Innovation and Network Multiplexity: R&D and the concurrent effects of two collaboration networks in an emerging economy

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Abstract

This study focuses on the multiplexity of firm R&D networks, and it investigates two types of boundary-spanning networks: the bipartite network between firms and government-sponsored institutions (GSIs), and the traditional firm–firm network. We apply a social network perspective to examine the effects that these kinds of networks have on firm innovativeness, in relation to the effects of the firm's internal R&D efforts. We define the firm-GSI network as bipartite, and we investigate how the structural characteristics of this network (cohesion and centrality) affect innovativeness. We then decompose the innovational effects of firm–firm networks into two categories (intra- and inter-sector) to distinguish the effects of these collaboration networks. Furthermore, we investigate how these various external collaborative networks interact with a firm's internal R&D efforts for driving innovativeness. Our empirical study of 420 manufacturing firms in Mexico evaluates evidence from surveys and secondary data. The findings indicate that the structural properties of both firm–GSI and firm–firm networks have positive effects on innovativeness, but firm–GSI network cohesion has a stronger negative interaction with R&D in influencing firm innovativeness. Moreover, intra-sector centrality in a firm–firm network has a stronger negative interaction with R&D than inter-sector centrality does in driving firm innovativeness. We contribute to the literature by integrating insights from the perspectives of network multiplexity, social embeddedness, and resource complementarity in regard to inter-organizational behavior. Our study also provides meaningful guidelines for both managers and policy makers. The study's findings are robust to concerns of common method bias and alternative model specifications.

Keywords: Network multiplexity; firm innovativeness; government-sponsored institutions (GSIs); emerging economy; strategic alliance.

Classification codes: O320 Management of Technological Innovation and R&D, O330 Technological Change: Choices and Consequences; Diffusion Processes.

1 INTRODUCTION

Innovation strategy research has increasingly recognized that effective boundary spanning of a firm's knowledge sources is central to a successful innovation strategy, and that a combination of internal R&D and acquisition of external knowledge is vital for the success of strategic innovation (Chesbrough, 2006; Love et al., 2014; Veugelers and Cassiman, 1999). Accordingly, recent models of innovation have shown that firms are increasingly "opening" up their R&D borders through various types of collaboration networks (Ahuja, 2000b; Aral and Van Alstyne, 2011; Tortoriello et al., 2014). In addition to developing firm-firm research collaborations, firms may seek to collaborate with government sponsored institutions (GSI) for the external knowledge needed to create new products, processes, and technologies (Carnabuci and Operti, 2013). This trend is especially salient and critical for small and medium enterprises (SMEs) in emerging economies, due to their relatively limited resources and capacities for innovation (Baumann and Kritikos, 2016; Lee et al., 2001). As firms seek to systematically open up their R&D borders, one of the challenging tasks for managers is to balance their activities between external and internal R&D. For policy makers, it has grown increasingly important to design effective public support for R&D investment through GSI-firm collaboration. These policy makers also aim to help the recipients achieve an optimal configuration that maximizes the benefits of input resources.

At the heart of this challenge lies the problem of how internal R&D interacts with external research activities. Some literature has offered analyses regarding the competing effects of complementarity and substitutability. To date, however, such analyses have yielded contradictory sets of empirical evidence. One stream of research has indicated that internal and external R&D efforts are complementary activities, which jointly improve a firm's innovativeness (Cassiman and Veugelers, 2006; Lokshin et al., 2008; Rothaermel and Hess, 2007; Schmiedeberg, 2008). A number of other studies have indicated that the relationships between internal and external sources of innovation are non-complementary, or even substitutionary (Hess and Rothaermel, 2011; Laursen and Salter, 2006). These mixed findings push both scholars and practitioners to achieve a more profound and systematic understanding regarding the joint effects that external and internal R&D efforts have on a firm's performance in terms of innovation. In considering the boundary expansions of a firm's knowledge sources and resource networks, it is clearly useful to take a multiplex network perspective for exploring the innovation impact of external R&D efforts on innovation. This approach is helpful because it is important to differentiate between the effects that firm-GSI collaborations and firm-firm research collaborations have on firm innovativeness, as these types of collaborative networks are different in nature. We address three research gaps to advance the literature, and we provide guidance for both firm executives and policy makers.

The first gap relates to firm–GSI research alliances. Studies have investigated knowledge-transfer alliances (Bellucci and Pennacchio, 2016; Lakpetch and Lorsuwannarat, 2012) and have identified certain success-related factors (Mindruta, 2013; Schofield, 2013; Steinmo, 2015), but this line of research has failed to offer a definite conclusion regarding the impact of such alliances on firm innovation. Overall, research has suggested that government-sponsored innovation programs may be effective in achieving economic and social goals (Hsu et al., 2009; Wei and Liu, 2015). However, the magnitude of this effect varies with firm characteristics (Stuart et al., 2007), orientation towards innovation (Bellucci and Pennacchio, 2016), and industry-related factors (Lakpetch and Lorsuwannarat, 2012). Several researchers have found that government-sponsored programs often have insignificant (Hsu et al., 2009; Wu et al., 2006) or even negative effects on firm innovation (Broekel, 2015; Yu et al., 2016). These negative effects may arise due to discrepancies between the partners' objectives (Fontana et al., 2006), limitations in human resources (Jung and Andrew, 2014), or the crowding of internal R&D input (Yu et al., 2016).

Despite the significance of this topic, the causes for these discrepancies in findings have not yet been clarified. Therefore, we propose a unique social network approach for capturing the structural nature of such firm-GSI networks. In these networks, direct links to guide the free flow of information, knowledge, and resources from GSIs to firms are likely to exist only as bipartite ties between the GSIs and the participating firms. Such bipartite networks are distinct from the more traditional ego-networks of research alliances between various firms. Thus, it is relevant to examine the innovation-related outcomes of various types of collaborative firm relationships from a network multiplexity perspective. Advantageous positions in a collaborative network (in terms of centrality or cohesion) can enhance the prominence of a firm and the benefits from information and knowledge that it can obtain within its network (Guler and Nerkar, 2012; Larcker et al., 2013). Bipartite network cohesion fosters knowledge spillovers and recombination among the bipartite network members due to the members' active engagement, and to their circulation and effective application of quality information (Guler and Nerkar, 2012). In comparison, bipartite network centrality benefits firms primarily in terms of access to information and knowledge (Gulati, 1995; Lee et al., 2015), transmission of processes and norms (Mahmood et al., 2011), and legitimacy signals (Lin et al., 2009).

The second gap is related to firm–firm alliances. Studies of firm–firm alliances have predominantly used aggregated measures to examine network structures, and these studies have treated all of the firm–firm interactions within a collaborative network as the same (Carnabuci and Operti, 2013). However, firms may establish collaborative relationships with partners within their own sector, or with partners across different sectors. Although these relationships may influence innovation via similar mechanisms, such as increased access to resources and knowledge spillovers (Jensen and Roy, 2008; Mitchell and Singh, 1996), the effects that intra- and inter-sector collaborations have on firm innovativeness may differ, due to the distinct nature of the shared resources. Basically, similar types of knowledge are exchanged between firms that are in the same network communities (industries) (Burt, 1992). Specifically, intra-sector collaboration offers more advantages in terms of knowledge assimilation and recombination, due to the greater within sector similarity of product lines, technologies, operating procedures, business norms, managerial routines, and the generally enhanced absorptive capacity between firms in the same sector (Cohen and Levinthal, 1990).

We bridge the first and second gap to address the third gap, which is related to the interplay between internal and external R&D activities. The diversified resources and knowledge that firms acquire externally may interact with the resources and capabilities they develop internally through investment and strategic management (Lin et al., 2009). The complementarity (or substitution) between external and internal knowledge and resources significantly influences a firm's decision to optimize its resource allocation between various R&D activities (Arora and Gambardella, 1990; Das and Teng, 2000). Firm's internal R&D efforts positively affect firm innovation primarily by contributing to more efficient utilization of the available financial and human resources through accessing, modifying, exploring, and generating new technologies (Hoffman et al., 1998). Based on the above analyses and due to the same boost of internalization and recombination of acquired resources and knowledge, a stronger negative interaction effect may arise between firm-GSI cohesion and firm R&D, than the effect which arises between firm-GSI bipartite centrality and firm R&D. Similarly, a stronger negative interaction effect is more likely to happen in the interplay between centrality in an intra-sector alliance and a firm's own R&D efforts, than it is to happen in the interplay between centrality in an inter-sector alliance network and a firm's R&D.

By taking a network embeddedness and network multiplexity perspective, our study aims to make several contributions to the literature on cooperative research networks and firm innovation. First, we characterize the two widely adopted but distinct forms of collaborative networks (the bipartite firm-GSI network and the regular firm-firm collaborative network), and we develop an integrated framework for investigating their effects on innovation. Second, we extend our understanding of firm-GSI collaboration by differentiating between the effects that various structural characteristics of these networks (i.e., bipartite network cohesion and bipartite network centrality) have on firm innovativeness. Third, we advance knowledge in this area by decomposing the intra- and inter-sector effects that firm-firm alliance networks have on firm innovativeness. Fourth, we theorize the interplay between firms' efforts in pursuing innovation through external collaboration, and their internal R&D efforts toward developing innovative products or manufacturing techniques. In summary, we answer the call to investigate the effects of multiplex networks, and of interactions between internal and external R&D activities. We conduct this investigation in the highly relevant context of SMEs operating in an emerging economy (e.g., Bao et al., 2012).

