

The impact of collaboration network on new product development

Evidence from the automobile industry of China

Collaboration network on NPD

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Received 4 June 2019
Revised 2 September 2019
Accepted 27 September 2019

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Abstract

Purpose – Researchers agree that collaboration networks can be an important implement in a firm's innovation process, but there is limited empirical evidence on actually how they facilitate the new product development (NPD). The paper aims to discuss these issues.

Design/methodology/approach – Using longitudinal and multisource data on a sample of firms engaged in the Chinese automobile industry, the authors examine the structural properties of collaboration networks and their possible influences on firms' NPD performance.

Findings – The results indicate that the structural features of the technology-based collaboration networks in the automobile industry have a low degree of collaborative integration and they influence firms' NPD performance in diverse ways. The authors find that the direct ties, indirect ties and structural holes of the collaboration networks are all positively associated with firms' number of new products. However, the authors have not found the evidence that the number of direct ties can moderate the relationship between the indirect ties and the NPD performance.

Originality/value – First, previous researches concerning the network mainly focused on their influence on technology innovation, few scholars studied the relationship between collaboration network and NPD. Second, the data used in this paper are true and valid, they are all from relevant departments of the Chinese government. Third, the empirical research of new products in China's manufacturing industry is relatively new.

Keywords Collaboration network, China automobile industry, New product development performance

Paper type Research paper

1. Introduction

In face of hyper market competition and ever-changing consumer preferences, NPD has become one of a major effort in the success of modern companies. It is assumed among researchers that, NPD plays an increasingly important role in the market position, long-term profitability and firm survival (Pauwels *et al.*, 2004; Chan and Ip, 2011). NPD has become a vital driver for firms to gain a sustainable competitive advantage in the market, particularly salient in emerging economies such as China. Only by constantly launching new products, firms can better adapt to the changing market environment and maintain the long-term growth of the firm (Lee *et al.*, 2014).

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This study is sponsored by a Grant from National Natural Science Foundation of China (No. 71233002). The author is very grateful to the editors and anonymous reviewers for their valuable comments and suggestions, which greatly improved the quality of the paper.



Recent studies show that NPD is often affected by the internal and external factors of the firm. Based on the perspective of organizational learning, Katila and Ahuja (2002) believes that the search depth has an inverted U-shape relationship with new product innovation, while the search scope positively affects new product innovation. Li *et al.* (2010) show that exploratory and exploitative learning both have an inverted U-shape relationship with new product development (NPD). Frankort (2016) argues that firms can improve their NPD output by acquiring knowledge resources from the R&D alliance.

Actually, NPD can be viewed as a process of knowledge crystallizing into a product, which requires the firm to provide complementary skills and expertise for problem-solving (Kogut and Zander, 1992). Alegre *et al.* (2013) believe that knowledge and technology are the source of competitive advantage in the NPD. However, with the increasing complexity of the NPD activities, it is difficult for firms to cope with the complex and varied economic environment by relying solely on knowledge and technical resources within the firm. Firms need to seek support from external organizations (Barczak *et al.*, 2009). Recent studies have found that interorganizational networks are a collection of potentially valuable information and resources that provide an opportunity for companies to access external technologies and knowledge (Zaheer and Bell, 2005).

Collaborations are seen as a means to gain complementary technologies and resources from partners in the network (Ferreira *et al.*, 2015). Based on the perspective of structuralism, Adler and Kwon (2002) have posed that the structure of network relations affects the acquisition of social capital by firms. Researches have shown that the technological-based collaboration networks have an important impact on the technological innovation activities of the firms. Based on both a competence and governance point of view, Vanhaverbeke *et al.* (2012) suggest that direct ties, indirect ties and a nonredundant structure among a firm's ties play different roles on the creation of core and noncore technology. Guan and Liu (2016) hold that direct ties, indirect ties and the non-redundancy among ties in a collaboration network can affect organizations' exploratory and exploitative innovations in diverse ways. Rojas *et al.* (2018) demonstrate that in the firm-government sponsored institutions (GSIs) collaboration network, network cohesion and centrality both have a positive effect on firm's innovativeness. Liang and Liu (2018) find that in the government-sponsored collaboration network, direct ties have an inverted U-shaped effect on innovation performance, while indirect ties have a positive effect on innovation performance. Kim (2019) points that a firm included in the main components of an inter-firm network has better innovation performance.

Despite recent studies have emphasized the significant influence of collaboration networks of acquiring external resources for technical innovation in turbulence environments, few scholars have explicitly examined its direct impact on the NPD. Thus, an interesting research issue remains: how can a firm exploit collaboration networks to develop new products? Next, we analysis the impact of collaborative network structure on the development of new products in China's auto industry.

