# A Review of Innovation Networks

## — What and How to Motivate Firm Innovation —

Yang Xiaotian

## Abstract

Networking has radically become a significant subject spanning a wide range of organizational topics across different levels of analysis, and more importantly, the application of social network analysis to inter-organizational contexts has been drawn considerable attentions in two decades. One of major issues to which inter-organizational network studies contribute was cooperative R&D. As a result of this trend, innovation networks have been increasingly studied with a variety of agglomeration forms such as strategic alliances, clusters, industrial districts, and R&D consortia. Although there have been some review articles on networks, this review concentrates more on the accumulated debates on effects of various network indicators on firm's innovation. I begin with a holistic typology of innovation network research based on egocentric and whole-network levels of analysis. I apply social network analysis to tease out antecedents of firm's innovation performance as a consequence to review the key controversial findings in the innovation network literature. The antecedents are summarized from the structural and relational embeddedness of firms and properties of overall network, including centrality, direct ties / indirect ties, strong ties / weak ties, structural holes, closure, centralization, density, configuration of ties, diversity and governance. Based on these findings, I tease out five explanatory mechanisms with controversial nature (costs, resources, knowledge, trust and power) based on several traditional theories used to explain how to motivate firm's innovation in networks. Finally, I try to indicate challenges and gaps to identify valuable topics and give directions for future research. It is especially necessary to more explore the boundary conditions for the controversial researches on the influence of antecedents on firm's innovation.

## 1. Introduction

Over the last twenty years, networking has radically become a significant subject spanning a wide range of organizational topics across different levels of analysis, although it is initially paid attention in social network studies. The application of social network analysis (SNA) to interorganizational contexts has been also increasingly drawn considerable attentions, in which one of major issues was cooperative R&D (e.g., Wasserman and Faust, 1994; Borgatti and Foster, 2003; Brass et al., 2004; Balkundi and Kilduff, 2006; Kilduff and Brass, 2010; Carpenter, Li and Jiang, 2012; Conway, 2014). Networking are considered as a contributive factor for mutual learning and knowledge diffusion, since the high-efficiency innovation is not created only by an independent attempt but by joint endeavor in which firms deepen mutual interaction as the access to external knowledge (Sakakibara, 1997; Swan et al., 1999; Zeng and Chen, 2003; Fritsch and Franke, 2004; Zeng, Xie and Tam, 2010; Von Raesfeld, Geurts and Jansen, 2012; Omidvar, Edler and Malik, 2017). As a result of this trend, joint innovation has been increasingly studied in a variety of networks such as strategic alliances, clusters, industrial districts, and R&D consortia (e.g., Doz, Olk and Ring, 2000; Kamien and Zang, 2000; Sakakibara, 2002; Phelps, 2010; Gulati, Wohlgezogen and Zhelyazkov, 2012; Fonti, Maoret and Whitbred, 2017). The common underlying characteristics of these networks indicate that innovation networks are spatial concentration of a set of interconnected firms with the ultimate target of innovation which serve for information, knowledge and resources exchange and help to implement innovations by mutual learning (Powell, Koput and Smith-Doerr, 1996; Chen, 2004; Dhanaraj and Parkhe, 2006; Calia, Guerrini and Moura, 2007; Cowan, Jonard and Zimmermann, 2007; Boschma and Frenken, 2010; Corsaro et al., 2012; Möller and Halinen, 2017; Najafi-Tavani et al, 2018). A large number of studies have presented a series of motives to enter into such innovation networks: cost-sharing advantages, technological complementarities, resource sharing, market exploration and organizational learning benefits (e.g., Sakakibara, 1997; Cowan, 2005; Cowan and Jonard, 2009; Gronum, Verreynne and Kastelle, 2012; Rojas, Solis and Zhu, 2018).

However, despite the popularity and benefits of innovation networks, not all of scholars only draw attentions on positive effects. Networks themselves with a higher level of complexity, uncertainty and ambiguousness are hardly immune to conflicts, lack of coordination and free-ridings which dooms many complex innovations (Zeng and Chen, 2003; Jiang, Tao and Santoro, 2010; Dougherty and Dunne, 2011; Chen, Dai and Li, 2016; Fonti, Maoret and Whitbred, 2017). Such scholars proposing the negative effects of networks indicated an only about 50% success rate. The controversial nature of innovation networks called for a majority of scholars to study the influence of network embeddedness on innovation performance based on different theoretical mechanisms.

Contrary to these well-known comprehensive reviews of interorganizational relationship in the first twenty years where contradiction arguments on innovation in networks are not taken too seriously (e.g., Borgatti and Foster, 2003; Brass, et al, 2004; Provan, Fish and Sydow, 2007; Kilduff and Brass, 2010; Borgatti and Halgin, 2011; Phelps, Heidl and Wadhwa, 2012; Monaghan, Lavelle and Gunnigle, 2017), I argue it is indeed worthwhile to concentrate more on the accumulated debates to outline under what conditions collaboration in networks is beneficial to innovation and how it can be fostered.

In the paper, I firstly make efforts to develop a holistic typology of innovation network research based on two basic levels of analysis. Secondly, I restrict ourselves to the application of social network analysis to tease out antecedents and mechanisms of motivation to firm's innovation performance as a consequence. That is, to outline what could enhance the firm's innovation performance from the structural and relational embeddedness of firms and properties of overall network, and how they work based on the theoretical paradigms. Thirdly, I try to indicate several challenges and gaps to identify valuable topics in the future research.

## 2. Research Levels and Types of Innovation Networks

In order to provide a more holistic perspective to better grasp a set of phenomena in innovation networks, I believe it is necessary to make the distinction between levels of analysis. According to the general definition of networks by Brass et al. (2004) "a set of nodes and the set of ties representing some relationship, or lack of relationship, between the nodes.", there have been a number of scholars raising the distinction between egocentric (micro-level) versus network-level (macro-level) research based on the multilevel definition involved in firms (nodes) and relationships (ties), in accordance with the perspective of methodological individualism versus collectivism (Granovetter, 1985; Kilduff and Tsai, 2003; Abbasi, Chung and Hossain, 2012). The analysis levels were differentiated in most studies chiefly based on the consideration of whether the consequence is at the whole network or the individual organizations level in which the antecedent can be either. Egocentric views draw on the individual organization concerning with explaining how firm's embeddedness in a network affects its innovation outputs. Network-level perspectives focus on explaining which network properties are supportive to the collective innovation success. However, the ego and the whole levels of networks are not independent from each other but they influence each other, similar to social sciences. Thus, both the antecedents and consequences of researches should be considered from the two basic levels, so that a holistic typology can be developed to illustrate four types of innovation network researches, shown as a two-by-two table (see Table 1). It should be mentioned that I am only concerned with the studies on innovation performance as a consequence in the article, although there are a large number of innovation-related consequences paid attention to in studies on innovation networks, such as innovation policy, commercialization, and diffusion.

