R&D COOPERATION, FINANCIAL CONSTRAINT AND INNOVATION PERFORMANCE

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SUMMARY

This study investigates whether, and with whom, R&D cooperation can alleviate the adverse influence of financial constraint on firms' innovation performance. Specifically, three different types of R&D cooperation are considered in the study: cooperation with suppliers, with customers and with research institutes. Using the data of manufacturing firms from the Chinese Enterprise Survey, we find that R&D cooperation can effectively improve innovation performance when firms are facing financial constraints. Furthermore, we find that R&D cooperation with customers is more effective than cooperation with suppliers and research institutes in mitigating the negative effect of financial constraint on new product development, while R&D cooperation with suppliers is more effective than cooperation with customers and research institutes in improving technological processes. Overall, our findings provide direct evidence that R&D cooperation can be an effective strategy to improve innovation performance when firms face financial constraints.

It is well known that innovation is the key driver of economic development. Successful innovation depends not only on new knowledge in the innovation process, but also on sufficient financial support. More recently, a positive association between financial support and innovation has been well documented by a large number of studies (Xiao and Zhao, 2012; Doh and Kim, 2014; Hsu *et al*., 2014). However, some characteristics of the innovative activities, for instance, information asymmetry between innovators and investors, lack of collaterals and outcome uncertainty, make it difficult for firms to finance innovative activities from outside sources, which hinders R&D investment and thus innovation performance (Brown *et al*., 2012).

This study investigates whether, and with whom, R&D cooperation can be an effective strategy to alleviate the adverse influence of financial constraints on firms' innovation performance. Since the 1980s, R&D cooperation has been an important strategy in many sectors, particularly in biotechnology and information technology (Hagedoorn, 2002; Belderbosa *et al*., 2004). Several studies have explored the motivation of R&D cooperation from theoretical and empirical perspectives. Among the driving factors, obtaining financial resources is important in R&D cooperation. Basic research and technology development require a large input, for example, for purchasing special equipment and employing high quality research personnel (Miyata, 1996). Small and start-up firms may face difficulties in covering the costs using their internal financial resources. It is also difficult for them to finance R&D activities from capital markets due to asymmetric information (Miyata 1996; Bayona *et al*., 2001). Thus, alliance with larger firms is an effective strategy to obtain financial resources (Bayona *et al*., 2001). Also, R&D cooperation can provide positive signals to outside investors about the quality of R&D activities (Levitas and McFadyen, 2009), reducing asymmetric information between innovators and investors and help obtain funds in the capital market.

The literature about empirical studies also provides evidence supporting the positive association between insufficient financial resources and R&D cooperation. Staropoli (1998) shows

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that small biotechnology firms in the USA always require financial resources from pharmaceutical firms. Lerner *et al.* (2003) also show that small biotechnology firms in the USA opt to finance their R&D projects through contract research with larger firms, especially when external financial resources are unavailable. Bayona *et al.* (2001) find that firms lacking financial resources to carry out R&D activities are more willing to cooperate with others. In addition, Abramovsky *et al.* (2009), Becker and Dietz (2004) and Belderbosa *et al.* (2004) also find evidence supporting that financial constraint is an important determinant of R&D cooperation.

Despite considerable literature on the motivation for obtaining financial resources through R&D cooperation, few papers examine whether cooperative R&D can attenuate the adverse influence of financial constraint on the innovative activities of enterprises, except Czarnitzki and Hotten (2012). It is also unclear with whom is R&D cooperation more effective in relieving the influence of financial constraint. In this study, we investigate whether R&D cooperation can be an effective strategy in alleviating the negative effect of financial constraint on innovation performance. We also investigate the role that different types of R&D cooperation partners play in innovative activities when firms face financial constraints. Specifically, we consider three types of R&D cooperation in this study: cooperation with suppliers, customers and research institutes. Similar to Zeng *et al.* (2010), in this study we consider two types of innovation performance: product and process innovation performance. The former measures firms' innovation performance in new product development and, the latter measures innovation performance in improving technological processes.

Using the data from the Chinese Enterprise Survey, carried out by the World Bank between December 2011 and February 2013, we find that financial constraint is indeed the stumbling block of manufacturing firms innovation activities, while cooperating with others in R&D activities can help innovative firms to effectively alleviate this adverse influence. Furthermore, we find that cooperation with customers is more effective than cooperation with suppliers and research institutes in mitigating the negative effect of financial constraint on new product development, while cooperation with suppliers is more effective than with customers and research institutes in improving technological processes. Overall, our findings provide direct evidence that cooperative R&D can be an effective strategy to alleviate the influence of financial constraint on the innovation performance of firms. The findings also provide policy implications for innovative firms when implementing specific R&D cooperation strategies in different types of innovative activities.

Related Literature Review

R&D cooperation driven by financial constraints

In the past decades, R&D cooperation has been an important strategy in many sectors. Considerable literature has explored the motivations of R&D cooperation from theoretical and empirical perspectives. In this section, we only review the literature related to R&D cooperation driven by seeking outside financial resources.