2. Theoretical background and hypothesis

NPD is a specific innovation activity, it is seen as a process in which ideas or technologies are materialized, managed, new knowledge is created and embodied in the product, and eventually introduced to market (Mu *et al.*, 2009). The NPD encompasses a series of information-processing, knowledge-searching and problem-solving activities (Adams *et al.*, 1998; Caner and Tyler, 2015; Frankort, 2016; Katila and Ahuja, 2002). Organizational learning holds that the NPD requires the firm to acquire, disseminate and use the market information (Adams *et al.*, 1998). Also, organizational learning argues that knowledge search which involves the exploration of new knowledge and utilization of existing knowledge in organizations to solve problems and develop new products (Katila and Ahuja, 2002). In particular, innovation study on NPD shows that the acquisition of complementary

knowledge and technical resources are necessary for innovation emerges as a major driver for interorganizational collaboration (Becker and Dietz, 2004; Faems *et al.*, 2005). On the other hand, network researchers similarly believe that the assimilation of external knowledge from interfirm networks is more beneficial to the firm's NPD activities (Simon and Tellier, 2011; Soh, 2003).

So far, there is no unified paradigm for the study of network structure. Ahuja (2000) studies the relationship between network structure and innovation from three aspects: direct ties, indirect ties and structural holes. Karamanos (2012), Vanhaverbeke *et al.* (2012) and Guan and Liu (2016) in line with Ahuja (2000), analysis the relationship between network structure and technical innovation from these facets: direct ties, indirect ties and structural holes, while Vanhaverbeke *et al.* (2012) also investigate the role of macro-level network structure on exploratory innovation from network density and clustering. Reagans and McEvily (2003) focus on two distinct features of network structure which are cohesion and range and find that both network features can ease knowledge transfer. Schilling and Phelps (2007) argue that two key structural properties of large scale networks, clustering and reach, can facilitate firm's knowledge creation. Karamanos (2012) examines the relationship between alliance ego-network structure, network centrality and structural holes, and exploratory and exploitative innovation. Moreover, Carnovale and Yeniyurt (2015) study the impact of ego network structure on ego network innovations from four aspects: network betweenness, density, brokerage and weakness. In order to examine the relationship between network structure and the NPD performance, we propose, in line with Ahuja (2000), that there are three features of a firm's network structure should be analyzed: direct ties, indirect ties and structural holes.

2.1 Direct ties

Scholars suggest that direct ties can provide these benefits: resource-sharing, knowledge spillovers and complementary (Ahuja, 2000; Vanhaverbeke *et al.*, 2012). We argue that a focal firm's direct ties may have a positive effect on NPD in following aspects. First, the benefits of direct ties arise out of acquiring critical and valuable knowledge and information (Ahuja, 2000; Karamanos, 2012). The knowledge-based views suggest that knowledge is the fundamental productive resource of a firm (Grant, 1997). NPD is a knowledge-intensive and multi-disciplinarily activity which needs interaction based on the exchange of knowledge and information (Goffin and Koners, 2011). Firms with more direct ties can acquire more skills, know-how and technologies from multiple partners, even facilitates diffusion of knowledge and the common adoption of best organizational practices, which can accelerate the firm's NPD process (Ahuja, 2000; Karamanos, 2012; Pallotti and Lomi, 2011). Second, collaboration with many direct partners allows firms to obtain complementary skills and knowledge from other organizations (Ahuja, 2000; Vanhaverbeke *et al.*, 2012). NPD is a process that requires the firm to provide complementarity and expertise to solve the problem (Fang, 2011). Interorganizational collaboration is proved to be one of the means to acquire complementary knowledge (Arranz and Fdez de Arroyabe, 2008). Then, the needs for special knowledge of NPD can be satisfied and the limitation of resource endowment in firm will be alleviated. Third, collaboration with direct partners may reduce the risk involved in a firm (Karamanos, 2012; Vanhaverbeke *et al.*, 2012). Short product lifecycle and volatile technological changes make NPD to be a high-risk activity (Droge *et al.*, 2008). The exchange of resources between organizations can realize the acquisition of new technology, enter new market, obtain the advantages of scale economy when larger projects generate more knowledge, and thus reduce the risk of NPD (Ahuja, 2000; Karamanos, 2012). As a consequence, we expect the following hypothesis:

- H1. A firm's number of direct ties in a collaboration network have a positive effect on its NPD performance.

