Management and Organization Review

Management and Organization Review 15:1, March 2019, 145–176
doi: 10.1017/mor.2018.49

A Delicate Balance for Innovation: Competition and Collaboration in R&D Consortia

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ABSTRACT This study examines how competitive and cooperative relationships within R&D consortia influence member firms' innovation output. We propose a U-shaped relationship between the presence of market competitors for a member firm and the firm's joint R&D output with other consortium members, and examine how the relationship is mediated by interactions with other members at the firm level and moderated by collaborative efforts at the consortium level. Using a unique sample of 320 firms from 52 R&D consortia in China, we find support for our predictions. This multi-level study extends our understanding of competition and cooperation in multi-party networks and provides insights for creating a balance between the two forces that is conducive to innovation.

KEYWORDS competition, cooperation, innovation, R&D consortia

INTRODUCTION

Firms in today's fast-paced environment increasingly rely on collaborations with competitors, suppliers, buyers, and complementors to pursue success in innovation. In addition to bilateral arrangements, multi-party structures such as R&D consortia have proliferated due to the limited capacity of firms to innovate internally on a sustained basis and their motivation to conduct basic research with industry peers (Park, Srivastava, & Gnyawali, 2014; Sakakibara, 2002). As R&D consortia often include firms that are direct competitors, there inherently exists a paradox of simultaneous competition and cooperation that, while enabling resource and risk sharing, can also incite opportunism (Kale, Singh, & Perlmutter, 2000; Polidoro, Ahuja, & Mitchell, 2011). This form of interaction, which encompasses a duality of value creation and value appropriation, is known as *coopetition* (Brandenburger & Nalebuff, 1996).

The phenomenon of coopetition has received increasing academic attention in recent years (Bengtsson & Raza-Ullah, 2016; Gnyawali & Song, 2016). One stream of research focuses on the coexistence of cooperative and competitive

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relationships, where firms cooperate with some actors and compete with others in a network (e.g., Afuah, 2000; Brandenburger & Nalebuff, 1996; Pathak, Wu, & Johnston, 2014). This work highlights the network context of coopetition but overlooks the cooperative and competitive interactions between individual firms (Luo, 2007). Another stream of research focuses on dyadic interactions (e.g., Bouncken, Gast, Kraus, & Bogers, 2015; Li, Liu, & Liu, 2011; Rai, 2013; Walley, 2007; Wu, 2014; Zhang, Shu, Jiang, & Malter, 2010). However, while cooperation and competition between a pair of firms can be delineated with relative clarity, such dynamics become markedly more complicated to unpack with an increase in the number of firms (Shan, Walker, & Kogut, 1994). Despite an increase in studies on multi-party alliances such as R&D consortia, which have examined their formation (Brockhoff, Gupta, & Rotering, 1991; Hagedoorn, 1993), stability (Olk & Young, 1997), and firm-level and industry-level impact (Branstetter & Sakakibara, 1998; Sakakibara, 2002), few have looked at coopetition among member firms. To understand the complex interfirm interactions embedded in R&D consortia, more multi-level studies are needed.

While a number of studies have addressed the impact of competition and cooperation on innovation, their findings are arguably inconclusive. While some suggest that cooperating with direct competitors could be detrimental for innovation (Kim & Parkhe, 2009; Quintana-Garcia & Benavides-Velasco, 2004), others find no relationship between coopetition and performance in innovation (Knudsen, 2007). Park et al. (2014) argue that a combination of moderate competition and high cooperation would be conducive to innovation. In contrast, Liu, Luo, Yang, and Maksimov (2014) find that the highest level of knowledge sharing – a prerequisite for innovation – occurs in competition-dominated relationships, whereas the lowest level takes place in cooperation-dominated relationships. Moreover, most of these studies focus on dyadic relationships. Aside from a few case studies (Bengtsson & Kock, 2014; Bengtsson, Kock, Lundgren-Henriksson, & Nasholm, 2016; Katz, 1986), there is sparse evidence for the impact of competition and cooperation on innovation in multi-party contexts. The inconsistent and incomplete findings warrant further empirical investigation.

Given the above considerations, our study aims to examine how competitive and cooperative relationships are related to member firm innovation within R&D consortia, using a unique sample of 320 member firms in 52 R&D consortia in China. This work contributes to the coopetition literature in several ways. First, it extends our knowledge of coopetition to multi-party contexts. Prior research on competition has mainly focused on either industry-level competition (e.g., Aghion, Bloom, Blundell, Griffith, & Howitt, 2005; Gilbert, 2006) or one-on-one competitive relationships (e.g., Chen, 1996; Park et al., 2014), both of which cannot be readily applied to the context of R&D consortia. To examine the impact on innovation of multiple competitors, this study focuses on how the presence of market competitors for a member firm is related to its collaborative innovation within a given consortium. The presence of market competitors varies across the

https://doi.org/10.1017/mor.2018.49 Published online by Cambridge University Press

consortium, as not all consortium members are competitors with one another. Moreover, specific to the setting of R&D consortia, we examine firm-instigated collaborative interactions and consortium-level collaborative efforts, which cannot be demarcated or otherwise jointly examined in dyadic relationships (Bouncken et al., 2015). Thus, we respond to recent calls for investigating the multi-level linkages of coopetition (Bengtsson & Raza-Ullah, 2016).

Second, our work provides a greater articulation of the mechanisms through which the innovation benefits of coopetition could be realized. In prior literature, competition and cooperation are often considered as two contradictory elements in a paradox, without a clearly specified link between the two elements (Czakon, Mucha-Kus, & Rogalski, 2014). Indeed, because prior studies have largely focused on the direct link between coopetition and innovative performance, we have a limited understanding of how competition and cooperation are linked in influencing innovation (Park et al., 2014). Furthermore, innovation performance is often measured in terms of knowledge acquisition or innovation output by individual firms, which cannot precisely capture joint R&D outcomes (Li et al., 2011; Wu, 2014). In this study, we address the intricate relationships among competition, cooperation, and joint innovation in R&D consortia. We propose that the relationship between the presence of a member firm's market competitors and its joint R&D output is mediated by firm-instigated collaborative interactions and moderated by consortium-level collaborative efforts. To isolate the effect of competition and cooperation on innovation within a given consortium, we focus on the output of member firms' joint R&D with other members.

Third, using unique data, our study offers novel empirical findings to the literature on coopetition, which is mostly comprised of conceptual papers and case studies (c.f. Gnyawali & Song, 2016). In 2010, the Ministry of Science and Technology of China launched a plan to facilitate multi-party collaboration on innovation and endorsed 56 R&D consortia totaling 1,899 members, including business enterprises, universities, research institutes, and industrial associations (please see more details in the methods section). We were able to collect survey data on 320 business members from 52 consortia. As a systematic effort to integrate R&D at the national level, the ministry set specific rules and guidelines for the consortia. In addition to being required to have a leading organization and various collaborative mechanisms (such as executive councils, expert panels, and routing meetings), the consortia were subjected to continual government monitoring. Akin to a quasi-experiment – in which many variables are controlled – this setting enabled us to better identify the effects of the constructs of interest. For instance, since only 'industry-leading' firms were allowed to join the R&D consortia, all competitors were presumably capable to similar degrees, and the count of competitors became the main concern. Notwithstanding the potential lack of generalizability, this new, multi-level dataset from China may introduce important evidence on coopetition and innovation in R&D consortia and provide useful insights for policy makers and managers working with R&D consortia. Moreover, few

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studies on R&D consortia in China exist, as prior research has mainly examined R&D consortia in advanced economies such as the US (Aldrich & Sasaki, 1995; Ouchi & Bolton, 1988), Korea, Japan, Taiwan (Mathews, 2002; Sakakibara, 2002; Sakakibara & Cho, 2002), and Europe (Hottenrott & Lopes-Bento, 2014; Quintana-Garcia & Benavides-Velasco, 2004).