Innovative firms, especially small firms and start-ups, often face financial constraints in their innovation activities because of insufficient internal funds and the difficulty to access external funds (Hall 2002; Brown *et al.*, 2012). To alleviate the influence of financial constraints on innovation activities, innovative firms cooperate with others. The cooperative R&D strategy can help financial constrained innovative firms obtain financial resources from partners directly. Staropoli (1998) notes that USA-based biotechnology and pharmaceutical firms play complementary roles. Small biotechnology firms require financial resources from pharmaceutical firms, while pharmaceutical firms wish to have access to their high-level research facilities. The motivation of seeking financial support motivates biotechnology firms to cooperate with large pharmaceutical firms. Also in the USA, Lerner *et al.* (2003) find that small biotechnology firms are likely to finance their R&D projects through cooperation with large pharmaceutical firms funds from the public markets are not available to them. Using data from the second European Community Innovation Survey (CIS-2), Tether (2002) finds that firms complaining of difficulties with both economics and financing of innovation are more likely to engage in cooperative R&D and reach agreements with different types of partners.

Cooperative R&D can also help innovative firms share R&D costs when they cannot find sufficient financial resources to cover them. Hagedoorn (1993) points out that in the generation of new products for sectors such as heavy electrical equipment, telecommunication systems and aviation, the manufacture of expensive capital goods is very costly. In this case, the necessary capital is frequently obtained through alliances with larger companies. Miyata (1996) finds that individual firms are willing to cooperate with others when R&D resources are costly. Through R&D cooperation, a partner can share costs and use expensive equipment or hire high quality research personnel, increasing the probability of successful innovation. Bayona *et al.* (2001) also find that R&D cooperation can help individual firms avoid the duplication of unnecessary R&D efforts and thus overcome the lack of financial resources.

Besides obtaining financial resources from partners or save in R&D costs directly, cooperating with others in R&D activities can also provide successful signals to the capital market, reducing the asymmetric information and helping innovative firms obtain financial resources. Using a sample of USA biotechnology firms, Levitas and McFadyen (2009) investigated how the signaling properties of a firm's R&D cooperation strategy might attenuate financial constraints. They find that R&D cooperation strategy provides important signaling mechanisms that reduce the asymmetric information between firms and the capital market, and reduce the firms financial constraints. Piga and Atzeni (2007) also find that through R&D cooperation, small and medium sized enterprises not only reduce their costs of R&D projects but also become more successful in accessing the credit market.

Cooperative R&D and innovation effect

Theoretical studies on industrial organization shed light on the role that technology spillover plays in cooperative R&D. Such studies point out that there exists an involuntary technology spillover in R&D activities, which may increase the technology stock and thereby the strength of competitors. In this case, innovative firms have less incentive to engage in R&D investment, since they cannot appropriate all the return. Cooperative R&D, however, can reduce the negative effect of technology spillover on R&D investment by internalizing technology spillover. So, innovative firms can benefit from R&D cooperation by eliminating the free-rider problem in R&D activities (d'Aspremont and Jacquemin, 1988; Leahy and Neary, 1997; Suzumura, 1992; Amir *et al.*, 2003).

Studies on the management domain explain the motivation of

R&D cooperation from a broader perspective. The main motivations for cooperative R&D include sharing R&D costs and seeking financial resources when firms face financial constraint (Miyata, 1996; Bayona *et al.*, 2001; Tether, 2002); pursuing economies of scale or synergistic effects by pooling complementary resources and skill (Hagedoorn 1993; Das and Teng 2000); obtaining high-level technology support and increasing the successful probability of R&D (Miotti and Sachwald, 2003); creating and/or diffusing new knowledge through inter-organizational interaction (Mowery *et al.*, 1996; Kastelli *et al.*, 2004) and; handling industry standards and government subsidy programs (Nakamura 2003).

Despite the numerous motivations for R&D cooperation, different types of cooperation may serve different purposes and have different effects. Horizontal cooperation (with competitors) may not only aim to internalize the technology spillover, but also pooling the technology and sharing the R&D costs and risks (Miyata 1996; Miotti and Sachwald, 2003), while vertical cooperation (with suppliers or customers) is believed to reduce the transaction costs in studies of industrial organization domain (Teece 1986). In the management sphere, vertical cooperation with suppliers is thought to guarantee the quality of inputs or reduce costs by improving technological processes (Hagedoorn, 1993), while vertical cooperation with customers can help firms reduce the risk associated with introduction of new products (Tether 2002). Firms cooperating with research institutes and universities seek high-level technology and to increase probability of successful innovations (Miotti and Sachwald, 2003).

