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Absorptive capacity and autonomous R&D climate roles in firm innovation

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ABSTRACT

Absorptive capacity is frequently an outcome of a firm's cumulatively path-dependent R&D investments. However, the query how absorptive capacity transforms R&D investment into firm innovation, in the context of autonomous R&D climate remains unclear. Using 165 firms in the Taiwan's information and communication technology industry, the results indicate that absorptive capacity partially mediates the relationship between R&D investment and firm innovation. Absorptive capacity accounts for 36% effects of R&D investment on firm innovation. The result also shows a negative moderating effect of R&D autonomy on the relationship between absorptive capacity and firm innovation.

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1. Introduction

Cohen and Levinthal (1990) define absorptive capacity (AC) as a firm's ability to value, assimilate, and utilize new external knowledge, which becomes a well-known notion in the multiple disciplines of management research. Although an increasing number of studies apply, measure, or extend the concept of AC, some concerns about the exploitation of the concept emerge accordingly since researchers fail to specify the underlying assumptions of the concept (Lane, Koka, & Pathak, 2006). Thus, identifying antecedents of absorptive capacity, including managerial antecedents (Dijksterhuis, van den Bosch, & Volberda, 1999; Lenox & King, 2004; Zahra & George, 2002), intraorganizational antecedents (Andersen & Foss, 2005; Argote, 1999; Van den Bosch, Volberda, & de Boer, 1999), or interorganizational antecedents (Lane & Lubatkin, 1998; Lane, Salk, & Lyles, 2001), becomes one of important tasks for management scholars. Despite the growing interest in exploring the antecedents of absorptive capacity, few of them capture the absorptive capacity process (Volberda, Foss, & Lyles, 2010). Among those capturing the AC process, the dimensions include Cohen and Levinthal's (1990) dimensions of recognition, assimilation, and exploitation, Zahra and George's (2002) four dimensions that constitute potential and realized AC, Lane et al.'s (2006) the three process dimensions of exploratory learning, transformative learning, and exploitative learning, and Todorova and Durisin's (2007) dimensions of recognition, acquisition, assimilation or transformation, and exploitation. Examining differing effects of organizational antecedents on AC would not only help clarify how to nurture AC, but also reveals why firms have difficulties in managing AC. For example, high levels of acquisition and assimilation of knowledge might determine a firm's ability to transform and exploit knowledge, which in turn affects the firm's innovation. Thus, the underlying tensions among these process dimensions of AC and the effects on firm innovation deserve much attention.

Since absorptive capacity is the result of cumulatively path-dependent R&D investments by a firm (Baum, Calabrese, & Silverman, 2000; Hennart, 1988; Powell, Koput, & Smith-Doerr, 1996), prior studies using R&D expenditures as a measure of AC investigate the relationship between AC and firm innovation (Caloghirou, Kastelli, & Tsakanikas, 2004; Cohen & Levinthal, 1990; Gambardella, 1992; Hall & Bagchi-Sen, 2002). However, a query whether R&D expenditures reflect AC arises if the process school of AC becomes holistic and generic. R&D expenditures may not fully capture the meaning of AC process since monetary inputs cannot represent a firm's process of AC. R&D intensity (R&D expenditure/sales) as the measure for AC (Caloghirou et al., 2004; Cohen & Levinthal, 1990; Gambardella, 1992; Hall & Bagchi-Sen, 2002) reflects a firm's overall capacity to recognize, assimilate, exploit, explore, transform, and acquiring external knowledge (Cohen & Levinthal, 1990; Lane et al., 2006; Todorova & Durisin, 2007; Zahra & George, 2002), since these prior studies believe that R&D employees may be essentially a subset of R&D expenditures. Indeed, R&D expenditures may reflect a firm's purchase on research equipment, payment for patent licensing fees, or recruitment for highly skillful engineers or employees. However, higher R&D expenditures may not completely reflect a firm's capacity particularly in knowledge acquisition and transformation processes since such the higher R&D expenditures are mainly in the use of paying for

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licensing fees. In fact, the people who are within the organization to pursuit the process of knowledge acquisition and transformation are the center of AC. Thus, this study primarily attempts to differentiate the effect of R&D personnel on firm innovation from the effect of R&D expenditures on firm innovation by examining in what proportion absorptive capacity (measured by R&D employees) accounts for the impact of R&D investment (measured by R&D expenditures) on firm innovation.

Furthermore, from the institutional theories, prior research mainly investigates how a firm's external environment interacted with a firm's AC affects its innovation performance (Lichtenthaler, 2009). However, efforts to explore how a firm's internal organizational climate affects the firm's AC and its innovation are relatively limited. Although a number of prior studies focus on the impact of organizational climate on innovativeness, they mainly investigate the direct effect of organizational climate on innovation. For instance, Denison (1990) argues that firms possessing a participative culture and a well-organized workplace outperform those that do not. Liu, Chen, and Yao (2011) also assert that multi-level autonomy supports in an organization will enhance harmonious passion, and then increase individual creativity. Thus, a firm with a participative culture or autonomous climate can achieve better innovation.