THEORETICAL BACKGROUND AND HYPOTHESES

To access the deeply embedded knowledge of industry peers (Hamel, 1991) and reduce development costs and time to market (Lin, 2003), firms are known to formally establish R&D consortia (Aldrich, Bolton, Baker, & Sasaki, 1998), which are partnerships consisting of multiple members that jointly formulate and carry out R&D activities (Doz, Olk, & Ring, 2000; Evan & Olk, 1990; Hagedoorn & Narula, 1996). As a basis for cooperation, member firms in an R&D consortium need to deliberate on the sharing of costs and outputs before engaging in joint R&D (Sakakibara & Cho, 2002). Nevertheless, due to agency and coordination costs associated with aligning the individual goals of member firms as well as interfirm operations, it can be difficult to achieve value-added cooperation in R&D consortia (Ahuja, 2000a; Park & Ungson, 2001). A major challenge associated with R&D consortia is the phenomenon of coopetition, or the simultaneously cooperative and competitive interactions among member firms (Luo, 2007). In this section, we look at the relationship between competition and innovation before moving on to examining firm-instigated collaborative interactions and consortium-level collaborative efforts.

The Presence of Market Competitors

The relationship between market competition and innovation has been extensively studied in the economics literature (Gilbert, 2006). On the one hand, as market competition increases, firms rely on incremental gains from innovating to beat the competition and are thus more likely to conduct R&D to 'escape' the competition (Aghion, Harris, & Vickers, 1997). On the other hand, according to the Schumpeterian model, intense competition leads to imitation that reduces the monopoly rents of innovation; market competition may therefore discourage R&D activities (Levin, Cohen, & Mowery, 1985). Aghion et al. (2005) suggest an inverted-U shaped relationship, in which the escaping-competition effect dominates in industries with low levels of competition, and the Schumpeterian effect is more pronounced in highly competitive settings. Since extant studies largely focus on industry-level competition and firms' individual R&D, their findings do not necessarily apply to competitors in the same consortium and their joint R&D activities. Indeed, a consortium does not resemble an industry setting, and members have not only private benefits but also mutual gain to consider (Khanna, Gulati, & Nohria, 1998).

In management literature, findings on the impact of competition on innovation in cooperative settings are also inconsistent. On the one hand, intense competition may constrain firm innovation in the context of collaborative R&D, due to decreasing trust and mutual commitment resulting from opportunism concerns (Kale et al., 2000). In highly competitive settings, for instance, McAdam and McClelland (2002) find that many firms simply copy their competitors' ideas in product innovation. Compared with joint R&D involving suppliers, clients, universities, and research institutes, which are known to increase innovation, collaborations with competitors have been found to exert a negative impact (Nieto & Santamaria, 2007). Huang and Yu (2011) show also that non-competitive collaborations are more likely to enhance the performance of firms' internal R&D activities than competitive collaborations. On the other hand, cooperation among competitors may facilitate knowledge sharing (Ahuja, 2000b; Gnyawali, He, & Madhavan, 2006; Polidoro et al., 2011). The proximity afforded in cooperative settings allows firms to benchmark their competitors with greater intensity and develop a better awareness of new technological undertakings (Lomi & Larsen, 1996; Pouder & St. John, 1996). Lado, Boyd, and Hanlon (1997) suggest that competitors are able to develop non-finite, symbolic, and idiosyncratic resources (such as altruism, trust, and reciprocity) in a cooperative network. Therefore, cooperation with competitors can be a win-win means of developing capabilities for mutual gain if a balance of value creation and value appropriation can be achieved (Emden, Calantone, & Droge, 2006). In addition to inconsistency in the findings, this body of work has mainly focused on one-on-one competition in dyadic relationships, with very limited attention paid to multi-party partnerships (Bengtsson & Raza-Ullah, 2016).

An R&D consortium may consist of businesses, universities, research institutes, and industry associations that are working on the same product or technology area. The business members may have competitive, supply, and complementary relationships with one another. Therefore, not all members are market competitors to a given firm. Considering the various relationships within a consortium, this study focuses on the presence of market competitors from a focal member firm's perspective. In other words, we mainly examine how individual firms view their competitive relationships within a consortium. Meanwhile, while consortium participation may affect a member firm's individual knowledge acquisition and follow-on innovation (Li et al., 2011; Wu, 2014), our study only addresses its innovation output within the consortium (i.e., the output of the member firm's joint R&D with other members). This construct varies across the consortium because member firms can work with different partners on different projects and thus have different output. In examining the effect of competition on innovation within a consortium, we propose a U-shaped relationship between the presence of a firm's market competitors in the consortium and the innovative output the firm can bring about by working with other members.

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A weak presence of market competitors means that most consortium members are not a focal firm's market competitors (i.e., the consortium does not include many of the firm's competitors). It does not imply low competition at the industry level, a situation in which there is not much incentive for innovation (Aghion et al., 2005). In fact, a weak presence of market competitors suggests the focal firm has a unique position in the consortium. Since few other members have the same access to the focal firm's market, its market knowledge and experiences are relatively rare in the consortium. Sharing similar R&D interests with the focal firm, other members may have complementary assets from other markets and non-business areas. To tap into the focal firm's relatively unique market access, other members need to build significant ties with the focal firm, conferring on the focal firm a central, strategic position (Wasserman & Faust, 1994). According to Gnyawali and Madhavan (2001), there are three potential benefits of being a central actor. First, the actor would have greater access to complementary resources from other consortium members, such as technology, know-how, and equipment. Such resource complementarity can drive and enhance joint R&D activities (Hagedoorn, 1993). Second, the actor has broader and earlier access to new technology information, an advantage that can provide opportunities for the actor to achieve timely and fruitful technology development (Zander & Kogut, 1995). Third, the actor has higher status and bargaining power in cooperative relationships, which can be leveraged to initiate collaborations with the most resourceful and capable partners amongst fellow consortium members. All in all, access to superior assets and opportunities enables such strategically positioned firms to take on more joint R&D and generate more innovation output.

Comparatively, when the presence of market competitors is moderately stronger, the focal firm has less incentive to engage in joint R&D and is less likely to occupy a unique position in the consortium. Other consortium members can choose to work with alternative partners (i.e., the focal firm's competitors) that have access to the focal firm's market. Without significant ties to other members, the focal firm is unlikely to obtain the information and resource benefits attributable to occupying a central position in the consortium. Meanwhile, concerns about making competitors stronger may render the focal firm reluctant to engage in interfirm knowledge transfers or devote critical resources to joint activities within the consortium (Mowery, Oxley, & Silverman, 1996). Instead, the focal firm is incentivized ex ante towards free-riding due to its expectations of opportunism (Porter, 1998). Without active participation in joint R&D, the focal firm is less likely to produce meaningful innovation output than in a consortium with few market competitors.

Nevertheless, when the presence of market competitors reaches a critical level (i.e., there is a critical mass of market competitors in the consortium), the focal firm will face yet a different situation. The competitors, accounting for a sizable proportion of consortium participants, may give rise to a bandwagon effect that induces the focal firm to pursue joint R&D. On the one hand, without actively participating in joint R&D, the focal firm risks becoming a laggard. Given a large number of market competitors, the focal firm faces greater pressures to stay current with technological developments. In a competitive setting, innovation leaders tend to benefit more than the followers (Boone, 2001). If a competitor's new technology has reached other members first, the focal firm's catch-up innovations are likely to have fewer adoptions and lower returns. On the other hand, targeting the same downstream market, the focal firm and its competitors may have similar motivations in undertaking joint R&D. As such, they may dominate other members and guide the direction of innovation in the consortium. They may even wield enough market power to set market-wide technology standards and be able to capitalize on the network effects (Suarez, 2005). Certainly, the drawbacks of having multiple competitors for joint R&D still exist. As a number of members have access to the same market, the focal firm does not have a unique strategic position in the consortium. Further, concerns about competitors' opportunistic behavior remain. However, while the bandwagon effect multiplies with the presence of market competitors, the drawbacks are unlikely to increase substantially (Beamish & Kachra, 2004). Once the presence of market competitors reaches a critical level, we expect the bandwagon effect to dominate the drawbacks. Therefore, when facing a strong presence of market competitors in the consortium, the focal firm is likely to be incentivized to actively pursue joint R&D. If not joining the bandwagon of new technology creation and adoption, the firm may be left behind with a gap of technology and profitability.

Given the above considerations, we argue that the way firms react to the presence of market competitors in an R&D consortium is distinct from how they respond to competition at the industry level. Specifically, we present the following hypothesis:

Hypothesis 1: In an R&D consortium, the presence of a focal firm's market competitors will be related to the firm's joint R&D output in a U-shaped relationship.