The literature also provides evidence supporting the positive link between R&D cooperation and its innovation effect. Becker and Dietz (2004) use the data from the first wave of the Mannheim Innovation Panel in Germany and find that cooperative R&D not only improves firms' innovation performance but also enhances the in-house R&D input. Belderbos *et al.* (2004) use two waves of the Community Innovation Survey in the Netherlands and find that cooperation with suppliers and competitors can effectively improve firms' productivity performance, while cooperation with competitors and universities can help to improve growth performance. Faems *et al.* (2005) use the data from the latter survey in Belgium and find that cooperation with universities can effectively enhance innovation performance in new product development. Zeng *et al.* (2010) examine a similar relation using the data of 137 Chinese manufacturing small and medium enterprises (SMEs) and find that cooperative R&D has a significant positive impact on innovation performance of SMEs. Moreover, they also find that vertical cooperation plays a more important role than horizontal cooperation and cooperation with universities or research institutes in SMEs. Czarnitzki and Hotten (2012) use data from an OECD R&D survey and find that vertical cooperation and cooperation with research institutes can attenuate the dependence of R&D investment on working capital (the proxy of firms' liquidity), but they don't observe that horizontal cooperation has the same effect.

In summary, the existing literature shows that financial constraint play a critical role in R&D cooperation. Through cooperation in R&D activities, innovative firms can obtain financial resources from partners directly, or provide good signals to reduce asymmetric information and obtain financial resources from the capital market. Previous literature also provides evidence that cooperative R&D can increase R&D investment and innovation performance. This study expands the related literature by examining whether, and with whom, R&D cooperation can improve innovation performance by attenuating financial constraints. Our study is close to that of Czarnitzki and Hotten (2012), where they explore similar relations by examining the sensitivity of R&D investment to the firms' liquid assets. In our study, we examine innovation output instead of innovation input, as Czarnitzki and Hotten (2012) do. Moreover, our data provide information on the firms financial constraints, which can help examine the aforementioned relation directly.

Methodology

Empirical strategy

The goal of this study is to examine whether cooperative R&D can be an effective strategy to mitigate the negative effect of financial constraint on innovation performance. To achieve the goal a regression model is formulated in Eq. 1.

$$\text{Innovation performance}_i = \beta_0 + \beta_1 \cdot \text{Financial constraints}_i + \beta_2 \cdot \text{Financial constraints}_i \cdot \text{R\&D cooperation}_i + \beta_3 \cdot \text{R\&D cooperation}_i + \beta_4 \cdot \text{R\&D intensity}_i + \beta_5 \cdot \text{Size}_i + \beta_6 \cdot \text{Group}_i + \beta_7 \cdot \text{Managerial innovation}_i + \beta_8 \cdot \text{Staff train}_i + \beta_9 \cdot \text{Industry dummies}_{i,j} + \varepsilon_i \quad (1)$$

In the model, we use the interaction between 'Financial constraints' and 'R&D cooperation' to examine the effect of R&D cooperation on innovation performance in financially constrained firms. A significant and positive coefficient on the interaction implies that cooperative R&D can effectively attenuate the negative influence of financial constraints on innovation performance.

However, the determinants of the innovation performance of the firms depend to some extent on the probability of the firm engaging in R&D activities. Factors explaining innovation performance may not be same according to whether the firm engages in R&D activities or not. Thus, there may be a potentially biased selection in examining whether cooperative R&D can alleviate the negative effect of financial constraint on innovation performance, and ignoring this bias may result in misleading results. To handle the potential selection bias, we follow Heckman (1979) procedure and use a two-stage approach in the regression. In the first stage, it is predicted whether a firm engages in R&D activities. A firm is assumed to engage in R&D activities if it meets the following condition, i.e., R&D dummy=1 if

$$\alpha_0 + \alpha_1 \cdot \text{Size}_i + \alpha_2 \cdot \text{State controlled}_i + \alpha_3 \cdot \text{Debt}_i + \alpha_4 \cdot \text{Competition}_i + \alpha_5 \cdot \text{Export}_i + r_i > 0 \quad (2)$$

In the second stage, the inverse Mills ratio obtained from the first stage regression is introduced into Eq. 1 to address potential selection bias, and then the new model is used to estimate the effect of cooperative R&D on innovation performance when a firm faces financial constraints.

Sample and variables

The data used for this study was drawn from the Chinese Enterprise Survey (December 2011 - February 2013), which collects data from key manufacturing and service sectors. Through the survey, the constraints to private sector growth and statistically significant business environment can be assessed. The survey follows a stratified random sampling methodology and uses standardized survey instruments and uniform methodology to minimize the measurement error. It collects data from 2700 privately owned and 148 state-owned firms with a restriction on minimum firm size, where the size is defined by the number of employees and set at five for all the industries. The questionnaire contains information of firms' innovation, including whether the firm carries out R&D activities or contracts with other

companies; the different types of partners for R&D cooperation; R&D expenditure; percent of sales accounted for by new products; percentage of production volume associated with new processes; and information on finance, competition and labor; and some basic information about the characteristics of the firms. The information allowed us to examine the role that R&D cooperation plays in attenuating the influence of financial constraints on the innovation performance of the firms.

