GEOGRAPHICAL PROXIMITY VS NETWORK TIE: INNOVATION OF EQUIPMENT MANUFACTURING FIRMS IN SHANGHAI, CHINA

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Summary: Recent theoretical arguments and empirical studies in economic geography have emphasized the importance of both geographical proximity and network tie for firm innovation. However, few studies have empirically assessed the effects of these two together. This paper examines and compares the effects of geographical proximity and network tie on innovation based on a unique dataset of equipment manufacturing firms in Shanghai, China. An extended spatial economic model is adopted for this analysis. We find evidence that network ties rather than geographical proximity promote firm innovation. This finding is different from previous studies using region as unit of analysis and suggests that geography and network may play different roles at different spatial scales. Moreover, we demonstrate that both internal factors such as firm's expenditures on R&D and human capital and external factors such as government expenditure on R&D and import of foreign technologies are important for innovation of Chinese equipment manufacturing firms.

Zusammenfassung: Jüngere theoretische Überlegungen und empirische Studien in der Wirtschaftsgeographie haben die Bedeutung sowohl geographischer Nähe als auch der Netzwerkanbindung für die Innovation von Unternehmen hervorgehoben. Allerdings haben nur wenige Studien die Auswirkungen beider Faktoren gemeinsam empirisch analysiert. Die vorliegende Studie untersucht und vergleicht die Auswirkungen geographischer Nähe und Netzwerkanbindung auf die Innovation, basierend auf einem einzigartigen Datensatz von Anlagenbauern in Shanghai, China. Für diese Analyse wird ein erweitertes räumliches Wirtschaftsmodell verwendet. Wir finden Belege dafür, dass Netzwerkverbindungen eher als geographische Nähe Innovationen fördern. Dieses Ergebnis unterscheidet sich von früheren Studien, die die Region als Analyseeinheit verwenden, und deutet darauf hin, dass Geographie und Netzwerk auf verschiedenen räumlichen Skalen unterschiedliche Rollen spielen können. Darüber hinaus zeigen wir, dass sowohl interne Faktoren wie die Ausgaben der Unternehmen für Forschung und Entwicklung und Humankapital als auch externe Faktoren wie staatliche Ausgaben für Forschung und Entwicklung und der Import ausländischer Technologien für die Innovation chinesischer Anlagenbauer wichtig sind.

Keywords: Geographical proximity, network, innovation, extended spatial economic model, economic geography, China

1 Introduction

With the rapid industrialization in recent four decades, China has become an influential nation in manufacturing. It is witnessed that many types of industrial products 'made in China' are taking a leading share in the world market[1]. However, many products are designed in foreign countries and only assembled in China. Moreover, many core components and manufacturing equipment are still controlled by foreign firms. This mode of production is arguably associated with high pollution and low profit, resulting in degradation of Chinese natural environment and poor living conditions of Chinese workers. Therefore, recently Chinese government is dedicated to upgrading the value chain of Chinese manufacturing industry by encouraging technological innovation and promoting 'designed in China' based on strategies such as 'Chinese Manufacturing 2025' plan.

A key to realize these ambitions is to accelerate the innovation in the manufacturing equipment industry. As the front of value chain, equipment manufacturing is not only the foundation of manufacturing industry but also generally more profitable than manufacturing itself. In a symposium of the ministry of industry and information technology on June 15 in 2015, Premier Li Keqiang emphasized that the core of 'Chinese Manufacturing 2025' should be 'Chinese equipment'. For this concern, Chinese central and local government provided much fiscal resource to the equipment manufacturing industry. A large number of equipment manufacturing industrial parks emerged in Chinese cities, such as the Sino-German Intelligent Equipment Manufacturing

[1] For example: The Economist (2015-3-12). https://www.economist.com/leaders/2015/03/12/made-in-china

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Industrial Park.[2] At the same time, many Chinese equipment manufacturing firms are buying technologies and forming innovation networks with both foreign and domestic partners.

