

The combined network effect of sparse and interlocked connections in SMEs' innovation

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Abstract

This paper aims to examine the relationship between the structures of inter-organizational connections and innovation results in the context of small and medium enterprises (SMEs). Existing literature shows that inter-organization connections can benefit firms in terms of innovation. However, there is a theoretical gap regarding how a combination of various structures of inter-organization connections affects innovation results. To close this gap, innovation network theory is employed to support our hypotheses. Consistent with prior research, we find that SMEs' innovation can benefit from having sparse connections and interlocked connections. However, in contrast to prior research, our research emphasizes the importance of the combined network effect between sparse and interlocked connections.

Keywords: Sparse; Interlocked; SMEs; Innovation

1. Introduction

Interest in understanding how inter-organization connections influence innovation has recently increased (Rothwell and Dodgson, 1991; Borgatti and Halgin, 2011; Söderholm et al., 2019). Inter-organizational connections are important to a firm's innovation capacity in business innovation modes, Science, Technology and Innovation

(STI) mode and Doing, Using and Interacting (DUI) (Jensen et al., 2007; Parrilli and Heras, 2016). The increase of a firm's innovation capacity through inter-organizational connections are evident in Europe (Fitjar and Rodriguez-Pose, 2013; Nunes and Lopes, 2015; Apanasovich et al., 2016; Thoma, 2017), North America (Ferrary and Granovetter, 2009) and Asia (Chen et al., 2011).

An interaction effect is a situation that the combined effect of independent variables on a dependent variable is greater (or less) than the sum of each independent variables individually (Jaccard et al., 2003). Including an interaction effect in a study is important, since it shows how independent variables work together to influence the dependent variable (Siemsen et al., 2010). It provides a better understanding of not only the relations between the independent and dependent variables, but also how the independent variables work together. However, the efforts of prior studies have almost exclusively focused on the variety of inter-organization connection structures that influence innovation results, over-looking one of the interaction effects between them. Thus, the novelty of this research is to explore whether various inter-organization connection structures can benefit from or conflict with each other. In this study, we aim to answer the question of how small and medium enterprises' (SMEs') innovation can be affected by a combination of different structures of inter-organization connections. Therefore, by advancing a conceptual framework as to how SMEs' connection could boost innovative activities, we aim to provide important theoretical and practical insights for SME managers and policy makers. To achieve this, this study performs network analysis on a dataset consisting of 1,056 firms.

A gap in the current theories concerns whether firms can take advantage of the combination of both sparse and interlocked network structures in innovation. SMEs are usually connected together in complex structures to achieve innovation. It is important to find out if the combined sparse and interlocked structures of SMEs' connections are valuable to innovation. Thus, the results of our research can advance the innovation network theory from seeking the effect of each network structure to the interaction effects of various combined network structures.

This paper is organised as follows. Section 2 presents the theoretical framework and hypotheses relevant to the study. Section 3 introduces the data and research method, and in Section 4 the results are presented and discussed. Section 5 draws conclusions from this study.

2. Theoretical framework and hypothesis development

Previous research (Fernandez-Olmos and Ramirez-Aleson, 2017) suggested three factors of SMEs can affect the success of innovation. They are the macro-economic condition (macro level), the life cycle of the business (industry level), and the age of the SME (firm level). In addition, how entrepreneurs perceive business information and resource (individual level) can also affect the success of innovation (Solomon and

Linton, 2016; van Weele et al., 2017). However, theories in this area can still be improved by considering the effects of inter-organizational connections among SMEs from a micro-level perspective (Van Lancker et al., 2016). Complex innovation processes cause SMEs to form networks in innovation to obtain access to external information and resources (van de Vrande et al., 2009; Zeng et al., 2010). The growing use of networks in SMEs' innovation is considered as a competitive advantage providing flexibility and rapid response (Narula, 2004; Vos, 2005). Thus, it is necessary to clarify and examine the effects of inter-organizational connections in SMEs' innovation.

Inter-organization connection in innovation is usually an ambiguous concept across academia and business practice. The degree of 'openness' in inter-organization connections is positively correlated to a firm's innovation performance (Laursen and Salter, 2006). 'Openness' means firms using a wide range of external business sources are more likely to achieve success in innovation. It has been supported by the observation that innovation usually consists of collaborative work to combine formerly separated knowledge into new knowledge and ideas (Aalbers et al., 2016; Leenders and Dolfsma, 2016; Oh et al., 2016). Innovation emphasizes gaining access to resources and knowledge through connections with external parties (Weiblen and Chesbrough, 2015; Mun et al., 2019; Pancholi et al., 2019). In innovation, the complex interdependency and connections among organizations need to be clarified and examined (Ritala and Almpantopoulou, 2017). Especially, inter-organization connections are critical to innovation in SMEs in obtaining external resources and knowledge (Cooke and Wills, 1999; Batjargal, 2003 and 2007; Liao and Welch, 2005; Müller et al., 2018). Thus, our study draws on the literature on innovation network theory to examine the relations between the various structures of inter-organization connections and innovation results in SMEs.

The agents of combining separated knowledge are firms, and as such network analysis has emerged as a robust method to link these micro-behaviours of firms and the macro-results from them (Cross et al., 2015). The work of Uzzi (1996) and Burt (1992 and 2015) suggests that efficient network structures of firms are either interlocked, featuring dense clusters of firms, or sparse, featuring loosely connected firms with a few connections. 'Connections' represent collaborations and investments in firm relationships, so, to combine knowledge and resources at minimum cost, firms should avoid similar or redundant connections between them. Sparse networks are usually taken advantage of by centrally located firms who aggregate knowledge and resources from others (Baker et al., 2016; Lynch et al., 2016). On the other hand, interlocked networks have short connection (or path) lengths which are conducive to the quick spread of knowledge and resources. Thus, firms in high-density networks are likely to be effective in innovation (Schleimer and Faems, 2016). Those firms in interlocked networks may not have the same intellectual reach as firms in sparse networks, but have higher levels of efficiency. Thus, in our model, we assume both sparse and interlocked network structures are related to a firm's innovation results.