In this study, all the firms in service sectors were eliminated because the questionnaire for this sector does not contain information about the types of cooperation partners, which is a key information. The state-owned firms were also eliminated since these firms do not show to what industry they belong. Thus, only manufacturing firms in the sample were considerted. In addition, we also discarded all the firms in the sample from which data was missing. As a result, a total of 986 firms were included in the study. Table I shows their sectoral distribution.

The variable 'Innovation performance' was measured by the percent of annual sales accounted for by new products and percentage of production volume associated with new processes. The former measures innovation performance of the firm in new product development (product innovation), while the latter represents the innovation performance in improving the technological processes (process innovation). As reported in Table II, only 549 of 986 firms report information on product innovation and the average percent of annual sales accounted for by new products was 24.4%. Only 940 firms report information about process innovation and the average percentage of production volume associated with new processes is 20%.

TABLE I
SECTORAL DISTRIBUTION OF FIRMS IN THE SAMPLE

Sector	Number of firms	Percent of sample
Food	102	10.34%
Textiles	75	7.61%
Garments	64	6.49%
Leather	7	0.71%
Wood	3	0.30%
Paper	9	0.91%
Recorded media	9	0.91%
Refined petroleum product	3	0.30%
Chemicals	98	9.94%
Plastics and rubber	87	8.82%
Non metallic mineral products	95	9.63%
Basic metals	61	6.19%
Fabricated metal products	106	10.75%
Machinery and equipment	80	8.11%
Electronics	93	9.43%
Precision instruments	9	0.91%
Transport machines	74	7.51%
Furniture	7	0.71%
Recycling	4	0.41%
Total	986	100.0%

TABLE II
DESCRIPTIVE STATISTICS OF THE MAIN VARIABLES

Variables	N	Mean	SD	Min	Max
Product innovation	549	0.244	±0.187	0.010	1
Process innovation	940	0.200	±0.177	0	1
Financial constraint	986	0.596	±0.491	0	1
R&D intensity	986	0.027	±0.071	0	0.769
Size	986	4.509	±1.280	1.609	10.309
Managerial innovation	986	0.536	±0.499	0	1
Staff train	986	0.807	±0.395	0	1
Group	986	0.105	±0.307	0	1
Competition	986	2.519	±0.824	0	3
Age	986	4.636	±0.073	4.500	5.371
State controlled	986	0.063	±0.243	0	1
Debt	986	0.352	±0.478	0	1
Export	986	0.161	±0.368	0	1

We constructed a dummy variable to measure the 'Financial constraints'. In the survey, the questionnaire asked 'To what degree is access to finance an obstacle to the current operations of this establishment?', the response option was from 0 to 4 and represents from no obstacle to very severe obstacle to access to financing. Using this option we constructed the 'Financial constraints' dummy variable, which takes the value of 0 if the firm has no obstacle to access to finance, and equals 1 otherwise. The descriptive statistics in Table II show that 59.6% of firms had obstacles to access to funds.

We introduced several dummy variables to define different types of R&D cooperation. In the survey, the questionnaire asked 'In what ways has this establishment introduced new products or services?' and 'In what ways has this establishment introduced new or improved processes?', which allowed to distinguish cooperation in product innovation from cooperation in process innovation and obtain the unbiased estimated result of R&D cooperation on different innovation performances. In this paper, R&D cooperation variables take the value of 1 if the firm cooperates with suppliers, customers and research institutes in product innovation and process innovation. We also introduced two general R&D cooperation dummy variables, which equal 1 if a firm cooperates with others, as partners, in product innovation or in process innovation. Different from the reviewed literature, this study does not consider the cooperation with competitors, since data is not available. As reported in Table III, only 53.2% of firms cooperate with others when developing a new product, while 59.3% of firms cooperate with others when improving technological processes, whatever the partners. Particularly, when developing a new product, 25.7% of firms cooperate with suppliers, 36.7% of them cooperate with customers and 26.8% cooperate with research institutes. Improving technological processes, 32.9% of firms cooperate with suppliers, 35.3% cooperate with customers and 23.5% cooperate with research institutes. Table III also shows that financially constrained firms are more likely to use cooperative R&D strategies when developing a new product, while financially constrained firms are only more likely to cooperate with research institutes in order to improve technological processes.

TABLE III
DESCRIPTIVE STATISTICS OF R&D COOPERATION

	Full sample	Financially non-constrained firms	Financially constrained firms	Wilcoxon's Z test
Cooperation in product innovation				
General R&D cooperation	0.532	0.479	0.569	-2.788 **
Cooperation with suppliers	0.257	0.190	0.302	-3.917 **
Cooperation with customers	0.367	0.330	0.392	-1.949
Cooperation with research institutes	0.268	0.211	0.307	-3.344 **
Cooperation in process innovation				
General R&D cooperation	0.593	0.566	0.634	-2.148 *
Cooperation with suppliers	0.307	0.308	0.307	0.054
Cooperation with customers	0.340	0.330	0.346	-0.488
Cooperation with research institutes	0.305	0.248	0.344	-3.211 **

*, ** Significant at 5% and 1% level, respectively.