However, while most prior studies argue that autonomy support can enhance both an individual and a firm's innovation (Abbey & Dickson, 1983; Amabile, Conti, Coon, Lazenby, & Herron, 1996; Denison, 1990; Liu et al., 2011; Ogbuehi & Bellas, 1992), research is scarce on how a firm's knowledge transformation process (i.e., AC) together with autonomous R&D climate interactively affects a firm's innovativeness. Can a firm's AC help to enhance firm innovativeness in an autonomous R&D climate? Thus, another objective of this study attempts to investigate whether autonomous R&D climate, has the moderating effect on the relationship between absorptive capacity and firm innovation.

To meet the above research objectives (see Fig. 1), this study conducts a questionnaire survey of 165 Taiwanese firms and collects a wide range of secondary data. This research employs the multiple negative binomial (NB) regression models to examine the developed hypotheses since the dependent variable is a count data. Empirical results show that absorptive capacity partially mediates the relationship between R&D investment and firm innovation, suggesting that absorptive capacity is the result of cumulative R&D investment. The result also finds the negative moderating effect of R&D autonomy on the relationship between absorptive capacity and firm innovation. The findings strengthen understating both theoretically and empirically on how R&D investment, absorptive capacity, and autonomous R&D climate interactively affect firm innovation.

2. Theoretical background and hypothesis development

2.1. R&D investment and firm innovation

Technological opportunities can provide the firms with a competitive advantage in transforming their products and production processes (Freeman & Perez, 1998; Miyazaki, 1995; Tushman & Anderson, 1988). The accumulation of competencies determines the possibility of responding to technological opportunities (Miyazaki, 1995). Thus, the amount of investment for a firm's R&D endeavor can determine the accumulation of its technological competencies (Caloghirou et al., 2004; Hamel & Prahalad, 1994; Sakakibara & Porter, 2001), which in turn determines its technological opportunities and firm innovation. As a result, a firm's investment on R&D activities is an important source for firm innovation. A number of studies suggest that a firm invests R&D activities continuously can foster the firm's innovativeness (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 higher R&D investment can result in a higher firm's innovativeness. Prior studies find that R&D investment has a positive relationship with a firm's innovativeness (Caloghirou et al., 2004). For instance, Sakakibara and Porter (2001) asserts that internal R&D reveals the opportunity for a firm's dynamic improvement and innovation while Henderson and Cockburn (1996) find that there is a positive relationship between research efforts and research productivity in the pharmaceutical industry.

2.2. R&D investment and absorptive capacity

A firm's ability to learn new knowledge through its interaction with external partners requires sufficient technical understanding to capitalize that knowledge. This internal capability, also usually referred as absorptive capacity (AC), provides such the foundation upon which firms may learn from the external R&D alliances. Zahra and George (2002) suggest that AC includes the capabilities of acquiring, assimilating, transforming

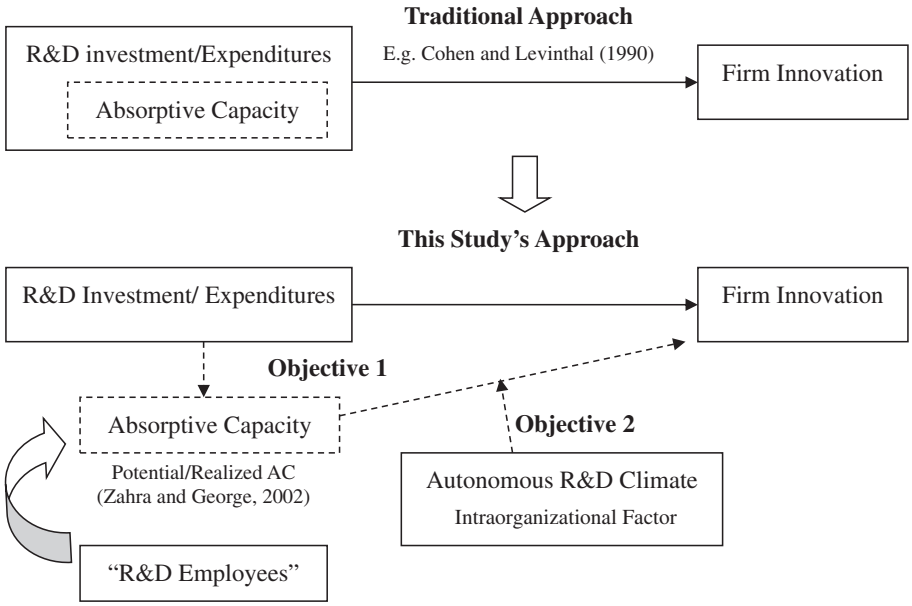

Fig. 1. Research objectives.

