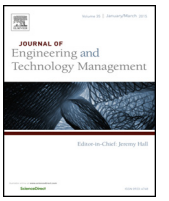
J. Eng. Technol. Manage. xxx (2015) xxx–xxx

Contents lists available at ScienceDirect

Journal of Engineering and Technology Management



Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective

Qinxuan Gu[a], Wan Jiang[b,*], Greg. G. Wang[c]

[a] Management and Organization Department, Antai College of Economics & Management, Shanghai Jiao Tong University, Shanghai, China
[b] College of Management & Economics, Tianjin University, Tianjin, China
[c] Department of Human Resource Development & Technology, College of Business and Technology, The University of Texas at Tyler, 3900 University Blvd, Tyler, TX 75799, USA

ARTICLE INFO

Article history:
Received 28 July 2014
Received in revised form 25 March 2016
Accepted 12 April 2016

Keywords:
Customer input
Network
R&D intensity
Innovation performance
Chinese high-tech SMEs

ABSTRACT

Drawing on the resource-based perspective, we empirically investigate the effects of external and internal sources on innovation performance by focusing on customer input, cooperative networks, and R&D intensity using a sample of Chinese high-tech small and medium-sized enterprises (SMEs). We find that customer input and cooperative networks have the positive impacts on the innovation performance of high-tech SMEs. R&D intensity positively moderates the relationship between customer input, network size, and innovation performance in high-tech SMEs, and does not serve as a moderator in the relationship between network duration and innovation performance in high-tech SMEs.

1. Introduction

In the "open innovation" era, innovation can be generated from a variety of sources. Firms may source innovation either internally from R&D activities and employee creativity, or externally from customer involvement and collaboration with strategic partners (Tsai et al., 2011). Research has shown that small and medium-sized enterprises (SMEs) tend to seek external sources and assistance due to their resource constraints (O'Regan and Kling, 2011; Zeng et al., 2010). Building innovation capabilities for SMEs has become increasingly critical to business mode transformation, particularly for high-tech firms. SMEs in this sector must be more creative and innovative in order to survive, compete, and grow because technologically-driven firms operate in a vibrant internal and external competitive environment characterized by rapid technological change, and shortened product life cycles (Gumusluoglu and Ilsev, 2009).

SMEs in China have witnessed a rapid expansion in numbers and scale since the economic reforms of the late 1970s, and have played a significant role in accelerating economic growth in the last three decades (Chen, 2006). With the development of a market-oriented economy in China and the acceleration of globalization processes, however, it is imperative that SMEs transform that extensive growth mode into an intensive one, as the extensive mode can no longer meet the requirements of global competition (Chen, 2006). Recently, high-tech SMEs have been encouraged by the Chinese government at all levels

* Corresponding author.
E-mail addresses: qxgu@sjtu.edu.cn (Q. Gu), jiangwan.008@163.com (W. Jiang), wanggreg@aol.com (G. G. Wang).

http://dx.doi.org/10.1016/j.jengtecman.2016.04.003
0923-4748/

through favorable technology and innovation policy (Wang et al., 2013). Therefore, understanding which sources can be used for enhancing innovation performance has become increasingly important for Chinese high-tech SMEs.

Drawing on the resource-based view, innovation is the result of unique resources and the accumulation of knowledge (Leitner, 2011). Successful innovation rests on external knowledge integration capabilities and technological capabilities (Verona, 1999). Empirical evidence regarding the role of the different forms of internal and external knowledge and their links to innovation is still limited, particularly for SMEs (Leitner, 2011). First, recent research has been focused on identifying the roles of external sources in SME innovation, such as Research and Development (R&D) outsourcing (O'Regan and Kling, 2011), cooperative networks (Bougrain and Haudeville, 2002; Zeng et al., 2010), and customer involvement (Kuusisto and Riepula, 2011). Developing relationships with customers allows SMEs to maximize the utilization of their limited resources (Appiah-Adu and Singh, 1998). However, few studies explore the specific role of customer input in the innovation performance of high-tech SMEs. Based on the resource-based view, we posit that customer input is one of the key factors that will allow high-tech SMEs to achieve greater innovation performance.

Second, firms are increasingly looking for external resources as they seek to develop innovation capability for business success (O'Regan and Kling, 2011). From the social capital perspective, networks have become valuable in transmitting resources for firm growth (Bratkovic et al., 2009; Kajikawa et al., 2010) and innovation (Ahuja, 2000; Gu et al., 2013). The resource-based perspective considers the creation and maintenance of networks as a mechanism in accessing scarce resources. The role of external networks may benefit resource-poor SMEs, enabling them to create competitive advantages (Gronum et al., 2012; Thorgren et al., 2009). Networks with external partners are extremely important for innovation as they help firms to combine new forms of knowledge and enhance information exchange with external actors (Leitner, 2011).

While research has examined the roles of different types of cooperative networks such as cooperation with customers and suppliers in general innovation performance (Zeng et al., 2010), there is a dearth of research examining the effects of the differing characteristics of cooperative networks, such as network size and duration, on the innovation performance of high-tech SMEs. In our study, drawing on the resource-based perspective, we seek to contribute to the research on the role of cooperative networks in innovation by focusing on the effects of two dimensions of the cooperative network, network size and duration, on innovation performance in high-tech SMEs.

Third, the resource-based view states that firm success is not only determined by external factors but also by internal characteristics (Prahalad and Hamel, 1990; Padgett and Galan, 2010). Thus, external and internal sources may have interacting effects on the innovation performance of high-tech SMEs. Research on SME innovation sources has been primarily focused on testing the effect of a particular source, either internal or external (Bougrain and Haudeville, 2002; Kuusisto and Riepula, 2011; O'Regan and Kling, 2011). To our knowledge, few studies have examined the interaction effects of external and internal sources on the innovation performance of high-tech SMEs. Investments in R&D are crucial characteristics for innovation performance (Leitner, 2011). Additionally, some studies have suggested that R&D expenditure should be included as a moderator in theoretical models that have received mixed or ambiguous empirical support (Padgett and Galan, 2010). Although the effect of R&D spending on firm performance has received much research attention (Le et al., 2006; Lin et al., 2006; Morbey, 1988), the roles of complementarity and interaction between customer input, network, and R&D intensity have been largely ignored in empirical studies. This study addresses that research gap.

