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Tensions in R&D networks: Implications for knowledge search and integration

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ABSTRACT

R&D Networks comprise different actors with various goals and motivations. Thus, such networks are filled with tensions that emerge from simultaneously existing, competing or contradictory organizing elements and demands. In this study, we examine the knowledge search and integration behaviour of firms participating in R&D networks in the Dutch aerospace sector. We find evidence of a multitude of tensions that have implications for knowledge processes of firms and within R&D networks. These tensions are grouped into dialectical and paradoxical tensions. In particular, paradoxical tensions require simultaneous attention to the different organizing elements, while dialectical tensions create either/or situations that need to be carefully managed. We find two types of dialectical tensions: openness of core knowledge exposure and inclusiveness of knowledge sharing behaviour; and three types of paradoxical tensions related to innovation goal alignment, coopetition, and actor interdependence. Overall, our results provide unique insights to how participants of R&D networks perceive tensions involved in knowledge search and integration, how the network role of the actors affects these perceptions, and what types of tension-resolving mechanisms are adopted in different types of networks.

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1. Introduction

Search and integration of valuable knowledge are key processes that motivate firms to participate in multi-actor R&D networks (Cowan and Jonard, 2009; Powell et al., 1996). Through the multi-actor knowledge processes, such networks provide opportunities for collective innovation efforts which would be unattainable without collaboration (Dhanaraj and Parkhe, 2006; Fjeldstad et al., 2012). However, R&D networks are far from being stable and easy-to-manage. Such networks are dynamic loosely coupled coalitions, that involve issues such as coopetition (see e.g. Yami and Nemeh, 2014), rotating leadership (Davis and Eisenhardt, 2011), appropriation challenges and knowledge leakage (Dhanaraj and Parkhe, 2006; Ritala et al., 2015), and other elements of relational and contractual complexity. To better understand these issues, this paper explores the tensions that emerge from R&D networks, and the outcomes of those tensions to knowledge search and integration processes. Much of the previous research on R&D networks adopts a rather structural perspective (see e.g. Ghosh and Rosenkopf, 2014), and pays less attention to the tensions that affect the internal dynamics of those networks. As the success of R&D and innovation activities is grounded on effective knowledge search and integration (see e.g. Savino et al., in press), we argue that it is important to

understand the role of tensions that affect these delicate inter-organizational knowledge processes.

To bridge the above-mentioned research gap, this paper studies the tensions of actors that join and participate an R&D network. While the literature over organizational (Birkinshaw et al., 2016; Gaim and Wählin, 2016) as well as inter-organizational tensions (Gnyawali et al., 2016; Tidström, 2014; van Fenema and Loebbecke, 2014) has started to accumulate, very little has been done yet in this area regarding the different types of tensions in R&D network context. Given the complex and uncertain nature of collaborative innovation (Dhanaraj and Parkhe, 2006), we argue that understanding the influence of tensions on the processes and outcomes of R&D networks could generate promising insights for both managers and academics in the field of R&D and innovation management. Foss et al. (2013) found that organizational design matters for external knowledge search in terms of innovation outcomes. Similarly, we expect that the organizational design in R&D networks – and especially the tensions emerging from such designs and configurations – affect actors' ability and willingness to search and integrate knowledge. Indeed, several authors have advocated the importance of how R&D networks are designed and organized (Dhanaraj and Parkhe, 2006; Fjeldstad et al., 2012), and recently called for more studies on the role of tensions and the related resolution mechanisms in inter-organizational networks and relationships (Gnyawali et al., 2016; van Fenema and Loebbecke, 2014). In the current study, our approach is qualitative and explorative in that we outline the general sources of tensions in R&D networks, after which we inductively identify the key tensions from the qualitative study in the Dutch Aerospace

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sector. We particularly focus on knowledge-related tensions, given that the valuable resources exchanged and created have argued to rely on mostly knowledge within and between actors and networks (e.g. Baum et al., 2010; Schilling and Phelps, 2007).