However, not much scholarly attention has been paid to Chinese equipment manufacturing firms. According to our knowledge, only Wu et al. (2012) has examined the innovation of China's equipment manufacturing industry from the perspective of technological capability and technology management. Few studies have examined the effects of geographical proximity and network tie on innovation of Chinese equipment manufacturing firms. Moreover, current studies based on the western context are still inconclusive on the effects of geographical proximity and network ties on innovation. First, while many economic geographers believe that geographical proximity is likely to facilitate information exchange and knowledge spillover, which are beneficial for innovation creation, the assumptions usually have not been developed based on elaborate mechanisms or tested on the basis of rigorous empirical analysis. As argued in some studies (e.g. Boschma, 2005), geographical proximity not necessarily promotes knowledge spillover. The advancement of communication technology and the deepening of globalization also imply a declining role of geography, although this argument is also controversial in economic geography (e.g. Yeung, 1998; Morgan, 2004). Second, with the advent of network era, more and more economic geographers have recognized the importance of collaborative network for innovation. However, the empirical findings are still mixed (Sun and Zhou, 2011; Ozer and Zhang, 2015). Third, although both geographical proximity and network ties are considered to be important for innovation, few theories have considered these two factors together. The only exception may be the theoretical perspective of 'local buzz' and 'global pipeline' (Bathelt et al., 2004). However, this perspective tends to interpret 'local buzz' as geographical proximity and 'global pipeline' as collaborative network, ignoring the differential roles played by geography and network at the local level. We can argue that firms may benefit from their local partners not through spatial proximity but via network links within a city or a region. The different methods and paradigms adopted by studies on geographical proximity and studies on network ties also make it difficult to compare their effects empirically.

[2] Some information of this industrial park is provided in: https://www.prnewswire.com/news-releases/shenyang-a-city-of-successful-transition-from-chinas-industrial-pioneer-to-innovative-manufacturer-300384157.html

Therefore, this study aims to examine and compare the effects of geographical proximity and network tie on firm innovation using a unique dataset of equipment manufacturing firms in Shanghai, China. It represents an attempt to extend our knowledge on the arguments between territorial innovation models and innovation network in economic geography. This study also examines the effects of both firm's internal attributes and external resources such as government support and technology importation on its innovation performance. The findings may throw some light on the policies to promote innovation of equipment manufacturing industry, which is one of the pillars of economy in both Germany as the current bellwether and China as the catch-up. In the following parts, we first review the theoretical arguments and empirical findings on the effect of geographical proximity and network ties on innovation in the literature, concluding with a summary of the findings and research gaps; the details of data collection and model development will be presented in the third section; the fourth section reports the major empirical findings and the fifth section concludes this paper.

2 Literature review

2.1 Geographical proximity and innovation

Economic geography has an established tradition of examining effects of geographical proximity on innovation (e.g. Segarra-Blasco et al. 2018; Oerlemans and Meeus 2005; Lublinski 2003). Existing studies mainly explain their relationship from three perspectives. First, based on Alfred Marshall's (1920) seminal work, some researchers emphasize the benefits of spatial agglomeration of and territorial closeness to firms in the same and related industries for innovation. It is argued that innovation is a cumulative activity and access to local knowledge externalities and labour pool is in favour of knowledge transfer and collaborative learning (D'Este et al. 2013). The research in this line usually adopts the theoretical angles such as localized knowledge spillover (LKS) (Läpple et al. 2016; Breschi and Lissoni 2001), related variety (Grillitsch et al. 2018; Frenken et al. 2007), and technological relatedness (Rigby 2015). Second, many studies attribute the importance of geographical proximity to informal interaction and tacit knowledge. It is believed that geographical proximity facilitates frequent face-to-face contacts (Weterings and Boschma 2009), which are critical for exchange of tacitly-held knowledge (Gertler 2003) and formation of inter-organization trust (Storper and Venables 2004). Tacit knowledge cannot be easily absorbed or codified via modern communication technology (Lawson and Lorenz 1999) yet is important for innovation (Stefano and Francesco 2001). This perspective is key in most territorial innovation models (Moulaert and Sekia 2003), including the industrial district, innovative milieu, local buzz and new industrial spaces. Third, a series of studies follow Jacobs (1969) and underline diversity or unrelated variety as the major engine for urban economy and innovation (Galliano et al. 2015). It is supposed that diversified industries within a region may spread risks of potential negative shocks (known as the portfolio effect) and lead to more radical innovation (Castaldi et al. 2015).

Many studies empirically examine the effect of geographical proximity on innovation and some do provide supporting evidences that geographical proximity matters for innovation. For instance, both Wixe (2018) and Triguero and Fernández (2018) show that firms are more likely to introduce product innovation if they locate in cities with high related industry diversity or regions with more R&D spent in the same sector to the firm, suggesting localized knowledge spillover and positive effects of geographical proximity on firm innovation. Galliano et al. (2015) find that firms located in both the specialized and diversified zones have higher probability of innovating, which supports the effects of geographical proximity in both Marshall's and Jacobs' framework. Similarly, He et al. (2018) and Läpple et al. (2016) provides supporting evidences of positive spatial spillover effects of innovation based on spatial economic analysis. However, empirical evidence on the importance of geographic proximity for innovation is far from conclusive. For example, Anselin et al (2000) reveal that spatial spillover effect on innovation is specific to industries, it is strong in the Electronics yet insignificant in the Machinery; Ter Wal (2013) suggests that geographical proximity becomes less important for production of knowledge and formation of co-inventor networks with the development of communication technologies and increasing codification of knowledge. Huber (2012) finds that about two thirds of the R&D workers report no real knowledge benefit by being located in the cluster; Grillitsch and Nilsson (2017) display that firms may suffer from negative spillover and gain less from local knowledge sources in knowledge-intensive regions. In addition, some researchers criticize the territorial innovation models and importance of geographical proximity for not rigorously validating the specific mechanisms (Rutten 2017; Malmberg and Maskell 2002). Boschma (2005) also contend that geographical proximity is only one of the different dimensions of proximity that matters for innovation, itself is neither a necessary nor a sufficient condition for knowledge spillover or creation.

