, and in turn become a firm's repertoire of innovation. This repertoire of innovation is a firm's crucial source of product development in the exploitation stage, which in turn affects the firm's product launch strategy as well as market performance. DeCarolis and Deeds (1999) assert that the stock of organizational knowledge can enhance a firm's performance. Hence, we hypothesize that a firm's market performance is expected to have a positive relationship with a firm's repertoire of innovation.

Hypothesis 4: A firm's repertoire of innovation is positively associated with a firm's market performance.

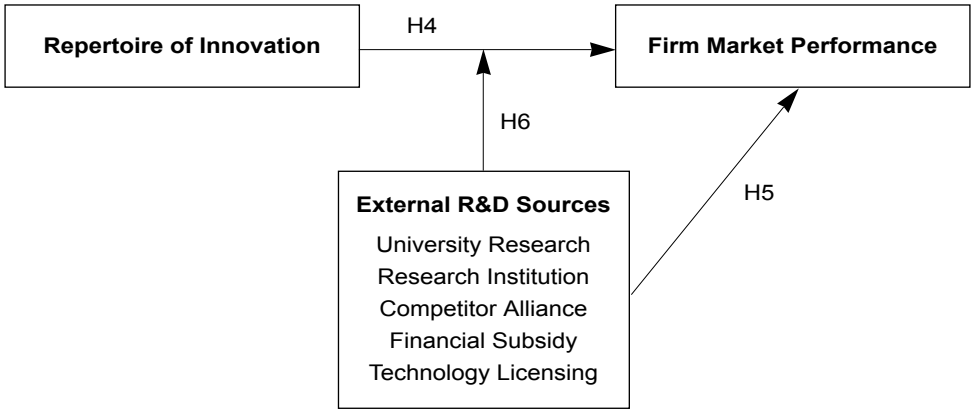

Figure 3 Exploitation and market performance

In addition to the repertoire of innovation, firms may need to conduct external collaborations in the exploitation stage due to funding pressure or the necessity to acquire core technologies possessed by competitors or research institutions. An increasing number of studies find that R&D collaborations with universities or research institutions increasingly take place in the product exploitation stage due to the government's encouragement (Tether, 2002) or funding pressure (Gibbons, Limoges, Nowotny, Schwartzman, Scott, & Trow, 1994). Previous empirical research suggests that firms with collaborative research projects with universities have better firm growth (Lindelof & Lofsten, 2004; Niosi & Banik, 2005). Moreover, a firm's market performance can be improved via inter-firm R&D collaborations (Branzei, 2005) as well as governmental subsidies (Grupp, 1997; Lackman, 2005; Lerner, 1999). Thus, a firm's external R&D collaborations or resources are expected to increase a firm's market performance.

Hypothesis 5: A firm's external R&D collaborations are positively associated with a firm's market performance.

Similarly, a firm's external R&D collaborations and resources may influence its market performance either directly (as predicted by Hypothesis 5) or indirectly via the interaction effect with the firm's repertoire of innovation. In the exploitation stage, since firms mainly employ the technologies already known for developing new products, firms are inclined to access external R&D resources, such as applied technologies from external R&D resources to complement their existing repertoire of innovation for developing various new products, which in turn increases their market performance. Thus, we hypothesize that a firm's external R&D collaborations and resources may moderate the relationship between its

repertoire of innovation and market performance.

Hypothesis 6: A firm's repertoire of innovation is more strongly positively associated with a firm's market performance when the firm accesses external R&D collaborations or resources.

Having developed hypotheses for this study, the next section introduces the research method employed for this study.

3. Research Method

Since this paper attempted to explore what R&D collaborations influence firm performance, a wide range of data from public databases was collected and a questionnaire survey of 165 Taiwan's information and communication technology (ICT) firms was conducted. After the data collection, Poisson regression was employed to examine Hypotheses 1, 2, and 3 for this research while ordinary least squares (OLS) regression was employed to examine Hypotheses 4, 5, and 6 due to the different nature of dependent variables in the exploration stage and exploitation stage.