Our research question is: What kind of tensions exist in knowledge search and integration processes in R&D networks and which mechanisms are applied to resolve these tensions? By focusing on tensions and their resolution mechanisms, rather than the general management or coordination of the networks as such, we analytically depart from the larger body of literature focused around managing or orchestrating R&D and innovation networks (e.g. Dhanaraj and Parkhe, 2006; Nambisan and Sawhney, 2011; Paquin and Howard-Grenville, 2013). We do this for three main reasons. First, almost each network contains more participating firms than orchestrating firms, so it is important to understand their perception of the networks rather than focusing on hub-firm coordination activities only. Second, many smaller firms have not much influence in deciding which other firms will be the network members, as they can only decide whether they will join the network or not, and in this assessment they will perceive and evaluate the inherent tensions. Third, tensions and related resolution mechanisms are often perceptual and local to the firm, and therefore studying them using our approach will provide important evidence of knowledge behavior of actors in R&D networks. Thus, in this study we develop an approach that analyzes the tensions perceived by the focal actor in R&D networks, and how this affects the relevant knowledge processes. We also examine how the network roles of the firms as well as the characteristics of the networks affect the perceived tensions and the related tensions-resolution mechanisms.

The remainder of this paper is structured as follows. First, we discuss the key concepts and the theoretical background of the study. Second, we discuss the qualitative case study methodology used to analyze tensions in Dutch Aerospace R&D networks. Third, we analyze in detail the findings related to different types of tensions and their role in knowledge search and integration processes. The study ends with discussion and implications. The findings provide evidence of a broad diversity of tensions in R&D networks, and show how the network role (central or peripheral) of the firm affects these perceptions. We also find patterns of different tensions related to networks having different characteristics in the knowledge proximity between actors. These findings contribute to the literature of R&D networks in providing an elaborated view of perceived dialectical and paradoxical tensions, as well as the related dynamics and contingencies.

2. Theoretical background

2.1. R&D networks

The term *R&D network* refers to a group of contractually and relationally interconnected organizations with a common mission and purpose that seeks to gain innovation benefits that could not be achieved independently (see e.g. Arranz and de Arroyabe, 2007). The participants include various types of private and public organizations that seek to share risks and achieve common R&D goals by pooling resources and integrating knowledge (e.g. Biggiero and Angelini, 2015; Lee and Kim, 2016-in press). R&D networks – as a context – belong to the broader literature on collaborative innovation (e.g. Fjeldstad et al., 2012), innovation networks (Dhanaraj and Parkhe, 2006) and interfirm networks (Ghosh and Rosenkopf, 2014). R&D networks focus on the early phases of the collaborative innovation, where knowledge is searched and integrated in order to create new, valuable combinations that have potential to create new products, processes, and services (see e.g. Aarikka-Stenroos and Sandberg, 2012).

In this study, we focus on the focal firm's participation in and perception of R&D networks. In our analysis, the focal firm is not always orchestrating or assembling the network (on orchestration, see Dhanaraj and Parkhe, 2006), but participates in the network and reflects on its own

role and perceived tensions as a part of the network. Many firms have no or only very limited influence on which other firms are in the network. Innovation and R&D network research has typically overlooked such “peripheral firms” and their decisions (Ritala and Huizingh, 2014), and thus we believe that the adopted broad-based perspective is valuable. In fact, when thinking about a typical hub-and-spoke network structure, the peripheral firms are the large majority, and have to adopt to the possibilities and limitations offered by the larger network fabric consisting of different actors and their roles.

2.2. Knowledge search and integration in R&D networks

Innovation processes consist of actors searching for knowledge, and of combination and integration processes of that knowledge (for a recent review, see Savino et al., in press). Martini et al. (in press) found that external search is ineffective when the firms are not able to share the knowledge internally. The same issue has been noted in the inter-organizational context. Knowledge integration across organizational boundaries is necessary in order to create novel knowledge combinations and eventually new innovations (Cowan and Jonard, 2009; Powell et al., 1996). In our study, we utilize these insights in the R&D network level in suggesting that knowledge sharing between the actors in the network is a complex and volatile process, which deserves more attention.

One stream of research concentrates on *knowledge search* and related strategies, processes and outcomes. For instance, several studies have highlighted the importance of external idea involvement in R&D processes (e.g. Henttonen et al., 2011; Laursen and Salter, 2006; Tether, 2002). This literature has shown that external ideas to firms' R&D processes create value and novelty due to the complementary knowledge and ideas that can be integrated in a firm's internal R&D, and facilitate subsequent development of innovations. Literature on open innovation (and especially inbound open innovation) provides extensive discussions of how such mechanisms work (see e.g. West and Bogers, 2014). It is noteworthy to mention that knowledge search behavior is a two-way, reciprocal phenomenon (Ritala et al., 2015; Tranekjer and Knudsen, 2012). This means that firms participating in R&D networks cannot easily assume an asymmetric search mode where they would receive valuable knowledge, but not allowing for other actors to search knowledge from their own domains. On the other hand, asymmetries in the search behavior could be a source of tension between the network actors.