**Table 1 A Typology of Innovation Network Research**

| Antecedents | Consequences | |
|---|---|---|
| | Focal firm's innovation output | Entire network's innovation output |
| Focal firm's embedded properties | Impact of focal firm's properties embedded in a network on its innovation | Impact of individual firm's embeddedness on a whole network' innovation outputs |
| Network's properties | Impact of a network on firm's innovation | Impact of network's properties on its entire innovation |

The summary table outlines the main network researches about the influence on innovation outputs based on a thorough literature search. First, the researches utilized firm-level properties related to firm's embeddedness in a network, position, and interactive ties with others to explain which one is most or least beneficial to its innovation outputs and how it works, most significantly by Burkhardt and Brass (1990), Burt (1992), Powell, Koput and Smith-Doerr (1996), Uzzi (1996), Gulati (1999), Ahuja (2000), Tsai (2001), Zaheer and Bell (2005), Gilsing et al. (2008), Yang, Lin and Peng (2011) and so on. Second, researchers tried to analyze how a firm's innovative performance is impacted by the network-level structural and relational properties (e.g., Bell, 2005; Schilling and Phelps, 2007; Phelps, 2010; Fritsch and Kauffeld-Monz, 2010; Bellamy, Ghosh and Hora, 2014). For instance, Phelps (2010) explored the influence of network's density and diversity on firm exploratory innovation. Third, researchers utilized firm-level phenomena to explain how individual firms' characteristics, behaviors and relationships with others affect collective innovation outputs of the whole network. Although the studies are not much, I can find some studies mainly on networks led by a hub firm (Dyer and Nobeoka, 2000; Nambisan and Sawhney, 2011; Gardet and Fraiha, 2012), where the hub firm are played a lot of roles in the entire network's innovation performance. For example, Dyer and Nobeoka (2000) took Toyota network as case to emphasis its role of motivation and management played in knowledge sharing and joint innovation in the buyer-supplier network. Nambisan and Sawhney (2011) indicatied a hub-based model of network-centric innovation taking the hub firm as an innovation integrator and a platform leader respectively. Finally, researchers took the entire network as the analytical unit to study how collective innovation success might be generated on consideration with the whole network's structural properties, governance and dynamic evolution (Dhanaraj and Parkhe, 2006; Boschma and Frenken, 2010). For instance, Boschma and Frenken (2010) presented that the perspective of network evolution may have implications for how the network might best be structured to facilitate achievement of the common R&D goals. Hence, the multilevel nature of networks makes it possible to do cross-level research taking network-level properties as contingency factors. Gilsing et al. (2008) highlighted the contingency effects that whole network properties create for the relationships between firms' ego-network positions and their creation of novelty.

## 3. Antecedents of Research on Innovation Network

The researches on innovation networks have been radically developed in social sciences. SNA can help us capture the complexity of the such networks as an effective tool, and look deeper into the varying positions, interaction structure, and embeddedness of firms in the network (Wasserman and Faust, 1994; Newman, 2003; Kilduff and Brass, 2010; Monaghan, Lavelle and Gunnigle, 2017). The paper mainly outlines the SNA-indicators as antecedents in both firm and network levels most or least beneficial to firm's innovation outputs (see Table 2), focusing primarily on network studies from top management journals in the previous two decades. It has been indicated that participating firms benefit from their structural and relational embeddedness in innovation networks, such as their centrality, direct and indirect ties, strong and weak ties, and structural holes. Some antecedents are also correspondingly studied from the perspective of the whole network including structural and relational properties of networks, such as centralization, density, strong/weak tie configuration, and closure. In addition, I sort out a set of keywords as main theoretical mechanisms to explain these controversial influences on firm's innovation, which would be deeply discussed in the next part.

Table 2 A summary of SNA-indicators as antecedents contributing to firm innovation

| SNA-indicators | Level of analysis | Impact on firm's innovation (representative researches) | Theoretical mechanisms |
|---|---|---|---|
| Centrality | ego | + (Ibarra, 1993; Shan, Walker and Kogut, 1994; Ahuja, 2000; Tsai, 2001; Gilsing et al., 2008; Knoke and Yang, 2008); inverted-U (Wang et al., 2014); it depends (Dong and Yang, 2016) | resource, knowledge, power |

| | | | |
|---|---|---|---|
| Direct ties / indirect ties | ego | + (Ahuja, 2000; Salman and Saives, 2005; Singh et al. 2016); it depends (Vanhaverbeke et al., 2006; Guan, Liu, 2016) | resource, knowledge |
| Strong ties / weak ties | ego | + strong ties: exploitation, weak ties: exploration (Granovetter,1973; Burt and Knez, 1995; Uzzi, 1997; Rost, 2011); inverted-U (McFadyen and Cannella, 2004) | knowledge, trust |
| Structural holes | ego/ whole | + (Hargadon and Sutton, 1997; Ahuja, 2000; Zaheer and Bell, 2005; Burt, 2004); - (Perry-Smith, 2006;); it depends (Rowley et al. 2000) | cost, resource, knowledge, power |
| Closure | whole | + (Coleman, 1988; Ahuja, 2000; Uzzi, 1997; Powell et al., 2005; Dyer and Nobeoka, 2000; Schilling and Phelps, 2007; Tortoriello, McEvily and Krackhardt, 2014); it depends (Rowley et al. 2000) | knowledge, trust |
| Centralization | whole | + (Ibarra, 1993); it depends (Newig, Günther and Pahl-Wostl, 2010; Moolenaar, Daly and Sleegers, 2011) | resource, power |
| Density | whole | + (Coleman, 1988; Burt, 1995; Dyer and Nobeoka, 2000; Uzzi, 1997; Kogut, 2000; Smith-Doerr and Powell, 2005; Gilsing et al., 2008; Phelps, 2010); - (Rowley, Behrens and Krackhardt, 2000) | Knowledge, trust |
| Configuration of ties | whole | + strong-tie network: exploitation, weak-tie network: exploration (Tortoriello and Krackhardt 2010); inverted-U (Wang, 2016) | resource, knowledge |
| Diversity | whole | + (Fleming, 2001); - (Ahuja and Lampert, 2001); inverted-U (Phelps, 2010) | cost, resource, knowledge |
| Governance | whole | + (Oxley and Sampson, 2004; Reuer and Ariño, 2007; Newig, Günther and Pahl-Wostl, 2010; Chen, Dai and Li, 2016) | trust, knowledge |

