ABSTRACT

This study investigates two types of firm capabilities (network and innovation) that would best support open innovation activities (inbound and outbound) to achieve radical innovation with the consideration of environmental dynamism. Based on a cross-industry survey of 201 firms, we find the effectiveness of firm capabilities and open innovation activities contingent on the level of environmental dynamism. Specifically, when the level of environmental dynamism increases, inbound open innovation activities, network capabilities, and innovation capabilities are able to enhance radical innovation, respectively. Overall, this study extends the discussion of open innovation to the areas of firm capabilities and environmental dynamism.

KEYWORDS: Innovation, Dynamic capabilities, Environmental dynamism

INTRODUCTION

This study investigates how dynamic capabilities support open innovation activities to achieve radical innovation, with the consideration of environmental dynamism. Radical innovation is the pursuit of completely new knowledge and skills in new product/service development that significantly alters consumption patterns in a market (O'Connor and Rice, 2013). Since radical innovation can create competitive advantages and new market opportunities, several studies have attempted to identify the drivers for effective radical innovation (e.g., Troilo et al., 2014; Oliveira and von Hippel, 2011; Hertog et al., 2010). Among these, the open innovation approach has received enormous attention for its contribution to achieving radical innovation (Parida et al., 2012; Huizingh, 2011; Gassmann et al., 2010).

The basic premise of open innovation is to use external knowledge and technologies to accelerate the innovation process and strengthen innovation performance (West et al., 2014; Chesbrough, 2003), consisting of inbound and outbound activities (Spithoven et al., 2011; Bianchi et al, 2011). Inbound activities refer to the ability to gain and explore knowledge from external parties, while outbound activities refer to a firm’s activities involving the exploitation and commercialization of its own internal knowledge (Gassmann and Enkel, 2004). The literature has confirmed that both inbound and outbound open innovation activities contribute to innovation performance (e.g., Cheng and Huizingh, 2014; Spithoven et al., 2011; Bianchi et al, 2011; Van de Vrande et al., 2009).
However, the literature also suggests that merely engaging in inbound/outbound open innovation would not suffice for radical innovation (Huizingh, 2011; Lichtenthaler, 2011). Firms need particular capabilities to deploy their skills, resources, and competencies to convert the variety of knowledge acquired from open innovation activities into breakthrough innovation (Lichtenthaler, 2011; Teece et al., 1997). From the perspective of the capability-based view, firm’s strategic programs, such as open innovation, cannot be fully and effectively implemented without the support of proper firm capabilities (Helfat et al., 2007; Eisenhardt and Martin, 2000). The interactions of these two programs, open innovation and firm capabilities, could have a significant impact on innovation performance. Prior studies provide empirical evidence to support this firm capabilities–innovation relationship, such as radical innovation capabilities for enhancing the effect of radical innovation on firm performance (Slater et al., 2014), service innovation capabilities for strengthening the effect of service resources on service innovation development (Kindström et al., 2013), and network capabilities for enhancing the effect of the industrial service offering on sales growth (Kelly et al., 2009; Kohtamäki et al., 2013). Nonetheless, the literature has not considered the joint effects of these two important programs on promoting radical innovation.

Another factor that could potentially affect the open innovation–radical innovation relationship is environmental dynamism. Contingency theory suggests that the effectiveness of a firm’s strategy relies on the fit between the strategy and the business environment (Hofer, 1975). Previous studies find the presence of environmental dynamism influences the open innovation–innovation performance relationship (e.g., Hung and Chou, 2013; Schweitzer et al., 2011). Nonetheless, they have not considered the interrelationship between environments and firm capabilities. In particular, capabilities-based researchers indicate that firm capabilities need to be congruent with the requirements of a changing environment (Eisenhardt and Martin, 2000; Teece et al., 1997). Isolating the effects of each contingent factor could downplay complex forms of interaction (Meyer et al., 1993) and, thus, oversimplify the actual effects of open innovation activities on radical innovation. Therefore, the external environment must be considered, along with firm capabilities, in forming an effective open innovation program.

In summary, this study aims to investigate the effectiveness of open innovation, firm capabilities, and their interactions on radical innovation performance, taking into consideration of environmental dynamism. First, drawing on a capability-based view (Eisenhardt and Martin, 2000; Teece et al., 1997), we propose that two particular firm capabilities, network capabilities and innovation capabilities, substantially enhance the effects of open innovation activities on radical innovation performance. Next, building on contingency theory, we examine how environmental dynamism influences the values of open innovation, firm capabilities, and their joint effects. This study should contribute to research and industry practices by providing a more comprehensive view of the inter-relationships of open innovation, firm capabilities, and environmental dynamism that are critical to enhancing radical innovation.