Another stream of relevant literature focuses on the processes of *knowledge integration* between firms in R&D and innovation networks. Integration of complementary and supplementary knowledge as such is a key motivation to form inter-organizational relationships (Grant and Baden-Fuller, 2004), and especially in R&D collaboration (Cowan and Jonard, 2009; Powell et al., 1996). The existing research concentrates, for instance, on how knowledge sharing and integration is facilitated and orchestrated (Dhanaraj and Parkhe, 2006; Nambisan and Sawhney, 2011). Many studies also argue that knowledge integration in networks is a delicate process, which is full of frictions, tensions, and contradictions (Alexy et al., 2013; Ghosh and Rosenkopf, 2014). In the remainder of this study, we will use the terms knowledge sharing and integration as synonyms.

We expect that firms participate in R&D networks for both reasons: to search for valuable external knowledge, and to share and integrate knowledge with other network actors. We also argue that these processes strongly depend on the key organizing elements of R&D network, and the related tensions. The following section discusses these issues.

2.3. Tensions in the organizing of R&D networks

The literature on R&D and innovation networks has discussed the coordination (e.g. Dhanaraj and Parkhe, 2006; Gardet and Fraihia, 2012; Nambisan and Sawhney, 2011), the structure and the dynamics

(Biggiero and Angelini, 2015; Calia et al., 2007; Powell et al., 1996; Van der Valk et al., 2011), as well as the interaction and knowledge exchange between actors (e.g. Lee and Kim, 2016-in press; Sammarra and Biggiero, 2008). Overall, this literature has shown that the organization of the network is tightly related to the knowledge processes. However, what is less explored is what inter-organizational tensions are involved and how they affect the knowledge search and integration behaviour.

Literature on organizational tensions has shown that strategic dualities and contradictions are found in all areas of organizing, and they have a major effect on organizational behaviour (Smith and Lewis, 2011; Smith and Tushman, 2005). Recently, it is suggested that tensions can be either a source of negative, suppressive or creative behaviour (e.g. Gaim and Wählin, 2016). In particular, Birkinshaw et al. (2016) suggest that organizations can deal with tensions arising from strategic dualities by viewing them as dilemmas, as dialectics, or as paradoxes. Dilemmas refer to competing choices with specific pros and cons, dialectics are ongoing processes to solve dilemmas, and paradoxes refer to contradictory but interrelated elements that simultaneously persist over time (ibid.). Recently, literature has started to explore paradoxical and other tensions in inter-organizational settings (e.g. Gnyawali et al., 2016; Järvenpää and Wernick, 2011; Tidström, 2014; van Fenema and Loebbecke, 2014).

R&D networks involve heterogeneous actors that behave differently (Corsaro et al., 2012); they have both joint and divergent goals, as well as different types of motivations, resources, and capabilities. Therefore, such networks represent a tension-laden context, which has an effect on knowledge search and integration processes. We argue that therefore a tensions approach (including dilemma, dialectic and paradox viewpoints) could be a feasible way to examine organizing in R&D networks. We especially highlight two broad themes related to tensions in R&D networks.

First, a broad research theme over tensions in R&D networks is that of *coordination*. Coordination and governance in inter-organizational relationships involves processes that are partially overlapping and sometimes in conflict. These include elements such as relational and contractual, formal and informal (e.g. Blomqvist et al., 2005; Poppo and Zenger, 2002), as well as coordination and self-organization (Biggiero and Angelini, 2015; Möller and Svahn, 2006). Thus, governance in R&D networks is subject to complex dynamics where different actors can adopt different roles, and various governance modes are utilized (e.g. Arranz and de Arroyabe, 2007; Aarikka-Stenroos and Sandberg, 2012). We expect that these issues play a major role in affecting the knowledge search and integration behaviour. One particularly persisting tension in R&D network is that of *coopetition* (Gnyawali et al., 2016). Coopetition refers to simultaneous competition and collaboration among members of the same R&D network (see Bengtsson and Kock, 2000; Gnyawali and Park, 2011; Ritala and Hurmelinna-Laukkanen, 2009). The phenomenon of coopetition in a R&D network context has been examined and recognized in several case-based studies (e.g. Carayannis and Alexander, 2001; Gueguen, 2009; Ritala et al., 2009). For instance, it has been noted that coopetition relationships can be helpful in effective knowledge integration due to shared industry and technology understanding of the competing actors, but at the same time the risks of unwanted knowledge spillovers are increased (e.g. Gnyawali and Park, 2011; Ritala and Hurmelinna-Laukkanen, 2009). Coopetition also involves inherent tension between knowledge sharing and protection, which affects the internal knowledge processes and innovation outcomes (e.g. Levy et al., 2003; Baumard, 2010; Estrada et al., 2016; Fernandez and Chiambaretto, 2016).