## 3.1 Centrality

"Centrality causes performance." (Tsai, 2001). A central position of a firm in the network has been shown to be supportive for its innovative success, which could provide it with access to critical knowledge and resources by other firms (Ibarra, 1993; Powell, Koput and Smith-Doerr, 1996; Ahuja, 2000; Tsai, 2001; Gilsing et al., 2008). It has been studied based on the three concepts of degree centrality, closeness centrality and betweenness centrality (Knoke and Yang, 2008). Firms with high degree centrality (the direct connectedness of a firm to all the other firms) exert power to control knowledge in the network based on resource dependent theory. The closeness centrality indicates the distance of a firm to all the other firms in a network, which explains how easy and quickly the firm acquire resource contributing to its innovation by connecting with others. The betweenness centrality is a measure of centrality in a graph based on shortest paths. That is, the more often an actor is located on the shortest path between other actors, the higher is the potential to control or moderate flows of knowledge and other resources, and to play the role of a broker or gatekeeper. However, recent scholars sent out different voices. For example, Wang et al. (2014) focused on social network of collaborations to put forward an inverted-U-shaped relationship between the degree centrality of a researcher's knowledge elements in the knowledge network and his exploratory innovation on consideration with the possibility of the value exhaustion. Dong and Yang (2016) found that degree centrality in an interfirm knowledge network has positive effect on new product development performance, while closeness and eigenvector centrality have negative impacts due to information overload.

### 3.2 Direct ties / indirect ties

Not only direct ties but also indirect ties play a role, reflected by the structural embeddedness. Ahuja (2000) proposed that both direct and indirect ties have positive impacts on firm's innovation, but they have different functions. Direct ties are absolutely more central to knowledge creation than to explicit knowledge transfer, which can be more effectively facilitated by indirect ties (Tsai, 2001; McFadyen M A, Cannella, 2004). Salman and Saives (2005) emphasized more value of indirect ties like Granovetter (1977). Even, Sammarra and Biggiero (2008) put forward the impact of indirect ties is moderated by the firm's level of direct ties. Singh et al. (2016) distinguish the roles of direct and indirect ties in terms of different kinds of knowledge transfer. Combinatory knowledge more easily transfers from direct ties than indirect contacts, while new knowledge transfer from both direct and indirect ties although knowledge from indirect ties would be more new and useful. Some scholars also studied their respective roles in exploratory and exploitative innovation (Vanhaverbeke et al., 2006; Guan and Liu, 2016). The number of direct ties of an organization in a collaboration network has a curvilinear effect on both its exploitative and exploratory innovations, while the number of indirect ties has a negative effect on its exploratory innovation and no effect on exploitative innovation.

### 3.3 Strong ties / weak ties

Relational embeddedness studies typically suggest that a firm who build strong ties with others is likely to possess more common information and knowledge through the voluntary and frequent mutual contact to promote trust and efficient cooperation with others, while weak ties are also put forward to avoid redundancy in the network and enable firms to generate novel and useful ideas (Granovetter,1977; Burt and Knez, 1995; Uzzi, 1997). However, McFadyen and Cannella (2004) indicated that the strength of ties has an inverted U-shape effect on knowledge creation. On consideration with the contingency of different kinds of knowledge and innovation, firms with strong ties possess more opportunities to exchange complex and tacit knowledge with others which is supportive to its exploitative innovation, whereas firms with weak ties enable to access entirely new knowledge which is better for its exploration innovation (Uzzi and Lancaster, 2003; Rowley, Behrens and Krackhardt, 2000, Rost, 2011).

### 3.4 Structural holes / closure

Structural holes are originally described as a gap between two firms with complementary sources due to embedded neighborhoods or other network structures by Burt (1995). Former empirical research tended to support that a firm as a structural hole in network enhances its innovation due to the advantage of its critical position connecting with diversity knowledge (Hargadon and Sutton, 1997; Ahuja, 2000; Zaheer and Bell, 2005; Fleming and Waguespack, 2007, Burt, 2004), but it is also worried due to the high maintenance costs of such ties and information overload (Perry-Smith, 2006; Zhou et al., 2009).

As a structural property of network, the network with many structural holes (low closure) would increase firm's access to diverse information and in turn enhance its innovation output (Hargadon and Sutton, 1997; McEvily and Zaheer, 1999), while the network with fewer structural holes (high closure) might promote trust generation and knowledge sharing, reduce opportunism leading to more productive collaboration (Coleman, 1988; Ahuja, 2000; Uzzi, 1997; Powell et al., 2005; Dyer and Nobeoka, 2000; Schilling and Phelps, 2007; Tortoriello, McEvily and Krackhardt, 2014). A large body of research have discriminated between the value of structural holes and that of closure under different conditions, such as the contingency of time (Soda, Usai, and Zaheer, 2004) and environments that favor an exploration or exploitation strategy (Rowley et al. 2000).

### 3.5 Centralization

Centralization as a structural property of overall network has been also studied focusing on its influence on firm's innovation (Ibarra, 1993; Newig, Günther and Pahl-Wostl, 2010; Moolenaar, Daly and Sleegers, 2011). Highly centralized networks can be organized as a hub-and-spoke pattern, which may have a positive effect on the innovation of the hub firm but a negative effect on other small firms due to poor knowledge sharing, power imbalance, learning race and free-riding.

### 3.6 Density

Network density as a structural property of overall network was put forward to describe the portion of the potential ties in a network that are actual ties (Burt, 1995).