The remainder of this paper is organized as follows. We first discuss the theoretical background of the research model and develop a set of hypotheses, followed by the presentation of statistical methods and results. Finally, we conclude with a discussion of the findings, the implications for current research and managerial practice, and limitations and future research.

Figure 1: The Research Model
THEORETICAL DEVELOPMENT

Figure 1 displays a research model with the proposed theoretical relationships among several variables/constructs, including open innovation activities (inbound and outbound), firm capabilities (network and innovation), environmental dynamism, and radical innovation. The model highlights how environmental dynamism moderates the main and interaction effects of open innovation activities and firm capabilities on radical innovation. This section defines the constructs and their dimensions, discusses the inter-relationships among the constructs, and accordingly proposes research hypotheses.

Open innovation activities and environmental dynamism

Open innovation activities have been touted for their value in introducing innovative products and services. Open innovation refers to “a distributed innovation process based on purposively managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization’s business model” (West et al., 2014, p. 806). Open innovation activities can be classified into inbound activities and outbound activities (Spithoven et al., 2011; Bianchi et al., 2011). Research regarding inbound activities mainly covers the exploration and integration of external resources (Hung and Chou, 2013; Enkel, 2010) and knowledge (Bianchi et al., 2011; Piller and Fredberg, 2009) from supply chain partners, including customers, suppliers, and research institutes. In contrast, outbound activities cover the exploitation and commercialization of internal knowledge, such as contractual agreement, alliances, and licensing, to enhance firm performance (Hu et al., 2015; Reed et al., 2012; Un et al., 2010). In practice, both inbound and outbound open innovation activities contribute to innovation performance (e.g., Cheng and Huizingh, 2014; Spithoven et al., 2011). Nonetheless, the engagement and performance of inbound and outbound open innovation activities could depend on the level of environmental dynamism (Hung and Chou, 2013; Schweitzer et al., 2011).

Environmental dynamism refers to the rate and unpredictability of change in a firm’s external environment (Tan and Litschert, 1994; Dess and Beard, 1984). Changes in technologies’ development, the variation of customer demand, and the intensity of competition among competitors are all important elements of environmental dynamism (Eroglu and Hofer, 2014; Schilke, 2014). A high level of environmental dynamism is characterized by rapid changes in technological advances, unpredictable customer demand, and the high intensity of competitive rivalry. On the other hand, a low level of environmental dynamism features stable
technologies’ development, predictable customer demand, and the low intensity of competitive rivalry.

How does environmental dynamism impact the effect of inbound and outbound open innovation activities? As discussed earlier, the contingent view posits that the benefits of innovation activities depend on the context in which these activities are implemented (Sirmon and Hitt, 2009; Levinthal, 2000; Hofer, 1975). In particular, because open innovation firms mostly operate within external environments that often influence their opportunities for innovation development (Huizingh, 2011), environmental context may influence the effects of open innovation activities on innovation performance (Hung and Chou, 2013; Schweitzer et al., 2011). The literature indicates that firms with diversified knowledge will have more opportunities to generate radical innovation (O’Connor and Rice, 2013; Helfat et al., 2007; Zhou et al., 2005). Following this line of thought, in a high level of environmental dynamism, firms are pressed to engage in inbound open innovation activities for better utilization of external sources and expansion of their scope of knowledge (Hung and Chou, 2013), which, in turn, can more effectively facilitate their radical innovation development.

In contrast, firms feel less desire to perform inbound open innovation activities to search for breakthrough knowledge in a stable environment, because firms within a low level of environmental dynamism have relatively little need to make use of external resources or knowledge (Schilke, 2014). This leads to the fact that the costs from searching for external knowledge would exceed the gains (Rosenkopf and Schilling, 2007). As a result, internal R&D activities become more important than external R&D collaboration to develop innovations (Berchicci, 2013). While firms may still be able to develop radical innovation through internal R&D, it will be more time-consuming and less cost effective than other firms with enough diversified knowledge to facilitate radical innovation development (O’Connor and Rice, 2013). Therefore, the following research hypothesis is developed.

**H1a.** The effect of inbound open innovation activities on radical innovation is stronger when environmental dynamism is high than when it is low.

