

Effects of Network Closure on Cooperative Innovation: Evidence from Dongying's Petroleum Equipment Industry in China

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Abstract: There are two opposing viewpoints on which kind of network configuration provides a more competitive advantage, namely, network closure or structural holes, with the latter occupying the dominant position in the literature. Using social network analysis and negative binomial regression methods, we graph the co-patent network of Dongying's petroleum equipment industry in China and explore its impact on enterprise innovation. The analysis is based on 17 face-to-face interviews, 31 enterprise questionnaires, and 354 co-patent records from the China State Intellectual Property Office identifying cooperative innovation for the years 1988–2013. We find that this network is closed, controlled by state-owned enterprises, and its closure has positive effects on enterprise innovation performance. This may be related to China's unique industrial development history, state system and policies, regional culture and circumstances, and enterprise characteristics. Therefore, for some industries in specific regions, the advantages usually attributed to structural holes and open innovation may not necessarily apply.

Keywords: network closure; structural holes; enterprise innovation; petroleum equipment industry; Dongying

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1 Introduction

It is generally believed that cooperative networks have mechanisms to enhance the innovation performance of enterprises (Maskell and Malmberg, 1999; Cooke, 2013; Bathelt and Li, 2014; Huggins and Prokop, 2017). Networks can promote the creation of information resources and opportunity acquisition, while also enhancing actor interdependence in order to overcome the dilemma between cooperation and free riding (Sorenson et al., 2006; Whittington et al., 2009; Huggins and Thompson, 2014). Network configuration, moreover, can be used to reveal the topological location of actors, the spatial scale, geographical distribution, and the strength of ties

which in turn represent information validity, accessibility, and common trust, all of which jointly affect network capabilities such as the technological level of the actors, social capital, and network capital (Ter Wal and Boschma, 2009; Rost, 2011; Huggins et al., 2012). Scholars have extensively studied network configuration and its effects. The main theoretical foundations of network configuration theory are the weak ties theory (Granovetter, 1973; 1985), the social capital theory (Lin et al., 1981; Coleman, 1988; 1990), and the structural holes theory (Burt, 1992; 1997; 2002; 2005).

The weak ties theory runs contrary to the view that cohesive and frequent strong network ties are helpful to obtain competitive advantages. Granovetter (1973; 1985)

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states that the key to achieve a competitive advantage is to encourage weak ties between the different actors. Coleman (1998; 1990) studies network closure and social capital, emphasizing the benefits of a closed network. A closed network provides the basis for information sharing within the regional actors, which in turn leads the actors to continue to integrating resources for the production of new knowledge and technology (Storper, 1997; Crescenzi et al., 2007). On the basis of previous studies, Burt (1992) develops the popular structural holes theory. In this theory, the so-called social capital is a metaphor for competitive advantage, and this competitive advantage comes from private relationships (Burt, 1992). However, the theory assumes that the social capital of actors is determined by their position within the network, instead of the strength of their ties as suggested by Granovetter (1973; 1985). Burt (2002; 2005) holds that in a more complex network, actors who occupy a central position and connect with more isolated actors will obtain more competitive advantages. These centrally located actors control the flow of information and resources in the network and thus become more powerful. Since information and resources are non-repeatable and non-ubiquitous, it is more conducive for actors to realize their goals.

However, behind the consensus, favoring the structural holes theory, scholars have divergent views on which kind of network configuration provides a more competitive advantage (Gemünden et al., 1996; Uzzi, 1997; He et al., 2014; Vermeulen and Pyka, 2018). On the one hand, network closure implies high cohesion and mutual trust, which is conducive to the creation of norms and daily routines in a certain area or within the scope of the network that facilitate the cooperation between actors (Lin et al., 1981). On the other hand, the structural holes theory suggests that competitive advantage is not the result of network closure, but the product of non-redundant connections and intermediary information flow between the different actors. Weak ties are more likely to play a bridging role in information transmission than strong ties (Burt, 2000). In recent years, however, some scholars have critically reflected on the embedders and closed traditional industrial clusters (Grabher, 1993; Wei et al., 2007), emphasizing the positive influence of technological gatekeepers and open innovation on clusters and networks (Morrison, 2008;

Giuliani, 2011; Mortara and Minshall, 2011; West J et al., 2014). Nevertheless, it appears that these scholars may have overcorrected as in some cases, for some specific industries, network closure may significantly promote innovation performance (Tan et al., 2015; Tortoriello et al., 2015). This appears to be especially true in China, due to the country's industrial development history, state systems and policies, regional culture and circumstances, and enterprise characteristics (Fan and Scott, 2003; Zeng and Bathelt, 2011).

