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Abstract

It is commonly accepted nowadays that external knowledge sources are important for firms' innovative performance. However, it is still not clear, what dimensions of firms' external knowledge search strategy are crucial in determining their innovation success and whether these search strategies are contingent on different innovation modes. In this study, we analyze how the innovative performance is affected by the scope, depth, and orientation of firms' external search strategies. We apply this analysis to firms using STI (science, technology and innovation) and DUI (doing, using and interacting) innovation modes. Based on a survey among firms in China, we find that greater scope and depth of openness for both innovation modes improves innovative performance indicating that open innovation is also relevant beyond science and technology based innovation. Furthermore, we find that decreasing returns in external search strategies, suggested by Laursen and Salter (2006), are not always present and are contingent on the innovation modes. Next, we find that the type of external partners (we label it "orientation of openness") is crucial in explaining innovative performance and that firms using DUI or STI innovation modes have different sets of relevant innovation partners. This shows that the orientation of openness is an important dimension – in addition to the scope and depth of openness. As respondents are located in China, this study provides evidence that open innovation is also relevant in developing countries.

Keywords: open innovation; DUI and STI innovation modes; scope, depth and orientation of openness; innovative performance

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1. Introduction

Technological innovation is a risky activity and only a fraction of the innovations that start as promising ideas make it to the market as successful new products and services. Increasing globalisation, shorter time-to-market windows, intensified competition, and the increased threat of a war for talent are trends that firms can only cope with if they innovate. Companies however increasingly realise that internal R&D may be prohibitively expensive and too slow to be first movers in the market. Co-operation with external technology partners has proven to be one solution (Bamford *et al.*, 2003). Similarly, open innovation offers a new way of framing and managing external sources of innovation (Chesbrough, 2003, 2006).

Recent studies have emphasised the importance of external knowledge sources and the use of networks in the innovation process (Cohen & Levinthal, 1990; von Hippel, 1988; Nonaka, 1994; George *et al.*, 2002; Caloghirou *et al.*, 2004). Firms rarely innovate alone and increasingly look to users, suppliers, universities, technology agencies, and even competitors for new ideas. Open innovation may show the advantage of free flows of new ideas, but it does not always result in positive effects. Collaborating with other organisations can lead to a leakage of key technologies and high costs for information search and knowledge integration. Furthermore, moving from closed to open innovation requires changes in corporate culture and organisational structure (Chiaroni *et al.*, 2009). Therefore, the influence of openness on a firm's innovative performance is an interesting research field to explore but until recently only a few empirical studies have analyzed this topic in detail.

In this study, we contribute to literature about the impact of firm's openness on their innovation performance in three ways. First, we extend the analysis of external search strategies. Laursen and Salter (2006) link external search strategy to innovative performance and find that searching widely and deeply is in a curvilinear way (an inverted U-shape) related to performance. However, in this study we claim that the diversity of partners and the intensity of the relations with external partners cannot explain innovation performance in a satisfactory way. The type of innovation partners should also be introduced into the analysis since firms rely for different kinds of innovations on specific knowledge sources and links (Todtling *et al.*, 2009). Firms introducing more advanced innovations are relying to a higher extent on R&D and patents, and they are cooperating more often with universities and research organizations. Firms that introduce incremental, not state of the art innovations rely more on knowledge links with business services (Todtling *et al.*, 2009).

Therefore, deepening on their needs different firms may have different external knowledge links and a different search strategy for accelerating internal innovation. The literature is however relatively silent about with whom firms carrying out different types of innovation. In analyzing the impact of openness on the innovative performance of companies we use Laursen and Salter's (2006) concepts of breadth (scope) and depth as two components of the openness of a firm's external search strategies. The *scope of openness* refers to the diversity of types of partners to which the innovating firm has a connection; while the *depth of openness* reflects the intensity of co-operation with these partners. In addition to depth and scope of openness, we also explore the *orientation* of a firm's external sourcing strategy. Firms may engage in a broad or narrow search for partners, but it is also important to find the right type of innovation partners – or the right orientation - depending on the technology they are looking for.

Second, we explore the effectiveness of search strategies for firms using two different modes of innovation (Jensen *et al*. 2007). One mode of innovation is the *science, technology and innovation* (STI) mode which is based on the production and use of codified scientific and technological knowledge. In contrast, the *doing, using and interacting* (DUI) mode relies on informal processes of learning and experience based know-how (Jensen *et al*. 2007). As the two innovation modes differ considerably with respect to the sources and size of the technological opportunities and the danger of knowledge leakage, we expect that firms' search strategies for the development of these two modes of innovation will also diverge to some extent. The arguments leading to the hypotheses are based on different insights to those used in Laursen and Salter (2006) because we are primarily interested in the difference between the DUI and STI modes of innovation.

Third, Our study is based on a survey of innovating companies in China. To our knowledge this is one of the first surveys about open innovation in developing countries. We test the hypotheses using a survey of external search strategies used by a sample of 209 Chinese firms that have a national or regional R&D centre in China's Zhejiang province. The survey explores the interactions of firms with exterior sources of knowledge during innovation processes.

In the empirical part of the paper, we test the relationship between the scope, depth, and orientation of openness and the innovative performance of firms using STI and DUI innovation modes. We find that openness in a firm's innovation activities improves innovative performance, although the influence differs for both innovation modes. More specifically, and in contrast with Laursen & Salter (2006), we find only decreasing returns with respect to the scope of openness for firms using the STI-mode. We find that the scope of openness has a linear effect on innovative performance for firms using the DUI-mode and the depth of openness has a linear effect on firm's innovative performance for both innovation modes. The results of the empirical analysis furthermore show that choosing the right type of partner is as important as the scope and depth of the external search strategy. This is in line with prior research about technological alliances and the orientation of an innovating firm when choosing the right type of partners is crucial to explain its innovative performance (Rothaermel, 2001; Rothaermel and Deeds, 2004; Faems *et al*., 2005).

In sum, this paper examines the influence of scope, depth, and orientation of openness on innovative performance when applied to the STI and DUI modes of innovation. By focusing on the differences between DUI and STI modes of innovation, we show how the seminal work of Laursen & Salter (2006) must be adapted to these two ways in which companies innovate. In addition, we find empirical evidence that the scope and depth of a firm's external search only offers a partial explanation for the benefits of open innovation; the orientation of openness is a crucial variable in explaining the success of open innovation. We find evidence that the STI and DUI innovation modes require different types of partners to develop commercially successful innovations. A successful orientation for STI-mode of innovation will not lead to success for DUI-mode of innovation and vice versa.

The paper is structured as follows: the following section develops a number of hypotheses based on a brief review of the role of the various external partner types and two modes of innovation. Section 3 analyses the survey data and variables, and Section 4 discusses the empirical results. In the final section we draw conclusions and focus on some managerial implications and policy recommendations.