We also included 'R&D intensity', 'Staff train', 'Managerial innovation,' 'Group' and 'Size' in the second stage regression. 'R&D intensity' captures the information on the firms R&D input, as it has been well documented that R&D input has an important influence on the firms' innovation performance. In this paper, 'R&D intensity' is the ratio of average R&D expenditure in past three years to the firm's total sales. 'Staff train' reflects the firm input from human the capital perspective, which has also been documented in the literature as having significant effect on innovation performance. We constructed a dummy to measure the 'Staff train; variable, which equals 1 if a firm provided technology training for its staff in the past three years, and 0 otherwise. The 'Group' variable captures information about whether the firm belongs to a group. Being a member of a group may lead to pooled resources and increased intragroup synergies, and hence higher innovation performance (Beers and Zand, 2014). In this study, 'Group' is a dummy variable, which equals 1 if a firm belongs to a part of a larger firm, and is 0 otherwise. The 'Managerial innovation' is also a dummy variable, which equals 1 if a firm has introduced new managerial processes in the past three years, and 0 otherwise. Managerial innovation is expected to improve innovation performance since good managerial processes can increase efficiency in innovation. The 'Size' variable is measured by the natural logarithm of the number of employees in the firm; it is expected to influence innovation performance positively, as larger firms always innovate more than smaller firms due to the availability of more financial resources (Beers and Zand, 2014). We also controlled the variation in innovation patterns across different industries in the model by using 'Industry dummies' that equal 1 if firm i belongs to industry j, and 0 otherwise.

In the first stage regression, we used the 'R&D dummy' variable to capture information of whether a firm engages in R&D activities. The questionnaire asked, 'In the last three years, did this establishment spend on research and development activities within the establishment?'. We let the R&D dummy equal 1 if the firm undertook R&D activities and 0 otherwise. We included the firm size in the first stage regression. It is believed that economies of scale exist in R&D activity, and empirical literature (e.g., Shefer and Frenkel, 2005) also provides evidence that investment in R&D is positively associated with firm size. The 'State controlled' variable was used to control the influence of ownership on R&D activity. Bruton *et al.* (2015) point out that the focus of government is on the maintenance of social concerns rather than firm efficiency; as a result, state controlled firms may give up innovation in order to maximize production and maintain employment. Zhang *et al.* (2003) also find evidence that "State controlled" firms have significantly lower R&D investment and productive efficiency than non-state-controlled firms in China. Here, State controlled is a dummy variable that takes a value of 1 if the firm's largest owner is the government or state, and equals 0 otherwise. David *et al.* (2008) note that the influence of debt on R&D investment is ambiguous. They find that the transactional debt imposes strict contractual constraints on innovators and provides inappropriate governance for R&D activity, while relational debt provides more appropriate governance and improve R&D investment. Therefore, we included the *'Debt'* variable in the first stage regression. It is also a dummy variable, which takes value of 1 if the firm has a line of credit or loan from a financial institution, and equals 0 otherwise.

Additionally, we controlled the influence of competition on R&D activity. Previous studies (e.g., Aghion *et al.*, 2005; Vives 2008; Gorodnichenko *et al.* 2010) find evidence that competition has an important influence on firms R&D activity and innovation. We used three 'Competition dummies' to capture the information on domestic competition of the firms, which equals 1 if the domestic competitors are ≤7, 2 if they are between 7 and 100, and 3 if they are >100. We also constructed a dummy variable to measure the international competition of the firms, which takes a value of 1 if a firm exported any product in 2011, and 0 if there was no export product.

Empirical Results

Effects of R&D cooperation on the relation between financial constraint and innovation performance

In this section we examine whether general R&D cooperation can attenuate the negative effect of financial constraint on the firms innovation performance. To avoid the potential selection bias mentioned above, the Heckman two-stage estimation procedure was employed. The estimated result of first stage regression is reported in Table IV.

The results show that the larger firms have a higher probability to engage in R&D activities. This is consistent with Shefer and Frenkel (2005), confirming that the existence of economies of scale in R&D activities leads large firms to have more incentives to invest in R&D projects, while the significant negative coefficient on the 'State controlled' variable implies that firms controlled by government are less likely to engage in R&D activities. This result is consistent with Zhang *et al.* (2003). A possible explanation, as Bruton *et al.* (2015) point out, is that those firms controlled by the government or state in China undertake more social responsibility and their profits are guaranteed by the government, which may result in less incentives for state controlled firms to invest in R&D projects. Results also show that firms that obtained credits from financial institutes have a higher probability to engage in R&D activities. Relational debt, as argued by David *et al.* (2008), can provide more appropriate governance and motivate firms to engage in R&D activities. As to the competition variables, results show that firms that face severe domestic competition are less likely to engage in R&D activities, while firms that face international competition have more incentives to invest in R&D projects. This result is consistent with Gorodnichenko *et al.* (2010), who find that globalization or international competition improves firms' R&D investment and innovation, while the negative relation between domestic competition and R&D activity, according to Dasgupta and Stiglitz (1980), can be attributed to the fact that too much competition reduces the monopoly rent of successful innovators, and thus motivation to engage in R&D activities.