In 2013, there were 1773 enterprises in China's petroleum equipment industry, of which the highest business revenues and profits came from exploitation and drilling equipment companies (more than 50% of the total number of enterprises), reaching combined revenues of 281.24 billion yuan (RMB) and profits of 19.76 billion yuan. As a national strategic industry providing petroleum drilling equipment, enhancing manufacturing technology could be beneficial not only for this industry, but also for the whole industrial chain through knowledge spillovers and technology diffusion. At present, China's economic development is in an important period of transformation and reform. With increasing emphasis on innovation, environment, and productive efficiency, the energy industry needs to be supported by the petroleum equipment industry. As one of the earliest, largest, most technologically advanced, and most concentrated domestic petroleum equipment industry bases, the configuration of Dongying's innovation network is representative of China. The question that naturally arises is whether this network configuration is a closed system with special industrial and regional characteristics. Moreover, what is the effect of the closure of this network on enterprise innovation performance? Could the existing theoretical frameworks and empirical results based on the studies in developed or Western countries explain the issues in emerging economies and China in particular? This study analyzes the above questions based on Dongying's petroleum equipment industry and explores whether and how a closed network configuration affects innovation and verifies whether the structural holes theory is suitable for this scenario. We focus on the petroleum exploitation and drilling industries as they are the main pillars of Dongying's petroleum equipment industry.

2 Materials and Methods

2.1 Study area

The Shengli Oilfield (in Chinese, 'shengli' means victory) is the foundation of the development of Dongying's petroleum equipment industry, and is also an important driving force behind the formation and evolution of the area's industrial cluster. In 1964, China's central government launched large-scale oil exploitation program around the Shengli Oilfield against the backdrop of a planned economic system. From the 1970s to the 1990s, many petroleum equipment enterprises, operating as subsidiaries of the Shengli Oilfield Group, were established as part of the reform and opening of the socialist market economy. Meanwhile, research institutes and colleges began to relocate to the area. In 2000, following the deployment of Sinopec's reorganization, the state-owned Shengli Oilfield Group was divided into two components. First, the listed enterprise 'Shengli Oilfield Company Ltd' was set up and then the remaining components were recombined or spun off as privately owned enterprises (POEs), in the context of increasing liberalization and growth of the market economy. As a result, local private capital, foreign private capital, and enterprises absorbed technology and personnel previously belonging to Shengli Oilfield Group to set up a large number of petroleum equipment manufacturing enterprises.

During 2005–2013, the output value of Dongying's petroleum equipment industry was ranked first in China. Its share of the Chinese gross output fluctuates but is generally maintained around 1/3. In terms of technology innovation, the number of co-patents and inventors in

the Dongying's petroleum equipment industry has experienced a prodigious exponential growth rate in the years 1988–2013 (Fig. 1).

By 2013, Dongying had formed five industrial agglomeration zones comprising 101 enterprises above the designated size, namely, the Dongying economic and technology development zone, the Shengli economic development zone, the Shengtuo industrial zone in Kenli, the Kenli economic development zone, and the Hekou economic development zone. High-end products and sophisticated petroleum equipment and technology are mainly developed and manufactured in the Dongying economic and technological development zone, supported by the convergence of high-end innovation resources. The Shengli economic development zone has become the focal point for information exchange, technology and product trading, personnel training, and exhibitions. The other three industrial zones focus on improving and upgrading the industry scales and technology level based on aggregate development (Fig. 2).

2.2 Data collection

Our empirical analysis is based on three sources of data. First, information about co-patents is obtained from the key industry patent information service of the patent search and service system by China's State Intellectual Property Office (SIPO). Second, a series of semi-structured one-on-one interviews were conducted between June 2013 and September 2013, to gain deeper insights into the petroleum equipment industry in Dongying. Finally, a semi-standardized questionnaire survey was also conducted during the same period.