Innovation networks can reflect the collaborations among firms. In firm collaborations, the choice of partner firm is usually not random (Carroll and Teo, 1996; Candi et al., 2013). For a collaboration to be innovative, business resources and information being combined are often sufficiently 'distant' from each other that their combinations are not 'obvious'. Thus, innovation networks can be abstracted away from the business communication aspects of SMEs to focus on the structures. SMEs interact through innovation networks, exchanging business resources and information and retaining resources and ideas that are innovative or innovation related. A successful innovation is usually initially unknown or unfamiliar to most of the SMEs in a network. It is assembled by combining a series of information and resources from connected SMEs.

A connection between organizations is a purposeful social unit that shares business information and resources to achieve the collective target (Levin and Cross, 2004; Lovejoy and Sinha, 2010). Building up connections between SMEs is usually time consuming and therefore has an opportunity cost. This is because SMEs only have finite or limited capacity for collaborations with each other. Collaborations take time and have labour cost and SMEs usually have a small number of staff with limited working hours in a day. Therefore, SMEs can only have a finite number of connections with others. SMEs' connections are not easily replaced or alternated by new connections. The connections among SMEs enable information and business resources exchange, but constrain their abilities to find alternatives. Once SMEs are connected, their connections constrain their ability to build new connections. In the short term, an SME sticks to its ego network structure and position, once its connections are built up. Thus, this research seeks efficient innovation network structures, those that can lead to SMEs' innovation success.

The connections among organizations can facilitate the integration of diverse resources and knowledge in innovation. Particularly in the case of SMEs' innovation, accessing diverse resources and knowledge in other SMEs through collaboration, albeit necessary, is not enough to enhance innovation results significantly (Thorpe et al., 2005; Konsti-Laakso et al., 2012). Although prior empirical evidence demonstrated that bridging connections between SMEs correlate positively with their innovation results, less attention has been devoted to combining various structures of those connections and the effects of combined connection structures.

The literature on organizational connections in innovation has recognized that sparse ties are positively associated with obtaining access to external knowledge and resources in innovation. Sparse connections are inter-organizational ties between a focal organization and otherwise disconnected alter organizations. There are no connections among those alter organizations. They are connected centrally to a focal organization. The number of an SME's sparse connections is positively associated with the diversity of accessible external resources and knowledge in innovation. Sparse connections are

beneficial to firms' innovative capabilities. Sparse connections reaching outside an organization are significantly related to the individual (Gilsing and Nooteboom, 2005; Ibarra et al., 2005; Cross et al., 2015) and organizational level of innovative results (Walker et al., 1997; Tsai and Ghoshal, 1998; Tsai, 2000; Gargiulo and Sosa, 2016). For instance, McEvily and Zaheer (1999) found that resource and advice seeking in innovation can be effective through sparse connections across organizational boundaries. SMEs with sparse connections can effectively gather the required business resources and information in innovation.

Sparse connections are usually central to an organization. In this case, an organization has the advantage in recombining business resources and knowledge from the others. For instance, a disconnected pair of an IT device design firm and an engineering firm can be bridged to create a new device by a third firm (Dan, 2014; Javaid, 2014). This third firm does not only take the advantage from the innovative products, but also can be a representative to lead this three-firm cluster. Meanwhile, a firm with sparse connections can usually be a gatekeeper to this recombined new business, given that obtaining and managing access to one firm takes less time and resources than doing so to two separate ones. Thus, SMEs with sparse connections are more likely to be successful in innovation than those without.

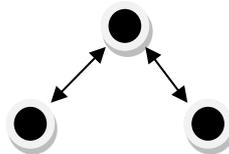


Figure 1: Sparse connections

Based on the above discussion, we propose our first hypothesis.

Hypothesis 1: *Sparse connections are positively associated with SMEs' revenue growth.*

SMEs also need interlocked connections and to be embedded in a cluster. A limit to SMEs generating innovation through sparse connections is that having new business resources and ideas is fundamentally far away for them to turn them into innovation results. Having interlocked connections helps SMEs to confirm and corroborate the view that innovation is developing in a promising area and the technological expertise attained is generating innovation. For instance, SMEs share and recombine diverse resources and knowledge into innovative outcomes, a new product or service. At the same time, they work against the difficulties associated with the uncertainties in their market, substitutes and technological evolutions. In fact, an innovation can easily be replaced or wiped out in the market by another, similar innovation or newly emerged technologies, even before it is formally launched (Gabbay and Zuckerman, 1998; Edelman et al., 2004; Fleming and Waguespack, 2007). Building on these insights, we argue that connections among SMEs are combined structures consisting of not only sparsely bridging ties but also interlocked ties.

In addition, interlocked connections provide SMEs with a number of equivalent communication channels which can monitor and confirm the direction of innovation. Interlocked connections are better than sparse ones when the resources and knowledge are clearly valuable from the source organization's view but not certain from the recipient organization's view. Reagans and Zukerman (2001) highlighted that interlocked connections are positively associated with the results of knowledge transfer in innovation. Furthermore, other prior research showed the advantages of interlocked connections in achieving a common view in inter-organizational innovation (Krackhardt, 1992; Uzzi, 1996; Pittaway et al., 2004). In the specific case of SMEs' innovation, interlocked connections can facilitate mutual understanding and help to build a common basis of implementing new ideas. Therefore, interlocked connections can support the transfer and implementation of diverse business resources and complex information in innovation.