Coleman (1988) suggests that a dense network, also known as network closure, generate trust and reciprocity social norms, which are conducive for voluntary knowledge transfer and sharing (Coleman, 1988; Portes, 1998). The trust and reciprocity of dense networks allow firms to reduce information asymmetries, make know-how shared less distorted, richer, and of higher quality (Dyer and Nobeoka, 2000; Uzzi, 1997; Kogut, 2000; Smith-Doerr and Powell, 2005; Gilsing et al., 2008; Phelps, 2010). However, several studies indicated that information obtained from such networks tends to be redundant, and the generation of new knowledge is superseded and restricted by the redundant knowledge, which conversely hinder the creation of novel ideas (Rowley, Behrens and Krackhardt, 2000).

### 3.7 Configuration of ties

From a whole-network perspective, configuration of ties was proposed by Uzzi (1996) as an indicator for the number of weak and strong ties separately in a network to evaluate its effect on firm's innovation (Tortoriello and Krackhardt 2010). A strong-tie network consisting of many redundant ties is conducive to the diffusion of existing knowledge and the transfer of tacit knowledge among firms due to trustworthiness in the network, while weak-tie networks are more beneficial for firm's exploration due to more opportunities and possibilities of the generation of new knowledge. Recently, an inverted U-shaped relationship was directly proposed between average tie strength of network as a continuum and novel knowledge creation (Wang, 2016). Under extreme conditions, Rost (2011) indicated that weak-tie networks have no value without strong ties, whereas strong-tie network have some value without weak ties.

### 3.8 Diversity

Network diversity increases the relative novelty of the knowledge that a firm can access, which provides benefits for a firm's exploratory innovation efforts (Fleming, 2001). However, it results in the decline of a firm's relative ability to recognize, assimilate, and utilize this knowledge due to the technological distance, and information overload increasing the costs of recombinatory innovation (Ahuja and Lampert, 2001). Phelps focused on the technological diversity of network and suggested an inverted U-shaped relationship between it and the firm's exploratory innovation (Phelps, 2010).

### 3.9 Governance

As a relational property of network, governance mechanism in network may provide more chance for inter-firm interaction, which is good for trust generation and knowledge sharing among firms (Oxley and Sampson, 2004; Reuer and Ariño, 2007; Newig, Günther and Pahl-Wostl, 2010). The governance in networks are considered as a wide range of forms such as self-governance, hub-firm governed, and administrative organization governed. Chen, Dai and Li (2016) suggested network-instigated governance manages the relational risks of competition and enhances the benefit of cooperation conducive to innovation. However, excessive governance may conversely hinder the voluntary of knowledge transfer and diffusion, and increase coordinate costs.

## 4. Theoretical Mechanisms of Research on Innovation Network

The studies have been embedded in multiple traditional theories to explain the mechanisms of network phenomenon, such as game theory, transaction cost theory, social capital, the resource-based view, resource dependence theory, strategic choice, organization learning, knowledge management and the relational view. A set of keywords are made repeated mention in these cumulative and intertwined theories in literature, which are related to controversial explanations in the analysis of the influence on innovation. Costs, resource, knowledge, trust and power can be identified as the theoretical mechanisms explaining why there are controversial effects and how to motivate firm's innovation in networks, which are respectively, partly, or collectively involved in those controversial researches. The summary of theoretical mechanisms can be shown in Table 3.

**Table 3 A summary of theoretical mechanisms most or least conducive to innovation**

| Theoretical mechanism | Related theory | Rationale for controversy | Representative research |
|---|---|---|---|
| Costs | game theory, transaction cost theory | input costs of R&D and coordination costs | Sakakibara, 2002; Gnyawali & Park, 2009; Emden, Calantone and Droge 2006 |
| Resource | resource-based view, resource dependence theory | resources complementarity and similarity | Emden, Calantone, and Droge 2006; Chung, Singh and Lee, 2000; Harrison, et al., 2001; Gnyawali and Park, 2009; Phelps, 2010 |
| Knowledge | resource-based view, organization learning, knowledge management | knowledge sharing and protecting | Huang and Yu, 2011; Jarvenpaa and Majchrzak, 2016 |
| Trust | social capital, relational view | reciprocity and opportunism | Coleman,1988; Tsai and Ghoshal, 1998; Beamish and Lupton, 2009; Phelps, 2010; Fonti, Maoret and Whitbred, 2017 |

| | | | |
|---|---|---|---|
| Power | social capital, resource dependence theory | power equitability and asymmetry | Burt,1992; Van der Vegt et al.2010; Nyaga, Lynch and Marshall, 2013 |

### 4.1 Cost-based mechanism

Cost sharing is considered as the primary motivation of firms participating in innovation networks from the economic perspective (Sakakibara, 2002). Especially, it is difficult for innovation for small firms on their own due to high capital investment and long development cycle (Gnyawali and Park, 2009). The key rationale of cost-sharing R&D cooperation in networks is that networks are considered as a hybrid structure, minimizing the input costs comparing to go-it-alone innovation in the hierarchy and the coordination costs comparing to cooperative R&D in the market in transaction costs theory. However, some scholars still emphasized the monitoring costs generated by the risk of opportunism and the coordination costs due to participating firms in different industry fields might instead increase R&D spending in game theory (Emden, Calantone and Droge 2006).

### 4.2 Resource-based mechanism

Resources and capabilities sharing are considered as another primary motivation of participation in innovation networks besides (Sakakibara, 2002). The creative potential of innovation networks is to develop more complex and efficient innovation projects to enhance R&D productivity through bringing together complementary resources and technologies based on resource-based view (Emden, Calantone, and Droge 2006; Chung, Singh and Lee, 2000; Harrison, et al., 2001). The large companies are eager to cooperate with small firms as a way of tapping into their cutting-edge research. Similarly, the small firms are eager to cooperate with large companies to gain access to their financial resources and abundant market information. Firms can not only cooperate to compensate for a lack of own resources, but also take advantage of the ego-network structures to control the flows of diverse resources, which fits the resource dependence paradigm. Hence, resource complementarity is believed to be advantage and premise of cooperative R&D, especially in studies on network diversity (Phelps, 2010). Sakakibara (2001) suggested that firms in different industry fields in R&D consortia may have more opportunities to acquire diverse resource and technology and in turn facilitate innovation outputs. However, resource similarity is also put forward as another premise on consideration of providing the necessary common ground to realize the technology's potential and to communicate with each other (Emden, Calantone and Droge 2006). The balance is reflected in the studies on the relationship between coopetition and innovation (Gnyawali and Park, 2009).