Firm Interactions with Consortium Members

The alliance and network literature have long pointed out the essential role of firm-instigated interactions in collaborative relationships (Dyer, Kale, & Singh, 2001; Gulati & Gargiulo, 1999; Ring & Van de Ven, 1992). Interfirm interactions help firms become aware of one another's technological capabilities, which lays the foundation for cooperation (Ahuja, 2000b). Close interactions between firms and between their personnel have been identified as effective means for transferring tacit, difficult-to-codify knowledge (Tushman & Katz, 1980). Such interactions and the ensuing communications also underlie tacit troubleshooting procedures (Zollo, Reuer, & Singh, 2002), helping firms circumvent conflict and economize on time otherwise spent on costly renegotiations (Uzzi, 1997). Moreover, the rapport produced by firm-instigated interactions has been demonstrated to

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reduce behavioral uncertainty and substitute for formal governance (Arinõ & Reuer, 2004). In particular, firm-instigated interactions have been noted as useful in multi-party networks, where the costs of centralized organizing may offset the synergies from collaborations (Lavie, 2006). A firm may even gain new opportunities for innovation by reaching beyond centrally embedded members and interacting with less embedded but potentially valuable members (Ahuja, Polidoro, & Mitchell, 2009). Therefore, a member firm's collaborative interactions with consortium members are expected to prompt the process of joint R&D and enhance innovative performance.

Furthermore, we explore how competition and cooperation, both related to innovation, are linked in R&D consortia. Prior research on coopetition usually portrays competition and cooperation as two contradictory elements in a paradox and encourages actors to seek an optimal equilibrium (Czakon et al., 2014). With the recognition that competition and cooperation do not necessarily conflict with one another, coopetition has been characterized as various combinations of high and low intensity of competition and cooperation, respectively (Bengtsson & Kock, 2000; Luo, 2005; Ritala, 2012). While acknowledging the interdependence of competition and cooperation, such an approach has yet to clearly depict tensions between the two constructs. In this study, we demonstrate how the presence of market competitors has a curvilinear relationship with interfirm interactions within an R&D consortium.

Specifically, we argue that when the presence of market competitors is weak, a focal firm tends to have relatively intense interactions with other members. As the firm does not directly compete with most consortium members, it likely experiences less conflicts of interest and has fewer concerns regarding knowledge leakage. Consequently, the firm may seek to interact with suppliers, buyers, and complementors in the consortium to streamline its value creation process and access divergent sources of knowledge (Ahuja et al., 2009). Moreover, the focal firm's unique position allows it to establish significant ties with others. With limited competitors, the firm's access to its market becomes a rare resource within the consortium. It is likely to attract attention from other members and enable the focal firm to establish a variety of interfirm interactions within the consortium (Wasserman & Faust, 1994).

As the presence of market competitors strengthens, the focal firm not only loses its unique position within the consortium but also encounters potential threat from competitors. To gain access to the focal firm's market, other members could partner with the focal firm's competitors. Without relatively exclusive access to its market, the focal firm's collaborative interactions will be negatively affected in both scope and quality. Meanwhile, in anticipation of opportunism from competitors, the focal firm may be less willing to share resources and exchange information (Mowery et al., 1996). Its greater intention to safeguard proprietary assets has the potential to reduce meaningful interactions in the consortium.

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Nonetheless, when there is a strong presence of market competitors, the focal firm's interactions with others may be enhanced by the bandwagon effect. To stay current with technological developments, the focal firm needs to closely monitor other members' R&D activities. Through intense interactions, the focal firm can efficiently gather information about others' behavior and competence (Polidoro et al., 2011), and learn early on about evolving technology and component availability (Porter, 1998). In addition, the existence of a critical mass of market competitors facilitates the establishment of R&D directions in the consortium, as well as industry standards. Given the potential benefits from these network effects, the focal firm is incentivized to participate in the innovation activities propagated by critical mass rather than being left out. Therefore, the focal firm is expected to interact more with consortium members.

In sum, we argue that member firms will respond to the presence of competitors in R&D consortia by modifying their collaborative activities, which in turn will affect their innovation output. In other words, interactions with consortium members mediate the relationship between the presence of a member firm's market competitors and its innovation output. By examining a process (firm interaction with consortium members), we attempt to unbox the 'black box' between a structural feature (the presence of market competitors) and a performance outcome (firm innovation output). Hence, we propose the following two hypotheses:

Hypothesis 2: In an R&D consortium, the presence of a focal firm's market competitors will be related to the firm's collaborative interactions with consortium members in a U-shaped relationship.

Hypothesis 3: A focal firm's collaborative interactions with consortium members will mediate the relationship between the presence of the firm's market competitors and its joint R&D output in the consortium.

Consortium-Level Collaborative Efforts

In addition to firm-instigated interactions in a consortium, which reflect a bottom-up process that individual members employ to manage their relationships, top-down efforts are often made at the consortium-level to enhance multi-party collaboration endeavors (Bengtsson & Raza-Ullah, 2016). Such efforts encompass consortium-wide collaborative mechanisms, as well as the development of resources devoted to these mechanisms (Aldrich et al., 1998).

Centralized mechanisms, such as a board of directors, a central management office, and designated administrative personnel, are often created to oversee joint R&D activities in the context of innovation partnerships (Hagedoorn & Hesen, 2007). Since the compartmentalization of R&D units within firms obstructs the integration of knowledge from joint R&D (Oliver, 2004), dedicated consortium-level routines may be critical for firms to effectively codify and transfer the knowledge produced in R&D consortia. In a similar vein, collaborative mechanisms at the consortium level play a critical role in retaining knowledge that might

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otherwise be lost if the members with such knowledge were to leave (Kale et al., 2000). Given the importance of centralized collaborative mechanisms, they are commonly adopted in R&D consortia.

In fact, in order to qualify for government endorsement, all the consortia in our study were required to set aside funds for specific R&D projects and establish collaborative mechanisms such as executive councils, expert panels, routine meetings, and knowledge exchange channels (Ministry of Science and Technology of China, 2009). Although the consortia developed similar governance mechanisms, they differed in the amount of resources dedicated to R&D collaboration. Therefore, in this study, consortium-level efforts mainly refer to the collective input of resources at the consortium-level.

We first posit that consortium-level efforts will strengthen the curvilinear relationship between the presence of market competitors and firm interactions with consortium members. The availability of consortium-level resources and support is likely to affect the magnitude of incentives for interfirm interactions. On the one hand, if there is a lack of consortium-level efforts, the presence of market competitors will likely make no difference for the focal firm. For instance, when there are few competitors, the focal firm has a unique position in the consortium, but any gains from leveraging the position is limited. Even with a strong presence of market competitors, the focal firm may not be motived to engage in joint innovation because other members are unlikely to have meaningful collaborative R&D due to the lack of consortium-level support. In other words, given a low level of consortium-level efforts, the focal firm expects few gains from interfirm interactions; neither centrality benefits nor bandwagon effects are sufficient enough to incite the focal firm to interact with other members. On the other hand, if there is a high level of consortium-level efforts, the focal firm's relationships with other members will have a meaningful impact on the focal firm's potential gains from the consortium. The focal firm will be incentivized to actively interact with other members to realize centrality benefits or follow the bandwagon to engage in joint R&D. Thus, the curvilinear relationship is likely to be more pronounced.

We also expect consortium-level efforts to strengthen the relationship between a member firm's collaborative interactions and innovation output within a consortium. In a way, the consortium's top-down efforts complement firms' bottom-up interaction processes (Bengtsson & Raza-Ullah, 2016). It provides resources and support to guide the directions of collaborative interactions and lessen the costs of interfirm exchanges, enabling more efficient and effective joint R&D. A high level of consortium-level efforts also raises the opportunity costs of opportunistic behavior. Member firms are more likely to share critical resources and engage in meaningful cooperation when the collective gain outweighs the temporary benefits from being opportunistic (Axelrod, 1984; Polidoro et al., 2011). In contrast, without adequate consortium-level efforts in facilitating collaborations, firms' interactions not only lack resources and support, but also face a greater threat of opportunistic behavior from other members. Therefore, we posit the following:

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Hypothesis 4: Consortium-level collaborative efforts will positively moderate the curvilinear relationship between the presence of a focal firm's market competitors and its collaborative interactions with consortium members.

Hypothesis 5: Consortium-level collaborative efforts will positively moderate the relationship between a focal firm's collaborative interactions with consortium members and the firm's joint R&D output in the consortium.