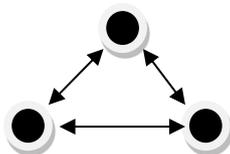


Figure 2: Interlocked connections

Based on the above discussion, we propose our second hypothesis.

Hypothesis 2: *Interlocked connections are positively associated with SMEs' revenue growth.*

Moreover, there are reasons to expect positive interaction effects between sparse and interlocked connections for SMEs' innovation results. Innovation is considered as behavioural consequences of SMEs with both sparse and interlocked connections. Both sparse and interlocked connections are important drivers of innovative results for organizations (Inkpen and Tsang, 2005; Galaskiewicz, 2007). From the network structure perspective, an SME's connection can be either sparse or interlocked, but cannot be both within a short time period. In addition, sparse connections increase the diversity of business resources and knowledge, and interlocked connections increase common understanding of complex implementation problems.

Although sparse connections are effective in gathering and obtaining access to external resources and knowledge, those connections do not automatically and directly generate innovation (Gulati, 1999; Obstfeld, 2005). As the external business resources and knowledge acquired across organizational boundaries are usually heterogeneous and diverse (Burt, 2015; Popa et al., 2017), sparse connections may lack the necessary common base to integrate them (Granovetter, 1973 and 1985; Krackhardt, 1992; Sydow and Windeler, 1998; Joshi, 2006). Moreover, business resources and knowledge are hard to mobilize and transfer across organizational boundaries, because of the lack of a common business language and shared approach (Podolny and Baron, 1997). As Obstfeld (2005) and Burt (2015) noted, obtaining new business resources and ideas

through different perspectives and implementing them into innovation are two distinct innovative processes. The diversity of business resources and knowledge provided by sparse connections might be an obstacle to their implementation. For instance, people belonging to different organizations might be subject and limited to their own responsibilities and tasks towards the implementation and transfer of business resources and knowledge into separated innovative results. Thus, SMEs that innovate through sparse connections often lose control and lack coordination.

The features of interlocked connections among SMEs could help to overcome those limitations of sparse connections. Interlocked connections refer to inter-connected ties among organizations (Granovetter, 1985; Nohria and Eccles, 1992). Interlocked connections are usually considered as structural redundancy in networks. In this case, each organization in interlocked connections is not considered as a unique bridge to connect any others. Prior research (Uzzi, 1996; Borgatti and Halgin, 2011) showed some specific advantages associated with interlocked connections. In addition to connecting cross-organization resources and knowledge to create innovation, the innovative prospect and value of these external resources and knowledge can be compared and confirmed by organizations located in different parts of an interlocked structure. Although certain resources and knowledge are not significantly valuable to some organizations, they can still be hugely beneficial to the others who are able to implement them in innovation (Kraatz, 1998; Koka and Prescott; 2002; Nebus, 2006). To sum up, SMEs' innovation through sparse connections can be affected by a lack of control and coordination, and interlocked connections can help to overcome this disadvantage of sparse connections. This means sparse and interlocked connections together can have more effect than the sum of their effects individually on the innovation results. Thus, we suggest there is an interaction effect between sparse and interlocked connections. Based on the above discussion, we propose our third hypothesis and model (see Figure 3).

Hypothesis 3: Sparse and interlocked connections are jointly and positively associated with SMEs' revenue growth.

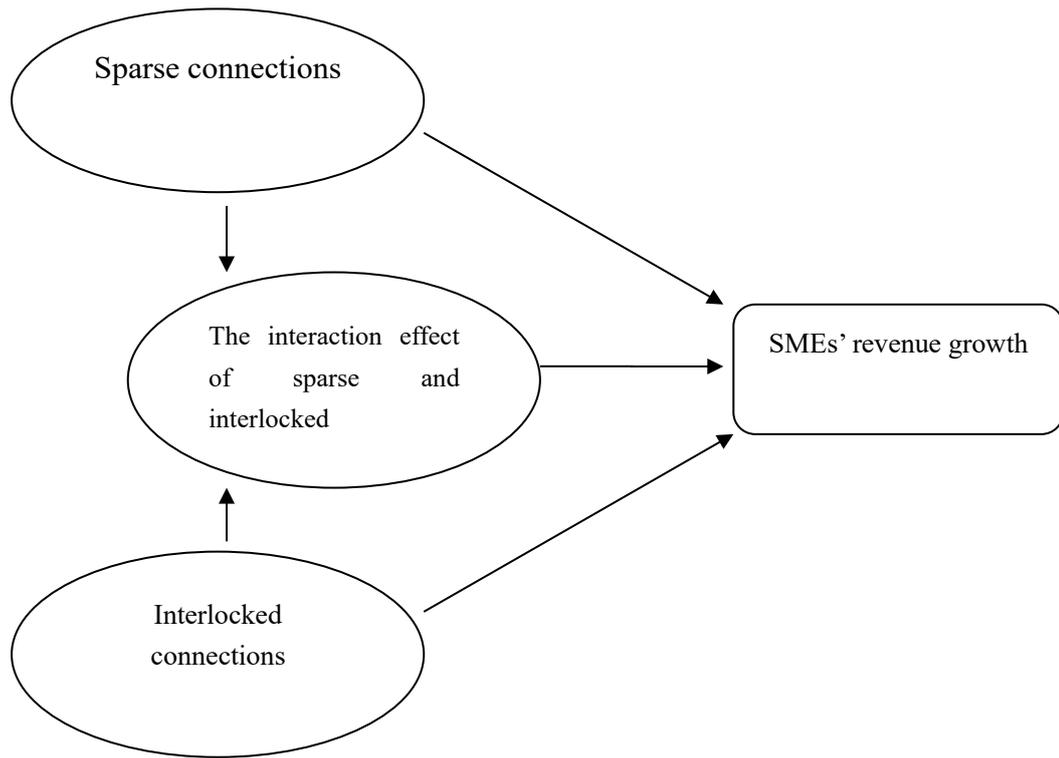


Figure 3: The theoretical framework

3. Methodology

This study performs network analysis on a dataset collected from the OECD ORBIS Database. The dataset consists of 1,056 firms. The data was collected for the purpose of calculating firms' sparse and interlocked connections. Previously, sparse and interlocked connections were tested separately. This research uses network analysis and regression modelling to test sparse and interlocked connections together, and also includes the interaction effects.