Environmental dynamism impacts outbound open innovation in a similar manner. As discussed earlier, outbound open innovation activities tend to utilize unused internal innovative knowledge through selling patents or direct licensing (Hu et al., 2015; Reed et al., 2012; Un et al., 2010). At a low level of environmental dynamism, customers are more concerned about product affordability and availability and care less about product variety (Fang et al., 2011), while competitors’ actions seem to pose no immediate threat (Patel et al., 2014). As a result, practicing outbound open innovation activities is more likely to exploit internal knowledge (the improvement and refinement of existing knowledge) than to explore internal knowledge (the development of novel knowledge) to fulfill customer needs. The exploitation of current knowledge would, thus, produce incremental innovation rather than radical innovation (Zhou et al., 2005; Cohen and Levinthal, 1990). Therefore,

**H1b.** The effect of outbound open innovation activities on radical innovation is stronger when environmental dynamism is high than when it is low.

**Firm capabilities and environmental dynamism**

Firm capabilities reflect its capacity to deploy resources that have been purposely integrated to achieve a desired objective (Teece et al., 1997). The strategic literature suggests that firm capabilities enable a firm to configure intangible and tangible resources and implement them efficiently (Eisenhardt and Martin, 2000). Because firm capabilities are rooted deeply in
organizational practices, they are the most valuable, inimitable, and non-substitutable resources possessed by firms (Helfat et al., 2007).

Previous researchers have discussed various types of firm capabilities related to radical innovation performance, including network capabilities (Kelly et al., 2009), innovation capabilities (Menguc and Auh, 2010; Camisón and Villar-López, 2014), openness capabilities, autonomy capabilities, integration capabilities, experimentation capabilities (Chang et al., 2012), and learning and knowledge sharing capabilities (Maes and Sels, 2014). This study chooses to examine two particular capabilities, network and innovation, since they are among the most frequently studied capabilities in the extant innovation literature (e.g., Eisenhardt and Martin, 2000; Pittaway et al., 2004; Helfat and Winter, 2011).

In general, empirical studies consistently find that both network and innovation capabilities effectively facilitate radical innovation development (Sluyts et al., 2011; Yam et al., 2011). Nevertheless, the influence of both firm capabilities could very well depend on the level of environmental dynamism (Schilke, 2014; Helfat et al., 2007). At a low level of environmental dynamism, the knowledge exchange process is likely to be slow and firms have little need or incentives to engage in heavy external network-related practices. As such, network capabilities rest on routinized practices that leverage knowledge learned from existing networks (Heimeriks, 2010), which encourages managers to stick to current knowledge and, thus, fail to develop radically innovative products (Zhou and Li, 2012). Therefore,

**H2a.** The effect of network capabilities on radical innovation is stronger when environmental dynamism is high than when it is low.

Firms with strong innovation capabilities are able to deliver new products to the market through either enhancing current competencies or introducing new skills or knowledge (O’Connor and Rice, 2013). When the level of environmental dynamism is low, firms can stay competitive without re-inventing current knowledge or technologies. They are likely to stick to existing routines, operations, and knowledge and introduce new products perceived as incremental innovation (Helfat and Winter, 2011). Put another way, stable environments allow innovation capabilities to exploit existing competencies, leading firms to produce incremental innovation and making innovation capabilities relatively less effective on radical innovation.

On the other hand, in the case of high environmental dynamism competition increases, technological development rapidly changes, and customer preferences become versatile. Previous studies indicate that high turbulent environments create opportunities for radical innovations and force firms to accelerate their rate of innovation development in order not to lag behind competitors (Danneels and Sethi, 2011; Zhou et al., 2005). Following these lines, we expect that a high level of environmental dynamism leads firms to strengthen their innovation capabilities, and eventually increase the possibility of radical innovation development. Therefore,

**H2b.** The effect of innovation capabilities on radical innovation is stronger when environmental dynamism is high than when it is low.

**Interactions between open innovation activities and firm capabilities**

According to Schilke (2014), when facing dynamic environments firms need to adjust their strategic activities and capabilities through scanning external environments, reviewing firm capabilities, comparing alternative strategic activities, and making adjustments. This illustrates that when open innovation firms face different levels of environmental dynamism, they need to adjust their open innovation activities. Hung and Chou’s (2013) results demonstrate that to gain
competitive edge in high technological and market turbulence, firms that practice open innovation activities rely more on exploring external resources and knowledge (inbound activities) rather than on exploiting internal resources and knowledge (outbound activities). Schweitzer et al. (2011) note that exploring external knowledge from suppliers and customers is more important in turbulent markets than in non-turbulent ones. These results provide further evidence that adjusting open innovation strategies along with firm capabilities is necessary under different conditions of environmental dynamism.