In the current study, we empirically investigate the main effects of external sources (i.e., customer input and cooperative network) on innovation performance in high-tech SMEs as well as the moderating role of R&D intensity, guided by the resource-based view. We tested all hypotheses using the database of Chinese high-tech SMEs from a Chinese government financial program. We first present the theoretical framework and hypotheses. We then describe the methodology of the study and report the empirical results. We conclude by discussing the implications for research and practice and identifying the limitations and directions for future research.

2. Theoretical framework and hypotheses

2.1. Resource-based approach

This study is informed by the resource-based view (RBV) (Barney, 1991). RBV posits that a firm possesses a valuable bundle of resources and capabilities (Wernerfelt, 1984), and some resources and capabilities can have superior effects on firm performance (Nath et al., 2010). Capabilities are represented by bundles of skills, abilities, and accumulated knowledge that enable the firm to achieve desired outcomes (Day, 1990; Nath et al., 2010), while information and knowledge are increasingly considered to be valuable resources and dynamic capabilities (Chen et al., 2011). The firm's survival and sustainable development depend on its resources and capabilities to create competitive advantages (Peteraf, 1993; Sirmon et al., 2011). Thus, RBV considers that firms must not only put their resources and capabilities to best use, but also develop their new resources and capabilities in order to maintain and develop more competitive advantages (Nath et al., 2010; Peteraf, 1993). We adopt the source-resource and capability-performance framework to analyze the effect of external and internal sources and their resulting resources and capabilities on high-tech SME innovation performance by focusing on customer input in providing information on customer needs and experiences, and cooperative networks in transmitting resources and capabilities, and R&D intensity in cultivating R&D capability and absorptive capability.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

2.2. Innovation performance

Innovation is widely recognized as a capability and critical source of success and competitive advantage in business organizations (Amabile et al., 1996; Gumusluoglu and Ilsev, 2009; Yang, 2012). From a process perspective, innovation is defined as 'a process that begins with an invention, proceeds with a development of the invention, and results in an introduction of a new product, process, or service to marketplace' (Katila and Shane, 2005; p. 814). This perspective emphasizes on an entire innovation process from generating new ideas to developing a new product, process, or service (Laursen and Salter, 2006).

2.3. Customer input and innovation performance

Customer input reflects a firm's functional marketing capability, an important source of enhancements for a firm's competitive advantage (Nath et al., 2010). Customer input provides information on customer needs and experiences. This information is a resource that firms can leverage in their innovation processes (Gruner and Homburg, 2000). One particular form of customer input in the innovation process is known as the "Voice of the Customer" (VOC) (Griffin and Hauser, 1993). VOC refers to 'a hierarchical set of customer needs where each need (or a set of needs) has been assigned to a priority level which indicates its importance to the customers (Griffin and Hauser, 1993; p. 2). An effective method for capturing customer input is to ask customers what they want a new product or service to do for them (Ulwick, 2002). Identifying customer needs and translating them into new products can increase the chance of success for new product development (Song and Thieme, 2006). The highest level of customer input deploys VOC throughout the entire process, including product design, manufacturing, and service delivery (Griffin and Hauser, 1993).

Firms that can successfully bring technological innovations into the marketplace are often highly customer-oriented (Lin et al., 2006). Han et al. (1998) found that customer orientation is positively related to technological innovation, which in turn has a positive impact on organizational performance. This is because the ability of a technological innovation to generate profits for the firm is contingent on the extent to which customers find it valuable. Foss et al. (2011) suggested that customers often play a central role in the preliminary stages of an innovation process. Gruner and Homburg (2000) reported that interactions with customers during the early and late stages of the new product development process have a positive impact on new product success. Sandberg (2007) also indicates that a firm's previous experience with customers may generate both incremental and radical innovations.

Small firms often exploit customers as a principal source of innovation since small firms often lack the internal resources available to large companies and interactions with and learning from customers can accelerate the speed of innovation and reduce uncertainty in new product development (Bierly Iii and Daly, 2007). This, in turn, improves the innovation performance of high-tech SMEs. Thus, we hypothesize:

Hypothesis 1. Customer input has a positive effect on the innovation performance of high-tech SMEs.

2.4. Cooperative networks and innovation performance

Networks have become valuable assets for firms (Bratkovic et al., 2009), because networks transmit knowledge, information, and technology (Bratkovic et al., 2009; Gu et al., 2013). Networking as a form of collaboration can help companies gain complementary resources and assets leading to better innovation performance (Hsueh et al., 2010; Keil et al., 2008). It can also potentially reduce the risks SMEs face and increase their chance of success (Bratkovic et al., 2009). Cooperative networks are formed by interdependent organizations through interactive exchanges, technical assistance, or connections, and such activities or connections lie between official structural hierarchical and market transaction relationships (Hsueh et al., 2010).

A wide range of actors may be involved in a network, including suppliers, clients, research institutions, educational institutes, professional and technical centers, intermediary institutions, and government agencies. Cooperative networks elevate SME competitiveness by providing technical assistance, market requirements, and information regarding strategic choices made by other firms (Bougrain and Haudeville, 2002). Inter-firm or cross-sector networks help SMEs secure and diffuse innovations by facilitating the flows of resources, information, and developing trust (Zeng et al., 2010). A number of studies have focused on examining the relationship between cooperative networks or external partnerships and the innovation performance of firms (Becker and Dietz, 2004; Dickson et al., 2006; Doloreux, 2004; Kaufmann and Tödtling, 2002; Nieto and Santamaría, 2007; Tether, 2002; Zeng et al., 2010). Researchers have examined the effects of different types of partnership and vertical and/or horizontal cooperation in different national contexts, such as in developed countries (Kaufmann and Tödtling, 2002; Nieto and Santamaría, 2007) and in developing countries (Biggs and Shah, 2006; Zeng et al., 2010). For example, in a longitudinal study of Spanish manufacturing firms, Nieto and Santamaría (2007) found that firms benefit most in the degree of innovation novelty from collaboration networks comprising different types of partners. In addition, using a sample of 137Chinese manufacturing SMEs, Zeng et al. (2010) concluded that 'vertical cooperation with customers, suppliers and other firms plays a more distinct role in innovation for SMEs than horizontal cooperation with research institutions, universities and government agencies' (p. 191). Biggs and Shah (2006) have also noted in their case studies that SMEs networked with informal governance institutions in Sub-Saharan Africa have more innovative activities.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

For smaller companies, cooperative networks are also used to manage cost more effectively through increasing revenues (Hanna and Walsh, 2002).