2.2 Indirect ties

Direct ties serve as channel of both resource-sharing and knowledge-spillover benefits, whereas indirect ties mainly emerge as a conduit for knowledge spillovers (Ahuja, 2000; Karamanos, 2012; Salman and Saives, 2005). We suppose that a focal firm's indirect ties may play a positive role on NPD for two reasons. First, indirect ties can be used as an information-gathering device (Ahuja, 2000; Salman and Saives, 2005). When developing new products, firms need to carry out knowledge search beyond the boundaries of organizations (Katila and Ahuja, 2002). The technological trajectory and experiences of the firms in related fields are embedded in the network, firms with more indirect ties can obtain large amounts of external knowledge from the network and learn more from the success and failure of partner's partner, so as to improve the probability of success of their R&D (Salman and Saives, 2005). Second, indirect ties can act as an information-processing or screening device (Ahuja, 2000). Each node in the collaboration network may pose as an information-processing mechanism, which can be used to absorb, select and classify new technological inventions, so that the related information in different technological fields can be indirectly entered into the vision of firms (Ahuja, 2000; Salman and Saives, 2005; Vanhaverbeke *et al.*, 2012). Indirect ties can even be used as an implement for monitoring the external environment to obtain complementary knowledge and new opportunities (Salman and Saives, 2005; Vanhaverbeke *et al.*, 2012). Therefore, indirect ties are undoubtedly an intangible asset for the NPD of a firm. According to the above analysis, we expect the following hypothesis:

H2. A firm's number of indirect ties in a collaboration network favors its NPD performance.

2.3 Direct and Indirect ties combined

Obviously, firms with more indirect ties are prone to be disturbed by numerous and confused information, limited management attention is mostly spent on dealing with the information from direct ties, while the attention to handle the information from indirect ties will be reduced (Ahuja, 2000). In addition, information from indirect ties may distort the content of information because of the existence of "noise" (Guan and Liu, 2016; Karamanos, 2012; Vanhaverbeke *et al.*, 2012). When information is passed through a long path, different partners attach their own interpretation to this information, which easily leads to information distortion, due to the fact that the fine-grained characteristics may be lost, and real information will not reach the focal firm (Guan and Liu, 2016; Karamanos, 2012; Vanhaverbeke *et al.*, 2012). Meanwhile, it is costly to monitor and exclude misleading information, because confirming each incorrect clue will waste the time and resources of the firm (Guan and Liu, 2016; Karamanos, 2012). However, R&D collaboration is a cross domain synergy between heterogeneous entities, direct ties is the bond for firms to obtain and use complementarity knowledge, firms with more direct ties means having a richer source of knowledge and acquiring skill, know-how, and technology from a number of partners (Ahuja, 2000). Gaining more knowledge is conducive to the expansion and accumulation of the knowledge base of firm. Zaheer and Zaheer (1997) suggest that the size of the benefit from information is determined by the firm's sensitivity to information and the ability to respond to the information. Most of the attention is mostly spent on coping with information from direct ties, and the attention that is used to deal with information from indirect ties is reduced due to the interference of a lot of messy information (Ahuja, 2000). Thus, the more the direct ties, the benefits of indirect ties will be diluted by their disadvantages (Vanhaverbeke *et al.*, 2012). As a consequence, we suggest that the effect of indirect ties should be negatively moderated by the number of direct ties, which lead to the following hypothesis:

H3. The effect of indirect ties on NPD performance will be moderated by the number of direct ties: the more direct ties, the smaller the benefit of indirect ties.

2.4 Structural holes

Structural holes are another important indicator in social capital, it is a kind of missing relation that inhibit information flow (Burt, 2007). The structural holes can bring the following benefits for firms. First, it implies that companies can access to various information and resource (Ahuja, 2000). Firms need different types of knowledge and technology to develop new products, and the organizations in the network come from different groups, which have different resource endowments (Koka and Prescott, 2008). Firms bridging structural holes may connect with different information fields, which makes it easier for firms to obtain the required strategic resources, reduce the information-searching uncertainty and information redundancy, thus provides an opportunity for companies to recombine information and knowledge to provide a unique new product to the market (Koka and Prescott, 2008; Zaheer and Bell, 2005). In the NPD process, the firms located in the position of structural holes have information superiority by integrating different knowledge and technology. Second, the organizations at both ends of the structural holes are disconnected from each other, and the firm located in the position of structural holes enjoys the control advantage (Burt, 1992). Firms bridging structural holes can control the information flow and knowledge diffusion in the networks and gain a better insight into the business motivations of competitors, thus obtain valuable information earlier than other firms in the network. Then, it will influence the pace and progress of technology innovation and market change, enable firms to take the lead in exploring new markets and introduce new products to meet the desires of customers (Koka and Prescott, 2008). Third, firms bridging structural holes maybe reduce the transaction cost of firms. Due to the inherent complexity of the firm, the collaboration between firms is highly uncertain, this will result in the collaboration with many organizations require high maintenance costs. Thus, companies that eliminate redundant relationships can more efficiently handle the flow of information between them in using limited management effort (Burt, 1992). Accordingly, we expect the following hypothesis:

H4. A firm's number of structural holes in a collaboration network favors its NPD performance.