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and exploiting knowledge. Absorptive capacity proponents (Cohen & Levinthal, 1990; Michalisin, Smith, & Kline, 1997) suggest that AC is a result of accumulation via intense and long-term training and learning experience, which is difficult to imitate or substitute in the short term. Thus, from the process school perspective, AC is a firm's inimitable process of recognizing (Cohen & Levinthal, 1990; Todorova & Durisin, 2007), assimilating (Cohen & Levinthal, 1990; Todorova & Durisin, 2007; Zahra & George, 2002), exploiting (Cohen & Levinthal, 1990; Lane et al., 2006; Todorova & Durisin, 2007; Zahra & George, 2002), exploring (Lane et al., 2006), transforming (Lane et al., 2006; Todorova & Durisin, 2007; Zahra & George, 2002), and acquiring (Cohen & Levinthal, 1990; Todorova & Durisin, 2007; Zahra & George, 2002) external knowledge. This reminds us that the input variables, such as R&D expenditures (e.g., studies by Caloghirou et al. (2004), Cohen and Levinthal (1990), Gambardella (1992), and Hall and Bagchi-Sen (2002)) may not appropriately reflect a knowledge-accumulation experience and process. The higher R&D expenditures may refer to the use in the purchase of research equipment, payment for patent licensing fees, or recruitment of highly skillful engineers or employees. In this case, higher R&D expenditures may not necessarily refer to a firm's capacity in knowledge acquisition and transformation processes. In contrast, the people who are within the organization to pursuit the process are the center of AC. Therefore, it might be more appropriate to capture the extent of a firm's AC process by measuring the firm's highly skilled employees who involve in such the process. In fact, Nelson and Phelps (1966) also posit the importance of highly-qualified and skilled employees on the firm's capacity to innovate and to adapt to new technologies. Thus, a firm's quality of human capital refers to the extent of a firm's AC. As a result, a proportion of R&D investment can be in the use of recruiting highly skilled employees or engineers, which can help a firm to accumulate sufficient long-term training and learning experience for highly-qualified and skilled engineers and employees. Such the highly skilled human capital refers to a better absorptive capacity in acquiring and transforming external knowledge (Cohen & Levinthal, 1990). H1: A firm's R&D investment associates positively with a firm's absorptive capacity.

2.3. Absorptive capacity and firm innovation

Prior studies investigate the impact of a firm's absorptive capacity on its innovation. Most of them find a positive impact of absorptive capacity on a firm's innovation performance both in a direct way (Caloghirou et al., 2004; Cohen & Levinthal, 1990; Gambardella, 1992; Hall & Bagchi-Sen, 2002; Lichtenthaler, 2009) and a moderating way (Fernhaber & Patel, 2012; Rothaermel & Alexandre, 2009; Tsai, 2001). Cohen and Levinthal (1990) argue that absorptive capacity is likely to harness new knowledge with prior related knowledge, which helps innovative activities. Firms have to possess the capacity to absorb inputs from external sources in order to generate outputs. Szulanski (1996) finds that lack of absorptive capacity is a major barrier to internal knowledge transfer within firms. Prior research also asserts that absorptive capacity, created and accumulated by internal R&D efforts and R&D human capital (Muscio, 2007), is complementary with external R&D collaborations, which in turn enhances innovation (Leiponen, 2005). H2: A firm's absorptive capacity associates positively with the firm's innovation.

2.4. Autonomous R&D climate, absorptive capacity, and firm innovation

The complexity of each firm's "set of values, beliefs, assumptions, and symbols that define the way in which a firm conducts its business" (Barney, 1986, p. 657) helps to make an individual firm's culture difficult to imitate. Denison (1990) argues that firms possessing a participative culture and a well-organized workplace, or called organizational climate, outperform those that do not. Thus, a firm with a participative culture or autonomous environment should achieve higher innovativeness. An innovative climate takes place when employees perceive that change and firms encourage the creativity in the workplace (Koys & DeCotiis, 1991). An autonomous climate encourages employees to solve new and evolving problems in an innovative way (Amabile et al., 1996) because employees feel free to apply innovative solutions than employees who receive detailed instructions (Cabrera, Collins, & Salgado, 2006). Therefore, a firm with higher R&D autonomy can facilitate an innovative climate that encourages employees to behave innovatively (Koys & DeCotiis, 1991) as they acquire, assimilate, transform and exploit external knowledge (Zahra & George, 2002), which in turn enhance firm innovation. H3: Autonomous R&D climate moderates the relationship between absorptive capacity and firm innovation. Fig. 2 summarizes the research framework of this study.