We operationalized this research by investigating the effects of collaborative networks on firm innovativeness among 420 manufacturing firms in Mexico. These firms were participants in the five key sectors of the Mexican economy: food, high technology, design, automobiles, and plastics. The results of this study provide managerial implications for firms seeking to collaborate with other firms and with GSIs. By demonstrating and interpreting the interaction effects between the firms' external collaboration strategies and their internal R&D efforts, our findings provide guidance to both managers and policymakers on how firms can optimize their strategies for internal and external knowledge acquisition, and how government R&D resources can best be allocated to promote greater innovation on SMEs.

2 THEORETICAL BACKGROUND AND HYPOTHESES DEVELOPMENT

The literature on innovation has commonly emphasized the importance of boundary expansion to enable firms to acquire the external knowledge and resources needed for enhanced innovation (Veugelers and Cassiman, 1999). Boundary expansion constitutes an "open innovation" strategy (Chesbrough, 2006) that contributes to the combination of internal and external sources of knowledge. The benefits associated with pursuing innovation through external collaboration are especially salient for SMEs. SMEs typically face several constraints in carrying out their innovation efforts, including the limited quantity and quality of R&D resources (Fontana et al., 2006; Miotti and Sachwald, 2003), the shortage of qualified personnel with the necessary management skills (Feller et al., 2002), competitive pressures (Baum and Oliver, 1991; Sakakibara, 2002), or government policies that favor large firms with greater capabilities (Kenney et al., 2004). Thus, boundary spanning research collaborations have become an important and feasible source of innovation and knowledge transfers, especially for SMEs.

This study takes a network perspective to investigate the relationship between firms' R&D activities and their levels of innovation performance, and it does so by focusing on two types of external R&D collaborations that are commonly practiced by SMEs (i.e., firm-GSI collaborations and firm-firm collaborations). We define firm-GSI collaborations as a bipartite network, and we define firm-firm collaborations as regular single-mode networks. We extend the literature by investigating how innovation is affected by cohesion and bipartite centrality in firm-GSI collaborative networks, and how innovation is affected by a firm's centrality in an intra- or inter-sector firm-firm research alliance. Furthermore, a firm's internal experience of technological exploration, i.e., R&D, leads to the development of firm-specific knowledge, and of absorptive capabilities that enable the firm to evaluate, recombine, and leverage externally generated knowledge (Helfat, 1997; Mowery, 1983). Previous research has suggested that when efficient alliance configurations provide access to more diverse sets of information and capabilities via boundary spanning, it becomes more likely that the desired benefits of innovation can be achieved at minimal cost in terms of redundancy, conflict, and complexity. Such efficient alliances can potentially maximize the complementarity between internal and external innovation activities (Baum et al., 2000). Therefore, we theorize and examine the interplay between the various types of collaborative networks and the firms' own internal R&D inputs. Our aim is to provide a set of practical implications for how to optimally develop external collaborations. Figure 1 depicts an example of network multiplexity, in which we can observe the concurrent effects of firm-GSI and firm-firm alliance networks. Figure 2 displays our theoretical framework.

----------Insert Figure 1 and Figure 2 here----------

2.1 Firm–GSI cooperative networks

The concept of additionality is widely used to explain and assess how government programs that promote innovation (such as subsidies, funding, or firm-GSI research alliances) affect the performance of a firm's own R&D program (i.e., input additionality) (Buisseret et al., 1995), or influence innovation-related outputs (i.e., output additionality) such as patents, papers, prototypes, new products, or services (Buisseret et al., 1995; Georghiou, 2002). The additionality from firm-GSI research alliances can also result in changes to a firm's innovation processes, routines, activities, or relevant corporate business/technology strategies, thereby facilitating the conversion of innovation inputs into outcomes that involve enhanced performance (i.e., behavioral additionality) (Falk, 2007; Georghiou, 2002). This study advances our understanding of these issues by exploring how different structural characteristics of firm-GSI networks contribute to a firm's innovation output, and how underlying mechanisms determine the interplay between firm-GSI and internal R&D efforts.

A firm-GSI cooperative network has a bipartite structure, formed through collaborative links between firms and GSIs. Bipartite networks are a special type of network, in which the nodes (firms or GSIs) belong to two distinct types (or sets) of organizations, and the connections (or links) exist only between nodes of different types (Leiponen, 2008). In a firm–GSI collaborative network, direct links exist only between GSIs and firms. Although the firms are linked through the GSIs, by definition there are no direct links between the firms themselves. The collaborative links between the firms and GSIs facilitate a bilateral flow of information and knowledge, but only a unilateral flow of resources. Information and knowledge can flow freely between the GSIs and firms, whereas resources (such as technologies), are provided to the firms by the GSIs. Such links with GSIs provide firms (i.e., SMEs) with the means to engage in technological development, which SMEs are usually unable to do alone due to their limited resources (Lee et al., 2001). GSIs provide consulting, networking assistance, and educational opportunities to SMEs. This ongoing collaboration also enables firms to develop links with researchers, which may encourage the migration of human capital. In emerging economies, SMEs often receive support from GSIs, which can enable the SMEs to secure competitive advantages through innovation (Stuart et al., 1999).

Firm–GSI collaboration has been an emerging topic; however, the empirical evidence concerning the effectiveness of firm-GSI collaboration for enabling innovation has been inconsistent and often contradictory. Some studies have demonstrated that government-sponsored innovation programs have had significant, positive effects on knowledge sharing (Ponomariov, 2013), granted patents (Wei and Liu, 2015), technology convergence (Jeong, 2014), and new product development (Xu et al., 2014). These various results seem to indicate that these programs have commonly achieved their economic and social goals (Hsu et al., 2009; Jung and Andrew, 2014). Still, the effects of such programs tend to vary with factors such as firm maturity (Stuart et al., 2007), orientation toward open and radical innovations (Bellucci and Pennacchio, 2016), industry sectors and innovation categories (Lakpetch and Lorsuwannarat, 2012), etc. Some government-sponsored innovation programs have been found to be at least partially ineffective (Hsu et al., 2009; Wu et al., 2006), or even to have negative effects on firm innovation (Broekel, 2015; Yu et al., 2016). Such outcomes are especially likely in cases involving organizational barriers, such as discrepant objectives between firms and universities (Fontana et al., 2006), gaps in human resources, divergence in R&D operations (Jung and Andrew, 2014), or the crowding of firm R&D input (Yu et al., 2016).

Our study extends the literature by associating superior firm innovation with a firm's advantageous structural positions (cohesion and centrality) in a bipartite collaborative network.

2.2 Bipartite cohesion and firm innovativeness in firm–GSI cooperative networks

Improving innovativeness through external networks is a viable approach for SMEs in emerging economies. In this section, we suggest that cohesion in a firm–GSI cooperative network positively influences innovation through three main mechanisms.

First, a closely knit network produces social norms and sanctions that promote cooperative exchange, a sense of obligation, and greater mutual trust (Coleman, 1988). These favorable conditions foster constructive engagement in firm-GSI collaborations. Cohesive networks improve communication and facilitate the transfer of fine-grained information through the cultivation of trust and openness to cooperation (Ahuja, 2000b; Gulati, 1995). In that case, the prevailing network norms lead to a culture of sharing and collaborating in tandem. Trust generated by cohesion encourages firms to engage freely in exchanging ideas and knowledge, with little concern for adverse consequences. In such tight, trusted network communities, both firms and GSIs are motivated to invest more effort and resources in sharing knowledge (Burt, 1992; Reagans and McEvily, 2003), thereby enhancing their confidence in experimenting with new technologies and exposing themselves to risk (Nahapiet and Ghoshal, 1998).

Second, cohesion fosters knowledge spillovers and recombinations that can enhance the absorptive capacity of the bipartite network members. Firms in highly cohesive networks can verify the quality, accuracy, and authenticity of the information they receive by comparing it with that of other GSIs and firms within their network. This capacity for validation facilitates information and knowledge exchange between the firms and GSIs in a cluster. That kind of exchange enhances the spillover of technologies and creative ideas, which leads to innovation (Guler and Nerkar, 2012). Moreover, in a cohesive community, firms and

GSIs engage with each other on a regular basis, and have a better understanding of each other's products and processes. The continuous circulation of information and knowledge within cohesive communities of GSIs and firms helps to create the tacit knowledge that is essential for exploratory tasks. That kind of knowledge is more likely to be contextual (Obstfeld, 2005) and interpretable (Nahapiet and Ghoshal, 1998). As a result of such an exchange, the member firms endeavor to create original, pertinent knowledge by internalizing and recombining the knowledge or techniques they have acquired. This enhanced absorptive capacity in turn improves the firms' innovativeness (Guler and Nerkar, 2012).