### 4.3 Knowledge-based mechanism

Broadly, knowledge is actually seen as a kind of important resources. From the perspective of knowledge management, prior studies have been manifested that networking as a form of linkage with firms provides a means for knowledge creation, sharing, acquisition, absorption, integration and innovation enhancing as a result (Huang and Yu, 2011), while unintended technology spillovers, sensitive knowledge leakage inevitably and innovation suppressing have been also put forward in view of the downside of firms' coopetition strategy (Jarvenpaa and Majchrzak, 2016). Thus, it is indicated that participating firms are often caught in the tension of knowledge sharing and protecting in innovation networks. However, studies on organizational learning prefer to more emphases that the cooperation in networks allows for the improvement of knowledge-bases by providing opportunities to mutual learn and exchange a large variety of knowledge.

### 4.4 Trust-based mechanism

Focusing on the view of social capital, Coleman (1988) emphasized the importance of trustworthiness in effective relationship in social network. Trust has been believed as a key ingredient for the recipe of successful knowledge exchange and synergistic creativity in innovation networks, which can regulate the magnitude and efficiency of knowledge transfer processes, and diminish exchange hazards and potential opportunism (Kogut, 1988; Gulati, 1995; Tsai and Ghoshal, 1998; Levin and Cross, 2004). It can be obtained by the structure of networks. For example, the higher closure in a network brings about the higher overall trust that is associated with lower transaction costs, which improve the efficiency of cooperative innovation (Coleman, 1988; Beamish and Lupton, 2009). However, highly trusted networks may fix the flows of information and knowledge due to the formation of strong ties in long periods, which may hinder the creative behaviors (Uzzi, 1997). Actually, trust and opportunism are inevitably simultaneous among firms in networks, although they paly opposite roles in cooperative innovation. There is always free-riding phenomenon as a typical kind of opportunism withholding their effort toward the joint innovation (Fonti, Maoret and Whitbred, 2017).

### 4.5 Power-based mechanism

Social capital theory has a strong power component besides (Coleman, 1988). Power can be derived from the firm's position in network with the increasing dependence of the firm on the resources of the others in resource dependence theory (Pfeffer and Salancik, 2003; Jensen and Roy, 2008). Equitable power in network can decrease exchange hazards and increase costs of opportunism among networked firms, while power asymmetry among participating firms in network brings about more free-riding, affects the willingness of the weak to pool their efforts in collaboration, and amplifies the risks for conflicts and even insincere cooperation, which stifles the incentive role of cooperative network on firm's innovation (Van der Vegt et al.2010; Nyaga, Lynch, Marshall, 2013). However, as to the strong firm in networks with power asymmetry, it may be easier to exert power in controlling critical resources and taking advantage of learning race, which in turn benefits for its innovation temporarily.

## 5. Discussion and Implications

I outlined controversial findings about antecedents on firm's innovation performance from two basic levels, and identified five explanatory mechanisms from intertwined theories in contradictory arguments. I explained what and how to motivate firm's innovation from social network perspective by means of teasing out the debates. Finally, I am about to discuss the implications of our review for future research, according to the current research development and the controversial nature of innovation networks.

### 5.1 More micro-level analysis

Besides the ego firm-level and network-level analysis, innovation performance is also affected by individual cognition and behaviors. Although Brass et al. (2004) explicitly provides an overarching review on network research in the interpersonal, interunit, and interorganizational levels of analysis, and Tasselli, Kilduff and Menges (2015) outlined the microfoundations of organizational social networks to explain the coevolution of individuals and networks, both the summarized micro interpersonal researches are rarely referred to innovation phenomenon. Actually, firm's innovation outputs are the results of individual innovative behaviors, affected by individual psychological factors such as cognition, emotion, attitudes and beliefs. For example, Jarvenpaa and Majchrzak (2016) did draw on interactive self-regulation theory and hot cognition microfoundations to articulate how interacting individuals in interorganizational dyads regulate their sharing and protecting behaviors to facilitate the learning and innovation in interorganizational collaborations.

### 5.2 Boundary conditions of controversy

The controversial nature of networks has been identified in lots of extant research. The work of three influential scholars, namely Granovetter, Burt and Coleman, have different conclusions with respect to the optimal network structure (Granovetter, 1973; Burt, 1992; Coleman, 1988). The debates of positive and negative effects on firm's innovation have been reviewed in the paper, which suggests that it is imperative to make efforts to analyze the boundary condition of controversial results and explore the trade-offs.

The distinct between exploitative and exploratory innovation essentially provides a basis for trade-off studies. Rowley, Behrens and Krackhardt (2000) suggested that the optimality of the network structure is indeed dependent upon the exploitative or exploratory environment. Inverted U-shaped analyses are also gradually drawn high attention to trade off the boundary conditions, such as relationship between the intensity of competition and the innovation output, and relationship between technological diversity and exploratory innovation. Besides, joint consideration of structural and relational embeddedness was paid close attention. Rost (2011) supported Burt's social capital theory complements Coleman's theory and put forward an effective combination of strong ties and low network density. Actually, small-world structure of networks indeed reflects the combination conducive to innovation, namely the dense and clustered relationships facilitating trust and close collaboration beneficial to faster knowledge transfer, and distant and more diverse relationships providing fresh and nonredundant knowledge to all network participants. These researches are exemplary efforts, and we still need more exploration to dig deeper into the boundary condition and trade-offs.

### 5.3 Influence of dynamic nature of networks on innovation outputs

Although the summarized typology is statics perspective, the dynamic nature of networks should be still drawn attention. Like other management studies, network studies have begun to shift from cross-sectional to more dynamic research. However, there is still an incomplete understanding of the influence of network evolution on innovation outputs, although there have recently been several pioneers making progress in disentangling the black box of the coevolution of structural and relational properties and firm's innovative behaviors (Zaheer and Soda, 2009). For instance, is it rather the success and potential to develop good ideas that brings firms in a central position (network dynamics) or do both effects play a role and even influence each other (co-evolution)? Why would some innovation networks disintegrate? What effect do members' joining or withdrawing have on the innovation of existing members in network? Such questions can hardly be answered with static research unless a dynamic perspective.