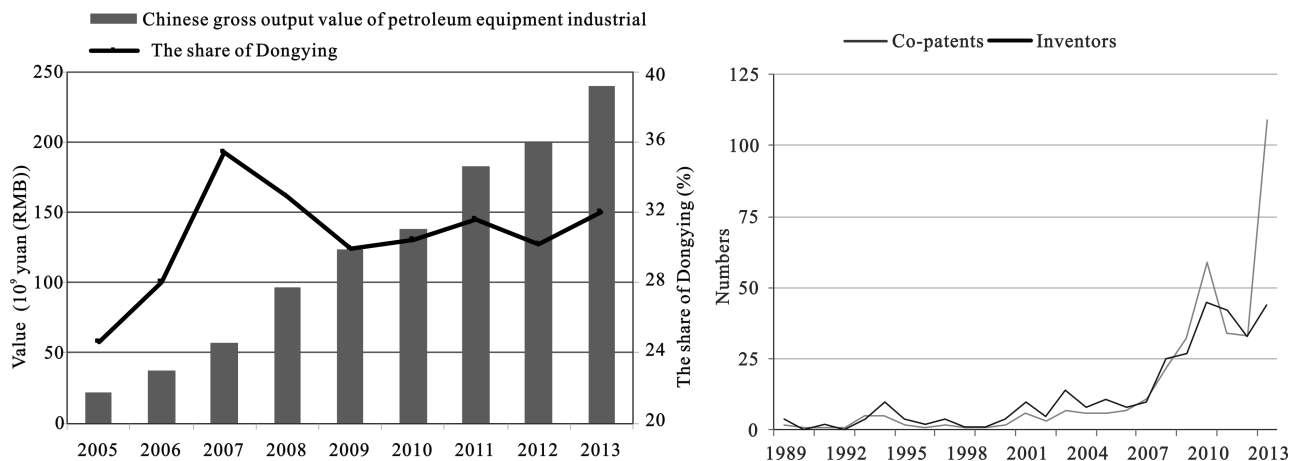


Fig. 1 Growth of Dongying's petroleum equipment industry. Sources: China petroleum and petrochemical equipment industry association (<http://www.cpeia.org.cn/>); SIPO (<http://www.chinaip.com.cn/>)

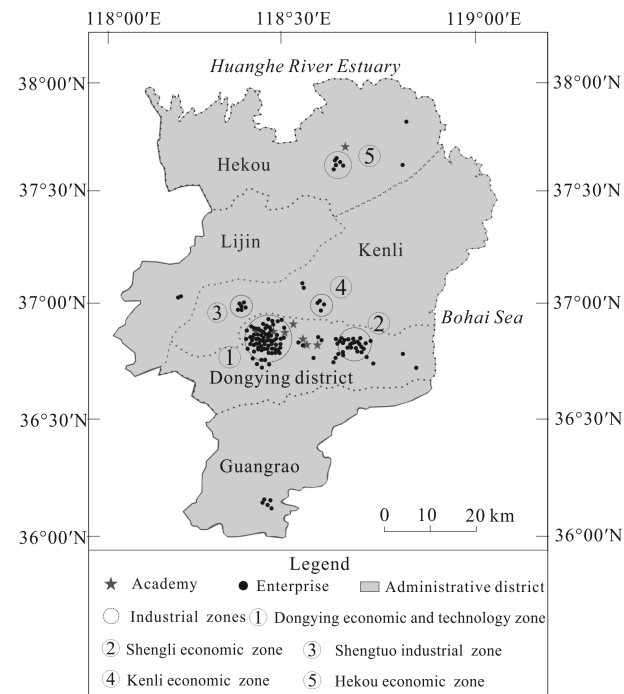


Fig. 2 Spatial distribution of Dongying’s petroleum equipment industry. Sources: industrial cluster inquiry platform of Dongying industry and commerce bureau (<http://www.dygs.gov.cn/search-list.aspx>)

Our research was organized into three steps:

First, we filtered the data (over 1000 patent records) obtained from the SIPO website and obtain 354 co-patents involving 122 innovation actors. The data filtering were: 1) we consider patent cooperation where knowledge and technology is exchanged between innovation actors, so patents with only a single actor are removed; 2) as we focus on the cooperative relationship between enterprises and between enterprises and research institutions, co-patents with individuals and government departments are removed; 3) we focus on co-patents where the actors belong to different institutions, so co-patents where the universities and research institutions developed their inventions with their own subordinates or enterprises, or if several institutions in the same affiliate relationship were involved, the corresponding co-patents is excluded; 4) if a co-patent had three or more organizations, and some of them have the same affiliate relationship, we only retain the most important actors according to the applicant sequence in the co-patent items.

Second, we conducted random face-to-face interviews with managers, executives, and chief engineers

from 17 enterprises and with three industry officials from the Dongying Commission of Economy and Information between June 6 and June 10, 2013. Before these interviews and with the help of the government, we distributed a questionnaire asking for company information such as history, location, employees, R&D, ownership, age, innovation-related linkages with their corresponding evaluations, partnerships and their geographical distribution, and new products and technological output, to each enterprise. We received 17 questionnaires, so the response rate of the questionnaire was 100%.

Third, subsequent surveys were carried out at the 6th China (Dongying) International Petroleum Equipment and Technology Exhibition between September 17 and September 19, 2013. In total, we distributed 58 questionnaires to managers, engineering directors, R&D managers, or engineering managers of local firms. Each questionnaire was completed under our guidance and retrieved immediately after completion. We received 26 questionnaires, implying a response rate of 44.8%. At the same time, some of the 17 enterprises we interviewed the previous June were revisited. All the interviews were recorded.

Next, we confirmed the basic information of surveyed enterprises through the appropriate website and previous interview materials to verify the reliability and validity of the questionnaires. We retained the enterprises matched the co-patent data mentioned above. In the end, 31 surveyed enterprises became our research objects (out of a total of 101 petroleum equipment enterprises in Dongying in 2013). Table 1 shows profiles of the surveyed firms.

Table 1 Profiles of the surveyed firms

Enterprises	Numbers
<i>Ownership</i>	
State	17
Non-state	14
<i>Size</i>	
Large	5
Middle	12
Small	14
<i>Age</i>	
<10 yr	6
10–20 yr	11
>20 yr	14

2.3 Research methodology

To explore the impact of input, firm attributes, and network closure on enterprise innovation performance, a regression model of the following form is used:

$$E(Y_i) = \exp(\mu_i + \alpha_1 \text{Input} + \alpha_2 \text{Firm attribute} + \alpha_3 \text{Network} + \varepsilon_i) \quad (1)$$

The dependent variable Y_i refers to the innovation performance of firm i in the research period, ε_i stands for an unobservable effect. *Input* refers to the innovation input of enterprises, including R&D investment and research developers. *Firm attribute* refers to the attributes of enterprises, including the ownership and age of the enterprises. *Network* represents the network configuration, which is combined with the topology and spatial scale. Table 2 shows these items in detail. We assume that the more concentrated the cooperation with a number of established partners, the closer the ties and their localization on a spatial scale and, therefore, the more closed the network (Reagans and McEvily, 2003; Breschi and Lissoni, 2004; de Nooy et al., 2011).

Table 2 Variables and measures

Variables	Detailed explanation	Source
Performance	The income proportion of new product to annual sales income	Questionnaires Enterprise websites
Input		
R&D funds	The proportion of R&D funds to annual sales income	Questionnaires
Research developer	The proportion of R&D personnel to total employees	
Firm attribute		
Ownership	1 means state-owned, 0 means others	Interviews
Age	Establishment of enterprises	Questionnaires
Network configuration		
Topology	The density of ego-networks of each enterprise, its value is between 0 and 1. The density of ego-networks reveals the degree of actor constraint in the network. The higher the density of ego-networks, the more constraints an actor faces and, consequently, the less freedom an actor has to withdraw from existing relations or to exploit structural holes, and the more exclusive and closed the ego-networks are	SIPO Interviews Questionnaires
Spatial scale	The proportion of local partners in the innovation network. It reveals the spatial selectivity of enterprise cooperation. A closed network has highly localized characteristics	