3.1 Dataset and Source

We collected data from Firm-Level Micro-Data in the OECD ORBIS Database. According to the OECD firm category (2019), the data includes small and medium firms with less than 250 employees and turnover less than 50 million euros, and also large firms with more than 250 employees and turnover more than 50 million euros. The sample comprises all the firms with product development expenditures in their financial statement in the information and communication technology (ICT) in the area of Beijing and Shanghai. We collected data for 1056 firms including 724 SMEs (369 from Beijing and 355 from Shanghai) and 332 large firms¹ (142 from Beijing and 190 from Shanghai). All the firms are from the information and communication technology

¹ We had to include large firms in the sample as SMEs alone cannot be connected. Therefore, we considered only those large firms which are connected with that particular SME.

(ICT) sector, as this sector is one of the most innovative and interconnected. We identified and included each firm based on whether it has product development expenditure in its financial statement in the dataset. Thus, the data we collected covers all firms that financially declared product development. The data covers joint innovation bank loan between 2009-2011² as recent research (Potrafke, 2015) has suggested that they are the most active areas and time period in product development, in terms of volume of products and number of firms. The data contains three years' (from 01/2009 to 12/2011) detailed firm-specific information including company profiles, collaboration partners, investment, sales, number of employees, and revenue. The data regarding collaboration partners provides information about the name list and connections in product development, which is then used to generate our independent variables. Firms' profiles, such as number of employees and revenue, are used to generate our control variables to distinguish the effects of firm size from the effects of firm connections. Since the dataset only includes company information, the analysis results do not cover connections between firms and non-profitable organizations, such as universities and governments.

The reason for selecting this dataset is to represent the active interactions among firms. In China, there are about 38 million SMEs, which is 97% of firms, providing 80% of employment, and contributing 60% of the total GDP in 2019 (OECD, 2020). Recent research (Potrafke, 2015) suggested that China has the most active SMEs in terms of volume of products and number of firms. The number of SMEs in China is increasing by a rate of about five million each year, which is a 10% yearly increase (OECD, 2020). Therefore, this research selects the dataset in the area of China to represent the active interactions among SMEs.

3.2 SMEs' Concept

The nature of SMEs has been under debate for decades. SMEs are considered as a source of product development, since they are more flexible and sensitive to changes in technologies than large companies (Thorpe et al., 2005). However, the definition of SMEs is not unified. The original purpose of introducing this concept was for taxation (Mulhern, 1995; Berger and Udell, 2006). This is because SMEs need support and protection policies. In product development, SMEs as organizations have less research and development power than large firms (Thorpe et al., 2005). There is no doubt that SMEs are distinguished from large firms by size. However, it has been argued that the size of a firm is not related to its results in product development (Pittaway et al., 2004). Product development SMEs are more likely to be based on incremental changes in technologies rather than radical and fundamental changes (Thorpe et al., 2005). Thus, the firm size matters even less in product development.

The definition of SMEs has a number of components. This includes number of

² We also use data for the period of 2009-2014 for robustness of the results as the ICT sector in China showed strong revenue growth, on average by 13.5% annually, during this period (EUSME, 2015).

employees, turnover level, legal status, and method of production (Storey, 1994). Size wise, SMEs have less than 50 workers and a turnover of less than 50 million euros; in contrast, large firms have 500 or more workers and a turnover of 500 million euros or more (Elaian, 1996; Weston and Copeland, 1998). Using size to define SMEs has been challenged as all firms are small in some sectors, for example, creative design, whilst no firms are small in other sectors, for example, car manufacturing (Storey, 1994). An SME has a relatively small share of the market and its contribution to GDP is also relatively small. Thus, in this research, SMEs are treated as firms with less than 50 workers and a turnover of less than 50 million euros. The dataset includes 724 SMEs (with less than 50 workers and 50 million euros in revenue) and 332 large firms (with more than 50 workers or 50 million euros in revenue). Therefore, in the analysis, the samples are inter-firm connections rather than inter-SMEs connections.

3.3 Firm Connection

The nature of firm connections in product development is considered as inter-firm-level collaborations (Gulati, 1999; Burt, 2012 and 2015; Cross et al., 2015). To reflect more relationships amongst firms, we use the data about joint financial commitments in product development. The nature of the connections is analyzed as collaborations and joint investments in firm relationships. To combine knowledge and resources at minimum cost, firms need connections between them (Baker et al., 2016; Lynch et al., 2016). Firms aggregate knowledge and resources with each other in product development. In product development, the connection between two firms is a purposeful social unit that shares business information and resources to achieve the collective target (Levin and Cross, 2004; Lovejoy and Sinha, 2010; Alam et al., 2019). Thus, the nature of these firm connections in product development is collaboration and joint investment. Joint financial commitments are formal collaborations among firms and also have no ambiguity. Since informal connections are often ambiguous and mixed with other types of connections, they are not recommended for analyzing big datasets (Burt, 2012 and 2015). Thus, we use joint innovation loan as the firm connections in product development.