Third, cohesion provides firms with advantages in effectively accessing and efficiently utilizing the resources within their clusters. Cohesion assists coordination between firms and GSIs by creating mutual awareness, which prevents the duplication of work already done by other GSIs and firms in the community (Schilling and Phelps, 2007). Cohesive networks are therefore likely to be fecund in producing undifferentiated efforts toward the development of related technologies, or initiatives based on similar foundations of knowledge or human capital. As the member firms can rely on the technology and knowledge that is already created by the GSIs or other firms, they can better pool and utilize their resources and human capital to exploit their potential for generating innovation (Guler and Nerkar, 2012). In addition, firms that are involved in cohesive communities with GSIs may receive additional technical and financial support that enables them to innovate (Guler and Nerkar, 2012; Obstfeld, 2005). Thus, we propose

Hypothesis 1a: A firm's cohesion in a firm–GSI collaborative network has a positive effect on firm innovativeness.

2.3 Bipartite centrality and firm innovativeness in firm–GSI cooperative networks

Firm–GSI networks differ from firm–firm collaborative networks. In the latter, the flow of information, resources, and knowledge is expected to be bilateral. However, firm–GSI collaborative networks have different mechanisms for the flow of each of these elements. Although information and knowledge can flow bilaterally between firms and GSIs, resources in the form of technical and financial support flow unilaterally from GSIs to firms. Hence, we suggest that firms with greater bipartite centrality are more innovative for the following reasons.

First, high bipartite centrality gives firms wider access to key and valuable information (Gulati, 1995). The links between firms and GSIs facilitate the flow of information in the following channels: GSI–firm, firm–firm (through GSIs), GSI–GSI (through firms), and firm–GSI. Active and intensive communication improves the network's capacity for information transmission (Lee et al., 2015) and helps to ensure that the information introduced reaches other firms and GSIs (Shore et al., 2015). Direct connections to GSIs and indirect connections to firms provide a focal firm with access to more and better quality information. For example, a firm may learn about the innovations happening in other industries and, with GSI support, may be able to implement those innovations in its own industry.

Second, greater interaction between GSIs and firms facilitates the effective transmission of processes and routines (Mahmood et al., 2011). Such transmission is enabled not only between the GSIs and firms, but also between firms that are indirectly connected through the GSIs. Thus, firms with high bipartite centrality are able to better exploit business opportunities, because their network connections make their processes and routines more efficient (Gulati and Gargiulo, 1999). The continuous interaction that comes with centrality provides firms with a bigger pool of opportunities and resources, thereby enabling them to identify innovations that will have a greater impact. This ability in turn helps them to focus their acquisition and deployment of resources on projects that favor innovation (Koka and Prescott, 2008).

Finally, firms can use their high bipartite centrality as a signaling device to improve their legitimacy and reputation (Lin et al., 2009). Firms can gain visibility and an enhanced reputation through positive associations with GSIs, which in turn can help them to gain trust from other parties as they seek access to knowledge and resources. Governments in developing economies continuously showcase the ways that their sponsored institutions (in this case GSIs) support the development of firms, especially SMEs. Overall, firms with a more central network position possess resource advantages and achieve superior innovative outputs due to their more direct associations with GSIs.

Hypothesis 1b: A firm's bipartite centrality in a firm–GSI collaborative network has a positive effect on firm innovativeness.

2.4 Firm–firm collaborative networks

Inter-firm research collaborations don't necessarily take place within the same industry. Instead, they are distributed between a large pool of actors in a wider cross-industry network (Jacobides and Billinger, 2006), seeking for diverse and complementary capabilities. However, most studies fail to theoretically or empirically differentiate strategic alliances based on the similarity and relatedness of the businesses. In this study, we identify and differentiate between two types of strategic alliances, i.e. intra- and cross-sector, and propose that firm's centrality in both intra-sector and cross-sector alliance networks positively influences firms' innovativeness for three reasons.

First, a central network position benefits a firm by giving it access to more diverse resources and capabilities, due to its relatively direct connections with multiple partners (Jensen and Roy, 2008). This centrality enables a firm to better understand market needs and to create products that better satisfy the demands of consumers (Owen-Smith and Powell, 2004). Hence, firms in a central position in the intra-sector or cross-sector research network tend to be more innovative. Second, new technological developments often require the synthesis of different sets of skills and knowledge throughout the innovation process (Powell et al., 1996). Therefore, it is challenging for firms to develop multiple, broad, sustainable competencies in the face of rapid technological change , and to do so with limited internal R&D resources (Mitchell and Singh, 1996). High transaction costs make the direct acquisition of innovative technologies prohibitive for most SMEs, which leaves internal development or collaboration as the only realistic alternatives (Mitchell and Singh, 1996). Compared to the path of internal development, collaboration can more easily enable firms to enjoy the economies of specialization without committing themselves to extra investments of financial and human resources (Tortoriello and Krackhardt, 2010). By tapping into the available competencies of alliance partners, a firm can enhance its own knowledge base and thereby improve its capacity for innovation (Owen-Smith and Powell, 2004; Tiwana, 2008). Third, intra-sector and cross-sector centrality facilitate the transfer of tacit information, and therefore smooth the way for knowledge spillovers (Milanov and Shepherd, 2013). As firms accumulate and internalize technical knowledge, they become more experienced and more capable of recombining additional external knowledge to enable innovation (Cohen and Levinthal, 1990; Zhou and Wu, 2010), thus achieving a stronger absorptive capacity (Cohen and Levinthal, 1990).

Despite the commonly positive impact of alliances on innovation, differential effects exist. Inter-sector alliances tend to be less beneficial in providing complementary resources and technologies, but they often offer significant advantages of knowledge assimilation and recombination. Intra-sector firms are generally more similar in terms of product lines, technology, operating procedures, business norms, and managerial routines. The common stocks of knowledge held by firms within the same industries not only obviate the need for making investments to comprehend the technologies of alliance partners, but such commonality also facilitates the transfer and internalization of knowledge (Ahuja, 2000a; Reagans and McEvily, 2003). According to organization theory, standard operating procedures that are configured around a core production technology tend to engender organizational inertia (Hannan and Freeman, 1984). Firms working in similar niches tend to develop similar operating protocols and knowledge bases over time. They also typically share common understandings of technologies and market segments, and therefore they are better equipped to exchange or jointly develop new technologies (Mowery et al., 1996). From an absorptive capacity perspective (Cohen and Levinthal, 1990), organizations are better able to evaluate and internalize knowledge from technologically similar firms. An organizational ability to assimilate new ideas and inventions from external sources often enhances the effectiveness of collaboration between technologically similar firms. Thus, organizations in the same sector encounter fewer obstacles in sharing the same perspective, and achieving joint development and technology exchange (Carlile, 2004; Carlile and Rebentisch, 2003). High centrality firms in intra-sector alliance networks therefore demonstrate strong knowledge assimilation and recombination, and deliver superior innovation performance. We postulate that:

Hypothesis 2a: A firm's intra-sector centrality in a firm–firm network has a positive effect on firm innovativeness.

Hypothesis 2b: A firm's cross-sector centrality in a firm–firm network has a positive effect on firm innovativeness.

2.5 Networks, R&D, and innovativeness

Firms' internal R&D efforts focus on improving resource utilization and enhancing absorptive capacity to explore and assimilate new technologies (Cohen and Levinthal, 1990; Hoffman et al., 1998). Firms enhance their R&D capability by organizing processes and principles to guide them in deploying their resources for new product development and improving their manufacturing processes in response to the changing environment (Kogut and Zander, 1992). R&D efforts positively affect firm innovation primarily by contributing to more efficient utilization of the available financial and human resources through accessing, modifying, exploring, and generating new technologies (Hoffman et al., 1998). R&D activities also facilitate the absorption of new ideas and knowledge, which leads to the generation of new products and technologies or the improvement of existing ones (Cohen and Levinthal, 1990).

Prior research has emphasized the importance of boundary spanners in facilitating the transfer of knowledge between organizations, and it has suggested two seemingly competing effects of network configurations on innovation. One stream of such research has stressed that collaborative networks provide firms with access to more diverse information and help them to produce desired outputs with minimum costs in terms of redundancy, conflict, or complexity (Baum et al., 2000). Prior literature has associated knowledge diversity and innovation output with firms' network structural positions such as centrality (Uzzi, 1997), closeness/degree centrality (Hansen, 2002), structural holes (Ahuja, 2000a), cohesion (Guler and Nerkar, 2012), reach (Schilling and Phelps, 2007), and bridging ties (Sytch et al., 2012). This literature has been tested in an array of industries, such as manufacturing, transportation, equipment, computer, electronics, pharmaceutical, biotechnology, and nanotechnology. The effects of network positions on innovation are discrepant. Some researchers have reported positive direct effects, and some have shown indirect effects through knowledge transfers (Tiwana, 2008; Tortoriello et al., 2012), or through the moderation of innovation mechanisms (Tortoriello and Krackhardt, 2010; Yu et al., 2016). Another stream of research on collaborative networks has highlighted the relations between network structural features and knowledge recombinations. Such studies have emphasized the effects of network cohesion (Guler and Nerkar, 2012; Tortoriello et al., 2012), clustering (Schilling and Phelps, 2007), density (Mahmood et al., 2011; Zaheer and Bell, 2005), direct ties (Hansen, 2002), simmelian ties (Tortoriello and Krackhardt, 2010), and tie strength (Inkpen and Tsang, 2005). Testing these different effects has indicated the importance of incorporating differing perspectives (based on the different network structural characteristics involved) when analyzing the interplay between external R&D networks and internal R&D efforts.