Although the roles of different types of cooperative networks in the innovation process and their performance have received much attention in the literature, few studies examine the effects of network size and duration. Network size and tie strength are two important dimensions of social networks offering different benefits (Adler and Kwon, 2002). In the literature, tie strength is often operationalized as a multidimensional construct including duration of the tie (Lowik et al., 2012), contact frequency, and emotional closeness (Hansen, 1999; Lowik et al., 2012). Network size refers to the number of partners in the cooperative networks. Each partner connection in the networks represents an information channel (Reagans and Zuckerman, 2001). Becker and Dietz (2004) have suggested that the number of R&D cooperation partners affects the development of new products. Thus, more partner connections provide more information and knowledge sources for the firm.

Network duration is a construct that represents the continuity of collaboration. Nieto and Santamaría (2007) have noted that continuity of collaboration has a positive impact on the novelty of product innovation. In previous studies, network duration is assessed by the length of network experience (Hanna and Walsh, 2002). Often, the longer the cooperation with partners, the closer the network relation is, and the more they learn from each other, because 'the innovative capability of firms is largely dependent on cumulative knowledge built over many years of experience' (Hoecht and Trott, 2006; p. 678). Regardless of the cooperation partner, firms need to sustain a pattern of interaction over time, and maintain a shared understanding and common ways of working together (Laursen and Salter, 2006; Nieto and Santamaría, 2007). It is important to use in-depth key external sources for the internal innovation process (Laursen and Salter, 2006). Thus, based on previous research, we hypothesize:

Hypothesis 2. The size of the cooperative network has a positive effect on the innovation performance of high-tech SMEs.

Hypothesis 3. The duration of the cooperative network has a positive effect on the innovation performance of high-tech SMEs.

2.5. The moderating role of R&D intensity

Among the internal and external sources, firms often consider internal R&D the most important innovation source (Laursen and Salter, 2004; Wuyts et al., 2004). Research suggests that to generate innovative products or services, firms need to make a considerable investment in R&D (Laursen and Salter, 2006). R&D intensity reflects the extent to which the firm attempts to control for technological opportunity and signifies the strategic importance of innovation to the firm (Lin et al., 2006). As such, an increase in R&D intensity often results in the development of new R&D capabilities and new technological knowledge (Bougrain and Haudeville, 2002; Lin et al., 2006).

Bogner and Bansal (2007) argue that internal R&D capabilities, particularly those with a basic research component, are critical to enabling a firm to generate creative outputs. Similarly, Artz et al. (2010) found that there is a positive relationship between R&D spending and patents. Although a number of studies have examined the relationship between R&D spending and firm innovation performance (i.e., Artz et al., 2010; Bogner and Bansal, 2007), less is known about the moderating role of R&D intensity in the relationship between external sources and the innovation performance of high-tech SMEs.

The resource-based view argues that a firm must be organized to deploy the valuable, rare, and inimitable resources effectively (Barney, 1991). Larger firms often depend on formal market research carried out internally, whereas small firms tend to choose customers as the principal source (Chen et al., 2011). Innovativeness, as reflected in R&D intensity, allows firm to achieve efficiency in its operations (Hitt et al., 1994). R&D intensity positively impacts a firm's technological competence and the rate of new technologies created by it (Parthasarthy and Hammond, 2002). Thus, the high-tech SMEs with high level of R&D intensity are more likely to have competences in capturing and implementing the ideas or information from customers, thus, motivate firm innovation of SMEs. Conversely, high-tech SMEs with low degree of R&D intensity may be less likely to effectively use and implement information from customers, which attenuates the positive effects of customer input on innovation performance. Hence, we propose:

Hypothesis 4. R&D intensity moderates the relationship between customer input and the innovation performance of high-tech SMEs such that the relationship is stronger when R&D intensity is higher than lower.

Drawing on the resource perspective of absorptive capacity, firms need to develop the absorptive capacity to take advantage of the innovative activity of external sources (Colombo and Garrone, 1996). R&D intensity indicates the strategic importance of innovation for a firm and constitutes an important input for the development of intangible capital (Kor, 2006). High-tech SMEs with high levels of R&D intensity are more likely to efficiently communicate with their external partners, exploit external information over time, and have strong capabilities to absorb external knowledge (Chen et al., 2011; Cohen and Levinthal, 1990). Conversely, high-tech SMEs with lower levels of R&D intensity have less competence to absorb and use the knowledge received from external partners, and cannot effectively transform creative knowledge or resources into the development of new products. Hence, R&D intensity may accentuate the positive impacts of network size and duration on the innovation performance of Chinese high-tech SMEs. We thus hypothesize:

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

Hypothesis 5. R&D intensity moderates the relationship between network size and the innovation performance of high-tech SMEs such that the relationship is stronger when R&D intensity is higher than lower.

Hypothesis 6. R&D intensity moderates the relationship between network duration and the innovation performance of high-tech SMEs such that the relationship is stronger when R&D intensity is higher than lower.

3. Method

3.1. Empirical setting and sampling

Industrial transformation from low to high-tech is a strategic priority for China's latest five-year (2011–2015) plan. Shanghai, as a key economic center in China, has been playing a leading role in this transformation (Liu et al., 2012). The local government actively fosters and supports innovation through an innovation fund, the Program for Accelerating Innovation in Enterprises (PAIE). The PAIE has been coordinated by the Shanghai Municipal Science and Technology Commission (SMSTC) since 2009. All local firms, especially high-tech firms, are encouraged to apply for funds. To obtain the financial support, applicants are required to provide their background data on sales, revenues from new products and services, R&D expenditure, and the number of patents in the past three years. They are also required to provide information regarding how the firm links to customer needs and experiences, what kinds and how many organizations the firm is cooperating with, and how long the cooperation has lasted. Furthermore, an expert panel evaluates the applicants' innovation capability based on the information provided in the application forms. The panel members are appointed by SMSTC from selected institutions including universities, research institutions, and government agencies. The SMSTC grants innovation funds to qualified applicants based on the panel's recommendations.

We used the PAIE applicant database for this study. We selected high-tech SMEs with fewer than 500 employees. The size as the selection criterion was based on the American Small Business Administration (ASBA)'s definition of SME, a widely used criterion of SMEs in the entrepreneurship literature (Wolff and Pett, 2000). Although the criteria for defining SMEs in terms of employee size, annual revenues, and asserts in China vary, scholars often adopt the ASBA criterion for research on Chinese SMEs (Zeng et al., 2010). Based on the employee size, we selected our sample from the applicant database for the period 2011–2012, resulting in a sample of 106 high-tech SMEs. The mean company size was about 122.15 (s.d.= 115.03, range = 10–485) and the average years of firm in operation was about 9.68 (s.d.= 3.94, range = 3–27). The sample firms came from five industries: pharmaceuticals, electronic communication, high-tech services, new energies and new materials, and environmental protection technology. Table 1 shows basic information of the sample firms.