3.1 Sample Firms and Data Collection

The sample firms in this research were Taiwanese manufacturing firms in the information and communication technology sector. Due to dissimilarities between manufacturing firms and trade-only firms, the trade-only firms were excluded from our sample selection. Moreover, only firms with seven or more established years were included in the sample for this study. Based on the above selection criteria, 415 sample firms were selected. The firms were selected on the basis of the stock code compiled by the Taiwan Stock Exchange Corporation (TSEC) and the Over-The-Counter (OTC). The codes starting with 23, 24, and 30, in the TSEC and 53, 54, 61, and 80 in the OTC were selected as sample firms in this study. All other publicly-held firms were identified by the code starting with 23 compiled by the Ministry of Economic Affairs (MOEA).

With the sample selection criteria, five sub-sectors of the Taiwan's ICT industry were included in this study: the semiconductor sector (13.9%), computer and peripheral sector (46.1%), optical electronics sector (12.7%), communication sector (6.1%), and other electronics sector (21.2%). The above parentheses were the percentages of the distribution for 165 valid sample firms. One-way ANOVA was further calculated to examine the difference among the five sub-sectors in the ICT industry in terms of the dependent variable (sales). The result showed that there was no significant difference among these five sub-

sectors (F=0.631, p > 0.1), suggesting that variance among sectors in the ICT industry did not affect the results in this study.

The questionnaire asked respondents whether the firms had adopted external R&D collaborations between 1996 and 2002, including collaborative R&D projects with universities, research institutions, and partner firms, as well as whether the firms had received subsidies and licensed technologies from the governmental sector. The full name of the intended respondent was investigated in advance of the mailing. Recipients of the survey package were CEOs or senior managers of sample firms. The first snail-mailed survey was conducted in September 2002 while the second snail-mailed survey was conducted in January 2003. Meanwhile, recognizing that a higher response rate is stimulated by face-to-face meetings, we decided to attend three trade exhibitions related to the ICT industry in Taiwan between September 2002 and October 2002. The numbers of respondents for the first mail survey, the second mail survey, and the face-to-face survey, were 81, 58, and 30 respectively, making the final total number 169. After excluding four invalid respondents, the total number of valid sample firms was 165, a 40% response rate for this study.

One-way ANOVA test was performed to examine the difference among the three sub-samples in terms of firm age and sales and the result showed the three sub-sample groups were not significantly different (firm age: F=1.532, p > 0.1; sales: F=1.765, p > 0.1). This suggests that our sample collection was valid. Moreover, the average number of service years of respondents was 7.4 years, suggesting that our respondents were eligible to answer the questionnaire.

In this study, secondary data, such as number of patent stock and revenues, were gathered via official government publications or governmental agent databases (MOEA in Taiwan and The U.S. Patent and Trademark Office) as well as corporate financial statements (Securities & Futures Institute in Taiwan).

3.2 Variable Measurement

3.2.1 Dependent Variables: Repertoire of Innovation and Market Performance

Previous studies have used several intermediate research outputs or performance indicators, such as patenting tendency (Baum et al., 2000; Shan et al., 1994), level of product innovativeness (Kotabe & Swan, 1995), products under development (Deeds & Hill, 1996), or milestone stages reached (Lerner et al., 2003), to measure the innovation performance. However, these indicators are used to measure different stages of the innovation process, such as patents for the exploration stage and product innovativeness for

the exploitation stage. Since we would like to investigate performance of R&D collaborations in the technology exploration stage, patenting was a relatively appropriate indicator for measuring innovation performance in this study.

Innovation performance, a repertoire of innovation in the exploration stage, was measured by a firm's patent stock between 1996 and 2002. Since a majority of Taiwanese ICT firms are OEM/ODM firms manufacturing products for US firms, which require Taiwanese firms to have US patents, both Taiwanese and US patents were taken into account for the innovation performance measurement. The indicator of patent stock was added by the total number of applications for both Taiwanese patents and US patents in a seven-year period between 1996 and 2002. It is appropriate to calculate number of patents on the basis of the application date rather than the issue date. Firms usually have already developed and used such technologies or products as they apply for patents. Such un-issued but applied-for patents should be regarded as the outcomes of innovation. Almeida and Phene (2004) also use patent application date to measure innovation performance.