2. Theory and hypotheses

Open innovation 'is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation respectively' (Chesbrough *et al.*, 2006, p.2). Compared to the traditional and closed innovation model, innovative firms are committed to open innovation that makes full use of external innovation resources, including technological and market-related resources. Moreover, internally developed ideas and technologies can be taken to the market through licensing and spin-offs if the business model of the new venture cannot be aligned with a firm's current business model.

2.1 The role of various innovation sources of open innovation

Open innovation is fuelled by different innovation sources. The management literature provides helpful insights to help pinpoint the contributions of both internal and external sources in determining the innovative performance of companies. We first describe some of these internal sources, and then describe the contribution of external sources of innovation.

Human capital is the first internal source of innovation. Traditionally, innovative performance has been related to the human capital found in R&D departments. However, the importance of knowledge originating from a firm's internal units outside the R&D lab, such as marketing and manufacturing is well understood (Tucker, 2002; Dundon, 2002). Several scholars maintain that innovation should be the responsibility of all employees, and not the task of a few specialists in the R&D department. Salesman, front-line employees, R&D personnel, managers, and service personnel can all be excellent innovators (Tucker, 2002; Shapiro, 2002; Christiansen, 2000; Dundon, 2002). Managers should try to embed innovation into each part of the organisation and make all employees feel responsible for producing new ideas. The GE 'Work-Out' creates an open collaborative workplace where everyone's opinion is welcome, and each employee is a participant in the innovation process

(Ulrich, Kerr, Ashkenas, 2002). Wal-Mart considers front-line employees as its most precious resource. The '15 percent rule' in 3M encourages employees to devote 15 percent of their work time to self-directed research. The Haier Corporation, a Chinese home electrical appliance manufacturer, is structured into various SBUs (strategic business units) where everybody can directly introduce novel products in the market. In the Baosteel Corporation, the largest Chinese steel manufacturer, the notion that 'all employees are innovators' enables the company to achieve extraordinarily innovative performances.

As well as internal sources, managers can also rely on a broad range of external innovation sources. Manufacturers should, for instance, fully understand the needs of users in order to develop successful products. However, this is often a costly and difficult task due to the stickiness of need-related information given by users. Manufacturers can invite users to participate in the new product development (NPD) process directly, in order to quickly obtain new product definitions. Manufactures can accelerate the innovation process and reduce the risks associated with market introduction (von Hippel, 1988). Through close contact with innovative users, manufactures can absorb radically new product concepts and select the most promising prototype versions. In this way, manufacturers can improve the efficiency of the innovation process. Furthermore, user interaction enables companies to acquire new technological skills, learn about relevant technological trends, and extend their innovation and technology-related networks (Lettl *et al*., 2006). Major users may share their experiences about the use and potential drawbacks of new products.

Firms can also accelerate innovation and reduce costs by facilitating the participation of suppliers in the design and development process (Clark, 1989; Clark and Fujimoto, 1991; Nishiguchi, 1994). Establishing iterative and long-term contact with suppliers ensures the full use of external resources and establishes a more flexible NPD process.

One of the basic premises of the open innovation paradigm is that no company possesses all technological resources internally. Even the most innovative companies with the most extensive internal capabilities cannot undertake technological innovation activity on their own (Teece, 1986). Great technology and ideas can be found in companies of all sizes (Chesbrough, 2003). R&D co-operation is considered as a mechanism to maximise company value by effectively combining its own resources with the complementary resources of its partners (Teece, 1986; Mitchell and Singh, 1992; Hagedoorn *et al*., 2000; Das and Teng, 2000). Firms also seek to collaborate with competitors to learn more about technological skills that can be difficult, time-consuming, and costly to develop internally. Sometimes competitors collaborate when they face common technological problems (Tether, 2002). Competitors may also be attractive partners with whom to team up in order to exploit complementary R&D resources to develop new products and reduce costs and risks (Miotti & Sachwald, 2003).

Universities and other public research institutions are important sources of new scientific and technological knowledge for firms pursuing radical innovations (Belderbos *et al*., 2004). Industry-science collaborations give firms access to new knowledge and increase their understanding of emerging scientific developments (Klevorick *et al*., 1995; Belderbos *et al*., 2004). Consequently, close collaboration with universities facilitates new breakthrough innovations and products (Belderbos *et al*., 2004).

Scanning and tracking external technology and obtaining advanced technology from partners to cover weak spots in a firm's technology portfolio are a valid way to strengthen innovative performance. Intellectual property organisations and technology agencies may play a bridging role that enables firms to search and acquire external knowledge. Huawei, a Chinese telecom manufacturing corporation, acquired core technologies through purchases and licensing. The company then improved the products and made radical applications in the market by licensing these technologies. In this way, the company rapidly increased its competitiveness in several product markets. Companies that are traditionally technology leaders can also create value by facilitating external paths to the market for internally developed technology; they thus profit from the use others make of their technology. IBM, for instance, earned $1.9 billion in 2001 from patent licensing and royalties on its software, chips, and systems (Chesbrough, 2003). Other technology leaders have followed similar strategies.

Open innovation is a strategy for detecting and assimilating new ideas that are complementary to a firm's existing R&D projects (Teresko, 2004). Using and integrating external knowledge is an important determinant in a firm's ability to acquire a competitive advantage in its product markets. Companies can acquire technology through R&D co-operation, technology acquisition, technology licensing, spin-ins, and corporate venturing. This reduces innovation costs and risks (Chesbrough & Garman, 2009). Lead users and suppliers may also be important sources of innovations. In short, open innovation has the potential to improve the effectiveness of a firm's innovation processes.

2.2 The negative impact of openness on innovative performance

In the previous section, we focused on the positive effect of co-operation with external actors on a firm's innovative performance. However, open innovation also entails significant managerial challenges and financial and cognitive costs. Over-searching may have a negative influence on performance for various reasons (Koput, 1997). Firstly, Williamson suggests that time and energy is required to nurture external linkages (Williamson, 1981). Compared to closed innovation, open innovation entails additional costs for the acquisition of information, as well as the transaction costs incurred with external technology suppliers. Harabi (1995) points out that accessing externally generated knowledge is not cost-free. Secondly, the use of external technologies requires that a firm develops the absorptive capacity to understand externally developed innovations (Cohen and Levinthal, 1990; Zahra and George, 2002; Todorova and Durisin, 2007). Access to external technologies and know-how is possible only if the firm had previously generated a knowledge base that enables it to understand, evaluate, assimilate, and use outside information and knowledge (Nieto & Quevedo, 2005). Cognitive limits restrict the amount of information that individuals can process. Too much interaction and information may overload developers (Gales & Mansour-Cole, 1995). Thirdly, the processing of many ideas can result in problems of managerial attention according to the attention-based theories of the firm (Ocasio, 1997;

Laursen & Salter, 2006). Fourthly, being open to external firms and organisations increases the chance of knowledge leakage (Gans & Stern, 2003; Laursen & Salter, 2005). Many technology-based start-ups are organised around the exploitation of new ideas; and within communities of practice ideas often leak (Laursen & Salter, 2005).