We draw on the literature of resource and knowledge complementarity and propose that in innovation, resource and knowledge complementarity (between internal and external R&D efforts) stimulates knowledge exploration by enabling the accessibility, acquisition, and recombination of diverse knowledge (Fang, 2011; Rothaermel and Boeker, 2008). However, negative effects may take place between firm's internal and external R&D activities if boundary spanning efforts overlap the firm's capability to improve developed from internal R&D, in such circumstances a negative interaction between internal R&D and external R&D collaboration in driving firm innovation may take place.

2.5.1 Firm-GSI cooperative networks and firm internal R&D

As previously described, firms that occupy central positions in firm-GSI networks are widely connected, both directly to affiliated GSIs, and indirectly to the other firms affiliated with these GSIs. With the rapid development of technology and the increasingly fierce competitive environment (Powell et al., 2005), it is crucial for firms to use collaborative networks as a locus of innovation (Owen-Smith and Powell, 2004; Stuart et al., 1999). Such networks help firms to acquire information regarding which technological opportunities to seize, and to secure diversified sources of technological knowledge and competency for conducting research and development (Powell et al., 1996). Having a central position in a network enables a firm to obtain wider connections to diverse sets of partners, and gain superior access to more nonredundant information and novel ideas from the external environment (Jensen and Roy, 2008). This centrality provides firms with access to a greater reservoir of diverse knowledge (Lin et al., 2007), which would be difficult to generate internally. That knowledge access can lead to more efficient exploration of technological breakthroughs (Koka and Prescott, 2008).

In comparison, cohesion helps to establish trust among its members, due to the shared norms and sanctions (Reagans and McEvily, 2003). This cohesiveness enables firms and GSIs to engage more closely and willingly with each other, to better understand each other's products and processes (Gargiulo and Benassi, 2000).The cohesive relationship conveys a clear normative order (Podolny and Baron, 1997), which not only broadens but also deepens the development of innovation activities (Buisseret et al., 1995). The resultant renovation of innovation processes (Davenport et al., 1998), and refinement of corporate technology and business strategies (Georghiou, 2002; Hsu et al., 2009) contribute to more optimal innovative performance. These improved innovation processes and routines facilitate knowledge spillovers and thus provide measures for the additionality of a GSI program (Buisseret et al., 1995; Falk, 2007). The additionalities associated with a cohesive network tend to reinforce a firm's capability for internalizing and recombining acquired knowledge or techniques, thereby achieving enhanced innovativeness (Hoffman et al., 1998). These additionalities therefore tend to substitute for R&D efforts, in terms of their contributions to improved resource utilization and the absorptive capacity to explore and assimilate new technologies (Cohen and Levinthal, 1990; Hoffman et al., 1998).

On the one hand, high bipartite centrality in firm–GSI networks tend to complement rather than overlap with a firm's internal innovation efforts, as this kind of centrality provides advantageous access to diverse knowledge. On the other hand, strong cohesion in a firm–GSI network fosters more efficient knowledge spillover and recombination, which overlaps with capability improvement through internal R&D activities. Thus, we predict a stronger negative interplay between firm–GSI cohesion and internal R&D compared to the effect that is found between firm–GSI bipartite centrality and firm R&D in driving firm innovativeness.

Hypothesis 3a: In firm–GSI cooperative networks, cohesion has a stronger negative interaction with firms' internal R&D than bipartite centrality does in driving firm innovativeness.

2.5.2 Firm-firm alliance networks and firm internal R&D

Inter-firm R&D collaboration involves boundary spanning between two firms, which could belong to the same or two different network communities (Burt, 1992). A central position in an intra- or cross-sector alliance network gives a firm greater access to diverse resources, knowledge, and capabilities through gaining connections with more partners (Jensen and Roy, 2008). The benefits from such alliances represent the accumulated technical, commercial, and social capital that the member firms acquire through their technical collaborations (Ahuja, 2000a). Centrality leverages different sets of skills and knowledge bases, and helps firms to explore new technological opportunities for enhancing firm innovativeness (Powell et al., 1996). The benefits from centrality, however, are greater in the case of inter-sector collaborations, because R&D alliances between firms from different industrial sectors provide access to distinct information, technologies, markets, and resources (Baum et al., 2003; Burt, 2005). This kind of inter-sector exchange creates unique opportunities to aggregate human and capital resources, and to obtain the information flows and knowledge spillovers from other sectors (Baum et al., 2010; McEvily and Zaheer, 1999).

In comparison, intra-sector alliances take place within a relatively closed world of a single industry (Watts and Strogatz, 1998). In such alliances, the benefits of participation stem from the greater efficiency in moving information, innovations, and other resources. The value of such alliances tends to lie in their superior coordination mechanisms, which facilitate knowledge internalization and recombination (Obstfeld, 2005; Reagans and Zuckerman, 2001). Intra-sector alliance partners own similar sets of knowledge and technological bases, product offerings, routines, and norms (Lin et al., 2007; Tsai, 2001), which foster more intense or frequent interaction between the firms (Baum et al., 2003; Rosenkopf and Almeida, 2003). This grants the alliance partners easier access and unique insights into knowledge elements, technological components, embedded know-how, and problem solutions (Hargadon and Fanelli, 2002). This kind of interchange facilitates the novel recombination of known elements of knowledge, problems, or resolutions

(Fleming, 2001; Nelson and Winter, 2009), and strengthens the absorptive capacity of dyadic partners in intra-sector alliances. This is particularly critical for complex tasks that require knowledge of the resources and skills among participating firms, and involve recombining heterogeneous inputs in an efficient manner (Porac et al., 1995; Sytch et al., 2012).

As internal R&D efforts heavily emphasize the knowledge exploration and recombination with enhanced absorptive capacity (Hoffman et al., 1998), the benefits of a central position in intra-sector alliances tend to substitute for the positive effects of R&D investment for enhancing the integration of acquired knowledge, rather than complementing the R&D investment in enabling the firm to effectively access, refine, and generate new technologies and designs. Therefore, we predict a stronger negative interplay between centrality in intra-sector alliance networks and firm R&D than between the centrality in inter-sector networks and firm R&D in boosting firm innovativeness.

Hypothesis 3b: In interfirm alliance networks, high intra-sector centrality in firm-to-firm networks has a stronger negative interaction with firms' internal R&D than cross-sector centrality does in driving firm innovativeness.

3 METHODS

3.1 Sampling and data collection

We operationalize our study with survey data from manufacturing firms in the western region of Mexico, specifically in the State of Jalisco. In Mexico, as in other developing economies, SMEs usually have limited financial and managerial resources, and are therefore heavily reliant on collaboration and government support to generate innovation (Wincent et al., 2010). Collaborative firm–firm and firm–GSI relationships are common in Mexico, making this a suitable context to test our framework.

We combined data from two main sources, firm surveys and secondary data from Mexico's statistics bureau (see Appendix B[1]). For the survey, a random sample of 420 firms was selected from a list of

[1] Appendices A, B, C, D, E are provided as online supplementary material.

companies provided by Mexico's statistics bureau (INEGI)[2]. The selected firms represented the five most relevant manufacturing sectors in Mexico: high technology, automobiles, plastics, fashion and design, and food. According to the list provided by Mexico's statistics bureau, there were a total of 18,631 firms in the State of Jalisco of which 8,828 were in the food sector, 1,031 in high technology, 7,776 in fashion, 316 in automobiles, and 680 in plastics. For each selected firm, the most senior manager was selected as the key informant. Interviewers were recruited and trained to conduct the surveys onsite. 420 senior managers from the 420 firms agreed to participate and were interviewed onsite. Studies have verified that this approach is an effective process for obtaining high quality data in emerging economies (Li et al., 2008). The respondents described their firm's collaborative relationships with other firms and GSIs and other organizational characteristics such as innovation and firm size. After ensuring that there were no missing data in the surveys, we obtained 420 complete responses, an effective response rate of 100 percent. As the Mexican government defines SMEs as firms having no more than 250 employees, all firms in our sample had a maximum of 250 employees, while 56% had between 7 and 200 employees, 88.8 % were fully founded by national capital, and 100% were privately owned. On average, the respondents had worked 10.5 years in the industry and 7.3 years with their firms. To minimize location effects and ease cross-firm comparisons, all of the firms were located in the State of Jalisco. In our sample of manufacturing firms, 199 were in the food sector, 37 in high technology, 155 in fashion and design, 15 in automobiles, and 14 in plastics.