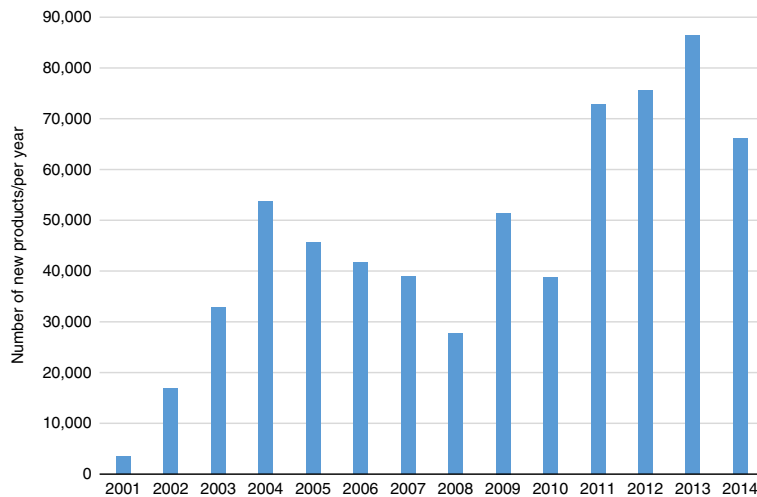
3. Data and method

3.1 Sample and data

We test our hypothesis by using a data set of Chinese vehicle manufacturers for three reasons. First, the auto industry has become an important industry to stimulate economic growth of China (Li *et al.*, 2015). According to the China Association of Automobile Manufacturers, China has produced and sold more than 28m vehicles in 2017[1], ranking first in the world for many years. Thus, this industry provides a fertile ground for understanding many interesting questions of companies in China such as technology spillover and technology collaboration (Motohashi and Yuan, 2010; Wang, Li, Ning, Zeng and Gu, 2014). Second, automakers have a strong incentive to protect their intellectual property through patenting (Dechezlepretre *et al.*, 2015), which allows us to use patent information to outline the technical activities of the firm. In addition, the regulated and well documented vehicle approval process by the Ministry of Industry and Information Technology (MIIT) provides an excellent access to acquire authentic and valid data on automaker firms' NPD outcomes.

To better examine our hypotheses, we construct a panel data set from two independent archival sources. First, we got the CD issued by the MIIT about vehicle manufacturer and product announcement, wherein the first batch of the announcement was released in 2001, and our data ended in 2014, then we extracted 651,204 new products data of 1,401 firms from the CD. Figure 1 shows the dynamic evolution of the number of automakers' new products approved each year.

Figure 1.
The number of
automakers' new
products approved per
year (2001–2014)



Second, the automobile industry is one of the ten key industries in China, and the State Intellectual Property Office (SIPO) has established the Patent Information Services Platform (PISP)[2] for these industries, so we extracted the automobile patents data from the PISP. Moreover, this database offers the patent application number, application date, applicants and IPC codes and so on. We first acquired 672,761 automobile patents granted during the period of 1985–2014 among which there are 505,150 automobile patents whose applicants are firms, universities or institutes. A patent may contain one or multiple applicants, so we can use joint applicants of each patent to construct the collaboration networks of firms (Guan and Liu, 2016; Wang, Rodan, Fruin and Xu, 2014). We adopted a typically used five-year moving window to construct our collaboration networks (Guan and Liu, 2016; Wang, Rodan, Fruin and Xu, 2014). Due to renaming phenomena or other mistakes, a same organization may have several different names, we also performed the process to unify the name of the organization (Guan and Liu, 2016). Finally, we got a sample of 129 firms in 2001–2014, with a total number of 1,314 firm-year observations, which was an unbalanced panel data.

3.2 Measurement of variables

3.2.1 Dependent variables. The dependent variable of this study is the NPD performance. Prior researches mainly use questionnaire to measure the NPD performance (Land *et al.*, 2012), while the number of new products is an important indicator for the success of the development of new products, it has been used in studies focusing on the R&D alliances (Caner and Tyler, 2015) and knowledge network centrality (Dong and Yang, 2016). Thus, we count the number of new vehicles announced each year by the MIIT to capture the NPD performance of the firm (Caner and Tyler, 2015; Dong and Yang, 2016; Frankort, 2016).

3.2.2 Independent variables. The independent variables in this research are direct ties, indirect ties and structural holes in collaboration networks. We computed these variables using UCINET 6.

Direct ties. In our study, the direct ties are measured by the number of organizations directly connected with the focal firm, which is the degree centrality of a focal firm in the network (Karamanos, 2012; Guan and Liu, 2016; Vanhaverbeke *et al.*, 2012).

Indirect ties. We count the number of partners that each focal firm can indirectly reach within k or less steps to measure the indirect ties, which is Reach_C (Karamanos, 2012).