2.3 Scope, depth, and orientation of external search

Open innovation models imply that firms change their searching strategies for new innovation ideas and technologies (Laursen & Salter, 2006). Innovative firms may increasingly benefit from collaborating with different innovation partners as developing new technologies becomes excessively expensive and product life cycles shorten. Consequently, we expect that firms which invest in a broader and deeper search may have a greater ability to innovative. The observation that openness has considerable potential to contribute to innovative performance does not mean that firms should establish close interactions with all possible types of external organisations. There are successful firms such as P&G, Nokia, and China's Baosteel Corporation that innovate in collaboration with users, suppliers, competitors, universities, and consultants. However, there are equally successful innovative firms (Intel, Wanhua Chemical Corporation and Hasien Pharmaceutical Corporation in China) that have close contacts with only a few agencies such as universities and research institutions. Different firms have their own unique technology base and market conditions. Therefore, we expect that the effect of the diversity and intensity of a firm's external sourcing relations on its innovative performance will depend on the type of industry to which the firm belongs.

To examine the influence of the scope and depth of a firm's external search for technology on its innovative performance, we developed two concepts that are in line with the work of Laursen & Salter (2006); and an additional concept that further enriches the open innovation concept. Together these three variables represent the openness of a firm's external search processes. The first concept refers to *the scope of the external search*, which is defined as the range of external actors upon which a firm's innovative activities rely. In other words, the scope of the external search focuses on the diversity of the external sources of innovation. The second concept refers to *the depth of a firm's external search* and is defined as the extent to which firms draw on different external sources. Thirdly, we are also interested in the *orientation of a firm's external search*. This concept refers to the role of different types of external actors in enhancing the innovative performance of firms. We expect that some partners have a more prominent role than others in invigorating the innovative performance of companies. Are value chain partners, technology related organisations, or universities and research labs effective external sources for improving the innovative performance of firms? Does the effectiveness of the orientation of a firm's external search depend on the type of innovation mode which prevails in its industry?

The orientation of openness is related to the differences in technology alliances introduced by Rothaermel (2001), Rothaermel and Deeds (2004), and Faems *et al*. (2005). It assumes that collaborations with suppliers and customers play a different role than collaborations with universities and research institutes. It also finds hard empirical evidence for these differences.

In a similar vein, we assume different types of external partners are useful in strengthening a firms' innovative performance – contingent on the type of learning mode. In short, not only are the scope and depth of external technology searches important; but also the type of partners with which an innovative firm co-operates.

2.4 Two modes of innovation and the propensity of co-operation

Managing innovation is quite heterogeneous across industries. One of the most popular categorisations is based on Lundvall's seminal work (Jensen *et al.* 2007). It explains this heterogeneity by distinguishing between two modes of innovation: the STI-mode (science-technology-innovation) and DUI-mode (learning by doing, using, and interacting) (Jensen *et al*., 2007). Science-technology-innovation is characterised by a scientific approach and is largely based on codified scientific and technical knowledge (Jensen *et al*., 2007). This innovation mode relies strongly on formalised research and development activities in the innovating companies. According to the intrinsic characteristics of technological innovation, firms using STI-mode of innovation have to cope with the rapid change of both technological opportunities and market conditions. There is a continuous change in user needs and in the set of competitors operating in their markets. R&D activities need to be integrated in the complete business environment and anchored to production and sales. In contrast, the DUI innovation mode is experience-based. Consequently, interactions are based on tacit knowledge. DUI mode of innovation usually originates in problem-solving situations. Human capital is essential and the skills and know-how of employees are developed. User-producer interaction plays a major role in this mode. Because STI and DUI innovation modes differ in many respects and have different requirements vis-à-vis external innovation partners, we argue that the mode of innovation is a contingency to take into account when exploring the role of external partners in innovation.

Accordingly, we divide the responding firms into two categories. The first are those firms in which STI innovation mode is dominant. We labelled it as STI-industries. The second category represents firms for which DUI innovation mode is most important. We labelled it as DUI-industries. The innovation activities of firms in the STI industries are mostly based on explicit scientific and technical knowledge and well-defined R&D activities. External innovation partners include science and technology partners such as universities, research labs, technical service companies, etc. Conversely, innovations of firms in DUI industries are largely based on experience and tacit knowledge. External innovation partners will be primarily value chain partners or even competitors. In this paper, we define pharmaceuticals, materials and chemicals, electrical and communication equipment manufacturers, metallic mineral product makers, and manufacturing industries as industries where the STI innovation mode is dominant (STI industries). Firms in machine manufacturing, car manufacturing, textile and clothing, paper and furniture manufacturing, and food manufacturing belong to industries where the DUI innovation mode is dominant (DUI industries).

Firms can access complementary resources by tapping into the innovation process of external partners. Firms in STI industries are usually involved in science-based and technology-intensive processes. Companies in high-tech sectors show a higher propensity to co-operate (Bayona *et al*., 2001; Belderbos *et al*., 2004; Gassmann, 2006). The resource-based perspective suggests that firms conducting expensive, risky, or complex research projects will seek R&D co-operation (Miotti & Sachwald, 2003). Major R&D spenders are much more likely to co-operate (Veugelers, 1997). The major reason why innovating firms co-operate is a lack of resources and capabilities to cope with emerging technologies. High-tech sectors are usually characterised by fast-changing technologies. Even the largest firms cannot keep pace with all technological developments by themselves (Brusoni *et al*., 2001). Highly uncertain projects must process more information and different types of information than more certain projects (Gales, Mansour-Cole, 1995). Moreover, firms in STI industries tend to be concentrated in high-tech or emerging sectors. High-tech industries often feature high levels of technological opportunities and high incoming spillovers (Belderbos *et al*., 2004). In most cases, firms in STI-industries have adequate absorptive capacities to evaluate, assimilate, and integrate valuable knowledge from external sources.

Firms in DUI industries also need to open their innovation process. From the resource-based perspective, it can be argued that because these firms seldom do basic research internally, they need to innovate jointly with users, suppliers, and other organisations to acquire the technologies and market-related information needed to solve the problems of customers or other actors in the value chain. Closer interaction and communication with users of products is a prerequisite for the experience-based learning that supports product innovation in the DUI mode (Jensen *et al*., 2007).

The free-riding problems produced by outgoing spillovers between partners may jeopardise enthusiasm for open innovation by technology-intensive firms. Innovations driven by science and technology are based on R&D and scientific knowledge. Codified knowledge dominates the process of innovation. Creating and utilising explicit knowledge plays a key role (Jensen *et al*., 2007). Codified knowledge is not sticky and knowledge transfer is easy. The dangers of knowledge leakage are therefore more probable in highly R&D-focused industries. Because of the high risk of outgoing spillovers (Belderbos *et al*., 2004) collaboration with competitors in high-tech sectors is quite rare (Miotti & Sachwald, 2003). But key technologies may also leak to competitors through common users and suppliers. Consequently, firms in STI industries risk leakage of their technologies when they have too many different types of partners and when the intensity of collaboration is too great. Hence, innovating firms may weaken their innovative performance when the scope and depth of their openness to external organisations is too great. Consequently, we can formulate the following hypotheses:

H1a: For firms in STI industries, the *scope* of openness to external organisations has a curvilinear (inverted U-shape) effect on innovative performance.