METHODS

Sample and Data

In order to study coopetition in R&D consortia, we collected data on the first batch of 56 R&D consortia sponsored by the Ministry of Science and Technology of China, which had announced a plan to facilitate multi-party collaborations on innovation in 2010.[1] The plan aimed to have business enterprises and research organizations work together on new technology creation, knowledge sharing and transfers, product commercialization, and industrial standard development. Prior to this plan, there had been no efforts to integrate R&D at the national level in China, and thus no systematic data on Chinese R&D consortia. The Ministry's initiative allowed us to accurately identify and gain access to the R&D consortia and their member firms. The R&D consortia in our sample were formed between 2002 and 2010 and had existed for at least three years when the data was collected in 2013, allowing for an adequate observation of R&D collaborations within the consortia.

The consortia focused on specific products or technologies. Based on China's industrial classification code, they were divided into six industrial sectors: agriculture, forestry, and farming related manufacturing; energy sources and utilization; chemical manufacturing, metal mining and production; machinery and equipment manufacturing; communication and information technology (see Table 1). The consortia each had a designated leading organization and multiple members. The number of members in each consortium ranged from 12 to 84, with 34 being the average. In total, there were 1,899 member organizations, with 1,190 being business enterprises and the rest being universities, research institutes, and industrial associations. While focusing on a same product or technology area, the business members of each consortium had competing, supplying, buying, and/or complementary relationships with one another.

To construct our sample, we first conducted semi-structured interviews with the leading organizations. Based on information gathered from the interviews and our literature review, we carefully designed a self-administered questionnaire to gather firm-level data for the consortia. Given their non-profit nature and strong affiliation with governments (Chen & Kenney, 2007), non-business members – such as public research institutes and universities – were not included

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Table 1. List of consortia

Industrial Sector	*Consortium Focus (number of members at the time of data collection)*
Agriculture, forestry, and farming related manufacturing	Tea (46), Soybean (28), Citrus (27)), Bamboo (44), Meat (33), Milk (55), Animal feed (10), Special biological resources (78), Livestock and poultry (20), Rapeseed (60), Rice (85)
Energy sources and utilization	Natural gas (14), Coal processing (25), Biomass (33), Solar power (57), Coal energy (14)
Chemical and pharmaceutical manufacturing	Fertilizer (20), Pesticide (48), Paint (16), Medical testing materials (18), Antibiotics (16), Flu vaccine (22), Vitamin (19), Synthetic fiber (44)
Metal mining and production	Mining waste processing (47), Iron and steel recycling (10), Non-ferrous metal (14), Mineral recycling (15), Aluminum (11), Hard alloy (23), Metal material recycling (68)
Machinery and equipment manufacturing	Textile machinery (36), Farming machinery (42), Numeric control tools (17), Medical equipment (60) Light weight vehicles (16), New energy engine (15), LED lighting (38), Polysilicon (26), Integrated circuit package (48), Scientific instrument (47) Navigation equipment (27), Food testing equipment (32)
Communication and information technology	New wireless technology (61), WLAN security (84), Data storage (25), Fiber connection (12), Open platform (73), E-commerce technology (41), Geographic information system (41), Aeronautical data processing (25), Open source software (23), Intelligent grouping (18), Satellite remote sensing system (23), Remote sensing data processing (30)

in our survey. The questionnaire was translated and cross-checked by bilingual researchers, and pre-tested with professional managers in China. Using member directories obtained from the leading organizations, we sent the questionnaire to the liaison persons of the 1,190 business members in charge of consortium collaboration via email. After two rounds of follow-up reminders, we received 320 valid responses from 52 consortia. The number of responses from each consortium ranged from 4 to 12, yielding an average response rate of 26.89%. To check for non-response bias, we examined the age and the number of employees of the business members and found no significant differences between the respondents and non-respondents. Given the inclusion of both consortium-level and member-level data, our final sample represents a unique source of information for a multi-level study on coopetition in R&D consortia.

Variables

This study focuses on how the presence of market competitors affects member firms' innovation in R&D consortia. Innovation output is commonly measured with patenting activity in prior literature (e.g., Ahuja, 2000a; Kim & Inkpen, 2005; Vakili, 2016). A rise in the number of patents reflects an increase in a

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firm's innovativeness (Hagedoorn & Schakenraad, 1994). In this study, we measured a member firm's joint R&D output in a consortium with the number of patents a firm had produced by working with other members. All of the consortia in our study stated that they had established mechanisms for member firms to jointly create new patents. In the questionnaire, the respondents were asked to specify the number of patents they had produced by working with other consortium members in the preceding three years.[2] The number varied not only across consortia but also between firms within a same consortium, as the firms did not necessarily participate in all the joint R&D projects of a given consortium.

To measure a firm's collaborative interactions with other consortium members, we calculated the weighted intensity of the firm's collaborative activities. Due to the implicit nature of interfirm interactions, firms often hold different perceptions and are subject to different degrees of influence. Perception-based indicators can therefore provide a broader view of interfirm relationships (Venkatraman & Ramanujam, 1986). In the survey, we asked each firm to evaluate its cooperative interactions with other consortium members during the preceding three years. On five-point Likert scales with 1 being the lowest and 5 the highest value, respondents rated the importance and intensity of the following items: joint technology development, joint new product development, commissioned R&D within the consortium, joint R&D sourcing from outside the consortium, setting technical and product standards, exchanging technological information, sharing R&D facilities and equipment, joint exploration of international markets, joint procurement, joint marketing, joint training, and joint pursuit of government support. An importance-weighted average of those collaborative activities was then calculated to capture the extent of a firm's collaborative interactions with others in a given consortium.

The main independent variable, *the presence of market competitors*, was measured with the proportion of a member firm's market competitors among its fellow consortium members. Market competitors are firms offering similar products in similar markets (Chen, 1996). Because a consortium would not typically include all market competitors and those included by default have collaborative relationships with one another, competition within a consortium is likely not equivalent to competition at the industry level. Competition indicators in the economics literature, such as the Herfindahl Index based on market share and concentration (Boone, 2008; Kwoka, 1985) and the Lerner Index based on average price cost margin across firms (Aghion et al., 2005), usually apply to the whole industry and cannot reflect the nuanced relationships among consortium members. A number of strategic management scholars have used the count of competitors to indicate market competition, considering both product and market similarity (Ang, 2008; Ritala, 2012). Following this approach, we counted the number of members that are considered the market competitors of a focal firm in each consortium, which allowed us to capture the presence of market competitors from an individual firm's perspective. To identify competitive relationships, we first consulted industry experts to assess if

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each unique pair of member firms in a same consortium offer similar products in similar markets. If so, they were considered market competitors to each other. Then we verified the assessments with the leading organization of each consortium. In the case of discrepancies, we contacted the member firms in question and used their own opinions. To account for differences in the size of the consortia, we divided the number of a firm's market competitors by the total number of consortium members excluding the focal firm. For a few consortia, the size and composition of firms changed slightly in the three-year period preceding our data collection. In such cases, the three-year averages of consortium members and each firm's market competitors were used in our analysis.

The moderating variable, consortium-level collaborative efforts, was calculated by dividing the consortium-level R&D expenditure in the preceding three years by the number of consortium members. As all of the consortia in our study had similar governance mechanisms, they differed in how much effort they actually put into R&D collaborations. We had asked the leading organizations to evaluate consortium-level collaborative efforts in the interviews, but their self-evaluations appeared to be subject to social desirability bias because of government monitoring (Fisher & Katz, 2008). Therefore, we decided to adopt the value of collective funding for R&D expenditure as a proxy for consortium-level collaborative efforts. To account for the varying sizes of the consortia, we divided the total consortium-level R&D expenditure in the preceding three years (in millions of RMB) by the number of consortium members and calculated the logarithm of the averaged R&D expenditure for our analysis.