The routine Network > Centrality and Powell > Reach Centrality in UCINET calculates this indicator, which means the closeness of every company to all other partners in the network (Karamanos, 2012).

Structural holes. Burt (1992) believes that structural holes can reflect the non-redundant relationships of nodes, and this allows firms to get high-yield information and facilitate information access. Burt (1992) provides four indices to characterize structural holes, we adopt constraint to measure the structural holes, which can reflect the ability of firms to use structural holes in the network. The calculation formula of the constraint is presented as follows:

$$constraint = \left(p_{ij} + \sum_k p_{ik} p_{kj} \right)^2, \quad k \neq i, j, \quad (1)$$

where, in the whole relationship of actor i , p_{ij} represent the proportion of the relationship invested to the actor j (Burt, 1992). The smaller the index, the less the structural holes occupied by actors. Finally, we use $(1 - constraint)$ to capture the structural hole of a firm (Karamanos, 2012).

3.2.3 Control variables. We control for various potential variables whose influence on the NPD performance might be confounded with the independent variables, which contain firm age, patent, standardization, technology diversification and regions.

Firm age. The technological innovation of the firm is a process of knowledge accumulation. The longer the survival time of the firm, the more knowledge the firm accumulates, it may affect the choice of the NPD of the firm in the future. Therefore, the age of the firm is taken as a control variable.

Patent. Großmann believes that the patent owned by the firm can affect the knowledge transfer in the process of the development of the new product (Großmann *et al.*, 2016). Therefore, the number of patents applied annually by the firm is used as a control variable.

Standardization. Großmann argues that the standardization ability of the firm also can influence the knowledge transfer in the process of the development of the new product (Großmann *et al.*, 2016). Therefore, the standardization capability is used as a control variable and measured by the number of standards drafted by the firm each year.

Technology diversification. Technical diversity of firms may drive the development of new products, and they maybe abler to absorb external knowledge (Frankort, 2016). We measure a firm's technology diversification in year t using a modified Herfindahl index (Chen *et al.*, 2010):

$$Technology\ diversification = 1 - \sum_j \left(\frac{N_{ijt}}{N_{it}} \right)^2, \quad (2)$$

where the N_{ijt} refers to the total number of patents held by the firm i in category j during the period under observation, the N_{it} refers to the total number of patents held by the firm i in a given period. This measure could range from 0 to 1.

Regions. The National Bureau of Statistics of China (NBS) divide the provinces of China into three major economic regions: the east, the middle and the west, according to the geographical location and economic development level of the provinces[3]. The east region is the province and city which first implement the coastal opening policy and have the high level of economic development; the middle region refers to the province in the economically sub-developed area; the western region refers to the economically underdeveloped western region. The three regions have great differences in the introduction of foreign advanced technology and state funding support. The NPD performance of firms may be different due

to the different regions in which the firms are located. Thus, we use two dummy variables to control the regions: west or middle (the default value is the east region).

3.3 Model specification

The dependent variable is the number of new products of the firm, which is the count data. The mean and variance are very different (151.780, 408.637), which indicating that there is excessive dispersion. Therefore, we select the negative binomial model to cope with discrete data (Guan and Liu, 2016; Liang and Liu, 2018). Since the sample is unbalanced panel data, there are a large number of observation data with inconsistent number of periods in the sample. The fixed effect model cannot be used to investigate time-invariant, which will have a large impact on the model estimation (Liang and Liu, 2018). In addition, the observation data come from Chinese automotive industry, and all firms with joint patents are observations. The sample belongs to a larger parent, but there are large changes in cross-section and time. Finally, we select the random effect model.

4. Results

4.1 Descriptive statistics

Table I shows the mean, standard deviation and correlation coefficient of each variable. The correlation matrix shows that most of the correlation coefficients are below the threshold value of 0.7 (except for $r_{\text{indirectties} \sim \text{structuralholes}} = 0.636$). In order to diagnose whether there is the multicollinearity problem between the explanatory variables, we find that all the variance inflation factor values are less than 2, indicating that the estimation results are not subject to the potential bias induced by a serious multicollinearity problem (Belsley, 1991).

4.2 Estimating results

Figure 2 provides an example to illustrate the technical collaboration activities of automobile industry in China. The degree of integration of the network structure can directly affect the technological knowledge exchange and information diffusion among organizations (Guan and Liu, 2016). Our results indicate that inter-organizational collaboration networks in the China automobile industry are featured by a low degree of collaborative integration, which leading to less knowledge exchange, information diffusion and joint problem solving among organizations (Guan and Liu, 2016).