Firms that practice inbound open innovation activities facilitate the acquisition of external resources and advanced knowledge, while firms commercialize internal resources and knowledge through outbound open innovation activities (Huizingh, 2011). With network capabilities, firms can effectively facilitate the knowledge exchange process by acquiring necessary crucial and advanced resources and knowledge from their network members to enhance radical innovation (Sluyts et al., 2011). In contrast, with innovation capabilities, firms practicing inbound open innovation activities can effectively integrate external and internal knowledge, which facilitates greater exploration of integrated knowledge (e.g., knowledge breadth), and, as a result, are likely to produce radical innovation (De Luca and Atuahene-Gima, 2007). In short, inbound/outbound open innovation and network and innovation capabilities have positive joint effects on radical innovation performance. Nevertheless, as discussed previously, the joint effects of inbound and outbound open innovation and network and innovation capabilities may be dependent on the level of environmental dynamism.

Inbound/Outbound activities and network capabilities. When a high level of environmental dynamism, customer preferences change rapidly, competitors employ competitive tactics (e.g., price), and the rate of change in the underlying technologies for products/services is fast. In these environments, firms that practice inbound open innovation activities and network capabilities are more likely to realize the maximum value of their inbound open innovation activities. This is because they can better benefit from using network capabilities to obtain advanced technological knowledge (Sluyts et al., 2011) and then offer new breakthrough products/services that meet customer preferences or outperform competitors.

On the other hand, in a stable environment, firms that practice inbound open innovation activities and network capabilities may not be able to fully utilize the effect of inbound open innovation activities on radical innovation because they have relatively little need to make sufficient use of network capabilities (Rosenkopf and Schilling, 2007), which leads them to focus on organizational routines (Tripsas and Gavetti, 2000). As such, external advanced knowledge obtained through network capabilities would be much less than the requirement of practicing inbound open innovation activities, which could decrease the likelihood of developing radical innovations. Likewise, a stable environment may limit firms’ tendencies to experiment with innovation development, which is more likely to weaken radical innovation development (O’Connor and Rice, 2013). Therefore,

H3a. The joint effect of network capabilities with inbound activities on radical innovation is stronger when environmental dynamism is high than when it is low.

H3b. The joint effect of network capabilities with outbound activities on radical innovation is stronger when environmental dynamism is high than when it is low.

Inbound/outbound activities and innovation capabilities. When the level of environmental dynamism is high, there is enough more uncertainty and opportunities that firms need to consider their options and choose appropriate responses to develop innovations (Zhou et al., 2005; Meyer et al., 1993). With innovation capabilities in these environments, firms practicing inbound open innovation activities may be more likely to develop radical innovations because innovation capabilities can help the firms reduce uncertainty and increase the possibilities of
correctly identifying the most appropriate innovation opportunities from their external parties (Atuahene-Gima, 2005; Yam et al., 2011).

On the other hand, when a level of environmental dynamism is low, innovation requirements are significantly decreased, because stable environments allow firms to obtain benefits from selling existing products/services (Schilke, 2014). In this situation, the costs of investment in developing innovation capabilities outweigh the gains. As a result, while having innovation capabilities is critical to firms’ innovation development, firms that practice inbound open innovation activities are less likely to explore external knowledge, which leads the firms to decrease the possibilities of developing radical innovation under a low level of environmental dynamism. Consistent with this reasoning, that innovation requirements are less needed and the costs of developing innovation capabilities are higher than the gains, we expect that with innovation capabilities, firms practicing outbound open innovation activities could also be unlikely to develop radical innovations in a low level of environmental dynamism. Therefore,

**H4a.** The joint effect of innovation capabilities with inbound activities on radical innovation is stronger when environmental dynamism is high than when it is low.

**H4b.** The joint effect of innovation capabilities with outbound activities on radical innovation is stronger when environmental dynamism is high than when it is low.

**RESEARCH METHOD**

**Measures**

The field study consists of a survey in which the main concepts are measured by means of multi-item constructs. For most concepts we used measurement scales from previous studies, and which had preferably been applied more often in open innovation studies.

Open innovation activities reflect the ability of firms to profitably access external sources of innovation (inbound activities), and to profitably commercialize internal innovation resources (outbound activities). The scale for open innovation activities is developed and extensively discussed in Cheng and Huizingh (2014) and consists of nine items, including five items for inbound and four items for outbound activities. Network capabilities reflect the ability of a firm to develop and utilize inter-firm relationships to gain access to various resources held by other firms. Network capabilities are measured by 14 items and adapted from the work of Walter et al. (2006). Innovation capabilities reflect a firm’s experience with technological applications and the potential for new technology development. Innovation capabilities are measured by seven items and adapted from Subramaniam and Youndt (2005).