Next we examined the effect of R&D cooperation on the relation between financial constraint and innovation performance. Table V reports results

TABLE IV
REGRESSION RESULTS OF THE FIRMS DECISION TO ENGAGE IN R&D ACTIVITIES

Variables	Coefficients
Size	0.167 ±0.035 **
State controlled	-0.904 ±0.216 **
Debt	0.442 ±0.090 **
Competition (>7 - ≤100 competitors)	0.080 ±0.186
Competition (>100 competitors)	-0.204 ±0.102 *
Export	0.472 ±0.120 **
Constant	-0.861 ±0.181 **
Log likelihood	-616.69
LR chi^2	130.76 **
Pseudo R^2	0.096
N	986

*, ** Significant at 5% and 1% level, respectively. Coefficients ±SE.

of the second stage regression for general R&D cooperation on two types of innovation performance. Columns 1 and 3 only consider the effect of financial constraint and other control variables on firms' innovation performance, and columns 2 and 4 introduce the interaction between 'Financial constraints' and 'R&D cooperation' to examine whether cooperative R&D influences innovation performance in financial constrained firms. As seen in Table V, the Wald test of rho is always significant at the 1% level, indicating that there is indeed a selection bias in the second stage regression and the use of the Heckman technique is appropriate in this study.

In Table V, the coefficients on the 'Financial constraint' variable are significant and negative across all the specifications, indicating that financially constrained firms have a worse performance both in new product innovation and process innovation than non-financially- constrained firms. The result is in line with Brown *et al.* (2012) and Czarnitzki and Hotten (2012), confirming that insufficient financial resources result in less R&D expenditure in financially constrained firms and thereby decreases performance both in new product and process innovation. However, the results of Table V show that the coefficients of 'R&D cooperation' across all specifications are not significant. This result is different from those of Becker and Dietz (2004) and Zeng *et al.* (2010), in which R&D cooperation has a significant positive association with firms' R&D innovative activities and innovation performance, implying that cooperative R&D cannot affect directly the innovation performance in the firms of our sample, while the coefficients for the interaction between 'Financial constraints' and 'R&D cooperation' are significant and positive (columns 2 and 4), indicating that firms that cooperated with others in R&D activities have better performances than those without such cooperation, both in new product and in process innovation when facing financial constraints. This result can be interpreted in the sense that cooperative R&D effectively alleviates the adverse influence of financial constraint on innovation performance. Cooperative R&D, as Lerner *et al.* (2003), Levitas and McFadyen (2009), Staropoli (1998) and, Tether (2002) note, can help financially constrained innovative firms obtain resources directly from partners or finance their innovative projects at the capital market indirectly, by reducing asymmetric information. The reduction of financial pressure improves fR&D investment and innovation performance. Thus, although we don't find significant evidence that R&D cooperation favors innovation performance directly, cooperative R&D can improve the innovative performance indirectly by alleviating the negative influence of financial constraint on innovative performance, which implies that R&D cooperation can be an effective strategy for innovative firms to improve innovation when facing financial constraints.

As to the other control variables, the significant positive coefficients on 'R&D intensity' in all four columns indicate that the larger the R&D expenditure is, the better is the performance in both product and process innovation. This result is consistent with Belderbos *et al.* (2004) and Beers and Zand (2014), indicating that better innovation performance needs new knowledge input. However, the coefficients on 'Staff train' are only significant in columns 1 and 2, implying that technology training for the staff has a more significant effect in product innovation than in process innovation. The result also shows that size affects innovation performance negatively. This is inconsistent with Beers and Zand (2014), and can be attributed to the fact that larger firms can benefit from their monopoly position and thus have less incentives to develop new products and improve their technological processes. Finally, the 'Group' and 'Managerial innovation' variables were found to have no influence on innovation performance.

Effects of cooperation partners on the relation between financial constraint and innovation performance

Besides the influence of R&D cooperation on the relation between financial constraint and innovation performance, we also explored with whom is the innovative firms' R&D cooperation effective in relieving the adverse influence of financial constraint on innovation performance. Previous literature (e.g., Miotti and Sachwald, 2003; Belderbos *et al.*, 2004) point out that innovative firms usually select different partners in R&D activities for special purposes. We looked at which type of R&D cooperation (with suppliers, customers and research institutes) is more effective when firms face financial constrains. As it was done with the general R&D cooperation in the models discussed above, we interacted financial constraint with suppliers, customers and research institutes cooperation. The main results are shown in Table VI.