In order to examine the hypothesis, we conducted a series of regressions to the sample data. Table II reports the random-effects negative binomial panel regression results for the NPD performance. In support of *H1*, Model 2 in Table II shows that the direct ties have a positive influence on the NPD performance, and is statistically significant at $p < 0.001$. Thus, the direct ties of collaboration network of a firm have a positive effect on its NPD performance, which supports *H1*. This shows that the direct ties of the collaboration network can improve the performance of the NPD performance of the firm. On the one hand, the firm can obtain the key knowledge and information, on the other hand, the firm can reduce the risk and cost of the NPD (Karamanos, 2012; Vanhaverbeke *et al.*, 2012).

According to Model 3, the result shows that the indirect ties of the collaboration network have a positive impact on the NPD performance ($\beta = 0.0016, p < 0.01$), and *H2* is confirmed. This means that it is necessary for firms to reach partners' partners in the development of new products, thereby reducing the threat of asymmetric information by obtaining heterogeneous knowledge. Interestingly, the indirect ties have a much smaller effect on NPD performance than direct ties.

Although the coefficients for this interaction term between indirect and direct ties is negative, there is no evidence for its effect on firm's NPD performance since the coefficients of this interaction effect are statistically not significant in Model 4, thus *H3* is

Variable	1	2	3	4	5	6	7	8	9	10
1. NPD performance	1									
2. Direct ties	0.149**	1								
3. Indirect ties	0.042	0.318**	1							
4. Structural holes	0.276**	0.636**	0.242**	1						
5. Firm age	0.232**	0.134**	0.123**	0.169**	1					
6. Patent	0.430**	0.262**	0.074	0.294**	0.112**	1				
7. Standardization	0.215**	0.084*	0.025	0.180**	0.113**	0.304**	1			
8. Technology diversification	0.195**	0.120**	0.130**	0.198**	0.162**	0.251**	0.202**	1		
9. Middle region	0.012	-0.061	-0.080	0.015	-0.006	0.153**	0.167**	0.191**	1	
10. West region	-0.038	0.018	0.101*	0.057	-0.015	-0.006	-0.089**	-0.128**	-0.284**	1
VIF	-	1.83	1.16	1.80	1.09	1.28	1.17	1.18	1.14	1.09
Mean	151.780	1.806	24.026	0.1045	11.443	44.991	0.772	0.728	0.257	0.189
SD	408.637	1.958	53.596	0.2619	9.126	155.423	2.440	0.270	0.437	0.391
Min.	0	0	1	-0.125	0	0	0	0	0	0
Max.	5,826	19	317.793	0.888	61	1,822	26	0.977	1	1

Notes: * $p < 0.05$; ** $p < 0.01$

Table I.
Descriptive statistics
and correlations

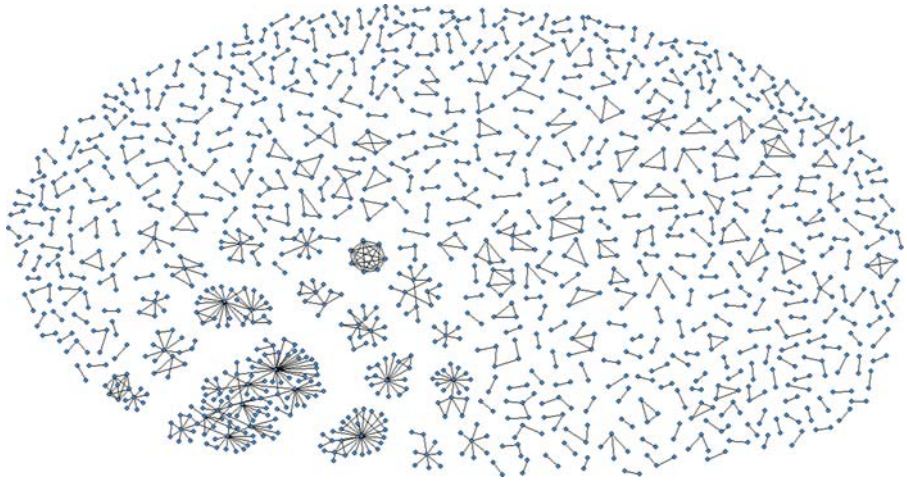


Figure 2.
A technology-based collaboration network featured by a low degree of collaborative integration (2005–2009)