H1b: For firms in STI industries, the *depth* of openness to external organisations has a curvilinear (inverted U-shape) effect on innovative performance.

The DUI mode of innovation is characterised by changes that continuously confront employees with new problems (Jensen *et al*., 2007). Innovation processes can be defined as processes for finding effective solutions to these problems. Successful innovations are mainly based on the experience of users and employees; and know-how dominates the process of innovation. The tacit character and appropriation of resources and previous experience will moderate the transfer of knowledge (Simonin, 1999). Competitors must develop an absorptive capacity in a particular technical area to be able to use the knowledge spillovers. Firms must therefore have a deep understanding of the activities of their competitors. Because of specific and proprietary knowledge, it is difficult to imitate another firm's products (Gopalakrishnan *et al*., 1999). As knowledge is largely tacit, open innovation can only be realised through intimate and long-term collaboration with other innovation partners. Conversely, the dangers of knowledge leakages are lower due to the stickiness of the knowledge that has to be transferred. Hence, it is easier to protect proprietary knowledge in DUI-industries than in STI-industries. Consequently, we expect that:

H2a: For firms in DUI industries, the *scope* of openness to external organisations has a positive effect on innovative performance.

H2b: For firms in DUI industries, the *depth* of openness to external organisations has a positive effect on innovative performance.

The scope of openness indicates how the diversity of external contacts can have an impact on the innovative performance of firms. However, it also hides useful information because some types of external sources of innovation may be useful – while others are not. We introduce the *orientation of a firm's external search* as a concept to analyze which types of external actors are crucial in enhancing innovative performance. Knowing which types of partners are instrumental in the success of an external search is important for the management of open innovation. We argue that the type of partners that are useful differ significantly between DUI and STI innovation modes. For the latter, we expect universities and research institutes to play a major role. Moreover, other technology-related organisations may also be instrumental for these firms. In contrast, firms using the DUI innovation mode will closely collaborate with value chain partners, and eventually with competitors. We expect that universities, research institutes, and other technology-related organisations will play a less prominent role in advancing innovative performance in the DUI-mode.

H3: The types of partners that have a positive effect on innovative performance are different for STI and DUI innovation modes. Science and technology partners are expected to have an effect on the STI innovation mode, and value chain partners on the DUI innovation mode.

3. Data and variables

Data for the analysis was obtained from questionnaires sent to innovative firms in China. We sent 515 questionnaires to the heads of R&D centres in companies that have a national or provincial R&D centre in Zhejiang. The Zhejiang province locates in the south-east of China and it is one of the most economically advanced and open regions in China. The innovative capabilities of firms in Zhejiang are stronger than in most other Chinese regions. There are a number of priority industries in high-tech industry including pharmaceuticals, chemicals, software, or traditional sectors such as machine manufacturing, and textile etc. Therefore Zhejiang may be representative for rapidly developing regions in the so called BRIC countries. Our survey was specifically designed to test the role of internal capabilities and external sources of innovation. It was conducted from October 2006 to May 2007. After we received 146 completed questionnaires, we sent the questionnaires for a second time to the non-responding companies. After the second request, we received 97 additional questionnaires. Of the 243 questionnaires we collected in total, 34 were subsequently eliminated as invalid. We therefore had 209 valid questionnaires, of which 79 were from STI industries and 130 from DUI industries.

The questionnaire consists of two parts. The first part requested information about the company. These data were directly retrieved from the directory of firms. The second part included a series of questions focusing on this paper's research topic. In the questionnaire, we used a Likert seven-point scale to evaluate the strength of the relationships with different innovation partners. High scores on the Likert scale indicate that the frequency of interaction with the partners under consideration is very high and that these firms have a close relationship with this type of partner in their innovation activities. Conversely, low scores indicate that interaction is sparse and that this type of external partner is less important for successful innovation.

We first tested our data for a possible response bias. We made a distinction between three groups of firms: those that responded the first time; those that answered on the second request; and firms that did not respond. We used a variable labelled as 'respondent' to reflect whether companies responded or not. This variable had a value '0' if the company did not respond, '1' if it responded the first time, and '2' if it answered on the second request. We used the number of employees to reflect the size of the enterprises. Table 1 shows the results of the ANOVA analysis: the Table shows the impact of the response status on the size and the age of firms. The F-value in Table 1 is not statistically significant, which indicates that the respondents and non-respondents are similar in terms of firm size and firm age.

Table 1: Testing for response bias

	Sum of squares	df	Mean square	F	Sig.
Firm size					
Between groups	23746090.09	2	11873045.05	0.402	0.669
Within groups	15139208439.65	512	29568766.48		
Total	15162954529.74	514			
Firm age					
Between groups	16.80	2	8.40	0.486	0.615
Within groups	8840.82	512	17.27		
Total	8857.62	514			

We also tested whether there were differences between the respondents and non-respondents in terms of industries to which they belong (see Table 2 for the list of industries). We tested whether the distribution across the industries differs for respondents and non-respondents through cross-table analysis. The value of Pearson Chi-square is 12.703 ($p = 0.694$). It shows that the samples of respondents and non-respondents have a similar distribution across industries. In short, Table 1 and the result of Chi-square test show there is no response bias between the two samples of respondents and non-respondents.

Innovative performance is the dependent variable and it is measured by six items: *number of new products*; the *ratio of new products sales to total sales*; the *speed of new product development*; the *success ratio*; the *number of patent applications*; and the *number of industry standards*. We used a seven-point Likert scale to measure the importance of each item. Respondents were asked to compare their firm's performance vis-à-vis competitors in the same industry. High (low) scores on the Likert scale indicate that the firm's innovative performance is strong (weak) compared with competitors. We took the average of the scores on these six items to evaluate the innovative performance as a synthetic 'innovative performance' indicator. Cronbach's alpha coefficient for the six items is 0.795 which represents a high degree of internal consistency.

The degree of openness of innovating firms was measured in two different but complementary ways (see also Laursen and Salter (2006) for similar measurements). The first is the *scope of openness* (the diversity of relations with external partners). This variable refers to the different types of partners with which innovating firms associate to achieve and sustain innovation. We included ten types of potential external partners in the survey: lead users, major clients, suppliers, competitors, firms in other industries, universities and research institutes, technology agencies, intellectual property organisations, venture capital funds, and governments (see Table 3). We operationalized the scope of openness as the number of types of external partners with whom the innovating firm has a relationship.

$$f_i = \begin{cases} 1 & \text{firms have cooperation with partner type i} \\ 0 & \text{firms have never cooperated with partner type i} \end{cases}, \qquad i = 1,2, \ldots,10$$

The scope of openness is equal to the sum of f_i. The ten items have a high degree of internal consistency between the different items (Cronbach's alpha coefficient equals 0.834).