Columns 1 to 3 of Table VI report the effects of three types of R&D cooperation on firms' performance in product innovation. Among the three types of R&D cooperation, only the interaction in firms that cooperate with customers shows a positive and significant coefficient. This indicates that cooperation with customers is more effective than cooperation with suppliers and research institutes in improving the firm performance in product innovation in the case of finan-

TABLE V
REGRESSION RESULTS OF GENERAL R&D COOPERATION ON FINANCIAL CONSTRAINT AND INNOVATION PERFORMANCE

Variables	Product Innovation		Process Innovation	
	(1)	(2)	(3)	(4)
Financial constraint	-0.041 ±0.017 **	-0.115 ±0.028 **	-0.037 ±0.012 **	-0.083 ±0.018 **
Financial constraints for R&D coop.		0.102 ±0.039 **		0.077 ±0.023 **
R&D cooperation	0.029 ±0.017	0.043 ±0.035	0.016 ±0.011	0.029 ±0.018
R&D intensity	0.476 ±0.078 **	0.473 ±0.078 **	0.246 ±0.073 **	0.239 ±0.075 **
Size	-0.021 ±0.007 **	-0.020 ±0.007 **	-0.017 ±0.006 **	-0.017 ±0.006 **
Staff train	0.081 ±0.022 **	0.084 ±0.022 **	0.003 ±0.014	0.003 ±0.014
Managerial innovation	0.023 ±0.019	0.024 ±0.019	0.019 ±0.012	0.017 ±0.012
Group	0.014 ±0.024	0.004 ±0.024	0.015 ±0.019	0.007 ±0.019
Constant	0.151 ±0.040 **	0.200 ±0.046 **	0.095 ±0.032 **	0.126 ±0.033 **
Industry control	Yes	Yes	Yes	Yes
Wald test of rho=0(chi2=1)	84.61 **	80.23 **	16.40 **	16.68 **
Log likelihood	-202.167	-196.339	-138.013	-134.127
N	549	549	940	940

*, ** Significant at 5% and 1% level, respectively. Coefficients ±SE.

TABLE VI
REGRESSION RESULTS OF DIFFERENT TYPES OF COOPERATION PARTNER ON FINANCIAL CONSTRAINTS AND INNOVATION PERFORMANCE

Variables	Product Innovation			Process Innovation		
	Cooperation with suppliers	Cooperation with customers	Cooperation with research institutes	Cooperation with suppliers	Cooperation with customers	Cooperation with research institutes
	(1)	(2)	(3)	(4)	(5)	(6)
Financial constraint	-0.036 ±0.018**	-0.070 ±0.023**	-0.057 ±0.019**	-0.057 ±0.013)**	-0.046 ±0.015**	-0.029 ±0.013 **
Financial constraints for R&D coop.	-0.029 ±0.038	0.068 ±0.032*	0.041 ±0.035	0.067 ±0.025*	0.024 ±0.023	-0.036 ±0.026
R&D cooperation	0.081 ±0.032*	-0.018 ±0.028	-0.01 ±0.030	-0.013 ±0.019	-0.01 ±0.019	0.051 ±0.021*
R&D intensity	0.494 ±0.080**	0.508 ±0.081**	0.475 ±0.082**	0.248 ±0.073**	0.259 ±0.074**	0.223 ±0.073**
Size	-0.021 ±0.007**	-0.020 ±0.007**	-0.021 ±0.007**	-0.017 ±0.006**	-0.017 ±0.006**	-0.017 ±0.006**
Staff train	0.077 ±0.022**	0.080 ±0.022**	0.085 ±0.022**	0.003 ±0.014	0.005 ±0.015	0.007 ±0.014
Managerial innovation	-0.019 ±0.018	-0.022 ±0.020	-0.022 ±0.019	0.017 ±0.012	0.022 ±0.013	0.018 ±0.012
Group	0.014 ±0.024	0.009 ±0.024	0.013 ±0.024	0.009 ±0.019	0.013 ±0.019	0.016 ±0.019
Constant	0.151 ±0.040**	0.170 ±0.041**	0.172 ±0.040**	0.110 ±0.032**	0.105 ±0.032**	0.089 ±0.032**
Industry control	Yes	Yes	Yes	Yes	Yes	Yes
Wald test of rho=0(chi2=1)	14.83**	18.93**	16.74**	78.08**	81.12**	85.46**
Log likelihood	-131.876	-136.787	-138.12	-198.741	-202.552	-199.446
N	549	549	549	940	940	940

*, ** Significant at 5% and 1% level, respectively. Coefficients ±SE.

cial constraints. This finding can be explained from two angles. First, vertical R&D cooperation can provide firms more information about the market and the demand of costumers, so cooperation with customers can help firms reduce the risk associated with new product development (Belderbos *et al.* 2004) and enhance innovation efficiency when R&D resources are limited. It may be a good signal to the capital market (Levitas and McFadyen 2009), helping firms obtain financial resources more easily and relieve the negative effect of financial constraint on innovation performance. Secondly, customers can benefit from vertical R&D cooperation since cooperative R&D can enhance the competitive strength of the total supply chain; thus, they have incentives to provide financial support to their upstream firms when these firms face financial constraints.