Variables	Model 1	Model 2	NPD performance		Model 5
			Model 3	Model 4	
Direct		0.0448*** (3.49)		0.0453** (2.64)	
Indirect ties			0.0016** (3.19)	0.0017* (2.25)	
Direct × Indirect ties				−0.0001 (−1.15)	
Structural holes					0.494*** (4.03)
Firm age	0.0191*** (4.88)	0.0323*** (5.01)	0.0326*** (5.24)	0.0326*** (5.09)	0.0329*** (5.17)
Patent	0.0008*** (7.64)	0.0003*** (1.69)	0.0004* (2.25)	0.0003*** (1.72)	0.0002 (1.18)
Standardization	0.0179* (2.54)	0.0193* (2.27)	0.0154*** (1.82)	0.0178* (2.10)	0.0193* (2.28)
Technology diversification	0.566*** (4.63)	0.587* (2.18)	0.522*** (1.95)	0.526*** (1.95)	0.555* (2.07)
Middle region	0.139 (1.27)	0.596*** (3.89)	0.608*** (3.95)	0.591*** (3.84)	0.587*** (3.83)
West region	0.029 (0.22)	0.139 (0.71)	0.156 (0.80)	0.135 (0.68)	0.116 (0.60)
Constant	−0.098 (−0.83)	−0.191 (−0.82)	−0.101 (−0.44)	−0.157 (−0.68)	−0.131 (−0.57)
Log likelihood	−5,038.60	−2,827.00	−2,827.57	−2,824.58	−2,821.65
Wald chi2	163.95	89.24	88.45	95.72	94.10

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.1$

Table II.
Random effects panel regression results for NPD performance

not corroborated. Accordingly, we can only assume that the direct ties of the collaboration network may affect the relationship between indirect ties and the NPD performance.

$H4$ specifies the effect of the structural holes in a firm’s collaboration network. Here, we find adamant evidence that the structural holes possess a positive effect on the NPD performance, and confirm $H4$. Therefore, the more structural holes of a firm’s collaboration network the better NPD performance of a focal firm.

4.3 Additional analysis

As a robustness check, we use a three-year window to construct the collaboration network which is often used in the literature of network (Gonzalez-Brambila *et al.*, 2013), and our estimates still confirm our assumption, the results are reported in Table III.

In addition, we also examine the effects of quadratic term. Interestingly, we get a contradictory conclusion when the quadratic terms of the direct ties of the networks with

Table III. Results of negative binomial regression of three-year's collaboration network

Variables	NPD performance		
	Model 1	Model 2	Model 3
Direct ties	0.046**** (1.73)		
Indirect ties		0.002* (2.14)	
Structural holes			0.386* (2.47)
Firm age	0.029*** (4.14)	0.027*** (3.83)	0.031*** (4.30)
Patent	0.0003 (1.25)	0.0004* (2.19)	0.0002 (0.99)
Standardization	0.016 (1.35)	0.016 (1.38)	0.016 (1.30)
Technology diversification	0.695* (2.35)	0.697* (2.35)	0.663* (2.25)
Middle region	0.561** (3.22)	0.571** (3.28)	0.612*** (3.49)
West region	0.022 (0.10)	-0.013 (-0.06)	0.017 (0.08)
Constant	-0.196 (-0.77)	-0.121 (-0.48)	-0.147 (-0.58)

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.1$

different window periods is joined into the regression. In the five-year window period network, we find the direct ties have an inversed U-shaped effect on firms' NPD performance. It maybe because of the increase of direct partners, there will be more free-riders, and companies have to disperse more resources and management time to maintain these ties, thus easily lead to the risk of knowledge spillovers and leaks (Karamanos, 2012; Vanhaverbeke *et al.*, 2012). In the three-year window period network, we find the estimated coefficients of direct ties is negative but not statistically significant, while the quadratic term of direct ties is positive and statistically significant. According to the above two conflicting discoveries, we argue that the direct ties of collaboration network have a positive effect on firm's NPD performance. We report the two regressions in Table IV, Model 1 is the results of five-year's collaboration network and Model 2 is the results of three-year's collaboration network. However, we did not find the quadratic term of indirect ties and structural holes are statistically significant, so we did not report these regression results.

5. Discussion and conclusion

5.1 Main findings

NPD performance depends not only on the knowledge and skills that can be found and utilized within the firm, but also on their ability to acquire external knowledge (Caner and Tyler, 2015; Dong and Yang, 2016; Frankort, 2016). In this study, we examined the structural characteristics of inter-organizational collaborative network in the automobile industry of China and their influence on the NPD performance of the firm from three aspects of direct ties, indirect ties and structural holes. Most of our hypothesis in this paper are supported.