The second variable is the *depth of openness* (the intensity of relations with external partners), representing the extent to which firms draw on each of these external partner types for their innovation activities. Firms that are more frequently in contact with external partners are more open than firms that partner infrequently. The depth of openness is based on the scores of the respondents answering the question 'what is the importance of co-operation with the following external partners in your firm's innovation activities?' The ten types of partners are enumerated in Table 3. Respondents could answer on a seven-point Likert scale: higher scores indicate that the innovation partner type is more important for a firm's innovative performance. Depth of openness is operationalised as the average of the ten scores. In this way, depth of openness is defined as the extent to which firms draw upon external innovation partners. The Cronbach's alpha coefficient of ten external sources is 0.895 meaning that ten items have a high degree of internal consistency and the reliability of the questionnaire is quite good.

This is a somewhat more refined measurement than that used by Laursen and Salter

(2006). These researchers coded each of the 16 types of external partners with 1 when the firm in question reported that it used the source to a high degree; and 0 in the case of no, low, or medium use of the given source. The 16 sources were then added subsequently so that each firm received a score of 0 when no knowledge sources were used to a high degree; and the firm received a score of 16 when all knowledge sources were highly used.

The *orientation of openness* is the third dimension. As different types of partners have different technological skills and capabilities, it is important that innovating firms choose the right type of partners for the specific help they need. We could split the various partner types into two main categories – value chain partners and technology partners such as universities and research labs – as suggested by Rothaermel (2001), Rothaermel and Deeds (2004), and Faems *et al*. (2005). However, the survey contains rich information about the types of partners and this allows us to operationalize the orientation of openness in a more detailed way. To explore the differences of how external sources are used in STI and DUI industries, we ran a factor analysis on data from the two industry types separately.

Several variables were introduced to control for possible confounding effects. We controlled for firm size, the intensity of internal R&D efforts, and industry effects. The relationship between firm size and innovative performance has been much debated. Economies of scale in R&D, the ability to spread risks over a portfolio of projects, and access to extensive financial resources give large firms an advantage over small firms (Veugelers, 1997). Moreover, large firms are better able to acquire the complementary assets necessary to guarantee the commercial success of innovative products (Teece, 1986). At the same time, small firms could outperform larger firms in terms of creativity, flexibility and speed; especially when new, disruptive technologies appear (Christensen & Bower, 1996). In this paper, the variable 'size', measured by the natural logarithm of the number of employees, has been included as a control variable within the different models.

The internal R&D activities of innovating firms are also considered an important factor influencing innovative performance. Therefore, we included 'R&D intensity' as a control variable. Furthermore, we included industry dummy variables to correct for fixed industry effects (Veugelers, 1997). Table 2 provides an overview of the distribution of respondents over nine industries.

Table 2: Overview of sample by industry

Industry	Frequency	Percent (%)
Pharmaceuticals	17	8.1
Materials and chemicals	27	12.9
Electrical and communications equipment	22	10.5
Metallic mineral products	13	6.2
Machine manufacturing	62	29.7
Car manufacturing	11	5.3
Textile and clothing	24	11.5
Paper and furniture	17	8.1
Food	16	7.7
Total	209	100

4. Results

4. 1 Descriptive statistics of internal and external innovation factors

We explored the knowledge sources for innovation in the responding companies that have an R&D centre in Zhejiang province. Table 3 lists the results of the descriptive statistics. In the questionnaire, firms rated the importance of internal resources and each type of external partner for their innovation process on a 7-point Likert scale ranging from unimportant (1) to very important (7). We calculated the mean of each item to indicate the importance of internal and external innovation sources for the responding firms.

Table 3 shows – not surprisingly – that internal R&D is the most important source of innovation for respondents. Employees from outside R&D departments also play an important role in technological innovations. Interactions with users and suppliers are also frequently mentioned by the respondents as important external sources of innovation. It is remarkable that many respondents mention competitors as a source of innovation. It is not possible to determine from the survey whether companies learn from competitors through information leakage, or from employees who are hired away from competitors, or whether they establish formal technology alliances with competitors to undertake joint R&D. Collaboration with firms in other industries is only practiced by a small minority of the respondents. This is an important finding as it has been shown that learning from other industries can be a fruitful way to innovate (Gassmann, 2006). Co-operation with universities and research institutes is somewhat less popular as external source of technologies. They represent an important source of innovation for high-tech companies, but not all firms in the sample collaborate with them. This finding extends beyond China, as many innovating companies in Europe and the U.S. do not co-operate with research institutes and universities. The role of technology agencies, intellectual property organisations, and venture capitalists is rather marginal: their services target large, technology-driven firms or high-tech start-ups, not the average respondent. The large variance regarding the government as an external source of innovation indicates that some firms maintain a close relationship with governments, while other firms do not value such relationships. In sum, Table 3 shows that Chinese innovating firms adopt relatively few innovation relationships with external partners, especially when it comes to ties with specialised companies such as technology agencies, intellectual property organisations, and venture capital funds.

From Table 3, we also find that firms in different industries draw from various sources of knowledge in their innovation activities. The values of the mean of STI firms are greater than the values of DUI firms in those items that include universities and research institutes, technology agencies, IP organisations, and VC enterprises. Firms in STI industries draw technology from universities, research institutions, technology agencies, and IP organisations to a greater degree than firms in DUI industries. Firms in DUI industries tend to draw knowledge from users, suppliers and other firms. However, these differences between STI and DUI industries are only statistically significant for suppliers, firms in other industries as well as IP organisations and VC funds. The fact that most respondents had an established R&D centre is responsible for the fact that STI and DUI industries have significantly different means for only four items in Table 3. If that condition were omitted, we would probably find more pronounced differences between the two types of innovation modes.