Market performance in this study was employed to evaluate a firm's performance in the stage of product exploitation (see Figure 3). The reason for using market performance as an indicator instead of counting the number of developed products was that the success of product exploitation and commercialization is more appropriately evaluated by the actual sales of products in the market than by the number of developed products. Traditionally, revenues or market shares are widely accepted as appropriate indicators for measuring a firm's market performance and market structure effects in the industrial organization economics literature (Amato & Wilder, 2004; Dekimpe & Hanssens, 1995; Grewal, Mills, Mehta, & Mujumdar, 2001; Ravenscraft, 1983; Rumelt, 1991; Slade, 2004). Though revenues can be used for measuring firm size, in this research, firm size was measured by a firm's number of employees in 2002 while market performance was measured by a firm's revenues. Shalit and Sankar (1977) claim that revenues are not highly interchangeable with number of employees. Therefore, two proxies can be employed in the same study. Market performance in this study was measured by the firm's revenues in 2002.

3.2.2 Independent Variable: The Choice of External R&D Collaborations or Resources

Since this study attempted to investigate the influence of multiple R&D collaborations on firm performance, based on previous literature, five types of external R&D collaborations were identified, including collaborative R&D projects with universities, research institutions, and competitors, as well as receiving subsidies and licensed technologies from

the governmental sector. Technology licensing in this research means that the developed technologies are licensed or transferred from an institution to a firm without collaborative R&D activities. Collaborative activities with government funded research institutions were included in collaborations with research institutions.

A questionnaire was designed to ask respondents whether firms had adopted these five types of external R&D collaborations in the period between 1996 and 2002. A dummy variable was employed to distinguish two different groups in this study, where firms were given a value of 0 if they did not conduct collaborations or a value of 1 if they conducted such collaborations. For those firms which adopted external R&D collaborations or resources, further five-point scaled questions regarding respondents' perception on the contributions of collaborative projects with universities, independent research institutes, and competitors were constructed. For instance, 'Your firm dedicated many resources to the R&D collaborations with universities (research institutions/competitors) between 1996 and 2002.' Moreover, questions, such as "Your firm replied on financial subsidies from the government greatly between 1996 and 2002" and "Your core technologies were mostly licensed from the government between 1996 and 2002", were constructed to assess the extent of external collaborative R&D projects. A five-point scale, ranging from '1' (strongly disagree) to '5' (strongly agree), was used to measure participants' responses.

3.2.3 Independent Variable: Internal Innovation Capability

A firm's internal innovation capability was measured by R&D intensity in this study. R&D intensity, defined as R&D expenditures divided by net sales, is suggested to have a positive relationship with the innovation output (Caloghirou, Kastelli, & Tsakanikas, 2004). Sakakibara and Porter (2001) assert that R&D intensity reveals the opportunity for a firm's dynamic improvement and innovation. Henderson and Cockburn (1996) find that there is a positive relationship between research efforts and research productivity in the pharmaceutical industry. Thus, R&D intensity is a significant determinant of a firm's innovation performance, which can be employed as an indicator of internal innovation capability. A firm's internal innovation capability was measured by seven-year average R&D intensity between 1996 and 2002 in this study.

3.2.4 Independent Variable: Repertoire of Innovation

In the exploitation stage of the innovation process, a firm's repertoire of innovation was an independent variable in the model. A firm's repertoire of innovation was measured

by a firm's patent stock, which was calculated by the total number of both Taiwanese and US patent applications between 1996 and 2002.

3.2.5 Control Variable: Firm Size and Internal Innovation Capability

Empirically, firm size is observed as having an impact on a firm's innovation performance (Freeman, 1982; Scherer, 1965; Symth, Boyes, & Pessau, 1975) as well as market performance (Said, HassabElnaby, & Wier, 2003; Scherer, 1965; Symth et al., 1975). Thus, this research needed to control for firm size in both the exploration stage and the exploitation stage of the innovation process. Firm size was measured by a firm's number of employees in 2002. These data were collected through the SFI database or the questionnaire. Moreover, a firm's internal innovation capability is also observed having impact on a firm's leadership in the market (Fan, 2006), and then it should be controlled if the relationships among the repertoire of innovation, external R&D collaborations and resources, and market performance were tested in the exploitation stage. A firm's internal innovation capability was measured by seven-year average R&D intensity between 1996 and 2002.