3.2. Measures

Customer input and network duration were measured by subjective indicators coded from the application forms. To ensure the validity of the latter two subjective measures, we conducted a two-hour face-to-face interview with six executives randomly selected from the sample firms to clarify the four levels of customer input and network duration reported on the application forms. We then developed a four-point scale in relation to the four levels as part of measures.

Table 1
Demographic characteristics of the firms.

Characteristics	Groups	Samples (N)	(%)	Cumulative (%)
Employees(N)				
	10–100	67	63.2%	63.2%
	101–200	17	16.0%	79.2%
	201–300	11	10.4%	89.6%
	301–400	5	4.7%	94.3%
	401–500	6	5.7%	100%
Firm age(years)				
	3–5	13	12.3%	12.3%
	6–10	62	58.5%	70.8%
	11–15	22	20.7%	91.5%
	>15	9	8.5%	100%
Industrial type				
	pharmaceutical industries	12	11.3%	11.3%
	Electronic Communication industries	51	48.1%	59.4%
	High-tech service industries	30	28.3%	87.7%
	New energy and new materials industries	12	11.3%	99.0%
	Environment protection technology industries	1	0.9%	100%

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

3.3. Customer input

As mentioned earlier, this variable was based on a four-point scale representing four levels of customer input representing the degree of customer involvement reported by the applicants: 1 = occasionally collecting information on customer needs and wants in marketing practices and delivering the information to the R&D departments; 2 = regularly collecting information on the customer needs and wants by conducting customer satisfactory survey or inviting them to participate in new product exhibition or marketing activities, and delivering this information to the manufacturing and R&D departments; 3 = regularly holding cross-functional meetings in R&D, marketing, engineering and manufacturing departments to discuss and clarify ideas of new product/service development as well as regularly collecting the information on customer needs and wants; and 4 = always deploying customer input throughout R&D, design, manufacturing and service delivery by combining several steps to capture, analyze, structure and use customer needs and wants.

3.4. Cooperative networks

This variable included two dimensions: network size and network duration. Network size was measured by the number of partners that have cooperative relations with the firm in technology or expertise. Such partners included educational and/or research institutions, government agencies, customers, suppliers, consulting firms, and intermediary institutes, among others.

Network duration was based on a four-point scale representing different levels of network engagement, 1 = contingent cooperation in business sustained for less than one month; 2 = regular cooperation in technical or professional assistance sustained for less than one year; 3 = cooperation in the co-development of new products or services sustained for more than one year but less than five years; and 4 = cooperation in the co-development of new products or services sustained for more than five years, or cooperation sustained since the establishment of the firm.

3.5. R&D intensity

Consistent with Cohen and Levinthal (1990), this measure was assessed by R&D expenditures divided by the total sales for the past three years.

3.6. Innovation performance

We measured innovation performance by revenues generated from new products and services from the past three years as it signals the actual outcome of introducing a new product or service to the marketplace (O'Regan and Kling, 2011). Revenues from new products and services were calculated by averaging revenues over the past three years in order to alleviate the bias in different years.

3.7. Control variable

Firm size may influence firm performance (Lin et al., 2006), and years in business may influence firm innovation capability (Laursen and Salter, 2004). Since competition and technological requirements vary across industries, firms' innovative efforts as an outcome of innovation performance may thus differ in different industries (Artz et al., 2010). Thus, following previous studies, we considered firm size, years in operation and industry as the control variables. Firms in our sample were selected from five different high technology industries categorized by Chinese government, which likely face different market conditions. We thus included four dummy variables, with environmental protection technology as the omitted base industry. Industry 1 = Pharmaceutical, Industry 2 = Electronic communications, Industry 3 = High-tech service,

Table 2
Means, standard deviations, and correlations.

Variables	Mean	s.d.	1	2	3	4	5	6	7
1.Firm age	9.68	3.94							
2.Firm size	122.15	115.03	0.07						
3. Customer input	1.95	0.89	0.30**	0.57***					
4. Network size	3.57	2.78	−.01	0.09	0.17				
5. Network duration	2.04	0.78	0.18	0.42***	0.47***	0.22*			
6. R&D intensity	0.32	0.38	−0.07	0.16	0.10	0.18	0.17		
7. Number of patents	13.89	16.08	0.09	0.37***	0.40***	−0.06	0.41***	0.11	
8. Innovation performance	3290.93	3961.51	0.23*	0.63***	0.64***	0.29**	0.53***	0.39***	0.20*

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

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

and Industry 4 = New energy and materials. We also controlled the number of patents because of its correlations with firm innovation. Consistent with the types of patents defined in the Chinese High-Tech Industry Administration (CHTIA), the number of patents was defined as the average number of patents per year that the sample firms possess, including invention patents, regular utility patents, design and reissued patents, and software copyrights issued in the three years prior to the application.

4. Results

The means, standard deviations, and correlations of the variables are reported in Table 2. The zero-order correlations showed that customer input, network size and network duration were positively related to innovation performance ($r = 0.64$, $p < 0.001$; $r = 0.29$, $p < 0.01$; $r = 0.53$, $p < 0.001$), respectively. To test Hypotheses 1, 2, and 3, we used hierarchical linear regression for the analysis. Following previous studies (Kim et al., 2008; Pearce et al., 2000), we first examined the variance inflation factors (VIFs) in the regression equations to detect multicollinearity. All of the VIF scores were below 2 and the mean VIF score is 1.23, which were well below the rule of thumb for multicollinearity of 10. Thus, multicollinearity was not a serious issue for our study (Cohen et al., 2003).

Model 1 in Table 3 shows the results of the regression analysis on innovation performance with the four control variables, firm size, years in operation, industry dummies, and the number of patents. The overall model was statistically significant ($p < 0.001$) with R-square at 0.47. Model 2 in Table 3 reports the results on innovation performance when all the controls and the independent variables were considered. The overall model was statistically significant ($p < 0.001$) with R-square at 0.64 (ΔR-square = 0.17, $p < 0.001$). As indicated in Model 2, customer input, network size and network duration were positively associated with innovation performance ($\beta = 0.37$, $p < 0.001$; $\beta = 0.17$, $p < 0.05$; $\beta = 0.22$, $p < 0.01$), respectively. Thus, Hypotheses 1, 2, and 3 were supported.