Table 3: The use of different external technology sources

item	Mean of all sample firms	Variance of all sample firms	Mean of STI firms[a]	Mean of DUI firms
R&D departments	5.6699	1.953	5.7447	5.6244
Employees outside R&D department	4.5694	1.756	4.5443	4.5846
Lead users	4.2249	2.598	4.2785	4.1923
Major users	4.5455	2.576	4.4018	4.6328
Suppliers	4.1770	2.464	3.9241*	4.3308
Competitors	4.1675	2.371	3.9747	4.2846
Firms in other industries	2.7847	1.737	2.5696*	2.9153
Universities and research institutes	3.6005	1.855	3.6582	3.5654
Technology agencies	2.7751	1.983	2.8481	2.7308
Intellectual property organisations	2.9713	2.355	3.1708*	2.8501
Venture capital enterprises	2.3397	2.283	2.829**	2.0424
Governments	4.0574	3.064	3.9367	4.1308

Note: a: Difference between the means of the STI and DUI industries (* = statistical difference on $p < 0.1$ ** $p < 0.001$)

4.2 Measurements of the orientation of openness

To calculate the *orientation of openness* – the different types of external sources of technology - we ran a factor analysis. For firms in STI industries, the KMO (0.747) and the chi-square for Bartlett's test of sphericity (241.99) were highly significant ($p < 0.001$). Similarly, for firms in DUI industries, the KMO (0.810) and the chi-square for Bartlett's test of sphericity (480.6) were highly significant as well ($p < 0.001$). Therefore, we can conclude that factor analysis is suitable for this data. Four factors will be retained according to the cumulative proportions of variance [1]. For data about firms in STI industries, four factors reflect 80.6% of the variance in the original data. For the DUI industries, four factors reflect

[1] As an alternative, we also ran the factor analysis according to the criteria of extraction with eigenvalues higher than 1 and with varimax orthogonal rotation. Two factors are retained for the data of firms in STI industries as well as in DUI industries. For the two datasets, the two factors respectively account for 67.6% and 66.1% of the variance. Lead users, Major users, Suppliers, Competitors and Firms in other industries have higher loadings on the first factor. Therefore, we label the first factor "values chain partners and horizontal connections". Universities, Technology agencies, IP organizations, VC enterprises have higher loadings on the second factor. Therefore, we label this factor "Technology related organization". We ran a regression analysis based on the factor analysis with the two factors as explanatory variables and the innovative performance as dependent variable. For firms in STI industries, value chain partners and horizontal connections have a positive impact on innovation performance. But there is a big difference between vertical collaboration and horizontal connections (see table 7 in the paper). Therefore, reducing the 4 types of external knowledge partners into two categories leads to considerable information loss. The same applies to firms in DUI industries.

78.5% of the information in the original data. Then we regrouped the external sources and labelled each of the four factors according to the rotated factor loadings with varimax orthogonal rotation. (A rotation method which maximizes the squared factor loadings in each factor, i.e., simplifies the columns of the factor loading matrix. In each factor the large loadings are increased and the small ones are decreased so that each factor only has a few variables with large loadings. The goal of rotation is to obtain a simpler factor loading pattern that is easier to interpret each factor.) The results are presented respectively in Tables 4 and 5.

Table 4: Rotated factor loadings pattern of the importance of external sources for firms in STI industries

	loadings				Name of the factor
	1	2	3	4	
Lead users (LU)	**0.694**	0.066	0.414	0.062	Value chain partners
Major users (MU)	**0.821**	-0.018	0.142	0.017	
Suppliers (S)	**0.819**	0. 242	-0.069	0.175	
Technology agencies (TM)	-0.100	**0.667**	0.201	0.432	Technology related organisations
Intellectual property organisations (IP)	0.098	**0.825**	-0.045	0.119	
Venture capital enterprises (VC)	0.168	**0.800**	0.282	0.008	
Competitors (C)	0.426	-0.073	**0.618**	0.250	Horizontal connections
Firms in other industries (OE)	0.058	0.321	**0.833**	0.071	
Universities and research institutes (UNI)	0.087	0.112	0.302	**0.859**	Universities and governments
Governments (G)	0.377	0.440	-0.244	**0.616**	

In Table 4, the variables loading highly on the first factor are Lead users, Major users, and Suppliers. We label this factor “Value chain partners”. The variables loading highly on the second factor are: Technology agencies, Intellectual property organisations, Venture capital enterprises.. We label this factor “Technology related organisations”. Similarly, we label the other two factors as Horizontal Connections, and Universities and Government. Hence, for firms in STI industries the external sources can be categorised into four groups.

Table 5 shows the results for firms in DUI industries where external sources are categorised again into four groups: value chain partners and competitors; universities and research labs; technology-related organisations and governments; and firms in other industries. The results of the factor analysis show that companies in both industry types perceive their external innovation partners in slightly different ways. These four types of partners in the DUI and STI industries will be used as the explanatory variables reflecting the *orientation of openness* for firms in both types of industries.

Table 5 Rotated factor loadings pattern of the importance of external sources for firms in DUI industries

	loadings				Name of the factor
	1	2	3	4	
Lead users (LU)	**0.695**	0.143	0.508	0.130	Value chain partners and competitors
Major users (MU)	**0.756**	0.206	0.012	0.294	
Suppliers (S)	**0.738**	0.421	-0.156	0.075	
Competitors (C)	**0.766**	0.086	0.305	0.048	
Technology agencies (TM)	-0.004	**0.610**	0.345	0.544	Technology related organisations
Intellectual property organisations (IP)	0.245	**0.741**	0.116	0.239	
Venture capital enterprises (VC)	0.147	**0.727**	0.081	0.195	
Governments (G)	0.282	**0.696**	0.280	-0.175	
Universities and research institutes (UNI)	0.134	0.262	**0.871**	0.095	Universities & research institutes
Firms in other industries (OE)	0.268	0.141	0.051	**0.844**	Firms in other industries

4.3. Results of the regression analysis

We calculated the correlations between the variables included in the empirical analysis and these are listed together with the descriptive statistics in Table 6.

Table 6. Descriptive statistics and correlations

Variable	Mean	S.D.	Min.	Max.	1	2	3	4
1. Performance	5.012	0.917	1.50	1.95				
2. Scope	7.115	2.482	1.00	10.00	.501**			
3. Depth	3.564	1.095	1.45	6.70	.479**	.888**		
4. Firm size	6.952	0.996	4.58	10.31	.234**	.073	.037	
5. R&D intensity	5.04	0.937	2	7	.452**	.322**	.300**	-.058

**Correlation is significant at the 0.01 level (2-tailed)

Table 6 shows a strong positive correlation between the scope and depth of openness and innovative performance. However, the scope and depth of the co-operation with innovation partners are also strongly correlated. To avoid multi-collinearity in the regressions (see below), we ran different regressions with scope and depth as alternative explanatory variables.

Tables 7 and 8 present the results for the influence of the scope, depth and orientation of a firm's external innovation sourcing on innovative performance. In all the models, we used firm size, R&D intensity, and industry dummy variables as control variables. The influence of openness on innovative performance was expected to be different for the two types of innovation modes. In accordance with Lundvall's taxonomy of innovations in STI-mode (science-technology-innovation) and DUI-mode (learning by doing, using, and interacting) (Jensen, *et al.*, 2007), we categorised the respondents according to these two types of innovation modes.

The results of the STI innovation mode are shown in Table 7. We used 'materials and chemicals' as a default industry dummy variable. The first model shows that the scope of openness has a positive and significant effect on innovative performance. In Model 2, we also introduced the squared term of that variable to test whether there is an inverted U-shaped relationship between the scope of openness and innovative performance. In this model, the coefficient of the squared term is negative and significant. Hence, the results of Models 1 and 2 indicate that the scope of openness is an important factor in explaining innovative performance. But when firms associate with too many types of external partners, their innovative performance starts to decrease. We found a curvilinear relation in Model 2 between the scope of openness and the innovative performance of the respondents that corroborates the first hypothesis. However, we must be careful when analyzing the results of Model 2 because the optimal innovative performance is reached at a scope of 8.7, which implies that the negative effect of over-reliance on too many types of partners will only occur when innovating firms associate with a very large set of different types of partners.