3.3 Research Approach

Since the first objective of this study was to distinguish whether a firm's external R&D collaborations affect a firm's repertoire of innovation and market performance, the first step of this research was to identify sources of R&D strategies employed by firms. A questionnaire survey helped this study to gather this information. In the meantime, industrial secondary data and corporate financial statements were also collected. After data collection, Poisson regression was employed to examine whether external R&D collaborations directly or indirectly affect a firm's repertoire of innovation for Hypotheses 1, 2 and 3. In addition, the OLS regression model was employed to examine whether external R&D collaborations directly or indirectly affect a firm's market performance for Hypotheses 4, 5, and 6.

The reason why this research did not use structural equation modeling (SEM) to examine the developed model was that the dependent variables in both the exploration stage and exploitation stage had different characteristics. In the exploration stage, repertoire of innovation measured by patent stock had a binomial distribution whereas in the exploitation stage, market performance measured by sales had a normal distribution. SEM was not appropriate for testing a dependent variable with a non-normal distributed data set. Thus, in this study, we did not employ SEM to examine our framework. Since one of the dependent variables, repertoire of innovation (measured by patent stock), had a binomial distribution

and was a count variable with a non-negative integer value, Poisson regression was suggested to deal with such a dependent variable (Hausman, Hall, & Griliches, 1984). In contrast, market performance measured by sales had a normal distribution and then a different regression method, OLS regression, was employed.

4. Results and Data Analysis

4.1 R&D Collaboration of Taiwanese ICT Firms

Table 1 summarizes different types of R&D collaborations in this research. As can be seen in Table 1, more than 60% of Taiwanese ICT firms have collaborative R&D projects with universities, research institutions, and competitors in the ICT industry. In contrast, more than 60% of firms in this research did not receive subsidies or licensed technologies from the government during the investigated period of this study. This implied that collaborative R&D projects with universities, research institutions, and competitors were main choices of external R&D collaborations for Taiwanese ICT firms.

Table 1 Descriptive summary of sources of R&D collaborations

Origin of R&D Collaborations	Number of Firms Having Alliances	Number of Firms Having No Alliance	Total Number
Universities	118 (71.5%)	47 (28.5%)	165 (100%)
Research Institutions	104 (63.0%)	61 (37.0%)	165 (100%)
Competitors	106 (64.2%)	59 (35.8%)	165 (100%)
Government Subsidies	62 (37.6%)	103 (62.4%)	165 (100%)
Governmental Tech. Transfer	43 (26.1%)	122 (73.9%)	165 (100%)

4.2 Descriptive Statistics and Correlations

Table 2 summarizes the descriptive statistic data for 165 firms and the correlation table for this research. The average firm size (in terms of number of employees) was 1,016. The internal innovation capability (in terms of R&D intensity) was 5.3%, which was lower than the average R&D intensity (7.2% in 1999) for OECD countries (OECD, 2002). This could be due to the characteristics of Taiwanese OEM firms, which are inclined to invest less in R&D activities (Dedrick & Kraemer, 1998). The repertoire of innovation (in terms of patent stocks between 1996 and 2002) was 55.63. The mean of repertoire of innovation was 1.78 while the mean of market performance (in terms of revenues) was 3,401,457,000 NT dollars. Moreover, as can be seen in Table 2, the correlations among variables were smaller than 0.6 and generally moderate.

Table 2 Descriptive statistic data and variable correlations

	Mean	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	1.78									
(1) Market performance[a]	3,401,457	1.00								
(2) Firm size (no. of employee)	1,016	0.54**	1.00							
(3) Internal innovation capability	5.33	-0.08	-0.12	1.00						
(4) Repertoire of innovation	55.63	0.56**	0.41**	0.02	1.00					
(5) University	2.53	0.07	0.13	0.22**	0.05	1.00				
(6) Research institutions	2.32	0.09	0.12	0.15	0.04	0.59**	1.00			
(7) Competitors	2.30	0.12	0.17*	0.05	0.14	0.35**	0.44**	1.00		
(8) Financial subsidies	1.46	-0.10	0.02	0.19*	-0.06	0.34**	0.24**	0.03	1.00	
(9) Technology licensing	1.32	0.06	0.18*	0.08	0.09	0.40**	0.35**	0.10	0.51**	1.00

N=165; ** $p < 0.01$; * $p < 0.05$; a. 1,000 NT dollars.