3. Methods

The research method includes a two-stage study. The first stage examined the mediating effect of absorptive capacity on the relationship between R&D investment and firm innovation. The second stage then examined the moderating effect of R&D autonomy on the relationship between absorptive capacity and firm innovation. This study uses negative binomial regression models to examine the developed hypotheses at both the stages since the dependent variable, firm innovation measured by patent number, is a counted construct.

3.1. Sample and data collection

This study selected sample firms from the Taiwanese information and communication technology (ICT) in the manufacturing sector. Sample firms are publicly listed firms on the Taiwanese Stock Exchange and locate their headquarters in Taiwan. The study selected sample firms on the basis of the stock code compiled by the Taiwan Stock Exchange Corporation (TSEC) and the Over-The-Counter (OTC), which the codes start with 23, 24, and 30, in the TSEC and 53, 54, 61, and 80 in the OTC. This research also identified other publicly-held firms by the code starting with 23 compiled by Minister of Economic Affairs (MOEA). As the majority of Taiwanese ICT firms have gone for the initiate public offers (IPOs) since the mid-1990s, this study includes sample firms for those with data available for a period of ten years or more (between 1996 and 2005). Consequently, this study selected 415 potential firms, accounting for approximately 80% of total production value of the Taiwan's ICT industry. Out of the 415 targeted firms, 165 firms returned a completed questionnaire by 2002, making a 40% of response rate. In order to create a time lag between independent and dependent variables, this study further collected secondary data for the dependent variable, patent number, between 2003 and 2005.

Recipients of the survey are CEOs or senior managers of sample firms and they evaluated items regarding a firm's R&D and innovation activities in the past seven years. This study conducted two mailed surveys in September 2002 and in January 2003. Meanwhile, recognizing a higher response rate stimulated by face-to-face meetings, the researcher attended 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, are 81, 58, and 30 respectively, making the final total number 169. After excluding four invalid responses, the total number

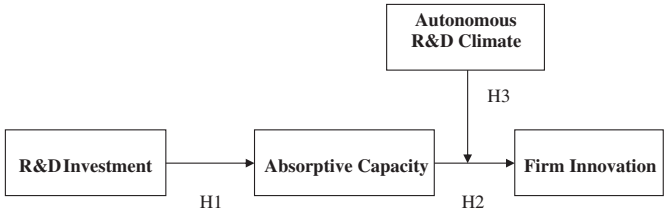

Fig. 2. R&D investment, absorptive capacity, autonomous R&D climate, firm innovation.

of valid sample firms is 165, a 40% response rate for this study. This study uses a one-way ANOVA test to examine the difference among the three sub-samples in terms of firm age and sales. The result shows that the three sub-sample groups are not significantly different (firm age: $F = 1.53$, $p > 0.1$; sales: $F = 1.76$, $p > 0.1$), suggesting no sample selection bias in this research. As for patent data, this study collects them via the governmental agent database, Taiwan Intellectual Property Office (TIPO), MOEA, in Taiwan.

3.2. Variable measurement

3.2.1. Independent variables

3.2.1.1. R&D investment. This study measures a firm's R&D investment by a seven-year average R&D intensity (R&D expenditures/sales) between 1996 and 2002 in this study.

3.2.1.2. Absorptive capacity. As noted by Volberda et al. (2010), several prior studies emphasize both the mediating role and moderating roles of absorptive capacity on innovation (Cohen & Levinthal, 1990; Rothaermel & Alexandre, 2009). However, most these measures for absorptive capacity are proxies such as R&D expenditures (Cohen & Levinthal, 1990; Rothaermel & Alexandre, 2009), or the survey items by asking questions of the R&D intensity in terms of R&D activities (c.f., Rothaermel & Alexandre, 2009). While absorptive capacity includes potential absorptive capacity and realized absorptive capacity in the extensive research by Zahra and George (2002), the measures for absorptive capacity become more specifically based on their definitions by using questionnaire surveys instead of proxies (e.g., Jansen, Van den Bosch, and Volberda's (2005) and Lichtenthaler's (2009) studies). However, though such efforts enrich the exploration on the causality between various factors and absorptive capacity, the explanatory power of results becomes constrained and biased due to respondents' self-report answers (Campbell, 1982). Particularly in the context of absorptive capacity, an individual respondent's (normally a top manager) perception on organizational processes might not be completely accurate. Thus, this study decides to use the proxy to measure such the important organizational concept.