2.2 Network ties and innovation

With the rise of network society (Castells 2010) and along with the relational turn in economic geography (Bathelt and Glückler 2003; Sunley 2008), a growing body of research has advocated network approaches to innovation in the recent two decades. Similar to studies of geographical proximity, the literature also explains the role of network for innovation in three ways. First, inter-organizational networks provide firms access to external resources and 'lacking knowledge' through both local buzz and non-local pipelines (Bathelt et al. 2004). Second, as facilitators of knowledge flow between partners, external network increases the firm's diversity of knowledge and capabilities (Sun and Zhou 2011). Since radical innovation is usually associated with diverse types of knowledge sources (Trippl et al. 2009), network is likely to improve firm's innovation performance. Third, based on the studies of social capital, network space and regional growth, Huggins et al propose a term 'network capital' to explain the role of inter-organizational network for firm's performance (Huggins et al. 2012; Huggins and Thompson 2014). They argue that organizational networks as a kind of relational asset is a strategic resource for firms to gain access to knowledge and enhance innovation. Therefore, firms usually invest in calculative and dynamic relations and innovation-seeking network, the value of which forms network capital. Besides, there are also some other benefits of networking for innovation, such as risk-sharing and property right safegarding (refer to Pittaway et al. 2005 for a systematic review).

Unfortunately, the empirical findings are still inconsistent on the effect of network on innovation (Sun and Zhou 2011; Ozer and Zhang 2015). Some studies reveal significant benefits of collaborating and interacting with external actors for the innovative performance of firms. For example, Sun and Zhou (2011) show that linkages with both foreign and domestic firms are helpful for innovativeness of Chinese firms; Fitjar and Huber (2015) suggest that both personal and inter-firm networks are positively related to firm innovation, although the finding mainly holds at international level (global pipeline) rather than the regional level (local buzz). Similarly, Huggins and Prokop (2017) find that holding central and influential positions within the knowledge network is likely to improve innovativeness of a region; Gui et al. (2018) suggest that the network properties in terms of degree centrality, structural hole and small-world quotient are crucial for knowledge production of a nation. However, there are also empirical evidences that the relationship between network and innovation is insignificant or unclear. For instance, in Miguélez and Moreno's (2013) study, while the connectivity (measured by number of ties between inventors) has positive effect on innovative capability of a region, the strength of these ties (measured as network density) has a negative effect; Stuart (2000) find that while organizations with large and innovative alliance partners perform better in innovation, number of partners does not has significant effect on innovation; Bell (2005) found that centrality in the managerial network is positively associated with firm innovation yet the institutional network is not; Broekel and Boschma (2012) also indicate that the effect of network ties on firm's innovation performance is insignificant. In addition, there are also some evidence of network failure for innovation (Pittaway et al. 2005).

2.3 Geographical proximity vs network ties: which is more important?

Despite of the large number of studies examining effects of geographical proximity or network tie on innovation separately, not many studies have considered these two factors together. There are indeed some studies unravelling the effects of geographical proximity on the formation of innovation network and flow of knowledge (e.g. Bell and Zaheer 2007; Abramovsky and Simpson 2011; Broekel and Boschma 2012; Ter Wal 2014; Cassi and Plunket 2015; Hansen 2015) or evaluating the knowledge network among spatially proximate firms within industrial clusters (Boschma and Ter Wal 2007; Ozer and Zhang 2015). However, little work has been done to compare the effects of geographical proximity and network tie on innovation. According to our knowledge, only four studies have explored the effects of geographical proximity and network ties on innovation at the same time (Maggioni et al. 2007; Ponds et al. 2010; Fornahl et al. 2011; Marrocu et al. 2013) and the findings of these studies are still inconclusive. If we follow Hansen's (2015) idea[3] and differentiate the relative importance of geographical proximity and network tie into competing (only one factor has significant effect) or complementary (both have significant effects on innovation) relationship, 3 of the 4 studies cited above suggest a complementary relationship. Specifically, Maggioni et al. (2007) and Marrocu et al. (2013) find that both geographically and relationally neighbouring regions have significant effect on innovation of the European regions. Ponds et al. (2010) show that R&D in both geographically proximate regions and relational regions weighted by number of inter-regional firm-university collaboration has significant effects on regional innovation in the Netherlands. However, the study by Fornahl et al. (2011) seems to support the competing relationship and suggests that the results depend on indicators: for geographical proximity, cluster index is significant yet geographical distance is not; as for network attributes, type of partners is influential yet number of links is not.