As reported in Model 4 in Table 3, the interaction of customer input and R&D intensity was significant in predicting innovation performance ($\beta = 0.23$, $p < 0.01$). Fig. 1 shows that there was a stronger positive relationship between customer input and innovation performance when R&D intensity was higher. Thus, Hypothesis 4 is supported. The interaction of network size and R&D intensity was significant in predicting innovation performance ($\beta = 0.18$, $p < 0.05$) while the interaction of network duration and R&D intensity was not significant in predicting innovation performance ($\beta = -0.03$, ns). Fig. 2 shows that R&D intensity strengthened the relationship between network size and innovation performance. Thus, Hypothesis 5 was supported, and Hypothesis 6 was not supported.

5. Discussion

Drawing on the resource-based view, this study showed that the external sources had main effects and interaction effects with the internal source in the innovation performance of high-tech SMEs. Specifically, customer input and cooperative networks (i.e., network size and network duration) were positively related to the innovation performance of high-tech SMEs.

Table 3
Results of regression analyses predicting the innovation performance of high-tech SMEs.

Variables	Model1	Model2	Model3	Model4
Controls				
Firm age	0.23**	0.11	0.12	0.10
Firm size	0.66***	0.37***	0.34***	0.33***
Industry1	0.01	0.12	0.05	−0.04
Industry2	−0.02	0.16	0.02	−0.18
Industry3	−0.23	−0.03	−0.08	−0.20
Industry4	−0.06	0.19	0.12	−0.03
Number of patents	−0.07	−0.16*	−0.17*	−0.15*
Main variables				
Customer input		0.37***	0.38***	0.34***
Network size		0.17*	0.12	0.06
Network duration		0.22**	0.20**	0.18**
Moderator				
R&D intensity			0.26***	0.19**
Interactions				
Customer input × R&D intensity				0.23**
Network size × R&D intensity				0.18*
Network duration × R&D intensity				−0.03
R^2	0.47	0.64	0.70	0.75
ΔR^2	0.47***	0.17***	0.06***	0.05**
F	12.27***	17.06***	19.52***	19.33***

Notes: Standardized coefficients are shown.
* $p < 0.05$.
** $p < 0.01$.
*** $p < 0.001$.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

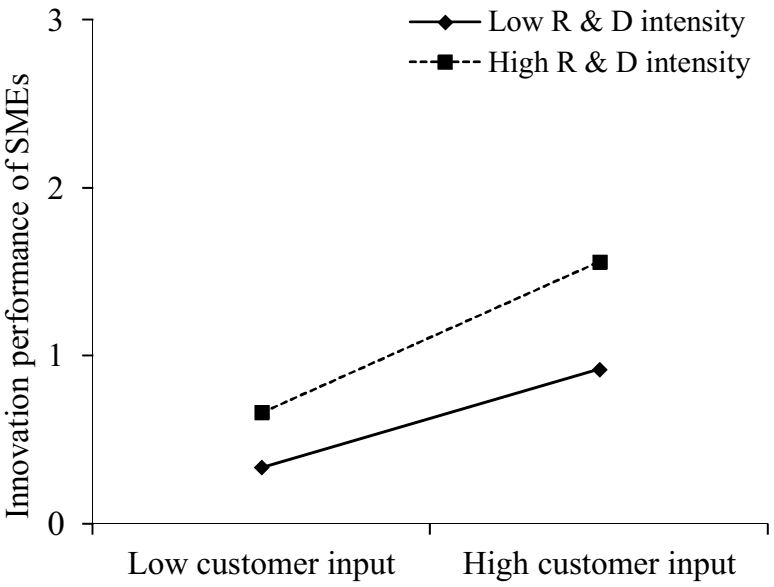


Fig. 1. The moderating effect of R & D intensity in the relationship between customer input and the innovation performance of high-tech SMEs.

Furthermore, R&D intensity positively moderated the effects of customer input and network size on the innovation performance of high-tech SMEs.

5.1. Contributions to research

This study contributes to the innovation literatures in several ways. First, our results indicate that customer input, or VOC, has a significant and positive impact on the innovation performance of Chinese high-tech SMEs. This result also confirms previous findings that customers play a central role in innovation process (Foss et al., 2011; Kuusisto and Riepula, 2011), and information on customer needs and wants is valuable resource that firms can leverage in their innovation process (Gruner and Homburg, 2000).

Second, our study extends the research on the role of cooperative networks by focusing on the effects of two dimensions of the cooperative network, network size and duration, on innovation performance in Chinese high-tech SMEs. Although previous studies have investigated the relationship between network and production innovation (Becker and Dietz, 2004; Nieto and Santamaría, 2007), our study has several significant differences. For instance, our definition of network was broader in scope as we included cooperation in technological as well as expertise-related fields. Moreover, cooperative

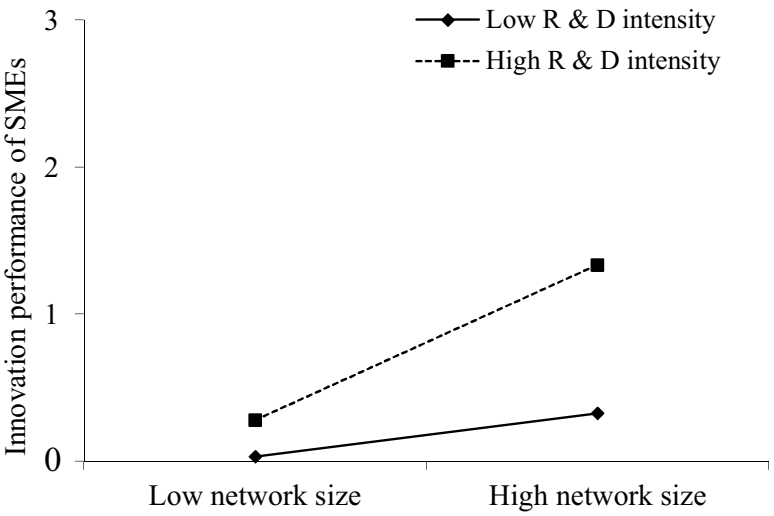


Fig. 2. The moderating effect of R & D intensity in the relationship between network size and the innovation performance of high-tech SMEs.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

networks and associated partnerships may function differently in different national and economic contexts. We used samples from Chinese high-tech SMEs in a developing country. Particularly, the *guanxi*-based Chinese context may complicate the partnership mechanisms in subtle ways (Chen et al., 2013). Our results show that network size is positively related to the innovation performance of high-tech SMEs, which contributes to the network and innovation literatures.