Given that all 420 firms in our sample provided useful and complete responses, nonresponse bias was not a concern in our study. Appendix A lists the questionnaire items in detail.

[2] Network studies can benefit from having the whole "universe" of firms/nodes. However, for the purpose of our study it was not feasible to survey all of the firms in Mexico and their partners. This random sampling issue is addressed in the literature (Wasserman *et al.*, 1994) and network scholars have suggested that when it is not feasible to collect data from the whole population, sampling is an acceptable and common practice (Banerjee, Chandrasekhar, Duflo, & Jackson, 2013; Wasserman *et al.*, 1994), and should be used (Wasserman *et al.,* 1994). Prior studies (e.g. Banerjee *et al*., 2013; Zander, 1999) have used random sampling to build networks and measure the clustering coefficient (cohesion in our study). The firms in our study were asked with which GSIs they had R&D collaboration, enabling us to fully and accurately identify all firm–GSI collaboration relationships in our sample.

3.2 Bipartite network construction

To determine the firm–GSI collaborative networks, managers were asked to state their firm's R&D projects and cooperation agreements with GSIs over the past five years, providing the names of the institutions, the names of the projects, and the project durations. Managers who reported cooperation with GSIs were asked to provide documentary evidence to verify their GSI counterparts and the project duration. Hence, cognitive bias, which tends to jeopardize studies using self-reported network data, was not a major concern in our study (Wasserman and Faust, 1994). The resulting collaborative relationships between firms and GSIs were modeled in a bipartite network. In this type of network, the nodes belong to two distinct types or sets, and connections (links) exist only between the nodes of different sets (Leiponen, 2008). A bipartite network allows the accurate representation of structural properties such as centrality and cohesion in our study context (Latapy et al., 2008). To ensure that this property was fulfilled in our bipartite firm–GSI network and that there were no firm–firm relationships between the firms within the network, we followed a rigorous process. First, we used our survey data to clearly identify firms with whom our focal firms in the firm-GSI network collaborated on R&D projects during the last five financial years, and then made a comprehensive list of these firms. Second, we compared this list with the list of focal firms in our firm-GSI network, and found no overlap between them. This meant that in our data, the 420 firms studied in the firm-GSI network had no R&D collaboration between themselves. The bipartite network comprised 420 firms and 96 GSIs, with 220 collaboration and agreement relationships (links) between firms and GSIs, creating a density of 0.0054 (Latapy et al., 2008). Each GSI had on average 2.29 collaborative relationships (links) while each firm had on average 0.52 links.

3.3 Firm–firm network construction

For the firm–firm networks, we asked the managers to report their R&D collaborations with other firms within and cross sectors. This approach enabled us to directly link the firms in collaborative relationships with each other and built one-mode ego-networks. One-mode ego-networks are defined as networks that represent the relationships between a focal node (firm) and other nodes (firms) that are directly linked to the focal node (firm) (Everett and Borgatti, 2005). To obtain a more detailed understanding of the mechanisms through which different types of networks influence organizational outcomes, we divided the firm–firm collaborative relationships into intra- and cross-sector collaboration. Then, we constructed a one-mode ego-network to represent each firm's intra-sector collaborative relationships, and another one to represent each firm's cross-sector collaborative relationships. As these ego-networks included all of the R&D collaborations of a focal firm, sample bias was not a major concern.

3.4 Measurements

Appendix A lists the questionnaire items and Appendix B provides the variable operationalization, source, and description details. All the appendices are provided as online supplementary material.

3.5 Dependent variable

Innovativeness. We drew from the literature on innovation assessment (He and Wong, 2004; Jansen et al., 2006) to construct a four-item measure of firm innovativeness. We used the four-item measure to evaluate the extent to which a firm was innovating. These four items captured four different types of innovation: product, process, organizational, and market. We used the method proposed by Anderson and Gerbing (1988) to refine the multiple-item measure of innovativeness and assess the construct validity. First, we ran exploratory factor analysis for the innovativeness multiple-item variable, which resulted in the expected factor solution. The four items to measure the four different types of innovation loaded on a single factor, thus the reliability analysis of the innovativeness measure showed satisfactory coefficient reliability. Second, we ran a confirmatory factor analysis (CFA) and found that the four items in the innovativeness measure loaded on a single factor. The factor loadings were significant ($p<0.001$): product innovation (0.74), process innovation (0.86), organizational innovation (0.89), market innovation (0.85), and the composite reliability was 0.90, exceeding the 0.70 benchmark. The average variance extracted (AVE) was 0.71, which is higher than the 0.50 cutoff (Fornell and Larcker, 1981). To evaluate the model fit, we relied on the comparative fit index (CFI), root mean square error of approximation (RMSEA), goodness of fit index (GFI), and incremental fit index (IFI) (Anderson and Gerbing, 1988). As the fit statistics were above the common thresholds (CFI=0.95, RMSEA=0.065, GFI=0.86, IFI=0.95), the innovativeness model fit the data satisfactorily. In line with the literature, we used the factor scores obtained from the CFA as a composite measure of innovativeness in the subsequent analysis (Poppo et al., 2016; Zhou and Wu, 2010). Therefore, this measure captures a firm's degree of innovation in terms of product, process, organization, and market.

3.6 GSI–firm network measurements

Cohesion. To capture cohesion, we used the bipartite min-clustering measure proposed by Guillaume et al. (2005) and Latapy et al. (2008). This measure captures the overlap between neighborhoods of nodes (i.e. firms). The min-clustering coefficient of a focal firm represents the tendency of this firm to have its neighborhood included in the neighborhood of other firms (Latapy et al., 2008). In a firm–GSI network, neighborhoods are created through the overlapping connections of firms due to their collaboration with the same GSIs. The min-clustering measurement takes this into consideration and captures whether a small set of firm–GSI collaborations is a subset of another much larger set. Min-clustering is defined as: $cc(u) = \frac{\sum_{v \in N(N(u))} cc(u,v)}{|N(N(u))|}$ where *u* and *v* represent a pair of nodes, $N(N(u))$ represents the number of nodes at distance 2 from *u* not including *u*, $cc(u,v) = \frac{|N(u) \cap N(v)|}{\min(|N(u)|,|N(v)|)}$, $\min(|N(u)|, |N(v)|)$ corresponds to the absolute minimum of total nodes that are neighbors of *u* and *v*, *u* and *x*, and so on.

The formula $cc(u,v) = \frac{|N(u) \cap N(v)|}{\min(|N(u)|,|N(v)|)}$, where $\mathrm{N}(u)$ and $\mathrm{N}(v)$ represent the neighborhood of nodes *u* and *v*, respectively, captures the overlap between neighborhoods of nodes. If *u* and *v* have no neighbors in common, then $cc(u,v) = 0$. If *u* and *v* have the same neighborhood, then $\mathrm{cc}(u,v) = 1$. Finally, if the neighbors between *u* and *v* overlap, the value of $cc(u,v)$ is between 0 and 1. Thus, $cc(u,v)$ defines a value for a pair of nodes and captures the degree of heterogeneity in the network by emphasizing that small neighborhoods may intersect with significantly larger ones.

The clustering coefficient for one node, $cc(u)$, is defined as "the average of its clustering coefficients with other nodes" (Latapy et al., 2008) . However, for this averaging, the pairs of nodes for which the overlap is empty are excluded, because nodes that have a disjoint neighborhood bring no information to the clustering coefficient. As defined by Guillaume et al. (2005) and Latapy et al. (2008), isolated nodes, which have no connections with other nodes, are also excluded from the min-clustering coefficient calculation because they are not part of any neighborhood. In the case that $|N(N(u))| = 0$, $cc(u)$ is predefined as zero, $cc(u) = 0$, because there are no nodes at distance 2 from u. Therefore, u has no overlap with other nodes (e.g. firms) and does not belong to any cluster or community. The clustering coefficient $cc(u)$ aims to measure the implication of having at least one neighbor in common with the rest of the neighborhood. Appendix D contains further details about the calculation of this measure.

Cohesion has been widely used in innovation studies to highlight the importance of within-cluster knowledge and information transmission (e.g., Schilling and Phelps, 2007). Furthermore, cohesion and clustering have been associated with fostered knowledge spillovers and recombination (Hansen, 1999), verified quality, accuracy, and authenticity of the exchanged information (Uzzi, 1997), access to and leverage of the resources (Greve, 2009), and additional technical and financial support (Guler and Nerkar, 2012), all of which represent the benefits proposed in our theoretical mechanisms. Therefore, cohesion served as an adequate measure for our study. The network measures were computed using the statistical software R and the igraph package (Csardi and Nepusz, 2006).

Bipartite centrality. To assess the bipartite centrality of firms, we used the bipartite degree centrality measure proposed by Borgatti and Halgin (2011), $d_i^* = \frac{d_i}{n_2}$, for $i \in V_1$; where d_i is the number of links that firm i has to GSIs and n_2 is the total number of GSIs in the bipartite network. Given that firms reported and provided documentary evidence of all of their GSI relationships, our bipartite centrality measure was accurate and did not suffer from network sampling bias (Wasserman and Faust, 1994).