The connections between small and large firms need to be effective for the rapid spread of knowledge and resources (Burt, 2007). Small firms are considered as ‘satellites’ surrounding large firms. Large firms usually have a high density of connections which are likely to be effective in product development (Schleimer and Faems, 2016). Small firms interact with large firms through these connections, exchanging business resources and information and retaining resources and ideas that are product development related. In our results, the connections do not tend to connect with either small or large firms. They are almost evenly distributed in the results. The extent of the connections is analyzed as the total network level. We included all the firms in the dataset to generate a total network rather than a partial one. All the firms with product development activities in the region are included. These include firms of all different sizes and all contracted product development partners.

We performed network visualization by using the Netdraw function in the Ucinet software package. Firms are analyzed as nodes in the network snapshots (see figures 4 and 5), joint innovation loans are lines between firms representing their collaboration in product development, and each firm's overall revenue growth in the three years after the joint innovation loan was approved is distinguished by the size of the node. Then, each firm's connections are quantified as the number of each firm's sparse connections and the number of each firm's interlocked connections by using the Netdraw function. Later on, they are tested against the firm's revenue growth in regression modelling to show the effect of firm connections. The snapshots provide information about the overall structure of the firm cluster as a whole and each firm's network structure of sparse and interlocked connections.

3.4 Measurement & Method

The independent variables are network structures including each firm's sparse connections and interlocked connections. The numbers of each firm's sparse and interlocked connections are calculated using the Ego Network Structure Count function in Ucinet. They are our proposed independent variables. Sparse connections are measured as the number of structural holes (Burt, 2015). Each structural hole is a network structure consisting of three firms, as presented in Figure 1 previously. Interlocked connections are measured as the number of triads (Wasserman and Faust, 1995), which is the network structure presented in Figure 2 previously.

Non-network factors influencing product development are used as the control variables. Specifically, we control the number of employees and the revenue to rule out the effects of firm size on product development. Also, in our pilot data analysis, we included locations as controlling variables; however, none of the locations (Beijing and Shanghai) is significant. Therefore, locations are not included in the model.

The dependent variable is firm's revenue growth. We use three years' revenue growth from new product developments as the measure of each firm's SMEs innovation results. We also use five years' revenue growth from the new product development to test the robustness of the results. Previous research has used revenue growth as a dependent variable to compare a firm's performance in innovation (Thornhill, 2006; Oke, Walumbwa and Myers, 2012). An alternative can be measuring innovation performance by a questionnaire survey with managers (for example: Rodan and Galunic, 2004; Burt, 2015); however, an innovation performance questionnaire survey is often measured through managers' self-assessments, which may not be comparable at the firm level. Thus, this research uses revenue growth as the dependent variable.

We adopt randomized permutation regression to test the correlations between firms' connection structures and the SME innovation. Network data about organizational connections can have some outliers in distribution. Randomized permutation regression can provide better results from the model coefficients to resolve the issue of overlying influencing outliers in network data (Wasserman and Faust; 1994; Hanneman and

Riddle, 2005). Thus, our choice of analysis provides a more robust model.

4. Results & Discussion

In the analysis, the samples are inter-firm connections and we used number of employees and revenue to control firm size; however, we did not find any results supporting large firms as the nexus for any type of connection. Figures 4 and 5 show the SME connections in the information and communication technology (ICT) sector in Beijing and Shanghai. The nodes are firms. The lines between them are joint SMEs' innovation loan from the Bank of Communication, which represents innovation collaborations and partnerships in this research. The size of each node represents each firm's overall revenue growth three years after the joint SMEs' innovation loan was approved. This is used to measure SMEs' innovation results in this research. Table 1 shows the descriptive statistics.

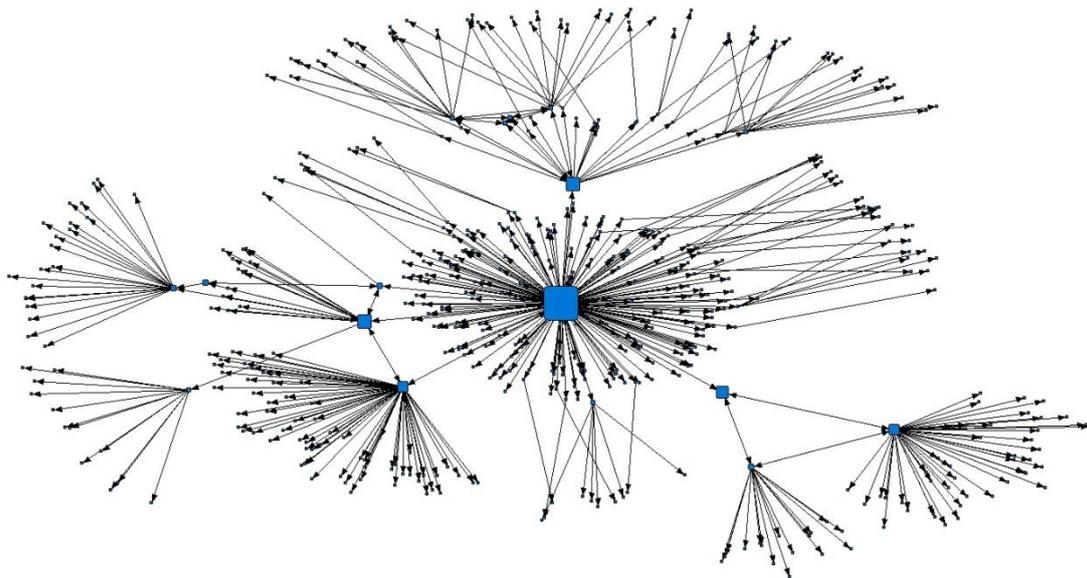
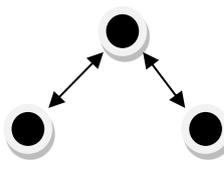
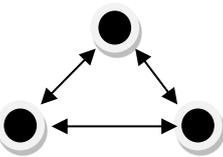


Figure 4: SMEs' innovation network in the information and communication technology (ICT) sector in Beijing (369 SMEs and 142 large firms).