Nevertheless, R&D expenditures as a common proxy for absorptive capacity is also problematic since R&D expenditures may be in the use on various entities, such as machineries, engineers, licensing fees, etc., which may not accurately reflect such the complex and implicit process of absorptive capacity. Thus, this study attempted to use another proxy for measuring absorptive capacity without losing its nature. Zahra and George's (2002) classification may be a starting point to re-consider such a proxy. Potential absorptive capacity includes knowledge acquisition and assimilation, capturing efforts expended in identifying and acquiring new external knowledge and in assimilating knowledge obtained from external sources. A highly skilled R&D employee has higher knowledge processing capacity, acquiring and assimilating new external knowledge possible. On the other hand, realized absorptive capacity includes knowledge transformation and exploitation, encompassing deriving new insights and consequences from the combination of existing and newly acquired knowledge, and incorporating transformed knowledge into operations. A larger number of R&D employees could share their complementary knowledge (March, 1991) and promote knowledge transfer and exploitation through "learning by doing". Thus, departing from Zahra and George's (2002) study, this study uses the number of R&D employees to measure absorptive capacity by asking respondents to provide the number of scientists and engineers in their R&D department between 1996 and 2002.

3.2.1.3. Autonomous R&D climate. This research revised Zain, Richardson, and Adam's (2002) measurement by asking whether top managers make innovation decision. The construct composes two items with a five-point Likert scale from 1 for strongly disagree to 5 for strongly agree, including: "Top management approves appropriate resources (reverse scaled)" and "Top managers make the final decision on the technology adoption (reverse scaled)".

3.2.2. Dependent variable

The dependent variable in this study is a firm's innovation performance. Prior studies measure innovation performance in a number of different ways, such as patent or scientific publications. Since patent data are relatively easy to access and Taiwan's manufacturing firms generally patent their innovative products or improved manufacturing processes, this study uses patent stock to measure a firm's innovation performance. In order to create a time lag between independent and dependent variables, this research calculates patent stock by the total number of patents on the basis of patent applications date (Almeida & Phene, 2004) between 2003 and 2005 while the independent variables are at the time before 2003. This research uses application date rather than issue date since firms might have already developed and used such technologies or products as they apply for patents. This research codes the patent number of the sample firms from the TIPO, the Taiwan's governmental patent database.

3.2.3. Control variables

3.2.3.1. Firm size. Firm size may have impacts on a firm's innovation output. Prior studies suggest that the output of innovation has a positive association with firm size (Freeman, 1982; Scherer, 1965; Symth, Boyes, & Pessau, 1975). Thus, this research controls for firm size in our research by measuring the logarithm of a firm's total assets at fiscal year end in 2002.

3.2.3.2. Previous innovation. In addition to firm size, a firm's previous innovation performance will also influence its current innovation performance. Therefore, this study also controls the previous innovation performance by measuring a firm's patent stock between 1996 and 2002.

3.2.3.3. External resources. Since external R&D resources are complementary to internal R&D accumulation for improving a firm's innovation (Inkpen, 1996; Lin, 2003), this study also needs to control such impacts of external R&D resources, including R&D alliances and public subsidies, on firm innovation. Thus, this research measures external R&D alliances and public subsidies by collecting primary data with a five-point scaled item through a questionnaire survey. External R&D alliances include three items: "Commitments to joint projects with universities", "Commitments to joint projects with research institutions", and "Commitments to joint projects with competitors" (Lee, Lee, & Pennings, 2001). Public subsidies include an item: "Receiving licensed or transferred technologies from the governmental sector" (Grupp, 1997).

3.3. Analytical statistics

The dependent variable, firm innovation (measured by patents), is a nonnegative-integer count variable and has a problem of over-dispersion, which tends to bias downward the estimated standard errors (Huang, 2011). Prior research suggests that negative binomial regression model is a remedy to overcome the over-dispersion problem (Keil, Schildt, & Zahra, 2008). Thus, this research follows the suggestion by using the negative binomial regression to examine the hypotheses.

At the first stage, this research establishes regression models to examine the mediating effect of absorptive capacity on the casual relationship between independent variable (R&D investment) and dependent variable (firm innovation). Based on the Edwards and Lambert's (2007) study, this research has to examine three relationships among R&D investment, absorptive capacity, and firm innovation for the mediating effect. First, this research has to examine the relationship between

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R&D investment and firm innovation (see Eq. (1)). Second, the research also separately examines the relationship between R&D investment and absorptive capacity (see Eq. (2)) as well as the relationship between absorptive capacity and firm innovation (see Eq. (3)).

$$\begin{aligned}\text{Innovation Performance} = {} & \alpha + \beta 1 * \text{Size} + \beta 2 \\ & * \text{Previous Innovation} + \beta 3 \\ & * \text{R\&D Alliance} + \beta 4 \\ & * \text{PublicSubsidies} + \beta 5 \\ & * \text{R\&D Investment} + \varepsilon \end{aligned} \quad (1)$$

$$\begin{aligned}\text{Absorptive Capacity} = {} & \alpha + \beta 1 * \text{Size} + \beta 2 * \text{R\&D Alliance} + \beta 3 \\ & * \text{Public Subsidies} + \beta 4 * \text{R\&DInvestment} \\ & + \varepsilon \end{aligned} \quad (2)$$

$$\begin{aligned}\text{Innovation Performance} = {} & \alpha + \beta 1 * \text{Size} + \beta 2 \\ & * \text{Previous Innovation} + \beta 3 \\ & * \text{R\&D Alliance} + \beta 4 \\ & * \text{Public Subsidies} + \beta 5 \\ & * \text{Absorptive Capacity} + \varepsilon \end{aligned} \quad (3)$$

At the second stage, by using multiple negative binomial regression models, this research constructs three base models and one moderating model to examine the interaction effect of the moderator. The purpose of the three base models is to establish a baseline against the added contribution of the moderator. The first based model examines the relationship between control variables and firm innovation while the second and third base models examine whether absorptive capacity and autonomous R&D climate have the direct impact on firm innovation. The fourth model examines the interaction effect of the moderator on dependent variable.