To make it even worse, the 4 studies cited above tend to have some methodological limitations. Specifically, 3 of them (Maggioni et al. 2007; Marrocu et al. 2013; Ponds et al. 2010) adopt spatial error regression (SEM) or spatial autoregressive regression (SAR) models to model regional innovation based on spatial matrix and relational matrix. The spatial model in these 3 studies is quite appropriate to accounted for the spatial and relational spillover effects and compare which is more important for innovation. However, as acknowledged by Maggioni et al. (2007), analysis at regional level is difficult to account for the intra-regional interactions or distinguish between contagious and hierarchical knowledge diffusion. In contrast, the study by Fornahl et al. (2011) employs specific indicators (e.g. distance and degree centrality) in negative binominal regression models to capture the effects of geographical

[3] Hansen (2015) originally uses the terms 'substitution' and 'overlap' to distinguish the effects of geographical and non-spatial proximity in collaborative innovation projects. 'Substitution' means that non-spatial proximity substitutes geographical proximity and 'overlap' means that geographical proximity facilitates non-spatial proximity. Noticeably, Hansen only models the effects of geographical proximity on non-spatial proximity and defines the relationship between the two as overlapping if they are positively correlated and substitutive if they are negatively correlated. However, he has not directly compared their effects on innovation and the two terms are not very proper to describe relative importance. Therefore, we use 'complementary' and 'competing' as an alternative.

proximity and network structure on innovation of biotech firms in Germany. Although this study is at the firm level, the indicator-based method fails to incorporate the rich distributive information by simplifying the complex spatial and relational patterns into limited indicators. The different units and varying calculating methods of the spatial and relational indicators also make it difficult to compare the effect of geographical proximity with that of network tie.

2.4 Summary

According to the literature review, many studies have recognized the importance of both geographical proximity and network ties for regional and firm innovation. However, the findings of the empirical studies are still inconclusive and much fewer studies have examined the effects of geographical proximity together with network ties on innovation using comparable methods. Moreover, the limited number of existing studies examining the effects of geographical proximity and network ties together tend to have methodological limitations and mixed findings. The previous studies are also mainly in the western context, yet much less attention has been paid to innovation of Chinese firms.

3 Data and method

3.1 Data

The empirical analysis in this study is mainly based on a unique dataset collected by the Torch High Technology Industry Development Center[4] under Chinese Ministry of Science & Technology. This dataset covers all firms in industrial parks in Shanghai in 2016. The final database is a subsample of 1,291 equipment manufacturing firms with investment in technology. We select the equipment manufacturing firms for analysis because equipment manufacturing industry is of strategic importance in both China and Germany and has drawn much attention by the Chinese and German government. This dataset contains around 200 statistical indicators of each firm, which is by far the most comprehensive and reliable database of Chinese firms. It contains rich information about individual firm's R&D, innovation outputs and technological transactions, which is not provided in the widely used Chinese Industrial Enterprises Database. The only weakness of this data is that it is cross-sectional and thus unable for us to examine the spatial spillover effects with time lags. We geocode the textual addresses of each firm in this dataset into location information of longitude and latitude based on Baidu API. The location information of each firm is double checked manually. The spatial distribution of these firms (Fig. 1) indicates that many equipment manufacturing firms are clustered in the industrial parks in the inner and outer suburb region. We also use the co-patent data to measure collaborative innovation network. Specifically, the National Intellectual Property Administration, PRC (http://www.cnipa.gov.cn/) was searched using the names of the above manufacturing firms as keywords. All patents with at least two inventors were retrieved and links between the equipment manufacturing firms in Shanghai are constructed based on co-inventorship of the same patent. In line with other studies (e.g. Fleming et al., 2007; Ter Wal, 2014), we assume that co-invention links exist for 5 years and adopt a 5-year moving window procedure to generate the co-invention links.