Table IV. Results of negative binomial regression of five-year's and three-year's collaboration network

Variables	NPD performance	
	Model 1	Model 2
Direct ties	0.123** (2.97)	-0.077 (-1.13)
Direct ties × direct ties	-0.005**** (-1.92)	0.014* (2.07)
Firm age	0.036*** (5.21)	0.027*** (3.85)
Patent	0.0002 (1.14)	0.0002 (1.08)
Standardization	0.019* (2.17)	0.018 (1.55)
Technology diversification	0.560* (2.08)	0.724* (2.44)
Middle region	0.577*** (3.75)	0.510** (2.91)
West region	0.122 (0.62)	-0.008 (-0.04)
Constant	-0.293 (-1.24)	-0.022 (-0.08)

Notes: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; **** $p < 0.1$

First, the number of direct ties of a firm in a collaboration network has a positive effect on its NPD performance. With the increase of product complexity, it is difficult for firms to maintain the NPD activities by relying on their own knowledge and technology. Firms need to obtain knowledge and technology through R&D cooperation, so as to expand their knowledge base (Frankort, 2016). On one hand, the direct ties of the collaboration network are a source and pipeline for the company to obtain a large amount of information and knowledge, the firm can acquire complementary skills through direct ties, and have the potential to enjoy the economies of scale (Ahuja, 2000; Vanhaverbeke *et al.*, 2012). On the other hand, technical collaboration with direct partners fetches knowledge that is novel to the firm or recombines the existing knowledge of a firm and that of its partners (Karamanos, 2012). Therefore, the focal firm in a collaboration network should be maintain a large number of direct partners to facilitate NPD.

Second, the empirical results of our study show that the indirect ties of collaboration network are a vital factor to improve the NPD performance. NPD is an activity that embodies the knowledge into the product, it entails to process a series of information (Adams *et al.*, 1998). The indirect ties of the collaboration network are a conduit of information, which can provide the potential information for the firm, perhaps imply the opportunity to develop new products, and thus increase the competitive advantage of the firm (Ahuja, 2000; Soh, 2003). Meanwhile, indirect partners may be serve as a “radar” by bring new information about ongoing projects or relevant developments from longer paths in the network (Karamanos, 2012; Vanhaverbeke *et al.*, 2012). Thus, when seeking for new information, a firm should conduct not only a local search around its collaboration network but also a distant search.

Finally, we find that bridging structural holes in collaboration networks can improve the NPD performance, which is different from the view that the structural hole position has no effect on NPD (Mazzola *et al.*, 2015). The organization at both ends of the structural holes in the collaboration network has a heterogeneous background and knowledge, firms can acquire diversified, non-redundant information and resources, so they can explore new market and identify potential danger faster, reduce uncertainty in product decision making, adjust the direction of NPD in time, avoid unnecessary waste of resources (Zaheer and Bell, 2005). In addition, a firm bridging structural holes acts as a technology broker in different industries is able to create new business concepts, appear new services or develop new understandings, in this way improve the likelihood to develop new products (Mazzola *et al.*, 2015). Hence, a firm should embed in open collaboration networks to benefit its NPD.

In addition, we find the effect of the combination of direct and indirect ties on the NPD performance is negative, but there is no convincing evidence that this effect is significant. The core technology of China’s automobile industry lags far behind the developed countries such as Europe and America, this may explain why the interaction terms is not significant. Therefore, there is no need to worry that the increase of direct ties of collaboration networks will dilute the benefits of indirect ties for firm.

5.2 Contributions

Overall, this paper makes several contributions to the literature. This study fills a gap in the social network literature by directly examining the role of collaboration network in connecting firm’s product development (Katila and Ahuja, 2002). Different streams of research have shown that the collaboration network may facilitate technology innovation (Guan and Liu, 2016; Liang and Liu, 2018; Vanhaverbeke *et al.*, 2012), while such networks may have consequences in the NPD as well (Dong and Yang, 2016). Therefore, the first contribution of our paper lies in offering an intuitive and systematic assessment whether the collaboration network structures affects firm’s NPD performance. Here, we find that the three aspects of network structural properties differ in the importance on firm’s

NPD performance. Furthermore, the study also contributes to the literature by showing that the importance of designing effective and efficient networks of the firm, which is well complementary for previous research (Ahuja, 2000). Accordingly, enriching the literature about organization design.

5.3 Limitations and further research

As with previous empirical studies, our research has some limitations that can be explored in further study. First, our empirical analysis is constrained to only one industry to test our assumptions, we select the Chinese automobile industry as the research sample, but the research collaboration and technological innovation of different industries have their own features. Therefore, our conclusions cannot be simply extended to other industries. In the future research, we encourage scholars to perform further studies in other high-tech industries to verify our assumptions. Second, we focus on the impact of the collaboration network structures on the number of NPD, we do not distinguish incremental and breakthrough new products in our theoretical and empirical analysis, the future research can explore the effect of collaboration network structures on different features of NPD performance. Third, the technology collaborations in our network contain collaborations between domestic firms and indigenous organizations as well as with foreign organizations, future study may construct different types of networks to investigate the effect of network structures on NPD performance.

Notes

1. www.caam.org.cn/newslist/a34-1.html
2. For details about the PISP, please refer to the following website: <http://chinaip.sipo.gov.cn/>
3. For details about the regions and provinces, please refer to the following website: <http://data.stats.gov.cn/easyquery.htm?cn=E0103>

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