3 Results and Analysis

3.1 Network configuration

Starting with the firms' willingness to collaborate, we calculate the location of each identified innovation partner, differentiating between locations within the same city (local scale), other locations in China (national scale), and overseas locations. As shown in Table 3, the technology collaboration is most frequently carried out at the local scale (61.29%), while the overseas scale is significantly less prominent (9.68%). Overall, state-owned enterprises (SOEs) prefer to cooperate with local partners (38.71%), while cooperation with national partners (12.90%) comes in at distant second, followed by cooperation with overseas partners. The cooperation figures for non-SOEs are similar to those of SOEs, while their spatial scale is wider when searching for partners. This result shows that the cooperative innovation and industry linkages of Dongying's petroleum equipment enterprises are clearly localized, especially in the case of state-owned enterprises. This phenomenon might be related to the development history, industrial specialization, the particular characteristics of the Chinese economic system, and regional culture (Ma et al., 2014; Lyu and Liefner, 2018).

In the period 1988–2013, there was a subgroup structure of the co-patents network as shown in Fig. 3. We find that Sinopec, Sairui, Shengli Oilfield Shengli Exploration and Design Institute Company Ltd (SLEDI), Shengli Oilfield Shengli Engineering Consulting Company Ltd (SLECC), CUP, Kerui, Shandong Shengli Petroleum Equipment Research Center (SLPERC), and Freet are the central actors in the network. These actors have formed a number of subgroups: subgroup-I centered on Sinopec, Sairui, and SLEDI; subgroup-II centered on Kerui and SLPERC; subgroup-III centered on Freet; subgroup-IV centered on CUP; and subgroup-V centered on SLECC (Table 4). These subgroups are centered on one or several innovative actors, forming their own exclusive and closed network systems.

Table 3 Share of firms collaborating with innovation partners on different spatial scales

Ownership	Local (%)	National (%)	Overseas (%)	Sum (%)
SOE	38.71	12.90	3.23	54.84
Non-SOE	22.58	16.13	6.45	45.16
Sum	61.29	29.03	9.68	100

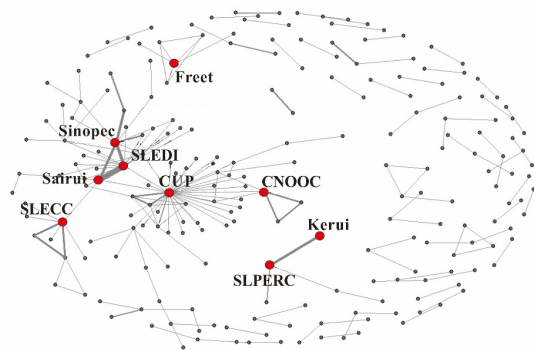


Fig. 3 The topology of the co-patent network of Dongying's petroleum equipment industry in the years 1988–2013. Circle represents key actors, line size represents the strength of the links

The key innovation actors of subgroup-I are Sinopec, Sairui, and SLEDI. Sinopec is a state-owned company that is the parent of the Shengli Oilfield Group, SLEDI is a spin-off of the Shengli Oilfield Group, and Sairui is a spin-off of SLEDI. The main partners are Shengji and Dongying Bosiman Petroleum Technology Development Company Ltd (Bosiman). The former is a spin-off of the Shengli Oilfield Group and the latter is a local private enterprise. This group has a multi-centered closure with strong ties; several key actors also have strong and closed ties with their partners. The network topology is convergent and complex, as innovative partners are almost all in a local scale, so there is remarkable regionalization in this case.

Kerui and SLPERC play major roles in subgroup-II. Kerui is a leading local private enterprise founded by a former deputy general manager of the Shengli Oilfield Group. SLPERC, which belongs to the Shengli Oilfield Group, is a renowned local research institute. Their main innovation partner is a private enterprise, the Shandong Hengye New Petroleum Technology Application Company Ltd (Hengye). This subgroup has a double-centered structure with singular strong ties between the key actors and weak ties with the others. This is a simple network with a few actors, and significant localization characteristics.