Number of firms	Number of ties	Number of sparse connections 	Number of interlocked connections 
511	527	1172	123

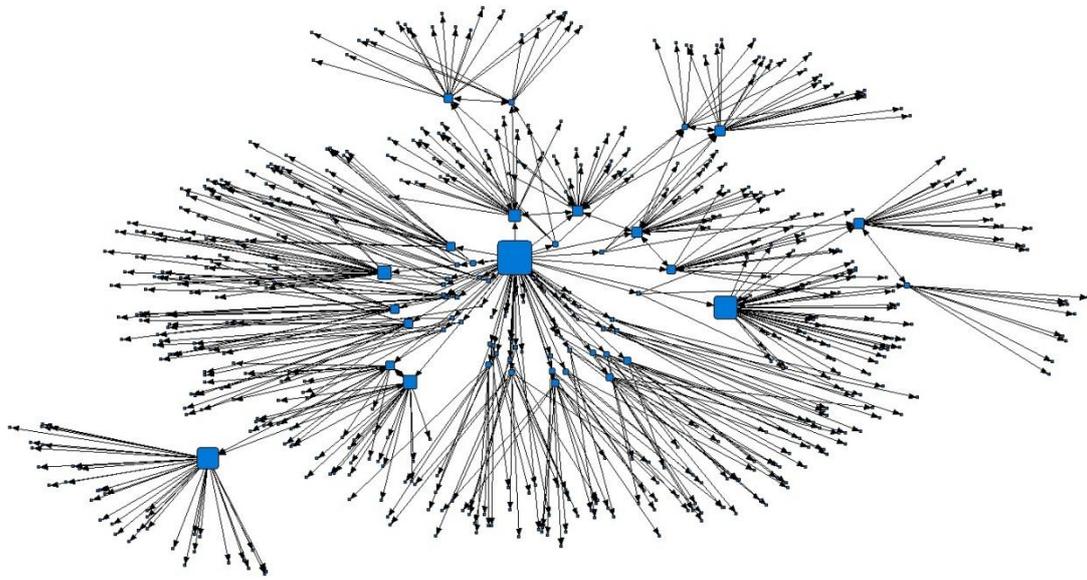


Figure 5: SMEs' innovation network in the information and communication technology (ICT) sector in Shanghai (355 SMEs and 190 large firms)

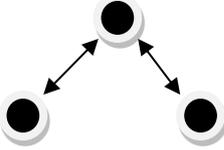
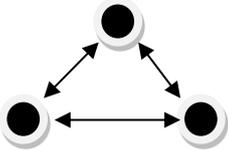
Number of firms	Number of ties	Number of sparse connections 	Number of interlocked connections 
545	561	1612	107

Table 1: Descriptive statistics

Variable	Mean	S.D.	Min	Max	1	2	3	4	5	6	7	8	9	10
1 3 years revenue growth (million Euro)	2.71	6.16	-1.25	6.5										
2 5 years revenue growth (million Euro)	3.97	7.72	-2.08	11.12	0.77**									
3 Company age (years)	9.36	8.68	3	56	-0.27**	-0.32**								
4 Budget (SMEs innovation loan received in million Euro)	3.62	3.12	0	12	-0.21†	-0.04	0.03							
5 IT design SME	0.12	0.29	0	1	-0.09	0.03	0.01	-0.07						
6 IT engineering SME	0.32	0.47	0	1	-0.30**	-0.29**	0.17*	0.41**	0.23*					
7 Number of employee	24.80	14.90	10	250	0.37**	0.32**	0.05	0.16†	-0.07	0.11				
8 Sparse connections	2.64	17.01	0	315	0.38**	0.47**	0.29**	0.04	0.03	-0.04	0.03			
9 Revenue (million Euro)	11.75	6.72	0.02	29	0.21*	0.15	0.00	-0.03	-0.10	0.07	-0.24**	-0.05		
10 Interlocked connections	0.22	1.40	0	22	0.24*	0.27**	0.12	-0.06	-0.10	-0.01	-0.09	0.08	0.09	
11 Sparse connections x Interlocked connections	0.21	1.12	N/A	N/A	0.10	0.14	0.01	-0.14	-0.06	-0.12	0.04	0.06	0.08	0.07

† $p < 0.1$; * $p < 0.05$; ** $p < 0.01$

As we discussed earlier, sparse and interlocked connections can influence innovation results. Table 2 shows the results of regression modelling.