3.2 Model and variables

The major problem for modeling is to select proper variables. The literature on determinants of innovation at firm level is usually based on knowledge production function (KPF; e.g. Anselin et al., 2000; Ramani et al., 2008; Ponds et al., 2010; Marrocu et al., 2013), in which the output is usually measured by patent application of firms and the input by R&D expenditure of both firms and public organizations. However, since not every applied patent can be authorized, we use the authorized patents of each firm as the dependent variable. Similar to previous studies, the major independent variables in our model are private and public R&D expenditure and number of full time researchers. Besides, we also incorporate some important control variables. Most of these variables are internal factors (characteristics of the firm). Specifically, *firm size* is included since many studies find this variable influential of innovation (e.g. Fitjar and Huber, 2015; Sun and Zhou, 2011; Ponds et al., 2010). While firm size is usually measured by number of employees, we also add the total assets considering that both capital and labor are important dimensions of manufacturing firms. *Human capital* is also shown as an important variable for innovation (e.g. Hansen, 2015; Marrocu et al.,

[4] The detail information of this center can be found at http://www.ctp.gov.cn/kjb/index.shtml

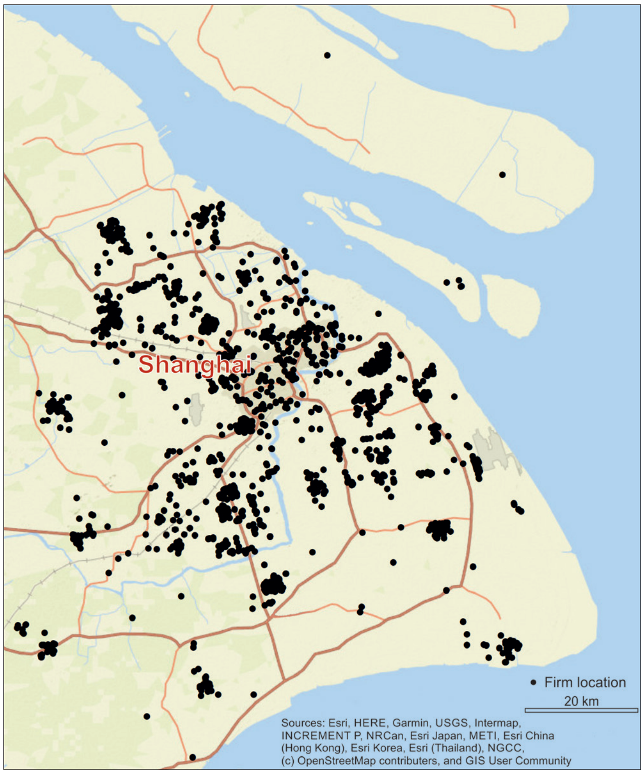

Fig. 1: The spatial distribution of samples in this study

2013; Ponds et al., 2010) and thus included in our model. *Firm age* is another factor considered to be related to firm innovation (e.g. Ozer and Zhang, 2015; Sun and Zhou, 2011; Weterings and Boschma, 2009) and is controlled in our model. Additionally, we take into account for some external factors (non-firm variables). Concerning that Chinese government is investing heavily in public R&D and provide considerable subsidies to encourage firm innovation in recent years, it is necessary to control the effects of public expenditure on R&D in each firm. Since many Chinese firms are actively buying technologies through M&A transactions and technical contracts, we also include the expenditure on importing foreign technologies and buying domestic technologies as control variables in our model.

Another important question is how to model and compare the effects of geographical proximity and network ties. The effects of geographical proximity is usually examined with spatial regression models, which are developed based on the first law of geography[5)] (Tobler 1970; Miller 2004) and the idea of spatial autocorrelation or dependence (Cliff and Ord 1981). Since 1970s, spatial econometrics was developed to deal with spatial relations (Paelinck 1979; Anselin, 1988; LeSage and Pace 2009) and the spatial regression models were widely used to estimate various spillover effects from neighboring regions, such as the Spatial Autoregressive Regression (SAR), Spatial Error Model (SEM) and Spatial Durbin Model (SDM). The main idea of spatial regression models is adding a spatial weight matrix to the standard ordinary least square regression model to account for spatial autocorrelation. As the illustrative example in Fig. 2 shows, we can use the matrix in the middle to reflect the bordering pattern of the four regions in the right. Noticeably, weight matrix is also able to describe the links between the four nodes in the left network. The equivalent weight matrix of geographical proximity and network tie suggests that the spatial regression models can be extended to capture effect of network ties using relational weight matrix. This ides has already been adopted by some recent studies to compare the effects of geographical proximity and collaborative network on innovation (Maggioni et al. 2007; Marrocu et al. 2013; Ponds et al.2010). The extended spatial regression model is argued to be better

[5)] Tobler (1970) summarizes the first law of geography as: "everything is related to everything else, but near things are more related than distant things".