Third, results indicate that cooperative network duration has a positive and significant impact on the innovation performance of high-tech SMEs. Previous research has investigated the effect of tie strength on organizational capabilities such as innovation and new knowledge exploitation (Li et al., 2008; Lowik et al., 2012; Uzzi, 1996). In this study, we focused on network duration, which was operationalized as a construct of tie strength (Hansen, 1999; Lowik et al., 2012; Perry-Smith, 2006). The results demonstrate the critical importance of longer cooperation for high-tech SMEs in enhancing innovation performance. Intuitively, longer network duration may facilitate better interactions and cultivate trust and high quality relationships with partners, through which greater quantities of the tacit and complex knowledge needed for innovation may be exchanged. This finding confirms that 'long-lasting embedded relationships can provide new knowledge over a long period of time' (Lowik et al., 2012; p.242), which in turn facilitates innovation. It is also consistent with finding of Nieto and Santamaría (2007) that continuity of cooperation has a positive effect on the novelty of innovation.

Finally, though researchers have investigated the relationship between the internal R&D expenditure and the innovation output of Chinese high-tech industry (Chen and Yuan, 2007), this study shows that R&D intensity can accentuate the impact of customer input and network size on the innovation performance of Chinese SMEs, which answers the call to investigate the moderating role of R&D intensity (Padgett and Galan, 2010). These results address the contention that R&D intensity, as a factor representing firms' internal innovative capability (Bougrain and Haudeville, 2002), is critical to high-tech SMEs' innovation performance. Our study also extends the literature by simultaneously considering internal (i.e., R&D intensity) and external sources (i.e., customer input and network size) crucial for the innovation performance of high-tech SMEs.

5.2. Managerial implications

Our study also offers managerial implications for practitioners seeking to improve innovation performance in high-tech SMEs. First, taking advantage of VOC throughout the innovation process not only enables leverage of customer knowledge, but can also extend the firm's marketing capabilities, which in turn enhances a firm's competitive advantage. Thus, managers in high-tech SMEs should recognize that customer input is critical for innovation performance. High-tech SMEs should be highly customer-oriented, rapidly identifying customer needs and translating them into new products. For example, the managers should motivate R&D employees to incorporate customer needs into product innovation by leveraging their job satisfaction and involvement in R&D project initiatives (Auer Antoncic and Antoncic, 2011).

Second, our study shows that longer cooperative network duration with partners and cooperative network size of high-tech SMEs can improve innovation performance. Hence, managers in high-tech SMEs must be aware of the importance of enduring cooperation with partners when establishing different types of cooperative networks to attain external knowledge, information, and other resources. They especially need to enhance their networking capability in creating long-term technological cooperation with partners to facilitate tacit and technological knowledge exchanges. This approach is likely to be effective in introducing new products and services for firms in emerging economies like China.

Third, our results emphasize the need for managers in high-tech SMEs to consider both external and internal innovation sources in improving innovation performance to leverage and develop firms' inimitable resources and capabilities. Thus, managers in high-tech SMEs should take an integrative perspective in making decisions in adopting and developing innovation resources and capabilities for the firm's specific contexts. For example, high-tech SMEs should not only concentrate on establishing and using good relationships with external customers and partners to receive information or knowledge, but also exploit their limited internal R&D resources in promoting innovation. Although most Chinese high-tech firms adopt a technology outsourcing strategy in the innovation process, its contribution is less significant than that of internal R&D (Chen and Yuan, 2007). Therefore, managers in Chinese high-tech SMEs should consider increasing both internal R&D investment and its output. As R&D employees influence a firm's product development competence (Crawford et al., 2011), Chinese high-tech SMEs also need to emphasize R&D human resource investment when they commit to developing competitive advantages.

5.3. Limitations and future research

This study is not without limitations. First, the sample consisted of high-tech SMEs, as these firms face a more dynamic and challenging environment and have a stronger intention to enhance innovation performance. These industry-specific attributes may constrain the generalizability of our findings.

Second, the regional nature of the sample may also limit the generalizability of the results, even though Shanghai is a key economic center in China. It is, therefore, necessary for future research to examine other industries and regions in China, or other developing countries.

Third, due to the restrictions in the database, we were unable to take into consideration cultural contextual variables specific to the Chinese context. For example, *guanxi*-based networks have been found to be critical in business cooperation (Chen et al., 2013) and our results different from those in western contexts (Becker and Dietz, 2004). This may also indicate

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

that *guanxi* may be a useful variable for understanding innovation mechanisms and networks in the Chinese context. Future studies need to consider this important variable in examining innovation performance in Chinese high-tech SMEs.

Last, our study empirically combined all types of external partners into one measure of network size. Although different types of external partners may share some activities, each of them is likely to have unique effects on an SME's innovative processes. Hence, future research should examine the unique effects of different types of external partners on the innovation performance of high-tech SMEs.

6. Conclusion

Drawing on the resource-based perspective, we have proposed and examined the effects of external and internal innovation sources on the innovation performance of high-tech SMEs, and focusing on customer input in providing information on customer needs and experience, and cooperative networks in transmitting resources and capabilities, and R&D intensity in cultivating R&D capability, based on a sample of Chinese high-tech SMEs. We have revealed that customer input, network size and network duration have positive impacts on the innovation performance of high-tech SMEs. Furthermore, R&D intensity strengthens the positive impacts of customer input and network size on the innovation performance of high-tech SMEs. These findings provide significant research and managerial implications for high-tech SMEs in the context of emerging economies like China.

Acknowledgements

We would like to thank the National Natural Science Foundation of China (Grant Nos. 71032003, 71472122).