We consider that the bipartite degree centrality measure is the most appropriate centrality measure for our study for several reasons: (1) degree centrality is one of the most commonly used measures of network position and the literature notes that it effectively measures the connectedness of actors in the network (Koka and Prescott, 2002; Newman, 2009; Wasserman and Faust, 1994); (2) in the study of networks as means to access external resources, high centrality is considered a reliable measure (e.g. Ahuja, 2000a); and (3) degree centrality has been associated with our theoretical mechanisms of access to key and valuable information (Freeman, 1979; Tsai, 2001), effective transmission of processes and routines (Mahmood et al., 2011), and more efficient use of resources for innovation (Ahuja, 2000a).

3.7 Firm–firm network measurements

Cross-sector centrality. Consistent with the literature (Baum et al., 2005; Borgatti and Halgin, 2011; Lin et al., 2009), we used the degree centrality measure proposed by Freeman (1979) to evaluate a firm's cross-sector network centrality, $C_D(p_k) = \sum_{i=1}^{n} a(p_i, p_k)$, where p_k is the focal firm and $a(p_i, p_k)$ represents the number of firm p_k's adjacencies or direct contacts. The cross-sector degree centrality measure captured the total number of firms in other sectors with which the focal firm collaborated on R&D projects.

Intra-sector centrality. Similarly, to calculate the intra-sector centrality, we used the degree centrality measure proposed by Freeman (1979). In this case, the degree centrality measure captured the total number of firms in same sector with which the focal firm collaborated on R&D projects. Because the firms reported all of their R&D collaborative relationships with firms, both within and across sectors, network sampling bias was not a concern in our centrality measurements (Wasserman and Faust, 1994).

3.8 Firm-level measurements

Internal research and development (R&D). In line with the literature (Clarysse et al., 2009; Cohen and Levinthal, 1990), to measure a firm's internal R&D, we used the percentage of annual sales dedicated to R&D activities. This is a continuous measure that represents the amount of R&D expenses divided by firm sales and it constitutes an input-oriented R&D measure[3]. As suggested by Cohen and Levinthal (1990) normalizing R&D by sales controls for the effects of firm size.

[3] We thank an anonymous reviewer for pointing out this issue. In Appendix C, we conducted further analysis using the following alternative R&D measures: (1) the percentage of staff dedicated to R&D activities (Halliday et al., 1997; Vedovello, 1997), (2) production area support for innovation through R&D (Forrester, 2000), (3) the binary R&D variable (Hoffman et al., 1998; Kogut and Zander, 1992), and (4) a composite measure of internal R&D.

Control variables. To account for the effects of extraneous variables, we included several controls. Firm size was measured as the logarithmic transformation of the number of employees. To control for sector or industry effects, we included four industry dummy variables.

Table 1 presents the descriptive statistics and correlations of the variables used in the main analysis.

----------Insert Table 1 here----------

4 ANALYSIS AND RESULTS

Given that the proposed model contains interaction terms between internal R&D, the firm–GSI network, and the firm–firm network variables, we used moderated regression analysis to test our hypotheses. To reduce the threat of multicollinearity, each variable that formed part of an interaction term was mean centered before the interaction term was created (Aiken and West, 1991). The mean centering technique only decreased the correlations between the product terms and the related individual variables, for instance "cohesion" versus "internal R&D X cohesion," not the correlation between product terms related to the same variable, for example "internal R&D X cohesion" versus "internal R&D X bipartite centrality". If all of the proposed interaction terms were to enter the model simultaneously, the high correlations between the interaction terms might have inflated the standard errors of the regression coefficient estimates and caused them to be insignificant (Sheng et al., 2013). Hence, a blockwise hierarchical approach was more appropriate to test the hypotheses (Elvira and Cohen, 2001). In these models, the highest VIF was 3.94, which was associated with the variable sector dummy 2 and was well below the 10 benchmark. Hence, multicollinearity was not a major issue in our analysis.

We conducted several additional analyses to rule out model misspecification concerns. Given that the information about the dependent and independent variables came from the same respondent, common method bias was a potential concern. We conducted a Harman's one factor test (Harman, 1976; Podsakoff and Organ, 1986) and extracted four factors with eigenvalues greater than 1, with the first factor explaining only 24.20% of the variance. Hence, common method bias is unlikely to be a major concern in our data. As our main theory is related to interaction effects, common method bias was a lesser concern as it reduces the likelihood of finding interaction effects (Wall et al., 1996). Second, the tests did not suggest the presence of heteroskedasticity (White, 1980). Third, we checked the outliers, normality of residuals, and influential observations, and found no violations of the assumptions (Greene, 2003). Fourth, we included additional control variables in Table C.2 of Appendix C, and obtained results qualitatively similar to those of the main analysis shown in Table 2.

Table 2 presents the standardized regression estimates of the main analysis to enable direct comparison of the effects of the coefficients with respect to their relative explanatory power over the dependent variable. Model 1 in Table 2 presents the following results. Cohesion is shown to positively affect firm innovativeness (β=0.07, $p<0.01$), supporting Hypothesis 1a. Bipartite centrality also shows a positive effect on innovativeness (β =0.15, $p<0.01$), thus supporting Hypothesis 1b. Firm–firm intra-sector centrality positively affects innovativeness (β =0.21, $p<0.01$), supporting Hypothesis 2a. Hypothesis 2b is also supported, as firm–firm cross-sector centrality positively affects firm innovativeness (β =0.04, $p<0.01$).

----------Insert Table 2 here----------

Hypothesis 3a proposes that firm–GSI cohesion has a stronger negative interaction with firms' internal R&D than bipartite centrality does in driving innovativeness. Model 2 in Table 2 shows a statistically significant negative interaction between internal R&D and firm–GSI cohesion (β = -0.32, $p<0.10$), while Model 4 finds no significant interaction between internal R&D and firm–GSI bipartite centrality (β = -0.18, $p>0.10$). Model 6 in Table 2 shows a significant negative interaction between internal R&D and firm–GSI cohesion (β = -0.51, $p<0.10$), but a non-significant interaction between internal R&D and firm–GSI bipartite centrality (β =0.03, $p>0.10$). Hence, Hypothesis 3a is supported, indicating that cohesion in a firm–GSI network has a stronger negative effect than bipartite centrality on internal R&D in driving innovativeness.

Hypothesis 3b suggests that high intra-sector centrality in a firm–firm alliance network has a greater negative effect than cross-sector centrality does on a firm's internal R&D in driving firm innovativeness. Table 2, Model 3 shows a significant negative interaction between internal R&D and firm–firm intra-sector centrality (β = -0.09, p<0.01), while Model 5 finds a non-significant interaction between firm–firm cross-sector centrality and internal R&D (β = -0.01, p>0.10). Model 6 shows a similar pattern. Thus, we find support for Hypothesis 3b.

We also conducted several robustness tests to examine the sensitivity of our results. For instance, we included additional control variables in the models, conducted a two-step econometric approach and tested alternate model specifications with various R&D measures. Details of these procedures are provided in Appendix C.

We further computed the economic significance and found that our proposed effects are sufficiently significant in driving firm innovativeness (considering that the mean of innovativeness is 0.26). In addition, Figure 3 depicts the economic significance of the interaction terms. Although the effect of some of our variables of interest may seem small, their influence on firm innovativeness remains significant after controlling for a set of variables, indicating their importance (Aiken and West, 1991). A detailed description of the economic significance can be found in Appendix E.

5 DISCUSSION, IMPLICATIONS AND CONCLUSION

The present study is built on the network multiplexity, social embeddedness, and resource complementarity literatures, and it advances our understanding on how 1) Firm-GSI collaboration and 2) Firm-firm intra and inter-sector collaboration, affect firms' innovation performance. We further explore the interplay between internal and external R&D activities, and shed light on how to manage internal and external R&D efforts.

5.1 Theoretical implications

First and foremost, our study confirms that some external R&D activities (Firm-GSI bipartite cohesion and firm-firm intra-sector centrality) have a negative interaction with internal R&D. This result is relevant because it solves the existing literature contradiction on the effects of internal and external R&D. Internally, firm's R&D efforts improve absorptive capacity and resource utilization to explore and employ new technologies (Cohen and Levinthal, 1990; Hoffman et al., 1998). Externally, firms rely on embedded and durable inter-organizational exchanges to gain access to different sets of technology, know-how, resources, and to assimilate externally acquired knowledge. High cohesion in firm–GSI networks tends to create additionality in the focal firm by changing its innovation-related processes, routines, practices, etc. to facilitate the conversion of innovation inputs to outcome performance (Buisseret et al., 1995; Falk, 2007). As such, high cohesion fosters innovation by increasing the efficiency of the knowledge flow and recombination, and improving the capability of knowledge internalization and assimilation. Therefore, the marginal effect of internal R&D expenditure on innovativeness will be mitigated with a high Firm-GSI cohesion. In comparison, high bipartite centrality enables firms to increase their innovation and productivity through wider access to more diverse knowledge and technology, both directly through their affiliated GSIs and indirectly through the collaboration of their affiliated GSIs with other firms (Koka and Prescott, 2008). Accordingly, we postulate and find evidence that the mitigation of the marginal effect of internal R&D on innovation is stronger for firm-GSI cohesion than firm-GSI centrality. These results provide insights into how firms can effectively manage the additionality of government-sponsored research to develop more complementarity (or less mitigation of marginal effects) in their multiplex ties by optimizing the configuration of their multiple networks.