The core of subgroup-III is Freet, formerly an engineering machinery factory of the Shengli Oilfield Group. In May 2005, it completed its ownership reform and was established as a limited liability company according to the Shengli Oilfield Group restructuring policy. The main innovative partners are the state-owned enterprise Chengdu Steel and Vanadium Company Ltd (CDSVC) of the Panzhihua Iron and Steel Group, the

local industry association of the Shengli Oilfield Perforation Society, and CUP. Several innovative actors are intertwined with weak ties and the complexity of the network structure is moderate. The cooperative innovation in this case is mostly local, but there are also a few instances of cooperation at the national scale.

CUP, the core of subgroup-IV, ranks number one among all domestic petroleum and petrochemical equipment research and development institutions, with an outstanding track record in terms of knowledge creation and technological innovation. CUP has various types of partners, such as the state-owned companies Sinopec and China National Offshore Oil Corporation (CNOOC), privately-owned Dongying Fanghua Petrochemical Technology Company Ltd (Fanghua), and the university spinout company Dongying Yuguang Technology Company Ltd (Yuguang). Their connection to CUP is weak except for a few state-owned enterprises. The network topology shows a divergent distribution and the overall network intensity is moderate, while the geographical patterns of the innovation links are all on the spatial scale.

Subgroup-V is centered on the state-owned enterprise SLECC. The main partners are the Shengli Oilfield Drilling Technology Research Institute (SLDTRI) and SLEDI. The former is a research institute affiliated with a state-owned enterprise, and the latter is a spin-off company from the Shengli Oilfield Group. This subgroup is similar to subgroup-IV, but with fewer actors and weaker ties. The spatial distribution of partners is concentrated in the local area.

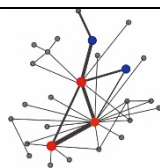

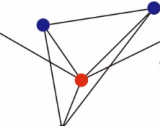
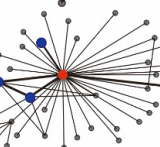
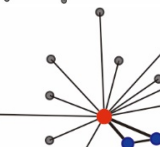
From the above analysis we may conclude that the main innovation actors of Dongying's petroleum equipment industry are essentially a number of state-owned enterprises and the spatial pattern of innovative links is highly localized. From the perspective of subgroup analysis, the network topology of state-owned enterprises and universities is more complex and diversified, but the ties between SOEs and those between SOEs and their spin-offs are intertwined, closed, and strong, while the innovation ties between universities and their partners are divergent and weak. The spin-off company is the only, singular, and strong link with the parent company; partner selection of the other non-SOEs is also singular and strong. Thus, the innovative partner selection process of Dongying's petroleum equipment companies is highly concentrated on several

specific local organizations, and these organizations interact to form several exclusive subgroups through strong ties. Therefore, network closure follows.

Based on the information obtained from face-to-face interviews and surveys, we suggest number of reasons for the observed network closure. First, since the right of supply and exploitation is a national monopoly, the petroleum equipment industry (i.e., the upstream of the oil industrial chain), is generally set up in nearby oilfields. As oilfields drive petroleum equipment companies to improve their products and upgrade their technology, these companies are essentially required to maintain close and immediate physical contact with oilfields, thus making cooperative innovation highly localized. Second, as incremental technological innovation and tacit knowledge are characterize the petroleum equipment industry, cooperative interaction plays a key role in industry upgrading (Saviotti, 1998; Lawson and Lorenz, 1999; Maskell and Malmberg, 2007). Moreover, while knowledge creation, production, and integration require internal research and development, intensive face-to-face communication is more important for technology innovation (Storper and Venables, 2004; Johansson et al., 2005; Suarez, 2005; Asheim et al., 2007).