4. Analytical results

4.1. Descriptive statistics results

Table 1 provides basic information about the 165 valid sample firms in this study. It shows that firm innovation (patent stock) between 2003 and 2005 is 26.08 while innovation performance (patent stock) between 1996 and 2002 is 41.42. The average R&D intensity (R&D expenditure as a percentage of sales) is 5.33%.

4.2. Correlation results

Table 1 also shows the result of the correlation between independent variables and firm innovation. The result shows that our dependent variable, firm innovation, has a positive relationship with firm size, previous innovation performance, absorptive capacity, and autonomous R&D climate. A number of constructs might have intercorrelations with each other. Myers (1990) and Bowerman and O'Connell (1990) suggest that if the largest variance inflation factor (VIF) is greater than 10 and then the concerns of multi-collinearity problem in the regression model may arise. Tests for multicollinearity among independent variables show that little multicollinearity exists among the independent variables in our study since the VIF is less than 2.

4.3. Hypothesis test

4.3.1. The mediation effect

To test the mediating effect of absorptive capacity on the relationship between R&D investment and firm innovation, this study employs the following four regression models. As Table 2 shows Model 1 tests whether R&D investment has impact on a firm's absorptive capacity. The result shows that R&D investment has a positive association with absorptive capacity ($b = 3.098$, $p < 0.01$), suggesting to support H1. Model 2 tests the impact of R&D investment on firm innovation. The result showed that R&D investment has a significant impact on firm innovation ($b = 0.039$, $p < 0.05$). Model 3 tests whether absorptive capacity has the impact on firm innovation. The result shows that absorptive capacity has a positive association with firm innovation ($b = 0.006$, $p < 0.001$), which supports H2.

In order to test the mediating effect of absorptive capacity, this research tests the full model shown in Model 4. The result shows that absorptive capacity has a positive association with firm innovation ($b = 0.006$, $p < 0.001$) but R&D investment has no significant impact on firm innovation ($p > 0.1$). The above results suggest that absorptive capacity has a partial mediating effect on the relationship between and R&D investment and firm innovation. This research further uses the Sobel test to test whether the mediation effect is significant. The result shows that absorptive capacity is a significant mediator between R&D investment and innovation ($z = 2.674$, $p < 0.01$).

4.3.2. The moderating effect

Table 3 shows the results of the interaction effect of absorptive capacity by R&D autonomy on a firm's innovation. Model 5, as a base model, shows that firm size ($b = 0.582$, $p < 0.001$) and previous innovation ($b = 0.002$, $p < 0.05$) have positive associations with firm innovation, consistent with previous studies. Models 6, which includes absorptive capacity as an independent variable, shows that the absorptive capacity has a positive association with firm innovation ($b = 0.006$, $p < 0.001$). Model 7, which includes autonomous R&D climate as a moderator, shows that autonomous R&D climate has no direct impact on firm innovation. Model 8 tests the interaction effect of absorptive capacity by autonomous R&D climate on firm innovation. As Model 8 shows, the coefficient of the interaction of absorptive capacity and autonomous R&D climate is negative and significant ($b = -0.004$, $p < 0.01$), suggesting that the interaction effect of autonomous R&D climate on the relationship between absorptive capacity and firm innovation is negative. The result fails to support H3.

Table 1
Means and correlations results.

Pearson's Correlation	Means	Standard Deviation	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Innovation Performance	26.08	83.22	1.00						
(2) Firm Size	14.84	1.31	0.50***	1.00					
(3) Previous Innovation	41.42	264.34	0.42***	0.40***	1.00				
(4) External R&D Alliances	2.38	1.51	0.11	0.12	0.10	1.00			
(5) Public Subsidies	1.91	0.55	0.01	0.16*	−0.02	0.23**	1.00		
(6) R&D Investment	5.33	8.06	−0.00	−0.10	0.02	0.17*	0.09	1.00	
(7) Absorptive Capacity	82.27	146.60	0.67***	0.58***	0.47***	0.23**	0.09	0.06	1.00
(8) Autonomous R&D Climate	2.91	0.85	0.19*	0.22**	0.14	0.05	−0.02	−0.01	0.29***

*** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$.

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Table 2
Mediating effect of absorptive capacity.