Our study also contributes to the innovation literature by extending the network perspective in the government-sponsored R&D area (Bellucci and Pennacchio, 2016; Blume-Kohout et al., 2015; Jung and Andrew, 2014). We define firm-GSI collaboration as a bipartite network because the information exchange and knowledge spillover occur mainly between firms and GSIs rather than between firms and between GSIs. We reveal that firms which are embedded in a highly clustered group in a firm–GSI network or situated more centrally in the bipartite network are initially more likely to show greater innovation. These findings address the dearth of research and advance our understanding on the network effects of bipartite firm–GSI alliances.

Our findings also contribute back to the literature on collaborative research networks. Although different networks exert different influences on organizational outcomes (Afuah, 2013), extant studies have predominantly used a single type of network (e.g. strategic alliances) to explain a firm's strategies with regard to innovation and collaboration. This mismatch between research approaches and business practices reflects the long-held concern that accounts of firm behavior are under-socialized due to the neglect of the multiplex nature of firm networks (Gulati, 1998). Thus, our study examines how two different types of networks, firm-GSI and firm-firm, influence innovation. We also extend the cooperative networks literature by differentiating the mechanisms through which intra- and inter-sector firm-firm alliances influence innovation via access to resources, knowledge spillovers, etc. We suggest that the effects of intra- and inter-sector collaboration on firm innovativeness may differ due to the distinct nature of the resources to be shared and the information and know-how obtained from firms in the same or different industries.

We take a novel social network perspective to advance the extant understanding of the relationship between firm internal and external R&D activities (e.g. Lokshin et al., 2008; Hess and Rothaermel, 2011; Vega-Jurado et al., 2009), for which the current literature has inconclusive findings. In firm-GSI collaboration, high bipartite centrality provides a firm with wider access to more diverse knowledge and technology (Koka and Prescott, 2008), complementing firm's capacity for knowledge recombination by internal R&D. In comparison, high cohesion will create additionality to facilitate knowledge internalization (Falk, 2007). This results in a more salient negative interaction between the cohesive firm–GSI network and internal R&D. Similarly, for the firm-firm network, intra-sector alliances help a firm to achieve effective knowledge transfer through an improved absorptive capacity. Therefore, we found significant negative effects between intra-sector centrality in firm-firm networks and internal R&D, but no effects for the interplay between cross-sector centrality and firm internal R&D. In this way, we contribute to the cooperative networks research and innovation literatures by adding this important network characteristic for improved understanding of R&D activities.

5.2 Practical implications

Our study has valuable practical implications for both managers and policymakers. It enhances our understanding of inter-organizational collaboration and the specific mechanisms that may drive successful innovative performance. Our study illustrates that although there are differences in the mechanisms and organizational benefits of highly centered and highly clustered firms in firm–GSI networks, both demonstrate superior innovativeness. These findings provide effective strategic guidance for firms to acquire external knowledge and capabilities. From a managerial perspective, both intra- and inter-sector firm–firm collaboration display positive effects in boosting firm innovativeness. Thus, both are valid collaboration options for strategic consideration when acquiring capabilities externally. The positive effect of firm–firm alliances on firm innovation is not likely to be offset by a firm's internal R&D if the allied firms are from different industries or unrelated areas. Our findings thus suggest that access to diverse skill sets and knowledge bases is a crucial criterion in inter-organizational collaboration and an important strategic consideration for resource allocation. A more important implication of our study is that inter-organizational collaboration is more beneficial when alliances provide firms with access to more diversified knowledge sets rather than enhancing their internalization capability, as there is a negative interaction effect between internal R&D and firm–GSI collaboration when firms have strong cohesion within a network.

From a managerial perspective, where a firm has sufficient internal R&D support, the priority in external research collaboration should be to hold a central position in both firm–GSI and inter-sector firm–firm alliance networks. However, where a firm lacks internal R&D investment, it can supplement this by joining firm–GSI collaboration with high cohesion and/or allying with firms in the same industry sector to enhance its capability to transfer and recombine knowledge. Managers should be cautious when aiming to develop a dual strategy that involves 1) a high level of R&D investment and firm-GSI collaboration cohesion, 2) a high level of R&D investment and allying with firms in the same sector or industry. Counterintuitively, these dual strategies may not have a favorable impact on firm innovativeness because 1) cohesion in a firm–GSI network fosters more efficient knowledge spillover between firms and GSIs, which overlaps with the enhancement of knowledge recombination by the firm's internal R&D activities, 2) a high number of alliances in the same sector enhance the integration of acquired knowledge, which overlaps with the absorptive capacity benefits of R&D. Strategically, managers should adopt a boundary-spanning collaboration strategy. When choosing partners, firms with sufficient R&D support and strong absorptive capacity should offer preference to different types of GSIs to avoid being trapped in a cohesive community and losing the benefit of knowledge diversity. Managers should also prioritize partners across industries for knowledge complementarity. Finally, in the long run, a properly managed multiplex alliance strategy will facilitate the development of new products and manufacturing processes to enhance firm's innovativeness.

Moreover, this study offers some important guidelines to policymakers for the distribution of limited government R&D budgets, especially in emerging economies. Given that a firm's internal R&D influences some of the effects of firm-GSI collaboration on innovativeness, policy makers should implement several initiatives to carefully assess 1) the degree to which a firm carries internal R&D and 2) a firm's collaboration with GSIs. When a firm has a lack of internal R&D support, policy makers should encourage the firm's engagement with multiple GSIs and with GSIs that form part of a closed group of GSIs and other firms (cohesion). However, when a firm has more than sufficient internal R&D support, the number of GSIs that the firm collaborates with should be limited, specifically the collaboration with GSIs that form part of cohesive groups. In addition, if a firm is actively engaged with highly cohesive GSIs, policy makers should advice the firm to carefully monitor its level of internal R&D support, such that the firm can reap the benefits of GSI collaboration on innovativeness and avoid any diminishing effects between internal R&D and GSI collaboration. Furthermore, in managing the firm-GSI relationship, the government may identify firms that bridge individual clusters in the network. The government should incentivize firms to collaborate with GSIs from different clusters, in order to connect the locally cohesive communities. In this way, diverse knowledge can be distributed throughout the network and benefit more firms. Lastly, policies should be made to motivate firms to collaborate across different industry sectors to enhance resource complementarity. Such policies will also reduce the likelihood that partners reinvest in the same technical area. Internally, these policies will help firms to avoid overinvesting in the same capability domain by suboptimized internal and external R&D strategies. The implementation of these recommendations will result in the efficient use of public resources to promote innovation in SMEs.

5.3 Conclusion

Our study draws on the perspectives of social embeddedness, network multiplexity and resource complementarity, and makes a significant contribution to the innovation and cooperative research networks literatures by focusing on the multiplex collaborative relationships between SMEs and between SMEs and GSIs. Our study takes a unique network perspective to explore the effect of the bipartite network structure on firm innovativeness, and provides insights into how governments and firms can strategically cooperate to develop technological capabilities. We further advance the research on inter-organizational collaboration by decomposing regular interfirm strategic alliances into intra- and cross-sector alliance networks. Moreover, we advance our understanding by investigating the interplay between external collaboration and internal R&D in driving firm innovativeness through knowledge expansion and technical exploration. Finally, our study of 420 manufacturing firms from the pillar industries of the Mexican economy answers the call to strengthen our understanding of the effects of multiple collaborative networks on innovation in the context of SMEs in an emerging economy.

5.4 Limitations and Future Research

This study has several limitations that also represent future research opportunities. First, in addition to firm–GSI alliances and interfirm strategic alliances, there are numerous ways firms can interact with each other. Further research on these multiplex firm networks will help to advance and complete our knowledge of social networks and firm innovation. Second, our study context is a single country, Mexico, which raises concerns about the generalizability of our findings. More studies on other emerging or developed economies will provide further substantiation of our proposed theory. Third, despite our careful avoidance of overlap between the firm–GSI and firm–firm networks in our sample, there could be rare cases in which firms participate in both firm–GSI and firm–firm R&D collaborations. For example, firm A and B could be linked with each other through collaboration and also both linked with a GSI.[4] Future research will benefit from the development of new methodologies and network measures to analyze firms under these special circumstances. Fourth, we used a random sample of Mexican firms to conduct our study as it was not feasible to survey all of the firms and their partners in Mexico. In the future, studies analyzing firm–GSI relationships could benefit from the use of archival data to build the whole firm–GSI network to investigate additional network mechanisms and their effects on firm innovativeness. Last, our dependent variable, firm innovativeness, was based on self-reported survey responses. Other objective measures could be used as proxies for R&D efforts and R&D output, such as new product sales and patent applications and registration, to capture firm innovation performance.