Columns 4 to 6 of Table VI report the results of R&D cooperation with different types of partners on performance in process innovation. In contrast with the prevous situation, the influence of three types of R&D cooperation in process innovation is different. The results show that the interaction coefficient between 'Financial constraints' and 'R&D Cooperation' is only significantly positive in firms that cooperate with suppliers. Cooperation with suppliers is more effective than cooperation with customers and research institutes in alleviating the adverse influence of financial constraints on process innovation. This may be attributed to the fact that cooperation with suppliers can guarantee the quality of input and reduce costs by improving technological processes (Belderbos *et al.* 2004, Hagedoorn 1993). Therefore, innovative firms have incentives to cooperate with suppliers when improving processes, which in turn enhances their performance in process innovation.

Comparing the effects of the three types of R&D cooperation on new product innovation performance with the performance in improving technological processes, we find that different cooperation partners play distinct roles in relieving adverse influence of financial constraint on the innovation activities of the firms. This is similar to Belderbos *et al.* (2004) and Czarnitzki and Hotten (2012), indicating that innovative firms should select appropriate cooperation partners in different innovation activities when facing financial constraints.

Conclusions

It has been well documented that financial constraint is an important obstacle for firms' innovation, and that innovative firms usually cooperate with others so as to alleviate the influence of financial constraints on innovative activities. However, the issue of whether and with whom R&D cooperation can attenuate such negative effects of financial constraint is still unclear. In this study, we contribute to the existing studies by investigating the role that cooperative R&D plays in innovative activities when firms face financial constraints. Specifically, we consider three types of R&D cooperation, with suppliers, customers and research institutes, and examine the influence of three types of R&D cooperation on the performance in product innovation and process innovation.

Using data of manufacturing firms from the Chinese Enterprise Survey, we find that financial constraints have significant negative effect on performance both, in product innovation and process innovation. It is consistent with previous literature (e.g., Brown *et al.* 2012) that insufficient financial resources impedes firms' innovation activities. Fortunately, we find that cooperative research can effectively improve innovation performance when firms face financial constraints, providing direct evidence that R&D cooperation can be an effective strategy to mitigate the negative influence of financial constraint on firms' innovative performance. Evidence is also provided in support of the viewpoint that seeking financial resources is a key motivation of R&D cooperation from a new perspective. In addition, we find that cooperation with customers is more effective than cooperation with suppliers and research institutes in new product development, while cooperation with suppliers is more effective in process innovation. The results imply that cooperation partners play different roles in relieving the pressure of financial constraint and improving innovation activities. It also provides important policy implications for innovative firms when implementing specific R&D cooperation strategies in different types of innovative activities.

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COOPERACIÓN EN I+D, LIMITACIONES FINANCIERAS Y REDIMIENTO INNOVATIVO

Ma Rufei, Ding Hao y Zhai Pengxiang

RESUMEN

Este estudio investiga si la cooperación en I+D, y con quienes, alivia la influencia adversa de las limitaciones financieras en el rendimiento innovativo de las empresas. Específicamente, tres tipos diferentes de coperación en I+D son consideradas en el estudio: cooperación con suplidores, con clientes y con instituciones de investigación. Usando data sobre empresas manufactureras del Chinese Enterprise Survey *se encontró que la cooperación en I+D puede mejorar de manera efectiva el rendimiento innovativo cuando las empresas enfrentan limitaciones financieras. Más aún, se halló que la cooperación en I+D con consumidores es más efectiva que aquella con suplidores e instituciones de investigación para mitigar los efectos negativos de la limitación financiera en el desarrollo de nuevos productos innovativos, mientras que la cooperación en I+D con suplidores es más efectiva que aquella con consumidores e instituciones de investigación en la mejora de procesos tecnológicos. En general, los resultados proveen evidencias de que la cooperación en I+D puede ser una estrategia efectiva para mejorar el rendimiento innovativo cuando las empresas enfrentan limitaciones financieras.*

COOPERAÇÃO EM I+D, LIMITAÇÕES FINANCEIRAS E REDIMENTO INOVADOR

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RESUMO

Este estudo investiga se, e com quem, a cooperação em I+D, alivia a influência adversa das limitações financeiras no rendimento inovador das empresas. Especificamente, três tipos diferentes de cooperação em I+D são consideradas no estudo: cooperação com fornecedores, com clientes e com instituições de investigação. Utilizando informação sobre empresas manufatureiras do Chinese Enterprise Survey *se observou que a cooperação em I+D pode melhorar, de maneira efetiva, o rendimento inovador quando as empresas enfrentam limitações financeiras. Ainda, se encontrou que a cooperação em I+D com consumidores é mais efetiva que aquela com fornecedores e instituições de investigação para mitigar os efeitos negativos da limitação financeira no desenvolvimento de novos produtos inovadores, enquanto que a cooperação em I+D com supridores é mais efetiva que aquela com consumidores e instituições de investigação na melhora de processos tecnológicos. Em geral, os resultados fornecem evidências de que a cooperação em I+D pode ser una estratégia efetiva para melhorar o rendimento inovador quando as empresas enfrentam limitações financeiras.*