### 5.4 Quantitative research method

There is still a set of issues in collecting data for interrogational network analysis. First, although a majority of extant network research utilized interviews or questionnaires, they often suffer from inadequate sample sizes, a subjectivity bias, and a limited access. Secondly, as to quantitative analysis, it is necessary for boundary specification in analyzing the influence of social network indicators on firm's innovation since interdependencies between firms in networks have to be explicitly modeled and analyzed. However, dynamic nature of network such as member's joining or withdrawing makes boundary of networks fuzzy although some have network rosters where membership is formally specified instead of self-defined. It can be tentatively done based on explicit geographic boundaries, or formalized membership in certain time, or the participation in an event. Third, it is difficult to analyze informal interorganizational interaction in networks, except through interviews and questionnaires. Instead, relative formal interorganizational interaction can be analyzed by the second-hand data such as archived documents of network events. In order to do more effective network studies, we still need more efforts in quantitative analysis to complement the subjectivity bias of case study, interview and questionnaires.

## Reference:

Aarikka-Stenroos L, Sandberg B, Lehtimäki T. Networks for the commercialization of innovations: A review of how divergent network actors contribute[J]. Industrial Marketing Management, 2014, 43(3): 365-381.

Abbasi A, Chung K S K, Hossain L. Egocentric analysis of co-authorship network structure, position and performance[J]. Information Processing & Management, 2012, 48(4): 671-679.

Ahuja G. Collaboration networks, structural holes, and innovation: A longitudinal study[J]. Administrative science quarterly, 2000, 45(3): 425-455.

Ahuja G, Morris Lampert C. Entrepreneurship in the large corporation: A longitudinal study of how established firms create breakthrough inventions[J]. Strategic management journal, 2001, 22(6-7): 521-543.

Balkundi P, Kilduff M. The ties that lead: A social network approach to leadership[J]. The Leadership Quarterly, 2006, 17(4): 419-439.

Beamish P W, Lupton N C. Managing joint ventures[J]. The Academy of Management Perspectives, 2009: 75-94.

Bell G G. Clusters, networks, and firm innovativeness[J]. Strategic management journal, 2005, 26(3): 287-295.

Bellamy M A, Ghosh S, Hora M. The influence of supply network structure on firm innovation[J]. Journal of Operations Management, 2014, 32(6): 357-373.

Borgatti S P, Foster P C. The network paradigm in organizational research: A review and typology[J]. Journal of management, 2003, 29(6): 991-1013.

Borgatti S P, Halgin D S. On network theory[J]. Organization science, 2011, 22(5): 1168-1181.

Boschma R, Frenken K. The spatial evolution of innovation networks. A proximity perspective[J]. The handbook of evolutionary economic geography, 2010: 120-135.

Brass D J, Galaskiewicz J, Greve H R, et al. Taking stock of networks and organizations: A multilevel perspective[J]. Academy of management journal, 2004, 47(6): 795-817.

Burkhardt M E, Brass D J. Changing patterns or patterns of change: The effects of a change in technology on social network structure and power[J]. Administrative science quarterly, 1990: 104-127.

Burt R S. Structural holes and good ideas[J]. American journal of sociology, 2004, 110(2): 349-399.

Burt R S. Structural holes: The social structure of competition[M]. Harvard university press, 1992.

Calia R C, Guerrini F M, Moura G L. Innovation networks: From technological development to business model reconfiguration[J]. Technovation, 2007, 27(8): 426-432.

Carpenter M A, Li M, Jiang H. Social network research in organizational contexts: A systematic review of methodological issues and choices[J]. Journal of Management, 2012, 38(4): 1328-1361.

Chen D, Dai L, Li D. A Delicate Balance: Governing Coopetition in R&D Consortia[C]//Academy of Management Proceedings. Briarcliff Manor, NY 10510: Academy of Management, 2016, 2016(1): 13398.

Chen S H. Taiwanese IT firms' offshore R&D in China and the connection with the global innovation network[J]. Research Policy, 2004, 33(2): 337-349.

Chung S, Singh H, Lee K. Complementarity, status similarity and social capital as drivers of alliance formation[J]. Strategic management journal, 2000: 1-22.

Conway S. A cautionary note on data inputs and visual outputs in social network analysis[J]. British Journal of Management, 2014, 25(1): 102-117.

Corsaro D, Cantù C, Tunisini A. Actors' heterogeneity in innovation networks[J]. Industrial Marketing Management, 2012, 41(5): 780-789.

Cowan R, Jonard N, Zimmermann J B. Bilateral collaboration and the emergence of innovation networks[J]. Management science, 2007, 53(7): 1051-1067.

Cowan R, Jonard N. Knowledge portfolios and the organization of innovation networks[J]. Academy of Management Review, 2009, 34(2): 320-342.

Cowan R. Network models of innovation and knowledge diffusion[J]. Clusters, networks and innovation, 2005: 29-53.

Dhanaraj C, Parkhe A. Orchestrating innovation networks[J]. Academy of management review, 2006, 31(3): 659-669.

Dong J Q, Yang C H. Being central is a double-edged sword: Knowledge network centrality and new product development in US pharmaceutical industry[J]. Technological Forecasting and Social Change, 2016, 113: 379-385.

Dougherty D, Dunne D D. Organizing ecologies of complex innovation[J]. Organization Science, 2011, 22(5): 1214-1223.

Doz Y L, Olk P M, Ring P S. Formation processes of R&D consortia: Which path to take? Where does it lead?[J]. Strategic management journal, 2000: 239-266.

Dyer J H, Nobeoka K. Creating and managing a high-performance knowledge-sharing network: the Toyota case[J]. Strategic management journal, 2000: 345-367.

Emden Z, Calantone R J, Droge C. Collaborating for new product development: selecting the partner with maximum potential to create value[J]. Journal of product innovation management, 2006, 23(4): 330-341.

Fleming L, Waguespack D M. Brokerage, boundary spanning, and leadership in open innovation communities[J]. Organization science, 2007, 18(2): 165-180.

Fleming L. Recombinant uncertainty in technological search[J]. Management science, 2001, 47(1): 117-132.

Fonti F, Maoret M, Whitbred R. Free-riding in multi-party alliances: The role of perceived alliance effectiveness and peers' collaboration in a research consortium[J]. Strategic Management Journal, 2017, 38(2): 363-383.