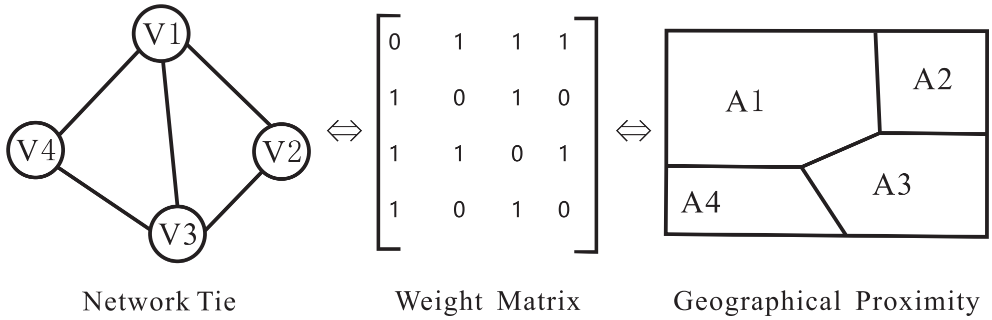

Fig. 2: An illustrative example of the equivalent weight matrix of network tie and geographical proximity

than regression on the indicators of network structure such as number of links (e.g. Sun and Zhou 2011), 'small worlds' and 'structural holes' (e.g. Cassi and Plunket 2015) because the latter only captures the linear effects of certain network characteristics[6] and cannot be directly compared with the spillover effects of geographical proximity. Therefore, we also adopt the extended spatial regression model in this paper. Different from the previous extended spatial regression models, we also include an interaction term between geographical proximity or network tie and the firm's absorptive capacity, which is found to play a moderating role in the firm's learning from its local or relational innovation environment (Tsai 2001; Fritsch and Kublina 2018).

Additionally, because a considerable share (61.6%) of manufacturing firms in this study produce no patents in the period of study, we adopt the Tobit regression technique with the lower threshold as 0. Tobit regression is designed to model variable with a censored distribution (usually with excess zeros; Hall and Zhang 2004) and widely used in social sciences such as economics (Mairesse and Mohnen 2002; Smith and Brame 2003) and accident research (Anastasopoulos 2016). The firm innovation output data is commonly with zero-inflated distribution (e.g. Sun and Zhou 2011) since the firm does not report any negative outputs despites of low level of R&D expenditure. Therefore, it is appropriate to use Tobit regression to model innovation outputs. Actually, a large number of previous studies on innovation have applied the Tobit regression method (e.g. Wakelin 1998; Ouwersloot and Rietveld 2000; Love and Roper 2001; Nassimbeni 2001; Roper et al. 2013; Afzal 2014; Cappelli et al. 2014; Zhang 2015; Läpple et al. 2016; de Matteis et al. 2019).

[6] This is problematic because theoretically the effects may be non-linear and methodologically the estimation may be biased because firms' attributes are depend on the attributes of their neighboring or linked actors.

Finally, the following log-linearized Cobb-Douglas KPF model combined with spatial Tobit regression method is specified for empirical analysis:

$$P_i^* = \alpha + \beta_1 \ln RE_i^f + \beta_2 RP_i^f + \beta_3 X_i + \varrho_1 WP_i^* + \varrho_2 AC \times WP_i^* + \varepsilon$$

where P_i^* is a latent variable of innovation output made by firm i. The observed authorized patents of firm i (P_i) equates to P_i^* when the latter is above 0, P_i equates to 0 when P_i^* is negative. RE_i^f stands for the R&D expenditures by the firm i and RP_i^f stands for the researchers in firm i. X denotes the control variables, including firm size (EMPLOYEE and ASSET), firm age (AGE), human capital (GRADUATE) and expenditure on importing foreign technologies (EFT) and buying domestic technologies (EDT). In line with previous studies (e.g. Ponds et al., 2010), we also include the expenditure on R&D by the government (RE_i^g) to control the roles played by public sectors. AC is the absorptive capacity, which is defined based on Tsai (2001) as R&D expenditure divided by sales. The independent variables are all in logarithm in the estimation except firm age and human capital. W refers to the spatial or network weight matrix. In the spatial weight matrix, the element r_{ij} at row i and column j in W is defined as the inverse distance between firm i and firm j; in the network weight matrix, r_{ij} is defined as the number of collaborative patents between firm i and firm j. In line with Weterings and Boschma (2009) and others, we bound the geographical proximity within a 50-km range. ϱ is an autoregressive parameter that accounts for the spillover effects of innovation output by the geographically or relationally proximate firms. ε is a stochastic error term. The model is estimated based on a spatial Tobit regression program, which has been applied in recent studies (e.g. Iim 2018; Hoshino 2019). The definition and descriptive statistics of these variables are shown in Tab. 1. We can find that the levels of innovation for manufacturing firms in Shanghai are unevenly distributed. The firms are also spending a lot in importing technologies from foreign countries.