Table 7 Determinants of innovative performance of respondents in STI industries

	Model 1	Model 2	Model 3	Model 4	Model 5
Scope	0.088** (0.037)	0.376** (0.172)			
$Scope^2$		-0.022* (0.013)			
Depth			0.223*** (0.084)	0.770* (0.407)	
$Depth^2$				-0.070 (0.051)	
Value chain partners					0.226** (0.092)
Technology related organisations					0.111 (0.087)
Horizontal connections					-0.069 (0.090)
Universities					0.184* (0.090)
Ln (size)	0.246*** (0.088)	0.260*** (0.088)	0.219** (0.088)	0.223** (0.088)	0.192* (0.092)
R&D intensity	0.364*** (0.088)	0.331*** (0.099)	0.351*** (0.087)	0.342*** (0.087)	0.320*** (0.089)
Pharmaceutical industry	-0.003 (0.245)	-0.004 (0.270)	0.085 (0.252)	0.109 (0.251)	0.082 (0.253)
Metallic industry	0.154 (0.264)	0.144 (0.291)	0.185 (0.262)	0.187 (0.261)	0.165 (0.264)
Electrical industry	0.219 (0.217)	0.254 (0.240)	0.252 (0.217)	0.246 (0.215)	0.295 (0.218)
Number of observations	79	79	79	79	79
R-squared	0.351	0.376	0.363	0.379	0.402
F-test (sig.)	6.477***	6.120***	6.839***	6.203***	5.158***

Notes: Standard error between brackets

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

Model 3 represents the impact of the intensity of the relations with external partners or the depth of openness. The coefficient for this variable is positive and significant. In Model 4, we tested for an inverted curvilinear effect between the depth of openness and innovative performance. The coefficient of the squared term is negative but not significant. Consequently, the depth of openness is an important factor in improving innovative performance and its impact is not hampered when firms have intensive relations with external partners. As a result, we do not find empirical support for Hypothesis 1b. This result can perhaps be explained by the fact that the respondents on average do not have intensive relations with external partners – the average depth per category is 3.56. As a result, over-reliance on partners may be a theoretical possibility, but Chinese firms using the STI-mode do not rely intensively on external partners for their innovations. Most Chinese firms seem to be in a position that is below the turning point where the depth of openness becomes counterproductive.

We are not only interested in the scope and depth of openness but also in the orientation of openness. In other words, we want to explore which types of external innovation partners have a positive effect on the innovative performance of the respondents. We divided the external partners into four groups which are the result of a factor analysis. Model 5 in Table 7 shows that firms using the STI-mode can benefit from their interaction with value chain partners and universities. On the contrary, relations with technology-related organisations and horizontal connections do not have an impact. We can now combine the results of Model 5 with those of Model 2 and see that STI-mode innovating firms can benefit from the combination of a selected set of external innovation sources. It also shows that the combination of technological linkages (universities and research institutes) and market relations (value chain partners) is crucial for the success of open innovation in the STI-mode. The outcome for technology related organisations is somewhat puzzling. Based on the theory of external innovation sourcing we expect that technology-related organisations may provide advanced technological solutions improving innovative performance of their client firms. Therefore it is assumed to be an important external source for STI-mode of innovation (science-technology-innovation). From interviews with R&D managers in responding firms and managers of venture capital enterprises we know that most venture capital funds in Zhejiang province prefer to avoid risks by investing in traditional manufacturing firms rather than high-tech industries. Venture capital enterprises have not yet played an important role in improving innovation in the province of Zhejiang.

We also tried a full model that included scope, depth, and orientation of openness. However, when we include variables such as scope, scope squared, depth, depth squared, and four orientations as explanatory variables, the VIF tests showed that collinearity is a serious concern. Therefore, we introduced the scope, depth, and orientation of openness separately in different models.

The results of the DUI-mode are shown in Table 8. The coefficient of scope of openness in Model 1 is positive and significant. Model 2 tests for a curvilinear effect and the squared term is found to be negative but not significant. In contrast with the STI-mode, we did not find a curvilinear effect. This is in line with Hypothesis 2a where we hypothesised a linear relation between the scope of openness and the innovative performance of the companies.

Models 3 and 4 in Table 8 show the effect of the depth of openness on the innovative performance of the respondents. Similar to the results for the STI-mode, we find there is a positive linear effect – the coefficient of the squared term in Model 4 is negative but not significant. This linear effect corroborates Hypothesis 2b.

Table 8 Determinants of innovative performance of respondents in DUI industries

	Model 1	Model 2	Model 3	Model 4	Model 5
Scope	0.161*** (0.026)	0.242* (0.130)			
$Scope^2$		-0.006 (0.010)			
Depth			0.351*** (0.058)	0.708** (0.329)	
$Depth^2$				-0.050 (0.045)	
Value chain partners and competitors					0.293*** (0.060)
Technology related organisations					0.214*** (0.063)
Universities					0.048 (0.062)
Firms in other industries					0.083 (0.060)
Ln (size)	0.147** (0.059)	0.142** (0.060)	0.187*** (0.059)	0.179*** (0.059)	0.153** (0.060)
R&D intensity	0.296*** (0.072)	0.289*** (0.073)	0.327*** (0.071)	0.322*** (0.071)	0.355*** (0.073)
Textiles and clothing industry	-0.293 (0.676)	-0.250 (0.681)	-0.336 (0.680)	-0.276 (0.681)	-0.357 (0.690)
Food industry	-0.108 (0.682)	-0.069 (0.687)	-0.202 (0. 685)	-0.142 (0.687)	-0.226 (0.694)
Paper and furniture industry	-0.363 (0.681)	-0.337 (0.683)	-0.438 (0.684)	-0.384 (0.685)	-0.478 (0.693)
Machine manufacturing industry	0.058 (0.669)	0.098 (0.673)	-0.045 (0.672)	0.022 (0.674)	-0.021 (0.683)
Car manufacturing industry	-0.029 (0.689)	0.009 (0.694)	-0.145 (0.693)	-0.060 (0.696)	-0.148 (0.702)
Number of observations	130	130	130	130	130
R-squared	0.477	0.479	0.471	0.476	0.477
F-test (sig.)	13.80***	12.25***	13.45***	12.11***	9.797***

Notes: Standard error between brackets

*** $p < 0.01$; ** $p < 0.05$; * $p < 0.10$

We are also interested in unravelling which type of partners help DUI-firms improve their innovative performance. The factor analysis (see Table 5) divides the partners into four groups. Model 5 of Table 8 shows that value chain partners and competitors, as well as technology-related organisations such as technology agencies, IP-organisations, venture capital enterprises, and governments have a positive impact on the innovative performance of firms using the DUI-mode. It is interesting to note that learning from competitors, as well as value chain members, plays a role in the DUI-mode. Copying competition is a valuable way of improving a firm's innovative performance – at least among the Chinese respondents. This is in line with the description of the DUI mode in section 2.4. On the contrary, relations with firms in other industries and universities and research institutes are not useful in improving innovative performance. It is interesting to observe that technology-related organisations are important external innovation sources while universities and research institutes are not. This implies that innovation policies should also focus on the DUI-mode, but not with universities as a main player which is the case in the STI-mode. A different innovation policy is required for both types of innovation modes.