4.3 Exploration Stage of Innovation

As mentioned earlier, Poisson regression was employed to examine the developed hypotheses in the exploration stage. Table 3 presents the estimation results for the four models.

In Poisson regression, the goodness of fit for the models is usually evaluated by deviance and the Akaike's Information Criterion (AIC). The above information criteria are in small-is-better form. For instance, the AICs were 22,656, 21,319, 13,398, and 12,613 in Model 1, Model 2, Model 3, and Model 4 respectively. It shows that the goodness of model fit increases as the variables were added into the model. In Model 2 and Model 3, when internal innovation capability and external R&D collaborations were added as predictor variables, the AICs in Model 2 and Model 3 compared with Model 1 decreased. Similarly, the decreasing AIC in Model 4 also suggests that the interaction effects of internal innovation capability and five types of external R&D collaborations have impact on firm innovation performance (i.e. repertoire of innovation).

Table 3 Multiple R&D collaborations in the exploitation stage-poisson regression results (Beta Coefficients)

Exogenous Variables	Model 1	Model 2	Model 3	Model 4
Control Variable				
Firm Size	0.00***	0.00***	0.00***	0.00***
Predictor Variables				
Internal Innovation Capability		0.05***	0.31***	0.21***
Collaboration with University			0.16***	0.39***
Collaboration with Research Institution			-0.10***	-0.09***
Collaboration with Competitor			0.41**	0.44***
Financial Subsidies			-1.73***	-1.28***
Technology Licensing			0.50***	-0.19**
Interaction Models				
Internal Innovation Capability × University				-0.04***
Internal Innovation Capability × Research Institution				-0.01*
Internal Innovation Capability × Competitor				-0.03***
Internal Innovation Capability × Financial Subsidies				-0.09***
Internal Innovation Capability × Technology Licensing				0.13***
Goodness of Fit[a]				
Deviance	22153	20814	12883	12087
Akaike's Information Criterion (AIC)	22656	21319	13398	12613

Wald Chi-Square significance: *** p < 0.001; ** p < 0.01; * p < 0.05.
Dependent variable: repertoire of innovation
a. Information criteria are in small-is-better form.

Table 3 presents the estimation results from Model 1, Model 2, and Model 3. As predicted, firm size was positively associated with firm repertoire of innovation ($p < 0.001$), suggesting that larger firms have a higher level of repertoire of innovation than small firms. The second model included internal innovation capability as an independent variable. As predicted, internal innovation capability (b=0.05, $p < 0.001$) was significantly positively associated with firm repertoire of innovation. This finding was consistent with Hypothesis 1, suggesting that a higher level of internal innovation capability can improve a firm's repertoire of innovation.

Model 3 includes five types of external R&D sources, including collaborative projects with universities, research institutions, and competitors as well as financial subsidies and technology licensing from the government as independent variables. As can be seen in Table

3, a firm's repertoire of innovation was significantly positively correlated with R&D collaborations with universities (b=0.16, p < 0.001) and competitors (b=0.41, p < 0.01) as well as with technology licensing (b=0.50, p < 0.001), but was significantly negatively correlated with R&D collaborations with research institutions (b=-0.10, p < 0.001) and financial subsidies (b=-1.73, p < 0.001). The above results partially supported Hypothesis 2, which stated that a firm's external R&D collaborations are positively associated with a firm's repertoire of innovation. The findings imply that while some types of external R&D collaborations or resources can improve a firm's repertoire of innovation directly in the exploration stage of the innovation process, other types of external R&D collaborations or resources cannot directly improve a firm's repertoire of innovation.

To further examine the moderating effects of external R&D collaborations and resources, this study used a regression model with interactions term (shown as Model 4 in Table 3). Of five types of external R&D collaborations and resources, all were found to have moderating effects on the relationship between a firm's internal capability and its repertoire of innovation. However, only the interaction effect of technology licensing by internal innovation capability was positively associated with repertoire of innovation (b=0.15, p < 0.001). The interaction effects of the remaining four types of R&D collaborations or resources by internal innovation capability were negatively associated with repertoire of innovation. Thus, Hypothesis 3 was mostly not supported.