Dependent variables	Absorptive capacity OLS regression		Patent stock (2003–2005) negative binomial regression					
	Model 1		Model 2		Model 3		Model 4	
	Coefficient	(S.E.)	Coefficient	(S.E.)	Coefficient	(S.E.)	Coefficient	(S.E.)
Firm Size	146.86***	(17.93)	0.62***	(0.070)	0.27**	(0.08)	0.30***	(0.08)
Previous Innovation	0.15***	(0.04)	0.00**	(0.001)	−0.00	(0.00)	−0.00	(0.00)
External Alliances	14.54*	(5.80)	−0.03	(0.060)	−0.10	(0.06)	−0.10	(0.06)
Public Subsidies	0.20	(15.71)	−0.17	(0.150)	−0.13	(0.14)	−0.15	(0.14)
R&D Investment	3.10**	(1.11)	0.04*	(0.016)			0.02	(0.01)
Absorptive Capacity					0.01***	(0.00)	0.01***	(0.00)
N	165		165		165		165	
F-ratio	29.36***							
Adjusted R^2	0.46							
Likelihood ratio chi-square			241.95		273.60		275.19	
Log pseudo likelihood			−585.27		−569.45		−568.65	

*** p < 0.001; ** p < 0.01; * p < 0.05

5. Discussion

The regression results show that a firm's absorptive capacity partially mediates the relationship between R&D investment and firm innovation. Moreover, autonomous R&D climate surprisingly negatively moderates the effect of absorptive capacity on firm innovation. This study provides further discussions as follows.

5.1. The mediating role of absorptive capacity

Previous studies suggest the number of R&D employees influences a firm's innovation performance (Nelson & Phelps, 1966). A firm's absorptive capacity, measured by the number of R&D employees, is an important factor affecting the firm's innovation. The results in this research support the above argument that the greater a firm's absorptive capacity, the better firm innovation. More importantly, this research also finds that a firm's absorptive capacity in terms of the number of R&D employees partially mediates the relationship between a firm's R&D investment and firm innovation. This research further calculates the indirect mediation effect and total effect.

The result shows that the indirect medication effect accounts for 36.1% of total medication effect (0.022/0.061), suggesting that more than one third of R&D investment has gone through firm innovation via the absorptive capacity in terms of R&D employees. The finding implies that although a firm's R&D expenditures may directly improve a firm's innovation as predicted, the firm should pay attention on investing on its R&D employees. Investment on R&D employees helps them to accumulate skills and experience (Nelson & Phelps, 1966), and therefore enhances the organizational absorptive capacity. Once the firm possesses better absorptive capacity, it means that the firm possess better capabilities of acquiring, assimilating, transforming and exploiting new knowledge (Zahra & George, 2002), which in turn leads to better firm innovation.

5.2. The moderation of autonomous R&D climate by absorptive capacity on firm innovation

While prior studies expect that a firm's autonomy as R&D climate may help the firm's innovation (Abbey & Dickson, 1983; Amabile et al., 1996; Cabrera et al., 2006; Koys & DeCotiis, 1991), the results provide a different story. The regression results suggest that a firm's autonomous R&D climate does not directly correlate to firm innovation but negatively moderates the relationship between the firm's absorptive capacity and firm innovation. This implies that although absorptive capacity can enhance a firm's innovation, the highly autonomous R&D climate may jeopardize the positive effect of absorptive capacity on firm innovation. For instance, the higher level of autonomous R&D climate refers that R&D employees have greater autonomy to decide the direction of research and development projects.

However, a firm needs to possess absorptive capacity to integrate the existing knowledge and external resources. If the firm has less coherent goals for such the integration due to over R&D autonomy, the innovation may fail due to the loss on the direction of R&D projects. As a result, highly autonomous R&D climate may decrease the positive effect of absorptive capacity on firm innovation. This study further divides autonomous R&D climate into two groups and to interpret its interaction effect. As shown in Fig. 3, compared to higher R&D autonomy, lower R&D autonomy can better enhance the higher absorptive capacity effect on firm innovation. One possible explanation is that although a high autonomous workplace provides a climate of creativity and

Table 3
Moderating effect of autonomous R&D climate (negative binomial regression).