Therefore, a technology-intensive industry like the petroleum equipment industry tends toward geographical agglomeration. Third, the petroleum supply is completely controlled by the ‘big three’—Petro China, Sinopec, and CNOOC—which are large state-owned conglomerates in the *Fortune Global 500*. Due to historically unique planned and public ownership economic system, a unique access rule for the Shengli Oilfield was gradually implemented, namely, only the spin-offs and the firms that are established by former senior or technical officers from the Shengli Oilfield can sell their products to the Shengli Oilfield. Thus, the Shengli Oilfield connects with these firms through strong private and informal relationships leading to the creation of many closed subgroup. In addition, because of the high technology and capital threshold, the number of enterprises in the same niche or sub-sector is very small. Therefore, petroleum equipment enterprises are well acquainted with each other. Their range of partner selection is extremely narrow and is consequently focused on a few organizations. Fourth, the Chinese have a relatively strong ‘*guanxi*’ concept, and the collectivism of the Chinese northern culture is more evident in the Shandong Province (Lyu and Liefner, 2018). This cultural

Table 4 Attributes of subgroups of Dongying's petroleum equipment industry during 1988–2013

Subgroups	Key actors	Network configuration	Closedness	Main partners	Spatial scale	Strength
I	Sinopec Sairui SLEDI		High	Shengji Bosiman	Local	Strong
II	Kerui SLPERC		High	Hengye	Local	Strong
III	Freet		Moderate	CDSVC Perforation Society CUP	Local and national	Weak
IV	CUP		Low	Sinopec CNOOC Fanghua Yuguang	All spatial scale	Moderate
V	SLECC		Low	SLDTRI SLEDI	Local	Weak

Notes: a red circle represents key actors; a blue circle represents main partners; line size represents the strength of the links

aspect may easily lead to the formation of groupuscules and play a vital role in building and maintaining the informal links in the closed network.

3.2 Regression estimate

From the analysis above, follows that the innovation network of Dongying's petroleum equipment industry is closed. Having also provides a number of reasons why this is the case, we now estimate the effects of network closure on cooperative innovation.

Descriptive statistics and Person correlation coefficient analysis indicate that the validity of the variables is strong and there is a significant correlation between independent and dependent variables. We use a negative binominal regression models in the analysis. The result is shown in Table 5.

Model I presents results of a baseline specification of knowledge production, including research developers and R&D funds. As expected, the coefficients of these dependent variables are both positive and statistically significant. Enterprises with higher percentages of R&D personnel to total employees and of R&D funds to annual sales income have higher innovation performance. In fact, increasing human capital input by 1 percent increases enterprise innovation by about 0.7 percent, and increasing R&D funds by 1 percent increases enterprise innovation by about 0.6 percent. Therefore, innovation input will have a significant impact on enterprise output, which is in accordance with previous research results (Maggioni et al., 2007; Ponds et al., 2010).

Models II, III, and IV gradually add firm attributes such as age, and network configuration to the estimated equation. Model II examines innovation performance under the influence of firm attributes. It shows that ownership and age have no significant positive effect on innovation performance. After adding the network closure variable in Model III, ownership stabilizes while age shows a reverse effect. Overall, models III, IV, and V reveal the impact of network configuration on innovation. As we can see, topology and innovation showed no significant positive correlation, while spatial scale has a significantly positive effect and remains stable even after adding the remaining variables. In fact, the elastic coefficient is above 0.2. Model V adds all variables to the analysis, and the result shows that the coefficient relating network closure and cooperative innovation is positive and significant. This suggests that a closed network can improve firm innovation, and the spatial attributes of network linkages have more impact on enterprise innovation performance than the topology. In other word, for Dongying's petroleum equipment industry, cooperation with local enterprises is more effective than non-local enterprises. Additionally, state-owned enterprises also play an important role in cooperative innovation in Dongying's petroleum equipment industry as their local networks display a higher degree of embeddedness, are stronger and more exclusive. Therefore, the degree of network closure in this case is higher. Overall, our findings provide significance evidence of a unique cooperative technological innovation model in China.

Table 5 Regression analysis results

Dependent variables	I	II	III	IV	V
Research developer	0.708** (0.005)	0.622 (0.010)	0.472 (0.001)	0.532 (0.000)	0.563* (0.009)
R&D funds	0.583* (0.029)	0.923* (0.047)	0.408 (0.033)	0.701* (0.032)	0.841* (0.022)
Ownership		0.343 (0.012)	0.426* (0.044)	0.370 (0.049)	0.600* (0.131)
Age		0.801 (0.005)	-0.517 (0.011)	-0.179 (0.035)	0.387 (0.027)
Topology			0.358 (0.002)		0.204* (0.012)
Spatial scale				0.189** (0.039)	0.216** (0.051)
Constant	0.694	2.544	7.163	2.823	3.876
F statistics	85.607**	55.116**	70.061**	12.948**	32.776**
Adjusted R ²	0.316	0.363	0.428	0.295	0.425