Tab. 1: Definition and descriptive statistics of variables

Variables	Definitions	Mean	Standard deviation
Dependent variable			
P_i	The authorized patents for invention of firm i	4.05	35.51
Independent variable			
RE_i^f	R&D expenditure by firm i (thousand Yuan)	32.49	218.97
RE_i^g	R&D expenditure by the government on firm i (thousand Yuan)	2.67	42.82
RP_i^f	Number of full time researchers (person)	60.70	211.68
AGE	Year since establishment of the firm	13.72	7.67
ASSET	Total asset of the firm at the end of year (thousand Yuan)	823.82	6,127.45
EMPLOYEE	Number of fulltime employment in the firm (person)	289.85	739.36
GRADUATE	Share of graduates over total employees (%)	8.49	12.97
EFT	Expenditure by the firm on importing foreign technologies (thousand Yuan)	5.64	128.89
EDT	Expenditure by the firm on buying domestic technologies (thousand Yuan)	0.27	6.35
AC	Absorptive capacity defined as R&D expenditure divided by sales	0.44	4.53
Weight matrix			
Geographical proximity	The inverse of spatial distance (in unit of km; with an upper bound of 50 km) between two firms	0.17	0.88
Network tie	The co-patents by two firms	6.32	9.11

Note: The mean and standard deviation of geographical proximity are calculated for spatial distance (not its inverse); the mean and standard deviation of network tie are calculated based on non-zero samples.

4 Results of analysis

We present the results of extended spatial Tobit regression of the patenting activity in Tab. 2. The first model accounts for the effect of *geographical proximity* and the second model accounts for the effects of *network ties*. Judging from the spatial and relational autoregressive coefficient ϱ, we can find an insignificant effect of geographical proximity yet a significant effect of network ties on innovation of equipment manufacturing firms in Shanghai. This result seems to support the competing instead of complementary relationship between geographical proximity and network tie. In other words, inter-firm knowledge spillover is mainly through the firms' collaborative connectivity rather than the localized milieu. This result contrasts the previous findings of regional-level studies (e.g. Maggioni et al. 2007; Ponds et al. 2010; Marrocu et al. 2013), which indicate that regional innovation is influenced by both geographical proximity and network ties and the former tends to play a more important role. While this finding may be caused by the industrial characteristics (e.g. the equipment manufacturing industry may rely more on non-local knowledge through collaborative networks) and cultural context (e.g. the channels of localized knowledge spillover, such as chatting, may be less developed in Chinese culture), it provides evidence that the mechanism of intra-regional knowledge spillover is likely to be different from the inter-regional spillover. This finding also challenges the Chinese industrial park policy. As a popular practice in Chinese cities and supposed successful engine of China's rapid economic development, Chinese industrial parks draw a lot of academic attention (e.g. Zheng et al. 2017; Zhou and Xin 2003; Walcott 2002). Chinese local governments usually attract different

Tab. 2: Extended Spatial Tobit Regression results (dependent variable: authorized patents)

	Geographical Proximity		Network Ties	
	Coef.	p>|z|	Coef.	p>|z|
Internal factors				
RE_i^f	0.073**	0.05	0.069*	0.06
RP_i^f	-0.058	0.21	-0.059	0.20
AGE	-0.004	0.34	-0.004	0.38
ASSET	0.010	0.81	0.012	0.77
EMPLOYEE	0.123**	0.04	0.127**	0.03
GRADUATE	1.350***	0.00	1.309***	0.00
AC	-0.011	0.57	-0.003	0.58
External factors				
RE_i^g	0.050***	0.00	0.048***	0.00
EFT	0.066***	0.00	0.066***	0.00
EDT	0.043	0.14	0.045	0.12
Constant	0.321	0.31	0.069	0.79
ρ_1 (patents by neighboring firms)	0.000	0.75	0.007*	0.07
ρ_2 (interaction term with AC)	0.000	0.71	-0.004	0.59
Lambda	0.001	0.48	0.014***	0.00
N	1291		1291	

Note: "*", "**" and "***" indicate the coefficient is significant at level of 0.1, 0.05 and 0.01, respectively.

high-tech firms to invest in their industrial parks with cheap land cost and high-level infrastructure, expecting to nurture innovative milieu and form inter-firm knowledge spillover. However, according to our finding, it seems that firms gain limited innovative benefits from their neighbouring firms in the same industry by locating in the industrial parks. Instead, the inter-firm ties formed by bottom-up and intentional innovative collaboration seem to be more effective in promoting firms' innovation, highlighting the importance of collaboration with non-local partners for innovation. It is also worth noting that neither the absorptive capacity itself nor its interaction with the innovation by geographically or relationally neighboring firms is important for the firm's innovation output. This is different from previous studies (e.g. Tsai 2001; Fritsch and Kublina 2018) and implies that the channels of knowledge flow rather than the ability to replicate and absorb knowledge is more important for innovation.