Table 2: Multivariate regression models

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
	3 years revenue growth				5 years revenue growth		
Constant	-0.507 (0.721)	-0.423 (0.812)	-0.202 (0.890)	-0.176 (0.891)	0.123 (1.007)	0.012 (0.928)	0.022 (0.912)
Company age	-0.022** (0.014)	-0.021** (0.012)	-0.023* (0.011)	-0.028* (0.016)	-0.022* (0.012)	-0.022** (0.019)	-0.023** (0.017)
Number of employee	-0.005 (0.024)	-0.007† (0.022)	0.002* (0.029)	0.003* (0.007)	0.036 (0.024)	0.041* (0.023)	0.042* (0.021)
Revenue	0.052 (0.104)	0.120* (0.117)	0.126 (0.126)	0.134 (0.132)	0.171* (0.122)	0.287* (0.231)	0.299* (0.21)
Budget (SMEs innovation loan received)	0.077 (0.11)	0.006 (0.114)	0.033 (0.147)	0.033 (0.152)	0.112 (0.177)	0.067 (0.151)	0.052 (0.143)
IT design SME	0.218 (0.293)	0.053 (0.322)	0.082 (0.361)	0.082 (0.367)	-0.527 (0.371)	-0.427 (0.322)	-0.402 (0.306)
IT engineering SME	0.272 (0.572)	0.213 (0.636)	1.007† (0.592)	1.006† (0.581)	-0.700 (0.682)	-0.227 (0.608)	-0.201 (0.601)
Sparse connections		0.272* (0.17)	0.324** (0.142)	0.337** (0.136)	0.271* (0.187)	0.322** (0.171)	0.337** (0.167)
Interlocked connections			0.280** (0.135)	0.286** (0.136)		0.472** (0.146)	0.469** (0.152)
Sparse connections x Interlocked connections				0.172** (0.072)			0.160** (0.062)
R^2	0.442	0.562	0.677	0.699	0.576	0.712	0.723
R^2 increase		0.120	0.115	0.022	0.134	0.136	0.011
N	1,056	1,056	1,056	1,056	1,056	1,056	1,056

† $p \leq 0.1$; * $p < 0.05$; ** $p < 0.01$; Robust standard errors in parentheses.

We use three years' revenue growth as a dependent variable for models 1³, 2, 3 and 4. Our result suggests sparse and interlocked connections have a significant influence on SMEs' innovation results. Sparse connections calculated by each SME's structural hole count are added in Model 2. Our results show that sparse connections are positively associated with SMEs' innovation results ($\beta = 0.2717$, $p = 0.042$). This finding is consistent with previous research (Burt, 2015; Cross et al, 2015; Gargiulo and Sosa, 2016). Model 3 adds interlocked connections calculated by each SME's triad connection count. Our Model 3 shows that the correlation between interlocked connections and three years' revenue growth is positive and significant, meanwhile sparse connections are also positively associated with the revenue growth (β sparse-connections = 0.3239, $p = 0.007$ and β interlocked-connections = 0.2802, $p = 0.004$).

³In Model 1, we use only the control variables to show the difference without the proposed independent variables.

Model 4 suggests interaction between sparse and interlocked connections can contribute to innovation results ($\beta = 0.1721$ $p = 0.041$). This finding adds a new point to the existing theories (Burt, 2015; Cross et al., 2015; Gargiulo and Sosa, 2016; Garcia-Perez-de-Lema et al., 2017). This new point is that sparse and interlocked connections together can influence innovation outcomes.

Results remain the same when we include five years' revenue growth as a dependent variable. This indicates the robustness of the results. The five years' revenue growth is used as a dependent variable for models 5, 6 and 7. Our models 5 and 6 show similar results concerning the correlations between these two structures of SMEs' connections and SMEs' five years' revenue growth. Model 5 suggests sparse connections can contribute to innovation results ($\beta = 0.2709$, $p = 0.041$). Our Model 6 includes interlocked connections; the influence on five years' revenue growth increased (β sparse-connections = 0.3221, $p = 0.006$ and β interlocked-connections = 0.4716, $p = 0.005$). Model 7 shows the interaction effects are also significant.

The R^2 increase indicates our hypotheses are supported and the model is robust. In our results, the R^2 increase shows the influence of SMEs' connections on innovation results (see Table 2). For example, compared to Model 1, R^2 in Model 2 is increased by adding sparse connections. Adding interlocked connections in Model 3, the results show increased R^2 compared to Model 2. Model 4 adds the interaction effects of sparse and interlocked relations, and the R^2 increased further. Similar results are shown in models 5, 6 and 7 testing against five years' revenue growth.

Table 3: Results of regression analysis

	3 years revenue growth	5 years revenue growth
Sparse connections	0.3367**	0.3373**
Interlocked connections	0.2861**	0.4691**
Interaction effects	0.1721**	0.1602**
Constant	-0.176	0.0221
R^2	0.6993	0.7217
R^2 Increase	0.2572	0.2796

† $p \leq 0.1$; * $p < 0.05$; ** $p < 0.01$.

Revenue growth

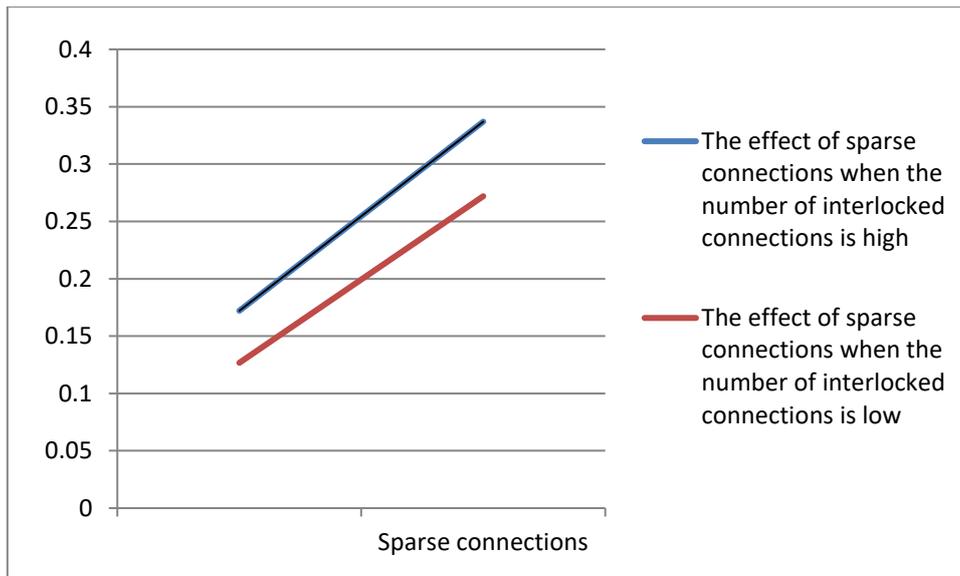


Figure 6: Interaction effect graph (3 years' revenue growth)

The results support our three hypotheses (see Table 3 and Figure 6). Whilst Model 1 shows SMEs' characteristics matter for innovation, the results show sparse and interlocked connections have a more significant influence. Moreover, the influence of sparse connections is even more significant when interlocked connections are added in the model. This suggests that sparse connections are less beneficial without interlocked connections. Finally, our models 4 and 7 show there is a significant interaction effect between sparse and interlocked connections.