Notes: Standard errors are shown in parentheses. * represents significant at the 0.1 level, ** significant at the 0.05 level, and *** significant at the 0.01 level

4 Conclusions

Consensus among scholars holds that closed networks are not conducive to the promotion of knowledge acquisition and innovation performance. However, the existing empirical results are largely based on studies conducted with data from developed economies and, therefore, can not fully explain the situation in China. For this reason, those models miss the chance to integrate features relevant in the context of China, and perhaps other newly industrializing countries. This study explores the network configurations in Dongying's petroleum equipment industry and its effects on innovation performance, based on an analysis of co-patent data from SIPO for the period 1988–2013, as well as additional data from questionnaires, and face-to-face interviews.

We find that there are many state-owned enterprises and spin-offs and subordinate organizations in Dongying's petroleum equipment industry. These enterprises have more advanced technology, better access to capital, more development experience and commerce and technology relationships. Consequently, they play key roles in cooperative innovation and knowledge creation. Their partner selection is highly concentrated on specific local organizations with many strong ties. As time passes, the network becomes solidified and relationships become stronger. In the network graph, it appears that a number of exclusive subgroups with strong characteristics of network closure have developed. The reason for this phenomena is related to the area's unique industrial development history, state system and policies, regional culture and circumstances, and enterprise ownership. The exclusiveness, localization and strong ties characteristic of network closure are jointly affected by industry-specific features such as high threshold to access, nearby oilfield location, the traditional acquaintance view and 'guanxi' concept of the Shandong people, the Chinese system of planned economic development and state-ownership, and the high importance of the petroleum equipment industry for national security.

Based on the negative binomial regression method, we find that the network closure has positive effects on enterprise innovation performance. Moreover, state-ownership also helps improve innovation performance. Scholars have reflected on the competitiveness of the closed and traditional industrial cluster in recent years, and most have emphasized the advantage of structural holes and open innovation; however, they have sometimes overcorrected in their assessment. Under the special condition of the regional innovation environment in Dongying, the innovative cooperation of the petroleum equipment industry has not resorted to open innovation or gatekeepers as people thought. On the contrary, enterprises will pay more attention to local and existing partners and those they have strong ties with.

This line of research has theoretical implications that run contrary to the previous understanding, and has important implications for the development and implementation of regional innovation policy. In recent years, increasing number of studies on industrial clusters suggest that excessive colonization and endogeneity may lead to regional locking, which is not conducive to enterprise innovation. However, for special industries in a

particular region, structural holes and open innovation advantages are not widely applicable. In China, especially in the industrial sectors involving national and energy security, industries are inherently closed, exclusive, endogenous and dominated by state-owned enterprises instead of small and medium enterprises that are usually perceived as innovative engines. To improve the level of regional innovation, these enterprises use exclusive, solidified and locally embedded networks to maintain cooperative relationships, cooperation efficiency and knowledge spillover between enterprises. We partly support that the reform policies—'reasonably and confidently build stronger, bigger and better state-owned enterprises'—sponsored by the central government for particular regions. Given the nature of our study, we do not claim that our findings may be generalized to other sectors and regions. More empirical research is necessary to unravel the complex effects of network closure on enterprise innovation performance.

The development of clusters is of great significance to the restructuring and upgrading of Dongying's petroleum equipment industry. Attracting foreign investment and developing an export-oriented economy are the basic experiences of China's Reform and Opening in the past forty years. However, for Dongying's petroleum equipment manufacturing industry involving national security and social stability, relying on national strength to operate internally in an enclosed manner has also led to great achievements. This industrial cluster has developed a domestically-oriented economy and independent innovation, relying on strong links between state-owned enterprises and their spin-offs to realize industrial upgrades. Under the constant presence of external shocks and internal fissions, the industrial cluster continues to adapt, evolve, and develop. The findings of this study shed light on the role of network closure on technology innovation while highlighting the limited number of studies in this area.

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