Fritsch M, Franke G. Innovation, regional knowledge spillovers and R&D cooperation[J]. Research policy, 2004, 33(2): 245-255.

Fritsch M, Kauffeld-Monz M. The impact of network structure on knowledge transfer: an application of social network analysis in the context of regional innovation networks[J]. The Annals of Regional Science, 2010, 44(1): 21.

Gardet E, Fraiha S. Coordination modes established by the hub firm of an innovation network: The case of an SME bearer[J]. Journal of Small Business Management, 2012, 50(2): 216-238.

Gilsing V, Nooteboom B, Vanhaverbeke W, et al. Network embeddedness and the exploration of novel technologies: Technological distance, betweenness centrality and density[J]. Research policy, 2008, 37(10): 1717-1731.

Gnyawali D R, Park B J R. Co-opetition and technological innovation in small and medium-sized enterprises: A multilevel conceptual model[J]. Journal of small business management, 2009, 47(3): 308-330.

Granovetter M S. The strength of weak ties[M]. Social networks. 1977: 347-367.

Granovetter M. Economic action and social structure: The problem of embeddedness[J]. American journal of sociology, 1985, 91(3): 481-510.

Gronum S, Verreynne M L, Kastelle T. The role of networks in small and medium-sized enterprise innovation and firm performance[J]. Journal of Small Business Management, 2012, 50(2): 257-282.

Gulati R, Wohlgezogen F, Zhelyazkov P. The two facets of collaboration: Cooperation and coordination in strategic alliances[J]. Academy of Management Annals, 2012, 6(1): 531-583.

Gulati R. Network location and learning: The influence of network resources and firm capabilities on alliance formation[J]. Strategic management journal, 1999, 20(5): 397-420.

Hargadon A, Sutton R I. Technology brokering and innovation in a product development firm[J]. Administrative science quarterly, 1997: 716-749.

Harrison J S, Hitt M A, Hoskisson R E, et al. Resource complementarity in business combinations: Extending the logic to organizational alliances[J]. Journal of management, 2001, 27(6): 679-690.

Huang K F, Yu C M J. The effect of competitive and non-competitive R&D collaboration on firm innovation[J]. The Journal of Technology Transfer, 2011, 36(4): 383-403.

Ibarra H. Network centrality, power, and innovation involvement: Determinants of technical and administrative roles[J]. Academy of Management journal, 1993, 36(3): 471-501.

Jarvenpaa S L, Majchrzak A. Interactive self-regulatory theory for sharing and protecting in interorganizational collaborations[J]. Academy of Management Review, 2016, 41(1): 9-27.

Jensen M, Roy A. Staging exchange partner choices: When do status and reputation matter?[J]. Academy of Management Journal, 2008, 51(3): 495-516.

Jiang R J, Tao Q T, Santoro M D. Alliance portfolio diversity and firm performance[J]. Strategic management journal, 2010, 31(10): 1136-1144.

Kamien M I, Zang I. Meet me halfway: research joint ventures and absorptive capacity[J]. International journal of industrial organization, 2000, 18(7): 995-1012.

Kilduff M, Brass D J. Organizational social network research: Core ideas and key debates[J]. Academy of management annals, 2010, 4(1): 317-357.

Kilduff M, Tsai W. Social networks and organizations[M]. Sage, 2003.

Knoke D, Yang S. Social network analysis[M]. Sage, 2008.

Kogut B. Joint ventures: Theoretical and empirical perspectives[J]. Strategic management journal, 1988, 9(4): 319-332.

Levin D Z, Cross R. The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer[J]. Management science, 2004, 50(11): 1477-1490.

McEvily B, Zaheer A. Bridging ties: A source of firm heterogeneity in competitive capabilities[J]. Strategic management journal, 1999: 1133-1156.

McFadyen M A, Cannella Jr A A. Social capital and knowledge creation: Diminishing returns of the number and strength of exchange relationships[J]. Academy of management Journal, 2004, 47(5): 735-746.

Möller K, Halinen A. Managing business and innovation networks—From strategic nets to business fields and ecosystems[J]. Industrial Marketing Management, 2017, 67: 5-22.

Monaghan S, Lavelle J, Gunnigle P. Mapping networks: Exploring the utility of social network analysis in management research and practice[J]. Journal of Business Research, 2017, 76: 136-144.

Moolenaar N M, Daly A J, Sleegers P J C. Ties with potential: Social network structure and innovative climate in Dutch schools[J]. Teachers College Record, 2011, 113(9): 1983-2017.

Najafi-Tavani S, Najafi-Tavani Z, Naudé P, et al. How collaborative innovation networks affect new product performance: Product innovation capability, process innovation capability, and absorptive capacity[J]. Industrial Marketing Management, 2018.

Nambisan S, Sawhney M. Orchestration processes in network-centric innovation: Evidence from the field[J]. The Academy of Management Perspectives, 2011, 25(3): 40-57.

Newig J, Günther D, Pahl-Wostl C. Synapses in the network: learning in governance networks in the context of environmental management[J]. Ecology and Society, 2010, 15(4).

Newman M E J. The structure and function of complex networks[J]. SIAM review, 2003, 45(2): 167-256.

Nyaga G N, Lynch D F, Marshall D, et al. Power asymmetry, adaptation and collaboration in dyadic relationships involving a powerful partner[J]. Journal of Supply Chain Management, 2013, 49(3): 42-65.

Omidvar O, Edler J, Malik K. Development of absorptive capacity over time and across boundaries: The case of R&D consortia[J]. Long Range Planning, 2017, 50(5): 665-683.

Oxley J E, Sampson R C. The scope and governance of international R&D alliances[J]. Strategic Management Journal, 2004, 25(8-9): 723-749.

Perry-Smith J E. Social yet creative: The role of social relationships in facilitating individual creativity[J]. Academy of Management journal, 2006, 49(1): 85-101.

Pfeffer J, Salancik G R. The external control of organizations: A resource dependence perspective[M]. Stanford University Press, 2003.

Phelps C C. A longitudinal study of the influence of alliance network structure and composition on firm exploratory innovation[J]. Academy of management journal, 2010, 53(4): 890-913.

Phelps C, Heidl R, Wadhwa A. Knowledge, networks, and knowledge networks: A review and research agenda[J]. Journal of management, 2012, 38(4): 1115-1166.