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Figure 1.
Firm-GSI and firm-firm alliances

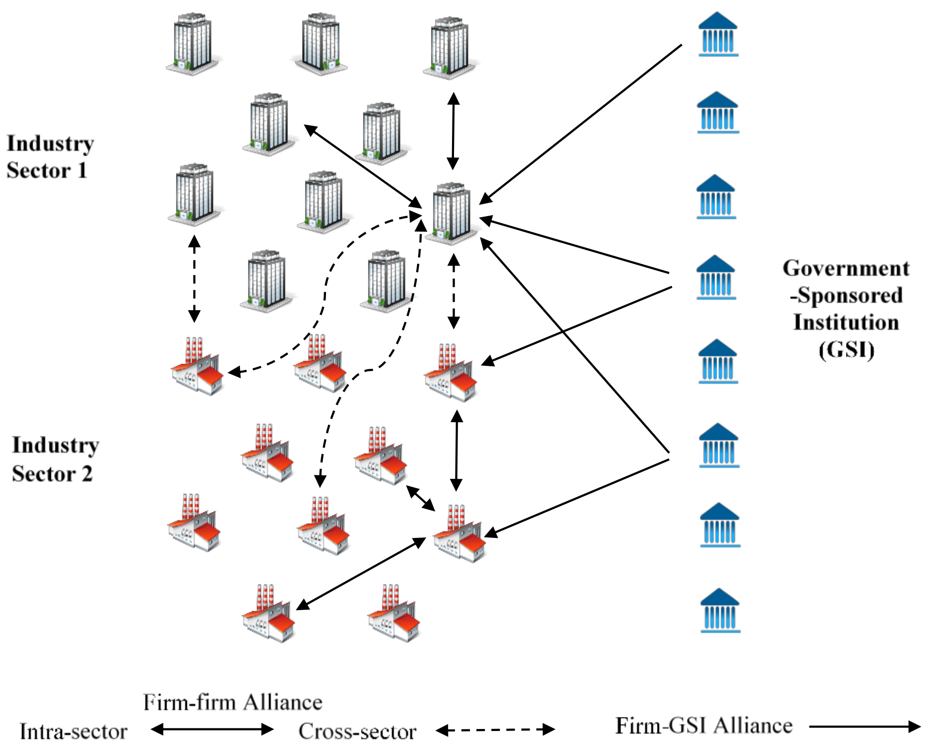


Figure 2.
Research Framework

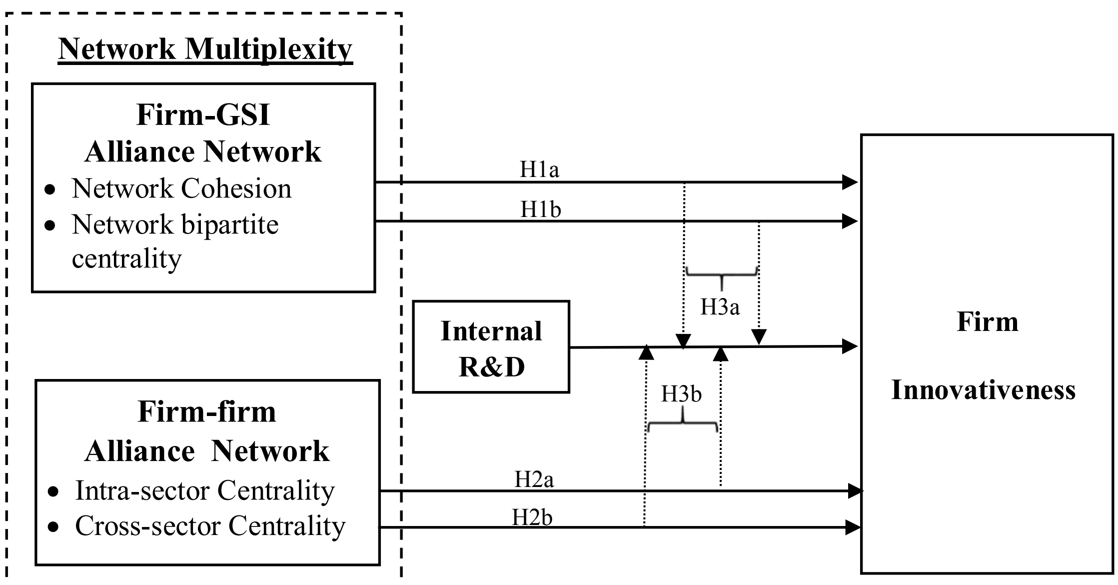
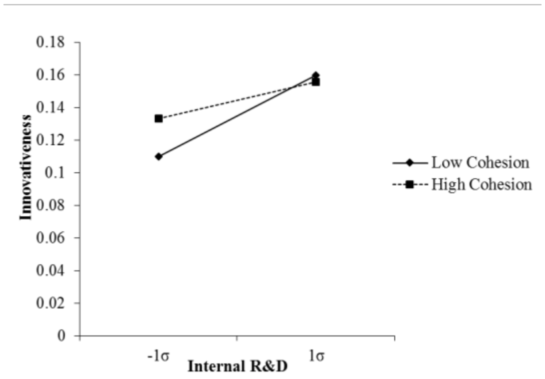


Figure 3.
Interaction Effects

Hypothesis 3a interaction



Hypothesis 3b interaction

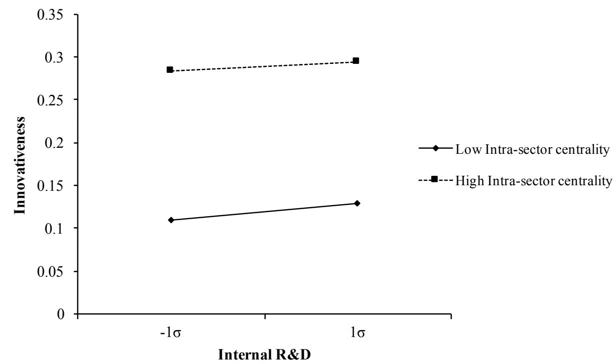


Table 1.
Descriptive statistics and correlations

	Variable	1	2	3	4	5	6	7
1	Firm innovativeness	1						
2	Internal R&D (% of sales)	0.34***	1					
3	Cohesion	0.18***	0.06	1				
4	Bipartite centrality	0.4***	0.14***	0.13***	1			
5	Intra-sector centrality	0.37***	0.20***	0.07	0.31***	1		
6	Cross-sector centrality	0.30***	0.11***	0.02	0.35***	0.26***	1	
7	Firm size	0.45***	0.18***	0.08***	0.43***	0.25***	0.31***	1
	Mean	0.26	0.03	0.08	0.23	0.13	0.41	2.62
	Std. Dev.	0.35	0.07	0.20	0.51	0.33	0.87	1.42
	Minimum	0	0	0	0	1	0	1
	Maximum	1.13	0.69	0.71	0.90	3.00	7.00	250

N=420 firms, ***p<0.01, **p<0.05, *p<0.10

Table 2.
Main analysis. Hierarchical regression estimates: Firm innovativeness

				Innovativeness				
Variables	Control Model	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Hypothesis
Cohesion		0.07***	0.08***	0.07***	0.07***	0.07***	0.09***	H1a
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	
Bipartite centrality		0.15***	0.15***	0.13***	0.16***	0.15***	0.05***	H1b
		(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.01)	
Intra-sector centrality		0.21***	0.30***	0.26***	0.19***	0.21***	0.25***	H2a
		(0.05)	(0.07)	(0.05)	(0.05)	(0.05)	(0.05)	
Cross-sector centrality		0.04***	0.05***	0.04**	0.05***	0.05***	0.04***	H2b
		(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	
Internal R&D (% of sales)		0.08***	0.09***	0.12***	0.09***	0.08***	0.13***	
		(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	
Internal R&D (% of sales) X Cohesion			-0.32*				-0.51*	H3a
			(0.18)				(0.28)	(stronger
Internal R&D (% of sales) X Bipartite centrality					-0.18		0.03	cohesion)
					(0.17)		(0.21)	
Internal R&D (% of sales) X Intra-sector centrality				-0.09***			-0.09***	H3b
				(0.02)			(0.02)	(stronger
Internal R&D (% of sales) X Cross-sector centrality						-0.01	-0.01	intra-
						(0.02)	(0.02)	sector)
Firm size	0.15***	0.03*	0.02*	0.03*	0.03*	0.03*	0.03*	
	(0.02)	(0.02)	(0.01)	(0.01)	(0.02)	(0.02)	(0.01)	
Sector 1 (dummy)	0.02	0.03	0.04	0.04	0.04	0.03	0.05	
	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	
Sector 2 (dummy)	0.02	0.01	0.03	0.04	0.03	0.02	0.05	
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	
Sector 3 (dummy)	0.07	0.04	0.06	0.07	0.05	0.04	0.09	
	(0.07)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	(0.06)	
Sector 4 (dummy)	0.26***	0.22***	0.22***	0.21***	0.22***	0.22***	0.19**	
	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	
Observations	420	420	420	420	420	420	420	
R-squared	0.22	0.33	0.35	0.38	0.36	0.34	0.40	

Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.10