Several control variables were included in our analysis. At the firm level, we controlled for firm size, R&D intensity, years in the consortium, ownership attribute, and distance to the leading organization. Previous literature on innovation has suggested that firm size tends to affect innovation activities (Camisón-Zornoza, Lapiedra-Alcamí, Segarra-Ciprés, & Boronat-Navarro, 2004). In this study, firm size was measured using the logarithm of a firm's average annual sales (in millions of RMB) in the preceding three years. R&D intensity, measured with the ratio of a firm's R&D expenses to its total sales, is also considered a main determinant of innovation (Cohen & Levinthal, 1990). To delineate a firm's R&D efforts, we separated expenses spent on joint R&D within a consortium (i.e., collaborative R&D with consortium members) and those spent on non-consortium R&D (i.e., R&D conducted independent of the consortium – by the focal firm itself or with non-members). Using corresponding numbers reported by the survey respondents, we calculated the intensity of within-consortium R&D and the intensity of non-consortium R&D in the preceding three years. Since innovation usually takes time, we also controlled for the number of years for which a firm had been a member of a given consortium. As the existence of state-owned or controlled enterprises is a typical feature of the Chinese economy, we measured ownership attribute with a dummy, where state-owned or controlled firms were coded 1 and otherwise 0. Moreover, considering that geographic distance affects

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coordination and knowledge distribution in R&D collaboration (Boschma, 2005), we controlled for a member firm's geographic distance from its corresponding leading organization, which played a central role in consortium formation and operation. Using their headquarters' locations, we measured the geographic distance in kilometers, and took its logarithm after adding one to the distance (because the distance could be zero). At the consortium level, we controlled for consortium size, as indicated by the total number of members in a consortium; and the percentage of non-business members, which might exhibit different behavioral patterns from business members in R&D collaboration (Agrawal, 2001). We used dummy variables to control for the industries represented by the consortia.

Analysis

This research examines the collaboration and innovation of individual firms nested within R&D consortia. To account for both firm-level and consortium-level factors, we employed multi-level modeling to examine the hypothesized relationships (Klein & Kozlowski, 2000). This approach facilitates an accurate examination of how explanatory variables at multiple levels contribute to the outcome of interest (Hitt, Beamish, Jackson, & Mathieu, 2007), allowing us to investigate our research questions that entail constructs from both the firm and consortium levels. Specifically, since the measure of innovation output is a count variable, we used negative-binomial multi-level analysis. The negative binomial distribution can accommodate overdispersion in count data, and thus may fit better than the Poisson distribution (Hox, 2010). Firm-level collaborative interactions, measured with a weighted composite index, was treated as a scale variable. In order to obtain unbiased estimation, multi-level analysis requires a sufficient sample size. Our final sample contains 52 consortia, which is greater than 30, the general rule-of-thumb requirement at the group level. While some consortia in our sample contain a limited number of members, research on multi-level modeling suggests that the group-level sample size is more important than the total sample size, and that an above-50 sample size at the group level is sufficient to generate accurate coefficient estimates (Mass & Hox, 2005; Snijders, 2005).

RESULTS

Table 2 presents the descriptive statistics and correlations. The standardized values of the explanatory variables – except for the dummies – were used in our analysis. Standardization helps to reduce multicollinearity in multi-level modeling, especially when estimating quadratic and moderating relationships (Kreft, De Leeuw, & Aiken, 1995). This approach is also in line with multi-level analysis, which usually focuses on the sign of a relationship rather than on a specific coefficient (Pike & Rocconi, 2012). To check for potential multicollinearity, we calculated the variance inflation factor (VIF) for all the predictive variables as well as

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Table 2. Means, standard deviations, and correlations

Variables	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Mean	13.800	3.461	0.300	2.034	6.224	4.010	0.053	0.009	0.486	5.483	35.230	0.402	4.062
Standard deviation	59.358	0.976	0.282	1.843	2.639	1.630	0.043	0.016	0.501	2.210	20.592	0.176	0.718
1. The number of patents produced by joint R&D in the consortium	1												
2. Firm interaction with consortium members	0.069	1											
3. The proportion of market competitors	0.174*	−0.034	1										
4. Averaged consortium-level R&D expenditure	0.081	0.116	0.006	1									
5. Firm size	0.166*	0.134*	0.049	0.079	1								
6. Years in the consortium	0.147	0.106	−0.046	0.338***	0.364***	1							
7. The intensity of non-consortium R&D	−0.085	−0.075	−0.101	0.144*	−0.463***	−0.062	1						
8. The intensity of within-consortium R&D	−0.028	0 .061	0.078	0.112	−0.245**	−0.074	0.117	1					
9. State ownership	−0.030	0.011	−0.277**	0.043	0.222*	0.109	0.040	−0.085	1				
10. Distance to the leading organization	−0.101	−0.047	0.069	−0.026	0.169*	−0.035	−0.078	−0.022	0.003	1			
11. The number of consortium members	0.007	0.063	0.041	0.000	−0.128	−0.020	0.101	0.093	−0.158*	−0.054	1		
12. The percentage of non-business members	−0.124	−0.138*	−0.215**	−0.403***	−0.114	−0.209**	−0.110	−0.085	−0.031	−0.067	−0.265***	1	
13. Self-evaluation of innovative performance	0.049	0.642***	0.019	0.155*	0.073	−0.021	−0.072	0.028	−0.136*	−0.142*	0.066	−0.074	1

Notes: N = 320; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; industry dummies are not reported here for space consideration.

the quadratic and interaction terms of interest. The VIF values ranged from 1.049 to 2.501, below the commonly used threshold of 4, suggesting that multicollinearity was not a concern.

To examine the number of patents produced by working with other members, we first estimated a null model with intercepts only. The null model showed significant random effect variance at 2.683 (standard error 1.254, $p < .05$), suggesting significant between-consortium differences and the need for multi-level modeling. Then we added firm-level and consortium-level predictors. The results are shown in Table 3. Model 1 is a base model without the squared term of the proportion of market competitors; Model 2 includes the squared term. As Chi-square statistics in Table 3 reflect differences in deviance compared to the null model, a significant increase of the Chi-square value suggests that Model 2 fits the data better than Model 1. While the proportion of market competitors only shows a marginal effect in Model 1,[3] both its linear and squared terms are significant and positive in Model 2. Specifically, the coefficient of the squared term indicates an exponential effect size of 1.883 (with a 95% confidence interval from 1.094 to 3.241), suggesting that the outcome mean is 1.883 times larger when the predictor is one standard deviation from its mean. Moreover, half of the negative ratio of the linear term to the quadratic term ($-0.458/2 \times 0.633 = -0.362$), which indicates the vertex (turning point) of a quadratic curve, falls in the range of the standardized proportion of market competitors. To validate the curvilinear relationship, we employed a method recommended by Simonsohn (2018) to estimate two separate lines (i.e., monotonic decreases and increases at the two ends of the curve). A breakpoint for the standardized value of the proportion of market competitors was found at 0.299.[4] Using the base model, two separate analyses were conducted on two sub-samples separated by the breakpoint. For the subsample with lower values (no more than 0.299), the coefficient of the proportion of market competitors was −1.028 (standard error 0.518, $p < 0.05$). For the subsample with higher values (greater than 0.299), the coefficient was 2.649 (standard error 1.169, $p < 0.05$). Two opposite and significant relationships were observed. These results suggest that there is a U-shaped relationship between the presence of a firm's market competitors and the firm's innovation output in an R&D consortium. Therefore, Hypothesis 1 was supported.

Similarly, for firm interactions with consortium members, a null model without predictors showed a significant random effect at 0.133 (standard error 0.063, $p < .05$), supporting the use of multi-level modeling. Models with explanatory variables are presented in Table 4. While the proportion of market competitors is insignificant in Model 1, its squared term is significant and positive in Model 2. Adding the squared term improved model fit, as suggested by the increase of Chi-square. Following Peugh's (2010) method, we obtained the global effect size of Model 2 (pseudo-$R^2 = 0.138$) and the local effect size of the squared term (the proportion reduction of variance = 0.023). Given the relatively small global effect, the effect of the squared term can be considered meaningful (Cohen,