4.4 Exploitation Stage of Innovation

In the exploitation stage of the innovation process, Models 5, 6, 7, and 8 were constructed to examine Hypotheses 4, 5, and 6, whether repertoire of innovation (patent stock) as well as external R&D collaborations and resources affect a firm market performance directly or indirectly (shown in Figure 3). In this exploitation stage, firm size and internal innovation capability were control variables for these models.

Table 4 Multiple R&D collaborations in the exploitation stage

Exogenous Variables	Model 5	Model 6	Model 7	Model 8
Firm Size *(Control Variable)*	0.54***	0.37***	0.37***	0.30***
Internal Innovation Capability (Control Variable)	-0.01	-0.05	-0.04	-0.01
Repertoire of Innovation		0.40***	0.40***	4.03***
Collaboration with University			0.03	0.16*
Collaboration with Research Institution			0.06	0.12*
Collaboration with Competitor			-0.02	-0.47***
Financial Subsidies			-0.09	-0.13
Technology Licensing			-0.02	0.13*
(Interaction Model)				
Repertoire of Innovation × University				0.75***
Repertoire of Innovation × Research Institution				0.23
Repertoire of Innovation × Competitor				-5.61***
Repertoire of Innovation × Financial Subsidies				-0.36
Repertoire of Innovation × Technology Licensing				0.85*
Adjusted R-Square	0.29***	0.42***	0.41***	0.73***
Adjusted R-Square Change		△0.13***	△-0.01	△0.32***

*** p < 0.001;** p < 0.01; * p < 0.05; Dependent Variable: Market Performance (Revenues)

Table 4 presents the estimation results from Model 5, Model 6, and Model 7. Model 5 explained 29% of the variance (adjusted R Square=0.29) in firm market performance. As predicted, firm size was positively associated with firm repertoire of innovation (b=0.54, p < 0.001), suggesting that larger firms had better market performance. Model 6, which included repertoire of innovation as an independent variable, explained 42% of variance (adjusted R Square=0.42) in firm market performance. The change or R Square (Chi Square of F-value) between Model 5 and Model 6 was significant (increasing 13%), suggesting that the added variable can significantly affect a firm's market performance. As predicted, repertoire of innovation (*b*=0.40, *p* < 0.001) was positively associated with firm market performance. This finding supported Hypothesis 4, suggesting that a higher level of repertoire of innovation can improve a firm's market performance.

Model 7, which includes five types of external R&D sources as independent variables, explained 41% of variance in firm repertoire of innovation (adjusted R Square=0.41), but the change of R Square between Model 6 and Model 7 was not significant (decreasing 1%). No significant relationship was found among the firm market performance and the five types of external R&D collaborations or resources and therefore Hypothesis 5 was not supported. The findings imply that the external R&D collaborations or resources cannot improve a

firm's market performance directly in the exploitation stage of the innovation process.

To further examine the moderating effects of external R&D collaborations and resources, this study used a regression model with interaction term (shown as Model 12). Table 5 shows the results of the interaction regression analysis. Model 8 explains 73% of the variance (adjusted R Square=0.73) in firm market performance. The change or R Square (Chi Square of F-value) between Model 7 and Model 8 was significant (increasing 32%), suggesting that the improved interaction model can significantly explain the moderation effect. Among five types of external R&D collaborations and resources, R&D collaborations with universities (b=0.75, p < 0.001) and technology licensing (b=0.85, p < 0.05) were found to strengthen the positive relationship between a firm's repertoire of innovation and its market performance whereas R&D collaborations with competitors were found to strengthen the negative relationship between a firm's repertoire of innovation and its market performance (b=- 5.61, p < 0.001). Thus, Hypothesis 6 was mainly supported.

5. Discussion

5.1 Internal Innovation Capability, External R&D Collaborations, and Repertoire of Innovation

The findings in this research are consistent with prior studies that in the exploration stage of the innovation process, a firm's repertoire of innovation can be increased via internal innovation capability (Dosi, 1988; Freeman & Soete, 1997; Hagedoorn & Duysters, 2002; Hall & Bagchi-Sen, 2002) or via external R&D collaborations with universities (Lockett et al., 2003; Power, 2003; Zucker et al., 2002) and competitors (Harding, 2001; Hemmert, 2003; Furukawa et al., 1990; Peters & Becker, 1998; Walker, 1995) as well as licensed technologies from the government (Cohen et al., 2002; Jang & Huang, 2005). However, external R&D collaborations with research institutions and financial subsidies from the government have a negative impact on repertoire of innovation, a finding not consistent with prior studies. This implies that Taiwanese ICT firms should improve their internal innovation capability as well as conduct R&D collaborations with universities and competitors or obtain licensed technologies to increase the firm's repertoire of innovation in the exploration stage of the innovation process.