The results of Model 5 indicate that increasing scope of openness (Model 1) comes with a caveat. Respondents using the DUI-mode can associate with different types of partners; but not all types of partners will be instrumental in increasing their innovative performance.

We did not insert a full model in Table 8. VIF tests showed that collinearity was a serious problem when we included scope, depth, and orientation of openness in one model. As in the case of STI industries, we introduced the three openness variables separately in different models.

There are a number of interesting observations to make about the control variables. The R&D intensity has a positive and significant effect on innovative performance. The size of the firm also has a positive and significant effect in both modes of innovations. Larger firms (all of whom within our respondent samples had R&D centres in the province of Zhejiang) have a stronger innovative performance than their smaller counterparts – irrespective of the industries to which they belong. This result indicates that there are economies of scale in R&D favouring larger companies. The industry dummy variables have no influence on innovative performance. It is furthermore interesting to observe that there are *no* substantial differences between the two innovation modes with respect to the impact of R&D intensity and the size of the firm on innovative performance.

5. Conclusions

Firms increasingly rely on knowledge from external sources to strengthen and accelerate internal innovation. Open innovation provides access to more ideas than can be developed in-house. Companies can improve their innovative performance significantly by leveraging technological discoveries and innovations developed by others. However, in line with Laursen and Salter (2006) we also argued that too many external relationships can worsen innovative performance because of increasing search costs and the potential danger of key technologies leaking.

In this study, we focus on the impact of the scope, depth and orientation of openness on innovative performance in Chinese firms. More particularly, we tested this relationship for firms using the STI or DUI innovation mode. Based on the empirical results, we conclude that both the scope and depth of openness have a positive impact on innovative performance. With regard to STI-mode, we find that the innovative performance of firms is a curvilinear function (inverted U-shape) of the number of relationships they have with different types of external organisations. Therefore, increasing the diversity of partners improves a firm's innovative performance up to an optimal number of partners – after which openness becomes counterproductive. This optimum is reached with 8.7 types of partners. Most Chinese firms have relations with a smaller number of types of partners – the average being 6.71 and the median 7.00. As a result, their scope of openness is still limited, which indicates that on average there is still room for Chinese companies to extend the diversity of their external relations and improve innovative performances. The intensity of the relationships with external partners (in terms of depth of openness) has a positive effect on innovative performance. In line with prior research we expected an inverted U-shaped relationship (see Hypothesis 1b), but no evidence was found that very intensive relations may be counterproductive. Therefore, we conclude that in the case of STI-mode, companies benefit from intensive or strong ties with a limited range of partners. Furthermore, empirical analysis also shows that the combination of technological linkages (universities and research institutes) and market relations (value chain partners) is crucial for the success of open innovation in STI-mode. Hence, a single-focused orientation on technological developments only is detrimental for the innovative performance of firms in the STI-mode of innovation.

For firms using the DUI-mode of innovation, openness to external organisations is positively related to innovative performance. This is true for both the diversity and intensity of the relationships with their partners. These firms can improve their innovative performance by further opening their innovation processes. To improve the indigenous innovation capabilities of Chinese innovating companies, it is important for these firms to establish appropriate mechanisms for scouting and sourcing external innovative resources. In the DUI-mode of innovation, firms profit from relationships with value chain partners and competitors as well as technology-related organisations. However, relations with universities and research institutes do not seem to directly improve innovative performance for this mode of innovation.

Empirical analysis also shows that the positive effects of openness are as important for firms using the DUI as well as the STI mode of innovation. It could be imagined that firms using the STI-innovation mode would benefit more from collaboration with external innovation partners because firms using this innovation mode are technology-intensive and experience an external environment with more technology opportunities. However, we find that open innovation is as important for DUI-mode of innovation. The main reason is that we defined external relationships broadly and included external partners such as competitors, users, and suppliers who have no direct link with science or advanced technologies. As external sources of innovation are broadly defined, we find that open innovation is as important for both innovation modes. The difference between STI and DUI innovation mode is the type of partners with whom innovating firms are associating. Firms using the DUI mode can profit from close relationships with value chain partners and competitors, as well as technology related organisations. Firms using the STI mode benefit from collaboration with universities, research institutions, and value chain partners.

The incoming spillovers from associating with partners are more obvious when firms developing the STI mode of innovation open their innovation process compared to firms using the DUI innovation mode. However, the danger of knowledge leakage is also greater for the former, and so outgoing spillovers may also be more substantial (Belderbos *et al.*, 2004). Therefore, it is important for firms using STI-mode of innovation to open their innovation process to selected external organisations; while firms using DUI-mode can open their innovation process quite widely without repercussions. This argument is supported by the results in our paper.

Open innovation does not imply that firms simply acquire the outside knowledge. They need enough internal technology capabilities to identify and acquire external knowledge and then integrate them into the process of internal innovation (Cohen and Levinthal, 1990). Chinese innovating firms still have a large gap to bridge concerning their internal R&D capabilities compared to firms in developed countries. Therefore the impact of openness on innovative performance may have be different for the firms in developing and developed regions. The results of this study show that open innovation generates is not only advantageous for innovating firms in developed countries, but also for firms in rapidly developing countries such as China. Although the current study is limited to innovating firms in Zhejiang province in China, it is highly likely that open innovation is important in many emerging countries. Innovating companies in developed as well as developing countries must associate with users, suppliers, and other external innovation partners.

The results of our study also indicate that different innovation modes also benefit from different types of partners. This is an important contribution to the literature since not only scope and depth but also the orientation of firms' external sourcing strategy should be taken into consideration. For developing STI-mode of innovations, firms should be open to some selected agencies in order to improve innovative performance. Vertical relations with lead users, major users, suppliers, and knowledge organisations such as universities and research institutions may be particularly important sources of new products. For developing DUI-mode of innovations, firms should learn from users, suppliers, competitors, and technology-related organisations such as technology intermediaries, intellectual property organisations, and venture capitalists to obtain complementary technical resources for developing new products. The range of external partners from whom firms may benefit in open innovation has until now probably been too tightly linked with science driven technologies. We find that open innovation is a current practice among Chinese firms in traditional manufacturing industries that innovate after learning from value-chain partners, competitors, etc. As a result, open innovation must be expanded to other types of innovation beyond science driven technological developments.

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