Environmental dynamism refers to the rate and the unpredictability of change in the external environment of a firm (Simsek, 2009). Environmental dynamism is measured by five items and adapted from Miller and Friesen (1982) and Jap (1999). To validate managers’ perceptions of environmental dynamism, we use an archival index to measure instability in market sales (Sutcliffe, 1994). We regress market sales for a period of three years before the survey and divide the standard errors of the regression by the mean level of the dependent variable (Dess and Beard, 1984). The results show that the correlation of the index with the subjective measure of environmental dynamism is significant ($r = 0.43$, $p < 0.001$, $n = 92$). The result supports the validity of the perceptual measure of environmental dynamism.

We operationalize radical innovation as a two dimensional construct, with dimensions of (1) subjective dimension and (2) objective dimension, both of which are measured in comparison to competition. Items for the two performance dimensions are adapted from Atuahene-Gima (2005). Specifically, the first two subjective items reflect a firm’s absolute and comparative levels of radical product/service introduction over the past three years, respectively. The other two
objective items indicate the information on the percentage of market sales coming from radical innovation and incidents of radical innovation. Since these two objective items receive some missing values, they are dropped from the measurement model.

To corroborate the performance information obtained from key informants, we use objective data for a subset of 92 firms for which such information is available to test the correlation of the radical innovation scale with the two subjective measurement items of radical innovation. Both results are significantly correlated (correlation with percentage of sales from radical innovation: \( r = 0.59, p < 0.001 \); correlation with number of radical innovation: \( r = 0.72, p < 0.001 \)) and provide support to subjective and objective performance data of radical innovation.

We control for sources of heterogeneity in firm characteristics, including firm size, firm age, R&D intensity, and industries. Larger firms tend to have more resources available, such as financial, personnel, and social capital, to undertake a greater number of innovation projects. Therefore, firm size is used as a control due to its potential impact on innovation activity (Shefer and Frenkel, 2005), and is measured on a logarithmic scale using the number of employees (Menguc et al., 2007). In addition, firm age is measured as the number of years the firm has been in operation, to control for the impact of a firm's age and experience in innovation. R&D intensity, the measure of R&D expenses divided by total sales, is included as a control variable, because it may affect firm capabilities and performance (Krasnikov and Jayachandran, 2008). Finally, we use dummy variables to control for the effects of industries, each industry possessing unique characteristics (Sheng et al., 2011). All multi-item measures are measured on seven-point Likert scales, and are presented in the Appendix.

**Questionnaire development**

Following Cheng and Krumwiede (2012), we use the double-translation method to translate the questionnaire from English into Chinese (English-Chinese-English). When the initial items are specified, as recommended by Churchill (1979), two samples are collected in order to allow for the purification process of the scale and obtain preliminary estimates of reliability and validity. A two-step method of pilot testing is then performed (Venkatraman and Ramanujam, 1986). The scale is first tested on a convenience sample of 37 senior managers with experience dealing with open innovation activities, firm capabilities, and innovation projects. Respondents are encouraged to evaluate the constructs and items contained in the questionnaire, and to voice any feedback or concerns. Accordingly, very few items are revised in terms of wording or formatting.

We then move on to the second pilot test, in which we conduct a pencil-and-paper pilot survey on another convenience sample of 86 senior managers in order to refine the measures. The second pilot test sample consists of different respondents than those in the first step, but who passed the same eligibility criteria as the first pilot test sample in terms of work experience and job nature. The second sample respondents are asked to complete a questionnaire, to indicate any ambiguity or difficulty they experience when responding to the items, and to offer any suggestions they might have.

As a result of the second pilot test, no item is eliminated in the exploratory factor analysis and the Cronbach's alpha values of all measures exceed 0.87, with high item-to-total correlations, suggesting the scales have a high degree of internal consistency. We then perform a confirmatory factor analysis, and results show that all factor loadings are significant. Overall, the entire scales are well-suited and appropriate to this study.