Table 4: Summary of findings

	3 years revenue growth	5 years revenue growth
Sparse connections	Hypothesis 1 supported	Hypothesis 1 supported
Interlocked connections	Hypothesis 2 supported	Hypothesis 2 supported
Interaction effects	Hypothesis 3 supported	Hypothesis 3 supported

A positive interaction effect is spotted in Table 2. Figure 6 shows that sparse connections have a stronger influence on the dependent variable when there are more interlocked connections, therefore, it is a moderation effect between sparse and interlocked connections. The influence of sparse connections is higher when there is a higher level of interlocked connections. In contrast, the influence of sparse connections is lower when there is a lower level of interlocked connections. Thus, the influence of

sparse connections is moderated by interlocked connections.

In addition, the correlation coefficients of number of employees are too small (between .002 and .04). Although the correlations are significant, the number of employees can hardly have an influence on the revenue growth in the models due to the small correlation coefficients. Revenue is not significant in Model 4; however, it is significant in Model 7. Due to this, the findings do not support any correlation between the size of firm and revenue growth.

5. Conclusion

Our results show that sparse and interlocked connections have a significant influence on SMEs' revenue growth. In particular, there is an interaction effect of sparse and interlocked connections in firm networks which can influence innovation. We present two findings. First, both sparse and interlocked connections are beneficial to SMEs' innovation. Second, the presences of both sparse and interlocked connections provides further positive effects on SMEs by making them more active and able to innovate further. Our findings show that sparse and interlocked connections together can provide more effects than the sum of their effects individually on revenue growth. Thus, we suggest there is a positive interaction effect between sparse and interlocked connections.

The novelty of this research is suggesting that various inter-organization connection structures can benefit from each other, rather than conflict with each other. Firms can increase their innovation capacity through inter-organizational connections (Chen et al., 2011; Fitjar and Rodriguez-Pose, 2013; Nunes and Lopes, 2015; Apanasovich et al., 2016; Thoma, 2017); however, it was not clear whether it is beneficial or harmful to have different inter-organizational connections at the same time. Due to the variety of inter-organization connections (Thomä and Zimmermann, 2019), SMEs need to optimize their inter-organization connection structures. This research suggested that SMEs with both sparse and interlocked connections perform better in innovation.

With regard to theory, our study fills the gap on different combinations of structures that have an impact on inter-organization connections and the subsequent impact on their ability to innovate. As discussed in the hypothesis development, SMEs that innovate through sparse connections may face to lack of control and coordination and interlocked connections among SMEs may help to overcome it. Figure 6 showed that sparse connections can have a higher level of influence when there are more sparse connections. This finding supports that interlocked connections can help to overcome the disadvantage of sparse connections by raising the influence to a higher level. Prior research did not combine different structures of organizational connections. Our findings show that a combined network structure of sparse and interlocked connections is more beneficial to SMEs' innovation than either only sparse or interlocked. This combined structure provides extra effects as the interaction effects in the model showed. This means having a combination of sparse and interlocked connections can provide the positive effect of each plus an extra effect on innovation results. On the other hand, the results show that sparse and interlocked connections do not reduce each other's effect on innovation results. One does not decrease the other. Thus, sparse and interlocked connections are an effective combination in innovation.

Our results are consistent with prior empirical evidence in supporting the observation that both sparse and interlocked connections are positively associated with innovation results (Burt, 1992 and 2015). This prior empirical evidence showed a positive correlation between organizational connections and innovation results (Rodan and Galunic, 2004; Lovejoy and Sinha, 2010). Our results confirm this positive correlation between the number of sparse and interlocked connections and innovation results. More importantly, sparse and interlocked connections have a similar level of effects. The R^2 changes from sparse and interlocked connections are almost equal. This means that they can influence innovation results almost equally.

In addition, our findings provide evidence and motivation to seek more effective combinations in the future. Firm connections are highly complex in the nature of their innovations. Sparse and interlocked connections are simple structures. This research includes the combined structure of both as a more complex structure. The results showed that this complex structure has more effects than the simple structures. Thus, in order to understand the complex structures of firm connections more effectively, combined structures need to be explored. This can further improve the understanding about how firms can collaborate together more effectively.

In terms of the contributions to management practices and policies, this research has implications for how firms can improve their external connections to achieve better innovation results. Our findings add evidence regarding the combined network structures to this research area. They suggest that firms with both sparse and interlocked connections are more likely to have better innovation results. Managers can contribute to the innovative nature of their firms by exploring the networking opportunities possible amongst dispersed and interlocked connections. More specifically, SME managers need to take a very active role in exploring the nature of the connections in their own industry. Policy makers need to develop policies that encourage SMEs to make use of both sparse and interlocked connections.

Due to the limitation of the dataset, this study only takes revenue growth into account. The findings reflect only the results of innovation rather than the processes. For example, this study is not able to distinguish radical and incremental innovation in the dataset. This is the limitation of this study. Further research is planned to improve our model with more data across different sections and contexts. Our results show the importance of combining various inter-organizational connection structures in the context of SMEs' innovation; this finding can be more generalized with similar data from different business contexts.

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