The results also show that only technology licensing from the government has a positive moderating effect on the positive relationship between internal innovation capability and repertoire of innovation. The other four types of external R&D collaborations and resources have a negative moderating effect on the positive relationship between

internal innovation capability and repertoire of innovation. This suggests that these four types of external R&D collaborations and resources may reduce the positive effect of internal innovation capability on repertoire of innovation. Fortunately, the Beta coefficients of these interaction effects are relatively small, suggesting that these negative moderating effects of external R&D collaborations or resources are less influential.

The above findings are consistent with the arguments in this study that different types of external R&D collaborations and resources will influence a firm's repertoire of innovation in different ways. In the exploitation stage of the innovation process, in addition to internal innovation capability, firms need the various external sources as complementary resources for improving a firm's innovativeness. Firms not only benefit from collaborative R&D projects with universities and competitors as well as from technology licensing directly, but also further benefit from the technology licensing to build the internal innovation capability, which in turn improves repertoire of innovation indirectly.

5.2 Repertoire of Innovation, External R&D Collaborations, and Firm Market Performance

Similarly, in the exploration stage of the innovation process, the findings in this research are consistent with prior studies that a firm's performance can be enhanced by the possession of a higher repertoire of innovation (DeCarolis & Deeds, 1999). However, neither external R&D collaborations nor resources have a direct impact on market performance. The findings are against a majority of prior studies suggesting that external R&D collaborations can help to improve a firm's market performance (Branzei, 2005; Grupp, 1997; Lerner, 1999; Lackman, 2005). This implies that a firm's market performance is mainly contributed by the firm's repertoire of innovation instead of external sources in the exploitation stage of the innovation process.

Although external R&D collaborations have no direct impact on firm market performance, the results in this research show that there are significant indirect impacts of external R&D collaborations or resources on firm market performance. A firm's repertoire of innovation is more strongly positively associated with a firm's market performance when the firms conduct R&D collaborations with universities or receive licensed technologies from the government, whereas a firm's repertoire of innovation is more strongly negatively associated with market performance when the firms conduct R&D collaborations with competitors. Nieto and Santamaria (2007) find that collaborations with suppliers, clients, and research organizations (including university and technology research institution) have a

positive impact on the innovation whereas collaborations with competitors have a negative impact. However, the results in this study show that collaborations with universities as well as acquisition of licensed technologies from the government can strengthen the positive relationship between repertoire of innovation and market performance whereas collaborations with competitors will lessen the positive relationship between repertoire of innovation and market performance. Thus, in the product exploitation stage, external R&D collaborations with competitors may lead to the diminishing contribution of a firm's repertoire of innovation to its market performance.

5.3 External R&D Sources on Exploration and Exploitation

The primary objective of this research is to distinguish whether different external R&D sources affect a firm's repertoire of innovation and market performance differently in the exploration stage and exploitation stage of the innovation process. As for the direct effect of external R&D sources, the findings suggest that R&D collaborations with universities and competitors as well as technology licensing can increase a firm's repertoire of innovation whereas R&D collaborations with research institutions or acquisition of financial subsidies from the government may decrease the repertoire of innovation in the exploration stage. In contrast, in the exploitation stage of the innovation process, none of five external R&D sources in this research has a direct impact on a firm's market performance. Thus, it can be concluded that a firm's external R&D sources are inclined to have a direct contribution to a firm's innovativeness in the exploration stage.

As for the indirect effect of external R&D sources, in the exploration stage, only technology licensing can strengthen the positive relationship between internal innovation capability and repertoire of innovation. The remaining four types of external R&D sources will lessen the positive relationship between internal innovation capability and repertoire of innovation. However, in the exploitation stage, R&D collaborations with universities and acquisition of licensed technologies from the government can strengthen the positive relationship between repertoire of innovation and market performance whereas collaborations with competitors will lessen the positive relationship between repertoire of innovation and market performance.