Table 3. Negative binomial multilevel modelling of innovation performance

	The number of patents produced by joint R&D in the consortium					
Variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Intercept	0.929 (0.646)	0.760 (0.846)	0.617 (0.863)	−0.526 (0.802)	0.640 (0.738)	0.140 (0.716)
Firm size	0.663* (0.252)	0.816** (0.283)	0.394 (0.297)	0.388 (0.266)	0.422 (0.285)	0.408 (0.276)
Years in the consortium	0.316 (0.206)	0.393† (0.231)	0.404† (0.235)	0.356† (0.214)	0.323 (0.238)	0.272 (0.230)
The intensity of non-consortium R&D	−0.486* (0.200)	−0.511* (0.212)	−0.654** (0.221)	−0.412† (0.212)	−0.590** (0.219)	−0.498* (0.218)
The intensity of within-consortium R&D	−0.347 (0.274)	−0.335 (0.278)	−0.293 (0.291)	−0.381 (0.312)	−0.311 (0.302)	−0.408 (0.323)
State ownership	0.177 (0.455)	0.289 (0.455)	0.122 (0.488)	0.611 (0.463)	0.210 (0.467)	0.213 (0.479)
Distance to the leading organization	−0.482* (0.203)	−0.570* (0.226)	−0.533* (0.229)	−0.378† (0.209)	−0.459* (0.230)	−0.377† (0.222)
The number of consortium members	−0.470† (0.250)	−0.450 (0.352)	−0.338 (0.359)	−0.489† (0.282)	−0.349 (0.338)	−0.397 (0.304)
The percentage of non-business members	−0.494 (0.261)	−0.386 (0.379)	−0.305 (0.388)	−0.255 (0.305)	−0.387 (0.351)	−0.432 (0.316)
Averaged consortium-level R&D expenditure	0.214 (0.244)	0.257 (0.345)	0.131 (0.356)	−0.348 (0.313)	0.137 (0.341)	−0.154 (0.340)
The proportion of market competitors	0.528† (0.304)	0.458* (0.231)	0.335 (0.321)	0.387 (0.295)		
(The proportion of market competitors)^2		0.633* (0.274)	0.213 (0.349)	0.464 (0.319)		
Firm interactions with consortium members			0.684** (0.227)	0.671** (0.231)	0.637** (0.232)	0.649** (0.234)
(Firm interactions with consortium members) x (Averaged consortium-level R&D expenditure)				0.581** (0.222)		0.487* (0.217)
Negative Binomial	3.248	3.138	3.082	2.977	3.152	3.079
Chi-Square	250.580***	276.397***	285.366***	259.217***	290.287***	296.131***

Notes: N = 320. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Standard errors in parentheses. Industry dummies were included in the analysis but are not reported here for space considerations. Chi-Square values were calculated in comparison to the null model. In negative binomial multilevel models, residue effect variance was set to 1.

Table 4. Multilevel modelling of firm interactions

	Firm interactions with consortium members		
Variables	*Model 1*	*Model 2*	*Model 3*
Intercept	3.515*** (0.246)	3.137*** (0.270)	3.112*** (0.271)
Firm size	0.085 (0.091)	0.141 (0.090)	0.151 (0.092)
Years in the consortium	0.063 (0.077)	0.052 (0.075)	0.037 (0.076)
The intensity of non-consortium R&D	−0.013 (0.079)	−0.007 (0.078)	−0.022 (0.079)
The intensity of within-consortium R&D	0.050 (0.090)	0.052 (0.089)	0.051 (0.090)
State ownership	−0.007 (0.172)	−0.015 (0.168)	−0.017 (0.170)
Distance to the leading organization	−0.035 (0.068)	−0.050 (0.066)	−0.037 (0.066)
The number of consortium members	0.069 (0.075)	0.007 (0.073)	0.002 (0.072)
The percentage of non-business members	−0.056 (0.083)	0.043 (0.084)	0.071 (0.087)
Averaged consortium-level R&D expenditure	0.116 (0.082)	0.106 (0.077)	0.120 (0.077)
The proportion of market competitors	−0.003 (0.081)	−0.180* (0.083)	−0.177† (0.106)
(The proportion of market competitors)^2		0.315** (0.099)	0.352** (0.102)
(The proportion of market competitors) x (Averaged consortium-level R&D expenditure)			−0.110 (0.096)
(The proportion of market competitors)^2 x (Averaged consortium-level R&D expenditure)			0.024 (0.089)
Residue effect variance	0.905*** (0.099)	0.885*** (0.088)	0.885*** (0.088)
Random effect variance	0.028 (0.058))	0.023 (0.056)	0.020 (0.054)
Chi-Square	300.389***	307.289***	298.124***

Notes: N = 320. †p < 0.10; *p < 0.05; **p < 0.01; ***p < 0.001. Standard errors in parentheses. Industry dummies were included in the analysis but are not reported here for space considerations. Chi-Square values were calculated in comparison to the null model.

1988). The vertex of the quadratic curve (0.180/2 × 0.315 = 0.286) is within the predictor's value range, suggesting a U-shaped relationship between the presence of a firm's market competitors and the firm's collaborative interactions with consortium members. To validate this relationship, we conducted a two-lines test, using the base model and two subsamples (Simonsohn, 2018). A breakpoint to separate the subsamples was found at 0.194 for the standardized value of the proportion of market competitors. For the subsample with lower values, the coefficient of the proportion of market competitors was -0.539 (standard error 0.259, $p < 0.05$). For the subsample with higher values, the coefficient was 0.456 (standard error 0.225, $p < 0.05$). As such, Hypothesis 2 was supported.

Hypothesis 3 predicted a mediating relationship, in which firm interactions with consortium members mediate the relationship between the presence of market competitors and firm innovation output in a consortium. Following the guidelines laid out by MacKinnon, Lockwood, Hoffman, West, and Sheets (2002), we examined the mediating relationship. First, the level of firm interactions with consortium members is related to the proportion of market competitors in a

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curvilinear fashion. Second, it is correlated with the logarithm of the patent count (Pearson correlation 0.223, $p < 0.001$). Third, the patent count and the proportion of market competitors are no longer related when firm interactions with consortium members is controlled for. As shown in Model 3 of Table 3, the term of firm interactions with consortium members is significant and positive, and the linear and squared terms of the proportion of market competitors become insignificant. Specifically, the term of firm interactions with consortium members has an exponential effect size of 1.982 (with a 95% confidence interval from 1.250 to 3.096), suggesting the outcome mean is 1.982 times larger when the predictor is one standard deviation above its mean. The Chi-square value of Model 3 also suggests a better model fit in comparison to Model 2. Fourth, the indirect effect (i.e., the amount of mediation) is significant. A Sobel test showed a Z-score of 2.188 ($p < 0.05$), supporting the mediating relationship. Since the Sobel test is very conservative and has limited power (MacKinnon et al., 2002), we also used the Monte Carlo method for mediation assessment (Hayes, 2013; MacKinnon, Lockwood, & Williams, 2004). The method generated a 95% confidence interval of the indirect effect between 0.048 and 0.442. Since the confidence interval excluded zero, the existence of mediation was confirmed. Thus, Hypothesis 3 was supported. Figure 1 summarizes the relationship in a path diagram.

Hypotheses 4 and 5 were concerned with the moderating effects of consortium-level collective efforts. As shown in Model 3 in Table 4, the interaction terms of the presence of market competitors and average consortium-level R&D expenditure do not show significant effects on firm interactions with other members, suggesting individual member firms' reaction to the presence of market competitors is unlikely to be changed by consortium-level efforts. Therefore, Hypothesis 4 was not supported by the data. A possible explanation is that all the R&D consortia in our study had adequate R&D funding because the Ministry of Science and Technology of China had considered funding as a prerequisite for government endorsement. As long as there was adequate R&D funding, firm interactions in response to the presence of market competitors would generally follow the hypothesized curvilinear relationship. If there were situations in which consortia lacked consortium-level funding in the data, the moderating effect might have been significant.

On the other hand, Model 4 in Table 3 shows a significant moderation term, suggesting that the averaged consortium-level R&D expenditure positively

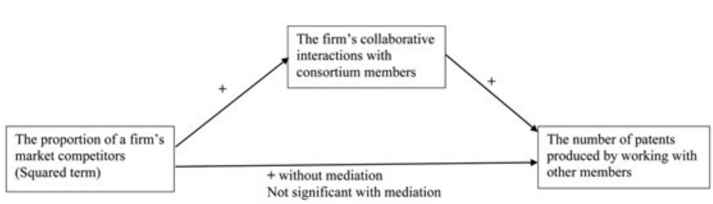

Figure 1. The mediating relationship

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moderates the relationship between a firm's interactions with consortium members and its count of patents produced within the consortium. The moderation term has an exponential effect size of 1.788 (with a 95% confidence interval from 1.158 to 2.768). To further examine the moderating relationship, we divided the sample firms into two groups along the mean of average consortium-level R&D expenditure and tested the effect of firm interactions with consortium members in each group. In the subsample with above-mean R&D expenditure, the coefficient of firm interactions with consortium members was 1.199 (standard error 0.355, $p < 0.001$), indicating an exponential effect size of 3.317 (95% confidence interval from 1.680 to 6.681). In the subsample with below-mean R&D expenditure, the coefficient was 0.274 (standard error 0.228) and insignificant. The results suggest that firm interactions with consortium members will help produce more patents only when there is a high level of consortium-level efforts. Meanwhile, considering that the effect of within-consortium competitors is mediated by firm interactions with consortium members, the proportion of market competitors may be dropped to improve model fit. Those two reduced models (Model 5 and Model 6) in Table 3 show greater Chi-square values. In particular, Model 6 indicates that adding the moderation term improves model fit (as compared to Model 5) and has a significant exponential effect size (=1.627, 95% confidence interval from 1.036 to 2.487). The results confirm that consortium-level efforts tend to enhance the positive impact of a firm's interactions with consortium members on its patent count. Such findings are consistent with our prediction in Hypothesis 5.