References

Adler, P.S., Kwon, S.W., 2002. Social capital: prospects for a new concept. Acad. Manage. Rev. 27 (1), 17–40.
Ahuja, G., 2000. Collaboration networks, structural holes, and innovation: a longitudinal study. Adm. Sci. Q. 45 (3), 425–455.
Amabile, T.M., Conti, R., Coon, H., Lazenby, J., Herron, M., 1996. Assessing the work environment for creativity. Acad. Manage. J. 39 (5), 1154–1184.
Appiah-Adu, K., Singh, S., 1998. Customer orientation and performance: a study of SMEs. Manage. Decis. 36 (6), 385–394.
Artz, K.W., Norman, P.M., Hatfield, D.E., Cardinal, L.B., 2010. A longitudinal study of the impact of R&D, patents, and product innovation on firm performance. J. Product Innovation Manage. 27 (5), 725–740.
Auer Antoncic, J., Antoncic, B., 2011. Employee satisfaction, intrapreneurship and firm growth: a model. Ind. Manage. Data Syst. 111 (4), 589–607.
Barney, J., 1991. Firm resources and sustained competitive advantage. J. Manage. 17 (1), 99–120.
Becker, W., Dietz, J., 2004. R&D cooperation and innovation activities of firms-evidence for the German manufacturing industry. Res. Policy 33 (2), 209–223.
Bierly Iii, P.E., Daly, P.S., 2007. Sources of external organisational learning in small manufacturing firms. Int. J. Technol. Manage. 38 (1), 45–68.
Biggs, T., Shah, M.K., 2006. African SMES, networks, and manufacturing performance. J. Banking Finance 30 (11), 3043–3066.
Bogner, W.C., Bansal, P., 2007. Knowledge management as the basis of sustained high performance. J. Manage. Stud. 44 (1), 165–188.
Bougrain, F., Haudeville, B., 2002. Innovation, collaboration and SMEs internal research capacities. Res. Policy 31 (5), 735–747.
Bratkovic, T., Antoncic, B., Ruzzier, M., 2009. Strategic utilization of entrepreneur's resource-based social capital and small firm growth. J. Manage. Organiz. 15 (4), 486–499.
Chen, Y., Yuan, Y., 2007. The innovation strategy of firms: empirical evidence from the Chinese high-tech industry. J. Technol. Manage. China 2 (2), 145–153.
Chen, J., Guo, Y., Huang, S., Zhu, H., 2011. The determinants of the choice of innovation source for Chinese firms. Int. J. Technol. Manage. 53 (1), 44–68.
Chen, C.C., Chen, X.P., Huang, S., 2013. Chinese guanxi: an integrative review and new directions for future research. Manage. Organiz. Rev. 9 (1), 167–207.
Chen, J., 2006. Development of Chinese small and medium-sized enterprises. J. Small Bus. Enterp. Dev. 13 (2), 140–147.
Cohen, W.M., Levinthal, D.A., 1990. Absorptive capacity: a new perspective on learning and innovation. Adm. Sci. Q. 35 (1), 128–152.
Cohen, J., Cohen, P., West, S., Aiken, L., 2003. Applied Multiple Regression/Correlation Analysis for the Behavioral Sciences, 3rd ed. Lawrence Erlbaum Associates, Mahwah, NJ.
Colombo, M.G., Garrone, P., 1996. Technological cooperative agreements and firm's R&D intensity. A note on causality relations. Res. Policy 25 (6), 923–932.
Crawford, J., Leonard, L.N., Jones, K., 2011. The human resource's influence in shaping IT competence. Ind. Manage. Data Syst. 111 (2), 164–183.
Day, G.S., 1990. Market Driven Strategy: Processes for Creating Value. Free Press, New York.
Dickson, P.H., Weaver, K.M., Hoy, F., 2006. Opportunism in the R&D alliances of SMES: The roles of the institutional environment and SME size. J. Bus. Venturing 21 (4), 487–513.
Doloreux, D., 2004. Regional networks of small and medium sized enterprises: evidence from the Metropolitan Area of Ottawa in Canada 1. Eur. Plan. Stud. 12 (2), 173–189.
Foss, N.J., Laursen, K., Pedersen, T., 2011. Linking customer interaction and innovation: the mediating role of new organizational practices. Organiz. Sci. 22 (4), 980–999.
Griffin, A., Hauser, J.R., 1993. The voice of the customer. Mark. Sci. 12 (1), 1–27.
Gronum, S., Verreynne, M.L., Kastelle, T., 2012. The role of networks in small and medium-Sized enterprise innovation and firm performance. J. Small Bus. Manage. 50 (2), 257–282.
Gruner, K.E., Homburg, C., 2000. Does customer interaction enhance new product success? J. Bus. Res. 49 (1), 1–14.
Gu, Q., Wang, G.G., Wang, L., 2013. Social capital and innovation in R&D teams: the mediating roles of psychological safety and learning from mistakes. R&D Manage. 43 (2), 89–102.
Gumusluoglu, L., Ilsev, A., 2009. Transformational leadership, creativity, and organizational innovation. J. Bus. Res. 62 (4), 461–473.
Han, J.K., Kim, N., Srivastava, R.K., 1998. Market orientation and organizational performance: is innovation a missing link? J. Mark. 62 (4), 30–45.
Hanna, V., Walsh, K., 2002. Small firm networks: a successful approach to innovation? R&D Manage. 32 (3), 201–207.
Hansen, M.T., 1999. The search-transfer problem: the role of weak ties in sharing knowledge across organization subunits. Adm. Sci. Q. 44 (1), 82–111.
Hitt, M.A., Hoskisson, R.E., Ireland, R.D., 1994. A mid-range theory of the interactive effects of international and product diversification on innovation and performance. J. Manage. 20 (2), 297–326.
Hoecht, A., Trott, P., 2006. Innovation risks of strategic outsourcing. Technovation 26 (5), 672–681.
Hsueh, J.T., Lin, N.P., Li, H.C., 2010. The effects of network embeddedness on service innovation performance. Serv. Ind. J. 30 (10), 1723–1736.
Kajikawa, Y., Takeda, Y., Sakata, I., Matsushima, K., 2010. Multiscale analysis of interfirm networks in regional clusters. Technovation 30 (3), 168–180.
Katila, R., Shane, S., 2005. When does lack of resources make new firms innovative? Acad. Manage. J. 48 (5), 814–829.
Kaufmann, A., Tödtling, F., 2002. How effective is innovation support for SMEs? An analysis of the region of Upper Austria. Technovation 22 (3), 147–159.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003