Powell W W, Koput K W, Smith-Doerr L. Interorganizational collaboration and the locus of innovation: Networks of learning in biotechnology[J]. Administrative science quarterly, 1996: 116-145.

Powell W W, White D R, Koput K W, et al. Network dynamics and field evolution: The growth of interorganizational collaboration in the life sciences[J]. American journal of sociology, 2005, 110(4): 1132-1205.

Provan K G, Fish A, Sydow J. Interorganizational networks at the network level: A review of the empirical literature on whole networks[J]. Journal of management, 2007, 33(3): 479-516.

Reuer J J, Arino A. Strategic alliance contracts: Dimensions and determinants of contractual complexity[J]. Strategic Management Journal, 2007, 28(3): 313-330.

Rojas M G A, Solis E R R, Zhu J J J. Innovation and network multiplexity: R&D and the concurrent effects of two collaboration networks in an emerging economy[J]. Research Policy, 2018.

Rost K. The strength of strong ties in the creation of innovation[J]. Research policy, 2011, 40(4): 588-604.

Rowley T, Behrens D, Krackhardt D. Redundant governance structures: An analysis of structural and relational embeddedness in the steel and semiconductor industries[J]. Strategic management journal, 2000: 369-386.

Sakakibara M. Formation of R&D consortia: Industry and company effects[J]. Strategic Management Journal, 2002, 23(11): 1033-1050.

Sakakibara M. Heterogeneity of firm capabilities and cooperative research and development: an empirical examination of motives[J]. Strategic management journal, 1997: 143-164.

Sakakibara M. The diversity of R&D consortia and firm behavior: Evidence from Japanese data[J]. The Journal of Industrial Economics, 2001, 49(2): 181-196.

Salman N, Saives A L. Indirect networks: an intangible resource for biotechnology innovation[J]. r&d Management, 2005, 35(2): 203-215.

Sammarra A, Biggiero L. Heterogeneity and specificity of Inter-Firm knowledge flows in innovation networks[J]. Journal of Management Studies, 2008, 45(4): 800-829.

Schilling M A, Phelps C C. Interfirm collaboration networks: The impact of large-scale network structure on firm innovation[J]. Management science, 2007, 53(7): 1113-1126.

Singh H, Kryscynski D, Li X, et al. Pipes, pools, and filters: how collaboration networks affect innovative performance[J]. Strategic Management Journal, 2016, 37(8): 1649-1666.

Soda G, Usai A, Zaheer A. Network memory: The influence of past and current networks on performance[J]. Academy of Management Journal, 2004, 47(6): 893-906.

Swan J, Newell S, Scarbrough H, et al. Knowledge management and innovation: networks and networking[J]. Journal of Knowledge management, 1999, 3(4): 262-275.

Tasselli S, Kilduff M, Menges J I. The microfoundations of organizational social networks: A review and an agenda for future research[J]. Journal of Management, 2015, 41(5): 1361-1387.

Tortoriello M, Krackhardt D. Activating cross-boundary knowledge: The role of Simmelian ties in the generation of innovations[J]. Academy of Management Journal, 2010, 53(1): 167-181.

Tortoriello M, McEvily B, Krackhardt D. Being a catalyst of innovation: The role of knowledge diversity and network closure[J]. Organization Science, 2014, 26(2): 423-438.

Tsai W, Ghoshal S. Social capital and value creation: The role of intrafirm networks[J]. Academy of management Journal, 1998, 41(4): 464-476.

Tsai W. Knowledge transfer in intraorganizational networks: Effects of network position and absorptive capacity on business unit innovation and performance[J]. Academy of management journal, 2001, 44(5):

996-1004.

Uzzi B, Lancaster R. Relational embeddedness and learning: The case of bank loan managers and their clients[J]. Management science, 2003, 49(4): 383-399.

Uzzi B. The sources and consequences of embeddedness for the economic performance of organizations: The network effect[J]. American sociological review, 1996: 674-698.

Van der Vegt G S, De Jong S B, Bunderson J S, et al. Power asymmetry and learning in teams: The moderating role of performance feedback[J]. Organization Science, 2010, 21(2): 347-361.

Vanhaverbeke W, Beerkens B, Gilsing V, et al. Explorative and exploitative learning strategies in technology-based alliance networks[C]//Academy of Management Proceedings. Briarcliff Manor, NY 10510: Academy of Management, 2006, 2006(1): I1-I6.

Von Raesfeld A, Geurts P, Jansen M. When is a network a nexus for innovation? A study of public nanotechnology R&D projects in the Netherlands[J]. Industrial Marketing Management, 2012, 41(5): 752-758.

Wang C, Rodan S, Fruin M, et al. Knowledge networks, collaboration networks, and exploratory innovation[J]. Academy of Management Journal, 2014, 57(2): 484-514.

Wang J. Knowledge creation in collaboration networks: Effects of tie configuration[J]. Research Policy, 2016, 45(1): 68-80.

Wasserman S, Faust K. Social network analysis: Methods and applications[M]. Cambridge university press, 1994.

Wilhelm M M, Kohlbacher F. Co-opetition and knowledge co-creation in Japanese supplier-networks: The case of Toyota[J]. Asian Business & Management, 2011, 10(1): 66-86.

Yang H, Lin Z, Peng M W. Behind acquisitions of alliance partners: exploratory learning and network embeddedness[J]. Academy of Management Journal, 2011, 54(5): 1069-1080.

Zaheer A, Bell G G. Benefiting from network position: firm capabilities, structural holes, and performance[J]. Strategic management journal, 2005, 26(9): 809-825.

Zaheer A, Soda G. Network evolution: The origins of structural holes[J]. Administrative Science Quarterly, 2009, 54(1): 1-31.

Zeng M, Chen X P. Achieving cooperation in multiparty alliances: A social dilemma approach to partnership management[J]. Academy of Management Review, 2003, 28(4): 587-605.

Zeng S X, Xie X M, Tam C M. Relationship between cooperation networks and innovation performance of SMEs[J]. Technovation, 2010, 30(3): 181-194.

Zhou J, Shin S J, Brass D J, et al. Social networks, personal values, and creativity: evidence for curvilinear and interaction effects[J]. Journal of applied psychology, 2009, 94(6): 1544.