As for the internal factors of the firms, both R&D, firm size and human capital are essential components of innovation for equipment manufacturing firms in Shanghai. Similar to previous studies, their effects are all positive. However, we found no evidence that firm age is related to firm innovation, indicating no accumulating effect of innovative capability of Chinese equipment manufacturing firms. While asset is usually adopted to measure firm size, it is not a significant predictor of firm innovation, supporting the rationale of using number of employee to measure firm size in previous studies (e.g. Sun and Zhou 2011). It is interesting to note that firm's patenting activity is not dependent on the number of full-time researchers. Comparing with the significant effect of GRADUATE, it appears that the innovation of Chinese equipment manufacturing firms is not necessarily promoted by the full-time researchers. However, for the limited space, we will not discuss these variables in detail considering that they are not the focus of this study.

Regarding the external factors, the resources provided by both government and market are important for innovation of equipment manufacturing firms in Shanghai. Specifically, R&D expenditure by the government is significantly and positively associated with firm innovation. This finding echoes some previous findings (e.g. Kleer 2010; David et al. 2000) and implies that the fiscal support by Chinese government does promote the innovation of equipment manufacturing firms. The expenditure spent on importing foreign technologies also has positive and significant effect on firm innovation, suggesting that foreign knowledge are important source of innovation for Chinese equipment manufacturing firms. The expenditure on buying domestic technologies is positively associated with firm innovation, however, the effect is insignificant. This demonstrates that domestic knowledge base is relatively less important for Chinese equipment manufacturing firms' innovation. This is understandable considering that China is still catching up with its foreign counterparts in equipment manufacturing industry.

5 Conclusions and discussion

This study examines the effects of geographical proximity and network tie on innovation based on a dataset of equipment manufacturing firms in Shanghai. The study contributes to the literature by examining and comparing the effects of geographical proximity and network tie at the firm level based on the extended spatial regression model. In addition, it thoroughly investigates the determinants of innovation of equipment manufacturing firms in Chinese context.

Our analysis reveals that network tie rather than geographical proximity is more important for the process of innovation generation. Based on the study by Hansen (2015), which distinguishes the overlap and substitution relation between geographical and non-spatial proximity, we define this as a completing relationship between geographical proximity and network tie. This finding is in contrast with previous finding at the inter-regional level and suggests that the collaborative network, which is not necessarily formed based on the distance decay law, is playing dominant roles in innovation. Accordingly, the network paradigm rather than the territorial analysis based on geographical proximity seems to be more proper to interpret the formation and spillover of firm innovation. This study also poses a challenge to Chinese industrial park policy, which successfully attracts firms to locate closely within an industrial park yet seems to be less effective to promote knowledge spillover.

Our analysis also offers initial evidences of how internal and external factors influence innovation of Chinese firms. As for the external factors, the firm attributes including R&D expenditure, firm size and human capital all have positive and significant effects on firm innovation. Regarding the external factors, R&D expenditures by government and import of foreign technologies tend to enhance firm innovation. These findings indicate that government support on innovation and the firms' engagement in importing technology from developed countries accelerate the innovation process for Chinese equipment manufacturing industry.

Finally, the authors are conscious that analysis can be extended in several directions. First, considering the particularity of both equipment manufacturing industry and Chinese context, caution should be given to generalize the findings in this study. More research is needed to further test and understand the relationship between geographical proximity and network tie based on other industries in other regions. Nevertheless, this is not contradictory to the contribution of this paper. On the one hand, this paper provides a general framework and method for future studies to compare effects of geographical proximity and network tie on innovation. On the other hand, regional difference is always a major topic in geography. Therefore, some of the findings in this paper (such as the insignificant effects of geographical proximity and absorptive capacity on innovation) is not bizarre but valuable for us to crucially evaluate the findings mainly based on western context. Second, this study only considers the firms in Shanghai and neglect the inter-regional network links. The analysis at this scale is relevant to the spatial range of industrial clusters and advances the previous studies at the inter-regional level. However, we cannot rule out the possibility of a different finding if we consider the links with other regions, although they are usually independent with the intra-city links and partly captured by the two indictors of technology trade in this paper. Therefore, more attention should be paid to the scale problem in future studies. Third, the role of Chinese government in firm innovation remains an interesting point for future studies. While the insignificant effect of geographical proximity poses challenge to Chinese industrial park policy, the significant effects of government expenditure on firm R&D suggests that the public expenditure by Chinese government is helpful for firm innovation. Nevertheless, some may argue that there are self-selection problem since the public expenditure may mainly spent on the firms with more innovation output but may be not efficient to create new innovation. Since this study cannot rule out this possibility based on the cross-sectional data, future studies may pay additional attention to the role of Chinese government in firm innovation.

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