**Sampling and data collection**
Data are drawn from the Top 1500 Taiwanese firms (China Credit Information Service, 2010). To determine whether a firm had provided radical new products/services, a description of radical new products/services (adopted from Baker and Sinkula, 2007), as operationally defined in this study, is provided. In addition, following Phillips’ (1981) suggestions, we select respondents based on three criteria: (1) the informant’s knowledge of the research topic; (2) the informant’s ability and willingness to communicate with the researcher; and (3) the informants who take responsibility for the development of radically new products/services and are highly familiar with the use of open innovation activities. Based on these criteria, a total of 748 firms are identified. Using Dillman’s (2000) total design method for mail surveys, questionnaires are mailed and each package includes a cover letter explaining the purpose of the study and a self-addressed stamped envelope in which to return the completed questionnaire.

This procedure yields 201 usable questionnaires, a response rate of 26.9%, which is within the acceptable range for top management survey response rates (Cheng and Krumwiede, 2012; Morgan et al., 2009; Baker and Sinkula, 2007). The sample represents six industries: electronic (22.4%), finance (20.9%), information technology (19.9%), telecommunications (18.9%), computer software (16.4%), and others (1.5%). The annual sales figures range from 2.04 million to 3.2 billion U.S. dollars, with 58.9% of firms reporting more than 1,000 employees. Non-response bias is assessed by comparing early and late respondents (responses received after a reminder mailing, 34.8%) regarding the variable means (Armstrong and Overton, 1977). t-tests revealed no significant differences between these two groups across strategic firm size, firm age, R&D expenses, and any of the variables, indicating no systemic differences between early and late respondents.

Because the measures for the independent and dependent variables are collected in the same way from the same respondents, there is a potential for common method bias (Podsakoff et al., 2003). To safeguard against this possibility, we undertake the following steps. First, we collect measures of the dependent variable from two separate sources (subjective and objective). Second, Harman’s one-factor test is used, where all variables are simultaneously entered into an exploratory factor analysis through principal components without rotation. The results indicate that no single factor explained more than 30 percent of the total variance in the variables. Finally, a confirmatory factor analysis is also conducted (Podsakoff and Organ, 1986), which compares a single-factor model with the proposed model. The results show that the single-factor model has a significantly worse fit (chi-square difference = 57.43; p < 0.01). These findings suggest that common method bias is not a concern in this study.

STATISTICAL ANALYSIS AND RESULTS

Psychometric properties

We first examine the univariate skewness and kurtosis of the variables and find that the figures are within acceptable levels. Next, we perform Kaiser-Meyer-Olkin (KMO) and Bartlett’s tests because both methods have been widely used in previous studies to ensure data have sufficient inherent correlations to perform an exploratory factory analysis. The results show the KMO index is 0.94, and Bartlett’s test of sphericity is significant (p < 0.001), both of which justify the use of the exploratory factory analysis.

To understand the factor structure and measurement quality, we conduct an exploratory factor analysis (a principal component analysis with varimax rotation) and use evaluation of the eigenvalues to identify the number of factors to retain. Reliability is then assessed and the results indicate the Cronbach’s alpha values for all measures are well above the threshold recommended value of 0.7 (Nunnally, 1978; See Appendix for detailed results).
Measurement validity, convergent, and discriminant validity

We then test the measurement models using a confirmatory factory analysis. The results indicate that all factor loadings are significant ($p < .01$) and well above the recommended value of 0.5 (Hair et al., 2010), and that the constructs fit the data satisfactorily (see Appendix). We proceed to examine construct convergent and discriminant validity. Composite reliability is an indicator of the shared variance among the set of observed variables used as an indicator of a latent construct (Fornell and Larcker, 1981). All indicators exceed 0.60 (Bagozzi and Yi, 1988) and demonstrate adequate convergent validity.

To assess discriminant validity, we compute the average variance extracted (AVE) by the indicators and then compare it with the variance that each factor shares with the other factors in the model. The value of the square root of each AVE is greater than the values of the inter-construct correlations, indicating the constructs are more strongly correlated with their own items.

Testing of the hypotheses

We test the hypotheses by using hierarchical moderated regression analysis based on the procedure suggested by Aiken and West (1991). To mitigate potential threats of multicollinearity, we mean center independent, dependent, and moderating variables (Aiken and West, 1991; Cohen et al., 2003). The largest variance inflation factor is 1.98, well below the benchmark of 4 (Hair et al., 2010). Therefore, multicollinearity is not a concern in the present data.
Table 1 summarizes the results of regression analysis. Model 1 includes control variables (firm size, firm age, and R&D intensity) only, Model 2 adds industry sector controls, Model 3 adds the main effects of inbound and outbound open innovation activities, network capabilities, innovation capabilities, and environmental dynamism, and Model 4 adds the interaction effects. The results in Table 2 reveal that Model 4 performs the best and explains 45% of the total variance in radical innovation. Thus, Model 4 is employed to test the research hypotheses.