Keil, T., Maula, M., Schildt, H., Zahra, S.A., 2008. The effect of governance modes and relatedness of external business development activities on innovative performance. Strateg. Manage. J. 29 (8), 895–907.
Kim, H., Kim, H., Lee, P.M., 2008. Ownership structure and the relationship between financial slack and R&D investments: evidence from Korean firms. Organiz. Sci. 19 (3), 404–418.
Kor, Y.Y., 2006. Direct and interaction effects of top management team and board compositions on R&D investment strategy. Strateg. Manage. J. 27 (11), 1081–1099.
Kuusisto, A., Riepula, M., 2011. Customer interaction in service innovation: seldom intensive but often decisive. Case studies in three business service sectors. Int. J. Technol. Manage. 55 (1), 171–186.
Laursen, K., Salter, A., 2004. Searching high and low: what types of firms use universities as a source of innovation? Res. Policy 33 (8), 1201–1215.
Laursen, K., Salter, A., 2006. Open for innovation: the role of openness in explaining innovation performance among UK manufacturing firms. Strateg. Manage. J. 27 (2), 131–150.
Le, S.A., Walters, B., Kroll, M., 2006. The moderating effects of external monitors on the relationship between R&D spending and firm performance. J. Bus. Res. 59 (2), 278–287.
Leitner, K.H., 2011. The effect of intellectual capital on product innovativeness in SMEs. Int. J. Technol. Manage. 53 (1), 1–18.
Li, D., Eden, L., Hitt, M.A., Ireland, R.D., 2008. Friends, acquaintances, or strangers? Partner selection in R&D alliances. Acad. Manage. J. 51 (2), 315–334.
Lin, B.W., Lee, Y., Hung, S.C., 2006. R&D intensity and commercialization orientation effects on financial performance. J. Bus. Res. 59 (6), 679–685.
Liu, J., Li, H., Xie, W., Bao, J., 2012. Shanghai Is Becoming a Pioneer in Industrial Transformation of China. Renmin Daily.
Lowik, S., Van Rossum, D., Kraaijenbrink, J., Groen, A., 2012. Strong ties as sources of new knowledge: how small firms innovate through bridging capabilities. J. Small Bus. Manage. 50 (2), 239–256.
Morbey, G.K., 1988. R&D: its relationship to company performance. J. Prod. Innovation Manage. 5 (3), 191–200.
Nath, P., Nachiappan, S., Ramanathan, R., 2010. The impact of marketing capability, operations capability and diversification strategy on performance: a resource-based view. Ind. Mark. Manage. 39 (2), 317–329.
Nieto, M.J., Santamaría, L., 2007. The importance of diverse collaborative networks for the novelty of product innovation. Technovation 27 (6), 367–377.
O'Regan, N., Kling, G., 2011. Technology outsourcing in manufacturing small-and medium-sized firms: another competitive resource? R&D Manage. 41 (1), 92–105.
Padgett, R.C., Galan, J.I., 2010. The effect of R&D intensity on corporate social responsibility. J. Bus. Ethics 93 (3), 407–418.
Parthasarthy, R., Hammond, J., 2002. Product innovation input and outcome: moderating effects of the innovation process. J. Eng. Technol. Manage. 19 (1), 75–91.
Pearce, J.L., Branyiczki, I., Bigley, G.A., 2000. Insufficient bureaucracy: trust and commitment in particularistic organizations. Organiz. Sci. 11 (2), 148–162.
Perry-Smith, J.E., 2006. Social yet creative: the role of social relationships in facilitating individual creativity. Acad. Manage. J. 49 (1), 85–101.
Peteraf, M.A., 1993. The cornerstones of competitive advantage: a resource-based view. Strateg. Manage. J. 14 (3), 179–191.
Prahalad, C., Hamel, G., 1990. The Core Competence of the Corporation. Springer, Berlin Heidelberg, Germany.
Reagans, R., Zuckerman, E.W., 2001. Networks, diversity, and productivity: the social capital of corporate R&D teams. Organiz. Sci. 12 (4), 502–517.
Sandberg, B., 2007. Customer-related proactiveness in the radical innovation development process. Eur. J. Innovation Manage. 10 (2), 252–267.
Sirmon, D.G., Hitt, M.A., Ireland, R.D., Gilbert, B.A., 2011. Resource orchestration to create competitive advantage breadth, depth, and life cycle effects. J. Manage. 37 (5), 1390–1412.
Song, M., Thieme, R.J., 2006. A cross-national investigation of the R&D-marketing interface in the product innovation process. Ind. Mark. Manage. 35 (3), 308–322.
Tether, B.S., 2002. Who co-operates for innovation, and why: an empirical analysis. Res. Policy 31 (6), 947–967.
Thorgren, S., Wincent, J., Örtqvist, D., 2009. Designing interorganizational networks for innovation: an empirical examination of network configuration, formation and governance. J. Eng. Technol. Manage. 26 (3), 148–166.
Tsai, K.H., Hsieh, M.H., Hultink, E.J., 2011. External technology acquisition and product innovativeness: the moderating roles of R&D investment and configurational context. J. Eng. Technol. Manage. 28 (3), 184–200.
Ulwick, A.W., 2002. Turn customer input into innovation. Harv. Bus. Rev. 80 (1), 91–97.
Uzzi, B., 1996. The sources and consequences of embeddedness for the economic performance of organizations: the network effect. Am. Sociol. Rev. 61 (4), 674–698.
Verona, G., 1999. A resource-based view of product development. Acad. Manage. Rev. 24 (1), 132–142.
Wang, G.G., Lamond, D., Zhang, Y., 2013. Innovation and Chinese HRM research and practice: problems and promises–introduction to editors' forum. J. Chin. Hum. Resour. Manage. 4 (2), 105–116.
Wernerfelt, B., 1984. A resource-based view of the firm. Strategic Manage. J. 5 (2), 171–180.
Wolff, J.A., Pett, T.L., 2000. Internationalization of small firms: an examination of export competitive patterns, firm size, and export performance. J. Small Bus. Manage. 38 (2), 34–47.
Wuyts, S., Dutta, S., Stremersch, S., 2004. Portfolios of interfirm agreements in technology-intensive markets: consequences for innovation and profitability. J. Mark. 68 (2), 88–100.
Yang, J., 2012. Innovation capability and corporate growth: an empirical investigation in China. J. Eng. Technol. Manage. 29 (1), 34–46.
Zeng, S.X., Xie, X.M., Tam, C.M., 2010. Relationship between cooperation networks and innovation performance of SMEs. Technovation 30 (3), 181–194.

Please cite this article in press as: Q. Gu, et al., Effects of external and internal sources on innovation performance in Chinese high-tech SMEs: A resource-based perspective, J. Eng. Technol. Manage. (2016), http://dx.doi.org/10.1016/j.jengtecman.2016.04.003