Coefficients	Model 5		Model 6		Model 7		Model 8	
	Coefficient	(S.E.)	Coefficient	(S.E.)	Coefficient	(S.E.)	Coefficient	(S.E.)
Firm size	0.58***	(0.07)	0.270**	(0.08)	0.28***	(0.08)	0.24**	(0.08)
Previous innovation	0.00*	(0.00)	−0.00	(0.00)	0.00	(0.00)	0.00	(0.00)
External alliances	0.00	(0.06)	−0.10	(0.06)	−0.10	(0.06)	−0.10	(0.06)
Public subsidies	−0.13	(0.15)	−0.13	(0.14)	−0.13	(0.14)	−0.16	(0.14)
Absorptive capacity			0.01***	(0.00)	0.01***	(0.00)	0.02***	(0.01)
Autonomous R&D climate					−0.08	(0.10)	0.16	(0.12)
Absorptive capacity × Autonomous R&D climate							−0.00**	(0.00)
N	165		165		165		165	
Wald chi-square	234.26		273.60		274.18		281.66	
Log pseudo likelihood	−589.11		−569.45		−569.16		−565.41	

*** p < 0.001; ** p < 0.01; * p < 0.05
Dependent variable: patent stock (2003–2005).

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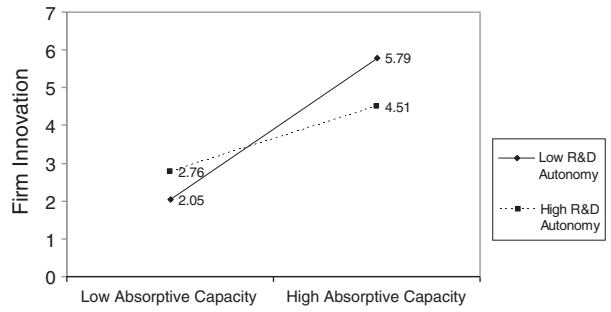

Fig. 3. Interaction effect of absorptive capacity by autonomous R&D climate on firm innovation.

innovation, a close monitoring by top managers signaling to team members and the rest of the company is also important for creativity and innovation (Sethi, Smith, & Park, 2002). Though top managers should not pay too much attention in processes of R&D because they may constrain R&D staffs' creativity, they should have a determinant goal for the research and development direction (Amabile, 1998). This implies that too much autonomy sometimes may not be an optimal climate for firm innovation. The results of this research partially exemplify this assertion. Although higher absorptive capacity in terms of R&D employees in an organization means its stronger capability of acquiring, assimilating, transforming and exploiting new knowledge, it also implies a higher need to integrate such a greater amount of absorptive capacity. As Fig. 3 shows, absorptive capacity can enhance firm innovation in both low and high autonomous R&D climate (both slops are positive). However, lower autonomous R&D climate can better facilitate an organizational climate for utilizing greater absorptive capacity, and then leads to a greater firm innovation. Thus, too much autonomy may offset the effect of absorptive capacity on firm innovation due to losing the consensus on R&D directions (Amabile, 1998).

5.3. Cross validation test

Concerns on multiple regression analysis (MRA) have increasingly caught researchers' attention due to possible limitations of using one-shot and one-person-per-firm self-reports as indicators of causal relationships between independent and dependent variables (Woodside, 2013). Thus, this research used cross validation test suggested by prior research (Gigerenzer & Brighton, 2009; Woodside, 2013) to remedy such the concerns. The cross-validation method randomly splits the sample into two exclusive subsets of approximately the same size, uses the model developed from the measures for one subset to predict the measures with the other subset and examines the correlation of the measures between the respective models. The results showed that the correlations between the observed measures and predicted measures are medium high and statistically significant (the correlation coefficient of model 1 with dataset 2 = 0.67; the correlation coefficient of model 2 with dataset 1 = 0.57), indicating the validity of current results.

6. Conclusion

Empirical results from this study contribute to understanding of the relationships between a firm's R&D investment, absorptive capacity, autonomous R&D climate, and firm innovation performance. A number of significant findings and implications stems from empirical results. First, absorptive capacity partially mediates the relationship between R&D investment and firm innovation, which confirms the expectation that R&D human capital is an important indicator for absorptive capacity, which plays an important knowledge transformation role in firm innovation. A firm's R&D investment can turn into innovative outputs (patents) via enriching the firm's absorptive capacity during the transformation process. Second, the results are somewhat surprising in the moderating effect of autonomous R&D climate. While previous research in this area suggests that the greater autonomy can help firm innovation, our results suggest that the lower R&D autonomy may better facilitate a climate for firms to utilizing the greater absorptive capacity for firm innovation. This echoes the assertion that the hand-off from the R&D team may not be a panacea for creativity or innovation. A certain level of coordinating or monitoring, such as a clear R&D direction, is necessary, particularly if a firm's absorptive capacity become greater.

Business practitioners can learn lessons from this research by understanding the mediation effect of absorptive capacity on the relationship between R&D investment and firm innovativeness as well as the negative interaction effect of absorptive capacity by autonomous R&D climate, suggesting that absorptive capacity has greater impact on firm innovation as the firm facilitates less R&D autonomy. Thus, firms should pay more attention to increase their investment on R&D human capital, which enhances their absorptive capacity by doing so. In the meantime, firms should reduce the autonomy of R&D staffs as they integrate internal knowledge with external resource to innovate in the greater absorptive capacity.

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