In addition, our control variables showed various relationships with innovation output. While the intensity of within-consortium R&D was insignificant, the intensity of non-consortium R&D was negatively linked to the number of patents produced via joint R&D. This suggests that, although spending more on collaborative projects does not necessarily increase joint R&D output, spending more on non-consortium projects is likely to hurt joint R&D output. It is plausible that member firms tend to pay more attention to their own projects than to collaborative projects with consortium members. Interestingly, the distance between a member firm and the consortium leader is negatively related to the firm's joint R&D output. This finding shows that, despite advances in communication technology, geographic distance still matters in multi-party R&D collaboration. Moreover, firm size lost its significance after the term of firm interactions with consortium members was added to the analysis, suggesting a possible relationship between the two variables. Since the linear term is insignificant (see Table 4), this relationship may be curvilinear. The number of years in a consortium did not show a significant effect. This is probably because the majority of the member firms joined their respective consortia when the consortia were founded, and thus lacked within-consortium differences in terms of time length. State ownership and the percentage of non-business members were also insignificant. Since those R&D consortia were sponsored and monitored by government agencies, member organizations, state-owned or private, business or not-business, were expected to conform to certain common rules and behavioral

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patterns. Lastly, the number of consortium members did not show meaningful direct effects either. While small consortia may not have adequate knowledge exchanges and industry-wide impact, large consortia are likely to suffer from information overload and managerial difficulties. There probably exists a curvilinear relationship between consortium size and innovation output.

In order to check the robustness of the above results, we allowed the firm-level variables to have random slopes in alternative multi-level models (Snijders, 2005). These models did not significantly improve model fit, and the results were similar to our findings on the hypothesized relationships. Moreover, we considered an alternative, subjective measure of innovation performance. While some scholars showed there was no major systematic disparity among patent counts, patent citations and new product announcements when measuring innovation performance (Hagedoorn & Cloodt, 2003), others were concerned that the number of patents might not fully account for the quality of innovation (Narin, Noma, & Perry, 1987). To address this concern, we asked the respondents to evaluate how much the consortium had helped them produce new products and technology, increase innovation capability, and improve the competitiveness of their products or services on a 5-point Likert scale, with 1 being the lowest and 5 the highest. The average rating was calculated as an alternative measure of innovation performance (Cronbach's alpha = 0.910). The results of multi-level analysis using this measure are shown in Table 5. As shown in Model 2, the squared term of the proportion of market competitors helps improve model fit and has a positive relationship with the self-evaluation of innovation performance. After adding firm interaction with consortium members in Model 3, the squared term becomes insignificant, suggesting a mediating relationship. These results are consistent with our findings obtained for Hypotheses 1, 2, and 3. Different from our prediction in Hypothesis 5, average consortium-level R&D expenditure does not seem to have a moderating effect (see Model 4 and Model 6); instead, it shows a marginal relationship with self-evaluated innovation performance. Certainly, such a marginal relationship does not provide adequate support for a positive direct effect. A possible explanation is that firms may use R&D input as an indicator of innovation performance (Hagedoorn & Cloodt, 2003). Assuming greater input leads to greater output, firms may have positive feelings towards the consortium's R&D efforts. However, such efforts may not yield actual patents if individual firms fail to actively interact with other members on R&D collaboration.

DISCUSSION

This study offers new insights into the interplay of competition and cooperation. The results highlight the intricate nature of coopetition by demonstrating a curvilinear relationship between the presence of a member firm's market competitors and its innovation output in an R&D consortium. Our findings also provide

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Table 5. Examining an alternative measure of innovation performance

	Member firms' self-evaluation of innovative performance					
Variables	*Model 1*	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
Intercept	3.943*** (0.173)	3.671*** (0.192)	3.820*** (0.156)	3.818*** (0.157)	3.923*** (0.137)	3.922*** (0.138)
Firm size	0.077 (0.065)	0.119† (0.064)	0.050 (0.052)	0.051 (0.053)	0.034 (0.051)	0.035 (0.052)
Years in the consortium	−0.070 (0.057)	−0.083 (0.055)	−0.080† (0.045)	−0.080† (0.045)	−0.077† (0.044)	−0.077† (0.044)
The intensity of non-consortium R&D	0.002 (0.055)	0.002 (0.054)	0.008 (0.044)	0.008 (0.044)	0.007 (0.044)	0.006 (0.044)
The intensity of within-consortium R&D	−0.008 (0.059)	−0.006 (0.058)	−0.034 (0.043)	−0.032 (0.043)	−0.033 (0.043)	−0.032 (0.042)
State ownership	−0.067 (0.120)	−0.066 (0.118)	−0.036 (0.096)	−0.037 (0.096)	−0.037 (0.095)	−0.038 (0.096)
Distance to the leading organization	−0.097* (0.049)	−0.106* (0.048)	−0.071† (0.038)	−0.071† (0.039)	−0.066† (0.038)	−0.066† (0.039)
The number of consortium members	−0.025 (0.060)	−0.015 (0.057)	−0.008 (0.045)	−0.007 (0.045)	0.007 (0.044)	0.008 (0.044)
The percentage of non-business members	0.025 (0.060)	0.032 (0.067)	0.041 (0.052)	0.041 (0.053)	0.012 (0.048)	0.012 (0.048)
Averaged consortium-level R&D expenditure	0.159* (0.066)	0.150* (0.062)	0.090† (0.047)	0.087† (0.050)	0.090† (0.049)	0.087† (0.051)
The proportion of market competitors	−0.028 (0.061)	−0.145* (0.071)	−0.038 (0.058)	−0.038 (0.058)		
(The proportion of market competitors)^2		0.227** (0.073)	0.086 (0.060)	0.087 (0.060)		
Firm interactions with consortium members			0.455*** (0.044)	0.454*** (0.045)	0.469*** (0.043)	0.468*** (0.043)
(Firm interactions with consortium members) x (Averaged consortium-level R&D expenditure)				0.010 (0.040)		0.008 (0.040)
Residue effect variance	0.415*** (0.046)	0.408*** (0.045)	0.274*** (0.031)	0.275*** (0.031)	0.273*** (0.030)	0.275*** (0.031)
Random effect variance	0.051 (0.035)	0.034 (0.031)	0.015 (0.020)	0.015 (0.020)	0.016 (0.020)	0.016 (0.020)
Chi-Square	169.798***	175.644***	255.791***	251.263***	261.763***	257.211***

Notes: N = 320. $^{\dagger}p < 0.10$; *p < 0.05; **p < 0.01; ***p < 0.001. Standard errors in parentheses. Industry dummies were included in the analysis but are not reported here for space considerations. Chi-Square values were calculated in comparison to the null model.

empirical evidence for the mediating effect of firm-instigated interactions and the moderating effect of consortium-level efforts.

Specifically, the U-shaped relationship between the presence of market competitors and joint R&D output suggest that having few market competitors provides the focal firm with a unique strategic position, while a strong presence of competitors creates a bandwagon effect, both of which would enhance joint R&D. This curvilinear relationship helps reconcile the conflicting findings in the extant literature. On the one hand, when the presence of competitors is relatively weak, the results are consistent with arguments that diversity in consortium members promotes participation in joint R&D (Okamuro, 2007), and collaborations with suppliers, clients, universities, and research institutes are more likely to increase innovation output than collaborations with competitors (Nieto & Santamaria, 2007). On the other hand, when the presence of competitors is relatively strong, the benefits of working with competitors, such as gaining knowledge (Gnyawali et al., 2006), awareness of technology development (Lomi & Larsen, 1996), and relational capital (Lado et al., 1997), become more pronounced. For a given member firm, a moderate presence of market competitors is not ideal. Neither does it offer the focal firm a unique strategic position, nor enough benefits from working with competitors to outweigh the threat of opportunism.