The results show that the interaction between inbound open innovation activities and environmental dynamism is significant and positive ($b = 0.26; p < 0.01$), supporting H1a. H1b proposes that environmental dynamism moderates the effect of outbound open innovation activities on radical innovation. The interaction term of outbound activities and environmental dynamism is not significant ($b = 0.08$), failing to support H1b.
H2a suggests that environmental dynamism moderates the influence of network capabilities on radical innovation. The interaction term between network capabilities and environmental dynamism is significant and positive (b = 0.23; p < 0.01), supporting H2a. H2b posits that environmental dynamism moderates the effect of innovation capabilities on radical innovation. The interaction term between innovation capabilities and environmental dynamism is significant and positive (b = 0.19; p < 0.05), supporting H2b.

H3a suggests that environmental dynamism may have a moderating effect on the relationship between the joint effect of “network capabilities and inbound open innovation activities” and radical innovation. The results support H3a, as the three-way interaction effect is positive and significant (b = 0.29; p < 0.01). Similarly, the three-way interaction effect of network capabilities, outbound open innovation activities, and radical innovation is positive and significant (b = 0.18; p < 0.05), supporting H3b.

H4a suggests that environmental dynamism has a moderating effect on the relationship between the joint effect of “innovation capabilities and inbound open innovation activities” and radical innovation. The results support H4a, as the three-way interaction effect is positive and significant (b = 0.24; p < 0.01).

Model 4 shows that the impact of firm age is significant (b = 0.17; p < 0.05), implying that firms with more experience in performing open innovation activities achieve better radical innovation performance. The other significant control variable is R&D intensity (b = 0.16; p < 0.05), which implies that R&D intensity provides firms with resources to better develop their radical innovation.

Overall, the findings provide a comprehensive review of the value of open innovation and firm capabilities to radical innovation. As suggested by the literature (Parida et al., 2012; Sluyts et al., 2011; Yam et al., 2011; Laursen and Salter, 2006), both open innovation and firm capabilities, respectively, contribute to the performance of radical innovation. The joint effects of open innovation and firm capabilities also appear to significantly contribute to radical innovation. Nonetheless, the value of open innovation activities and dynamic capabilities to radical innovation must be re-assessed jointly when facing different levels of environmental dynamism.

Unexpectedly, outbound open innovation by itself or the joint effect of outbound innovation and innovation capabilities are not more valuable in an unstable environment than in a stable environment (H1b and H4b). A possible explanation for the unexpected results is that, when environmental turbulence is high, firms need significantly greater innovativeness to satisfy customer needs and stay competitive (Tsai and Yang, 2013; Zhou and Li, 2012; Jaworski and Kohli, 1993). The level of innovativeness might be more attainable with external resources through network capabilities than with internal innovation based on innovation capabilities. Hung and Chou (2013) also advocate that exploring external resources and knowledge (inbound activities) rather than exploiting internal resources and knowledge (outbound activities) is a more effective approach to gaining competitive edge in high technological and market turbulence. In addition, because a high level of environmental dynamism implies an inability to accurately predict future customer needs or technologies development, it increases the risk of innovation investments (Calantone et al., 2010). This could decrease firms’ tendency to develop innovation capabilities (Subramaniam and Youndt, 2005), which could, as a result, reduce the effectiveness of outbound open innovation activities. Apparently, the choice of open innovation activities must be contingent on the level of environmental dynamism. Therefore, for managers of open innovation firms, it is always important and beneficial to build and maintain their external networks, regardless of the level of environmental dynamism. In contrast, the forms focusing particularly on innovation capabilities should be cautious with the limitation of outbound open innovation activities in an unstable environment.

CONCLUSION
The value of open innovation activities on innovation performance has received widespread attention in the past decade, but the relationship of open innovation activities and radical innovation development with the consideration of firm capabilities and environmental dynamism remains unknown. Building on a capability-based view that superior performance derives from appropriate bundles of firm capabilities (e.g., Eisenhardt and Martin, 2000; Teece et al., 1997), we suggest the incorporation of network and innovation capabilities into the development of innovation strategy. Additionally, drawing from contingency theory, we hypothesize that the individual and joint effects of open innovation activities and firm capabilities on radical innovation are contingent on the level of environmental dynamism. The statistical results verify the values of inbound/outbound open innovation, network and innovation capabilities, and their joint effects. Moreover, we confirm that the level of environmental dynamism moderates the main effects of open innovation and firm capabilities and their joint effects. Overall, this study makes several contributions to the literature with implications to managers.