It can be concluded from the findings that R&D collaborations with universities and acquisition of licensed technologies together with repertoire of innovation can increase a firm's market performance indirectly. More interestingly, while R&D collaborations with competitors via internal innovation capability can strengthen a firm's repertoire of innovation

in the stage of exploration innovation, R&D collaborations with competitors via repertoire of innovation will lessen a firm's market performance in the stage of exploitation innovation. Therefore, this research indicates that firms can meet their specific objectives by choosing appropriate external R&D sources in the different stages of the innovation process.

6. Conclusion

The major contribution of this research is that it investigates the interaction effect of multiple-source R&D collaborations on firm performance. In the exploration stage, R&D collaborations with universities and competitors as well as technology licensing from the government have a direct positive impact on a firm's repertoire of innovation while technology licensing has a positive moderating effect on the relationship between internal innovation capability and repertoire of innovation. In the exploitation stage, while none of external R&D sources has direct impact on a firm's market performance, R&D collaborations with universities and acquisition of licensed technologies from the government have a positive moderating effect on the relationship between repertoire of innovation and market performance whereas collaborations with competitors have a negative moderating effect. Moreover, the results also imply that firms should conduct R&D collaborations with competitors in the stage of exploration rather than in the stage of exploitation, since R&D collaborations with competitors have a positive effect in the exploration stage but a negative moderating effect in the exploitation stage.

For business practitioners, a firm's top management team has to understand that the choice of external R&D collaborations and resources may affect different types of firm performance. Firms need to make the optimal choice of external R&D collaborations and resources so as to achieve their strategic intention in the different stages of the innovation process. The results of this paper also shed the light for policy makers. Our results suggest that while technology licensing from the government together with internal innovation capability may directly and indirectly improve a firm's repertoire of innovation, technology licensing from the government together with a firm's repertoire of innovation may also indirectly improve a firm's market performance. Thus, the insight for policy makers is that technology licensing, compared to financial subsidy, is more likely to be complementary to a firm's repertoire of innovation.

This paper not only provides insights to firms for the choice of external R&D collaborations or resources but also provides the government with the direction of resource allocation for science and technology policies. This paper enriches existing theories and

empirical studies as well as provides suggestions to both business practitioners and policy makers regarding multiple R&D collaborations strategy.

A number of limitations have constrained our research. One major limitation is that the sample firms are widely spread throughout the ICT industry, which might lead to inadequate interpretations of the results. Although this study has tested the difference among sub-sectors in the ICT industry and the results shows no significant difference among these five sub-sectors in terms of market performance, future studies should enlarge the pool of sample firms as well as focus on a specific industrial sector so as to improve the representativeness of sample firms. Moreover, the extent of reliance on external R&D collaborations varies greatly across industries. For instance, compared with ICT firms, life science or pharmaceutical firms are likely to require more specialized R&D capabilities and rely on a greater variety of human capital from external sources. Future studies are encouraged to investigate the industries in which firms rely more on external R&D sources. Furthermore, though this paper advances our knowledge and understanding regarding the performance of multiple-source R&D collaborations, the complexity of the processes of conducting multi-collaboration R&D strategy necessitates further clarification in future studies.

Another limitation is that since this study only investigates types of external R&D collaborations instead of governance types of collaborations or the amount of dedication to collaborations, the issues of how the governance side of collaborations as well as how the power or relationship among external R&D partners affects firm performance remain unknown. Future studies are encouraged to clarify these issues. Moreover, this paper does not consider the different incentives to patent for internal R&D and external collaborative R&D. In this study, we propose that learning from external partners can help improve internal R&D capability, which in turn may improve innovativeness, which is measured by patents. Thus, we only count the firms' patents as the repertoire of innovation but do not count the partners' patents. It may be interesting to explore the power of incentives for sharing results among partners in future studies. Finally, time lag effect is also a limitation of this study. Since the choice of R&D collaborations was investigated by the questionnaire, which asked respondents to answer whether they had five types of R&D collaborations or resources between 1996 and 2002, we did not have information regarding the starting date and the ending date of each R&D collaboration or resource. Therefore, it was difficult to operationalize time lag effect in this study. Future studies are suggested to investigate the accurate starting and ending dates of the collaborations so as to cope with the time lag effect.

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