It should be noted that, while significant relationships have been observed in our data, the effect size of our model is relatively small (Cohen, 1988). This is not surprising because much of the variance in firm innovation output can be attributed to organizational mechanisms and individual level factors (Volberda, Foss, & Lyles, 2010), whereas our study focuses on more observable firm- and consortium-level variables. As Lewin, Massini, and Peeters (2011) have noted, innovation output depends on external routines like knowledge identification, learning, and transferring as well as internal routines like facilitating variation, managing selection and adaptive tensions, sharing knowledge, reflecting and updating. Such intricate processes of learning and innovation cannot be fully captured by R&D spending, a commonly used proxy for firms' absorptive capacity (Cohen & Levinthal, 1990). Nevertheless, while our data did not portray what took place inside the firms, the findings help us better understand how they tend to react to the structural features of R&D consortia. Given our focus on competition and cooperation in R&D consortia, our model can be deemed as reasonably meaningful (Cohen, 1988).

Overall, our findings shed some light on the nuanced relationships within a R&D consortium. In prior work on coopetition, the intensities of competition and cooperation are often given and could have various high-low combinations (Bengtsson & Raza-Ullah, 2016; Czakon et al., 2014). Our results show that the presence of a firm's market competitors has, in fact, a curvilinear relationship with its collaborative interactions. The findings support the existence of a low competition-high cooperation combination and a high competition-high cooperation combination in R&D consortia (Luo, 2007). Moreover, our results reveal the mechanisms through which competition affects innovation output in R&D

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consortia. Member firms react to the presence of market competitors by adjusting their interactions with others, which, in turn, affects joint R&D output. Also, consortium-level efforts can strengthen the impact of interfirm interaction on innovation output. The results highlight the differential roles of firm-instigated interactions and consortium-level efforts in attenuating the influence of coopetition on innovation. This insight has not been forthcoming in the alliance literature, which primarily focuses on dyadic relationships, in which collaborative mechanisms at the firm level cannot be meaningfully separated from those at the alliance level (Bengtsson & Raza-Ullah, 2016; Polidoro et al., 2011). By focusing on coopetition dynamics in R&D consortia, our study disentangles efforts by firms to manage collaborative activities from those at the consortium level.

Furthermore, this study answers calls by several recent papers for empirical research on coopetition in distinct contexts (Bengtsson et al., 2016; Gnyawali & Song, 2016; Park et al., 2014). Our research represents a novel effort to empirically examine the impact of competition and coopetition on innovation in the context of R&D consortia in China. Firms rarely report formal quantitative data on their collaborative activities in public statements, and performance outcomes specific to interfirm collaborations are often confounded with those from internal operations (Lavie, 2007). To overcome such empirical challenges, we compiled a unique dataset using information gathered from interviews, surveys, and archives. More importantly, we employed multi-level analysis to examine cross-level relationships using data at both the firm and consortium levels of analysis. In doing so, our article is able to shed light on when and how innovation output can be generated through consortium collaboration.

In addition, our analysis outlines the boundary conditions for the innovation impact of competition and cooperation in R&D consortia, thus offering useful insights for policy makers and managers working with large multi-party collaborations. Specifically, member firms need to pay close attention to their market competitors, the presence of which has a curvilinear impact on collaborative interactions and joint R&D output. When there is a weak presence of competitors, member firms can leverage their exclusive market access to elicit more collaborations within a consortium and generate more innovation output. When there is a strong presence of competitors, member firms benefit from joining the bandwagon to stay on top of technology developments. In addition, governments and leading organizations that oversee R&D consortia need to carefully consider the composition of members, which may significantly influence joint R&D output. They also need to recognize the importance of consortium-level efforts, which may enhance the effectiveness of interfirm interactions in R&D consortia.

Limitations and Future Research Directions

The limitations of this study should be acknowledged. First of all, some measures could be further refined. Assuming only capable firms were allowed to join the

https://doi.org/10.1017/mor.2018.49 Published online by Cambridge University Press

consortia, we used the proportion of market competitors to indicate competition within a consortium. The alliance literature suggests that partners with different characteristics may have different behavioral patterns (Ahuja, 2000a), which affect their relationships and performance (Li et al., 2011). It is possible competition within a consortium is subject to differences among competitors. Also, consortium-level effort was measured with a proxy of averaged consortium-level R&D expenditure. Although this proxy reflects centralized R&D input, it may not fully account for other types of collective efforts, such as patent pools (Lampe & Moser, 2016) and relational governance (Bouncken, Clauß, & Fredrich, 2016). Future studies could explore alternative measures for these variables.

Moreover, while both the structural and strategic aspects of R&D consortia evolve over time, we were only able to obtain cross-sectional data. Since we examined R&D collaboration during a three-year period, our ability to infer strong causal linkages for the relationship between coopetition and innovation is limited. In addition, although this study is a rare empirical study on multi-party alliances, it is necessary to consider the generalizability of our results. For instance, the organizing principles in R&D consortia are different from those found in other settings involving interfirm collaboration, such as alliances bound by production, marketing and distribution agreements. Also, our findings in China may not hold in other emerging market or advanced economies and should be interpreted carefully with the context in consideration.

Future research can work towards including other variables that may have an impact on the innovation performance outcome examined in our article. For instance, prior research suggests that coopetition in alliances could also be influenced by the network position of member firms (Ahuja, 2000a; Gnyawali et al., 2006), and the extent to which the firms are able to establish trust (Lado et al., 1997). In order to shape the competitive environment in a favorable way, firms tend to cooperate in the early stages (with greater common interests) of the value chain and then compete (with higher conflicting interests) in product markets (Sanchez, 2008). The inclusion of pertinent variables that capture these factors may help to further explain the impact of competition and cooperation on innovation. Moreover, government involvement in these consortia may affect the interplay of competition and cooperation therein. All the consortia in our study were endorsed and supported by the government, with government agencies involved in various ways, such as direct funding, tax credits, low-interest loans and subsidies, at the firm, project, and consortium levels. Because of practical constraints, we were not able to directly measure such government involvement. Future research in devising innovative measures to quantify government involvement in R&D consortia may be valuable.

Lastly, while our study focuses on the output of joint R&D within consortia, future research may explore other aspects of innovative performance, such as knowledge acquisition, patent citations, and new product announcements (Hagedoorn & Cloodt, 2003; Li et al., 2011). Since most patents were newly produced and many

R&D projects focused on basic research and process innovation, we did not have meaningful data on patent citations and new product announcements. In an extended study, we investigated the relationship between the presence of a member firm's market competitors and its knowledge acquisition, measured with the number of other members' patents the focal firm had accessed in the preceding three years. Neither linear nor curvilinear relationships were found, suggesting that the mechanisms underlying knowledge acquisition may be different from those that facilitate joint R&D. As suggested by Lee, Park, and Bae (2017) in a recent study, licensing-in others' technology does not always enhance follow-up innovation. While our main study focused on joint R&D output, this extended study examined member firms' private gain from consortium participation (Khanna, Gulati, & Nohria, 1998). More research is needed to understand the relative role of private gains and common benefits in R&D consortia.

NOTES

We are thankful for the comments from the editors and reviewers, and we also thank Michael S. Cheng for his research assistance. This research was supported by the National Natural Science Foundation of China (Grant No. 71272019 & 71872100).

[1] The Ministry identified two more batches of consortia in 2012 and 2013, respectively. Since we lacked information on these additional batches of consortia at the time of data collection, and many of them were not established long enough to have developed meaningful collaborations, these consortia were not included in this study.

[2] Given our research focus, we examined individual member firms' innovation output within a consortium. It should be noted that the member firms could produce patents outside of the consortium, working on their own or collaborating with non-members. The respondents were clearly instructed to separate the patents produced in the consortium from those produced outside of the consortium. Certainly, it is possible that firms may apply learning from consortium collaboration to their own innovation, which is beyond the scope of this study.

[3] Given the recent debate on statistical significance (Benjamin et al., 2018), we acknowledge that such a marginal relationship lacks statistical significance. In this article, marginal relationships are reported for informational purposes and are not considered as meaningful findings.

[4] In the two-lines test, the breakpoint is set to maximize statistical power rather than fit (Simonsohn, 2018).

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Manuscript received: April 29, 2017
Final version accepted: September 3, 2018 (number of revisions – 2)
Accepted by: Guest Editor Jay Barney