As with most studies, the design of this study is subject to limitations, which opens up opportunities for future research. First, although we collect data from across various industries and control for a number of important sources of firm heterogeneity, further research should extend our model to other specific industries (e.g., service or logistics). Second, single informant bias could be a concern, as only senior managers completed the survey. Future research could attempt to avoid such concerns by recruiting multiple informants, e.g., R&D managers or new product development managers. Because the implementation of open innovation activities and firm capabilities requires continuous investment of resources (West et al., 2014; Helfat et al., 2007), future studies should make a longitudinal analysis to provide a dynamic perspective of alignment and further contribute to this stream of research. Fourth, future research could consider other types of dynamic capabilities that interact with open innovation activities, such as marketing capabilities (Morgan et al., 2009), because open innovation activities may also need other business practices (e.g., marketing) to facilitate their implementation (Huizingh, 2011). Open innovation research is still in a developing stage (West et al., 2014), so additional studies to investigate these factors would provide a more complete understanding of the effectiveness of open innovation.

Appendix 1: Measurement items

**Inbound open innovation activities** (α = .90; CR = .91) (Cheng and Huizingh, 2014)
- Customers are directly involved in all our innovation projects. .83
- All our innovation projects are highly dependent upon the contribution of external partners, such as customers, competitors, research institutes, consultants, suppliers, government, or universities. .87
- Our firm often buys R&D related products/services from external partners. .78
- Our firm often buys intellectual property, such as patents, copyrights, or trademarks, from external partners to be used in our innovation projects. .77
- Our firm invests in other firms because we would like to get access to their knowledge or to obtain other synergies that are beneficial to our innovation projects. .86

**Outbound open innovation activities** (α = .87; CR = .88) (Cheng and Huizingh, 2014)
- Our firm often sells licenses, such as patents, copyrights, or trade-marks, to other firms so as to better benefit from our innovation efforts. .83
- Our firm often offers royalty agreements to other firms to better benefit from our innovation efforts. .78
- Our firm strengthens every possible use of our own intellectual properties so as to better .85
benefit our firm.
Our firm finds spin-offs to better benefit from our innovation efforts.  .76
**Network capabilities** (α = .91; CR = .95) (Walter et al., 2006)
We analyze what we would like to achieve with each partner.  .81
We remain informed about the goals, potential and strategies of our partners.  .75
We determine in advance possible partners with whom to discuss the building of relationships.  .76
We appoint coordinators who are responsible for the relationships with our partners.  .71
We regularly discuss with our partners how we can support one another in our success.  .79
We have the ability to build good personal relationships with business partners.  .73
We can imagine ourselves in our partners’ position.  .72
We can act flexibly with our partners.  .77
We always solve problems that arise together with our partners in a constructive spirit.  .84
We know our partners’ markets.  .70
We know our partners’ products/working procedures/services.  .80
We know our partners’ strengths and weaknesses.  .75
In our firm, employees develop informal contacts among themselves.  .83
In our firm, communication is common across projects and subject areas.  .78
**Innovation capabilities** (α = .90; CR = .92) (Subramaniam and Youndt, 2005)
How would you rate your firm’s capability to generate innovations in the products/services you have introduced in the last three years?
Innovations that make existing products/services obsolete.  .75
Innovations that fundamentally change existing products/services.  .86
Innovations that significantly enhance customers’ product/service experiences.  .76
Innovations that require different ways of learning from customers.  .84
Innovations that reinforce our existing product/service lines.  .78
Innovations that reinforce our existing expertise in existing products/services.  .71
Innovations on how we currently compete.  .79
**Radical innovation** (α = .88; CR = .90) (Atuahene-Gima, 2005)
Compared to your major competitor,
Our firm introduces new products/services that are more radically new to the market.  .80
Our firm introduces new products/services that offer more radical features.  .89
Our firm introduced more radical product/service innovations in the last three years.  .81
Our firm introduces new products/services that require more radical changes in customers’ ways of using them.  .85
**Environmental dynamism** (α = .88, CR = .89) (Miller and Friesen, 1982; Jap, 1999)
The modes of production/service change often and in a major way.  .81
The environmental demands on us are constantly changing.  .83
Marketing practices in our industry are constantly changing.  .75
Environmental changes in our industry are unpredictable.  .78

**REFERENCES**