Second broad theme is the *knowledge search and integration process itself*. Knowledge processes in R&D networks are challenging, since innovation activities always relate to varying levels of uncertainty, ambiguity, and risk-taking. However, in order to create value and strife, R&D networks require knowledge exchange to take place (e.g. Baum et al., 2010; Schilling and Phelps, 2007). Firms in inter-organizational relationships consistently face the paradox of sharing and protecting knowledge at the same time (Järvenpää and Majchrzak, 2016), and

this issue is especially highlighted in R&D context (e.g. Bogers, 2011; Alexy et al., 2013; Ritala et al., 2015). Laursen and Salter (2014) call this the 'paradox of openness', where the benefits of sharing are evident, but the risks related to it increase at the same time. To deal with such issues, firms have suggested to apply several knowledge sharing strategies such as 'selective revealing' (Alexy et al., 2013).

To better understand these types of tensions in R&D networks and their knowledge processes, we report in the following sections results from a qualitative study conducted in Dutch aerospace sector.

3. Methodology

3.1. Research design

The research setting is R&D networks in Dutch aerospace industry. The aerospace industry is a fast growing and globalized industry, which brings many managerial challenges (for discussion on R&D collaboration in European aerospace sector, see Fernandez et al., 2014; Biggiero and Angelini, 2015; Le Roy and Fernandez, 2015). The industry involves a highly competitive environment, organizations with very advanced technical capabilities, a high level of globalization, intense need for companies to use open innovation, and at the same time high level of secrecy to protect in-house intellectual property (IP). Along these lines, previous research (Dussauge and Garrette, 1995; Salvétat and Géraudel, 2012) has identified the aerospace engineering sector as being very appropriate for studying tension-related issues in R&D, such as competition.

Our research approach is a qualitative study, focusing on R&D networks as an organizing context and the knowledge search and integration processes that are enacted in them. The adopted qualitative approach follows from our research goals and the exploratory nature of the study, where we inductively derive the key tensions and related resolution mechanisms. This research approach enables us to gain a rich understanding of the studied phenomena and the enacted processes (see, e.g., Graebner et al., 2012). We collect data from representatives of six Dutch Aerospace sector firms that together comprise the key players in this sector involving the most important manufacturers and developers of materials and solutions for the broader global aerospace industry. Table 1 summarizes the data collection (for confidentiality reasons, the firm and network names have been anonymized). The interviewed firms have been selected due to their involvement and extensive experience in different types of R&D networks in the aerospace sector. Each of the firms were involved in several networks at the time of interviewing, but for each firms' case, we focused on just two networks (except for one network with Firm E). This diversity allows for a comparative setting across the firms and R&D networks, and thus helps in answering our research questions. The data collection and analysis procedures are discussed in detail in the following sections.

3.2. Data collection

The data collection includes three industry context interviews with experts and managers from the aerospace industry in Netherlands, and six thematic interviews focusing on R&D networks. The interviewees represent the different types of actors in the R&D networks (e.g. large and small firms, central and peripheral firms). Interviewing such a wide variety of actors enables us to identify different forms of knowledge sharing and related tensions. We also accessed publicly available documents and press releases related to each of the studied firms and R&D networks in order to obtain a broader perspective to the industrial profile of each firm, as well as to the nature of the collaboration and technologies developed in the various networks.

The first data collection stage consisted of three general level, in-depth interviews on the dynamics of R&D collaboration in aerospace industry networks followed an unstructured interview guide. We utilized

Table 1
Summary of the focal companies in the data & the analysed R&D networks.

Company	Industry profile	R&D networks discussed in the interviews
<p>Firm A: Parts integrator, 1000 + employees</p> <p>Interviews: R&D director (industry overview); R&D Project leader (case interview)</p>	<p>The company is a leading parts integrator in the aerospace industry, and has no major national competitors. The company designs, develops and manufactures aircraft systems for aircraft manufacturers and provides support services. It is involved in different parts of the aerospace industry value network.</p>	<p>AeroEffect:</p> <ul style="list-style-type: none"> – 9 actors: competitors, customers, governmental parties, universities, research institutes – Focal firm role: not a central role, supplier to a large player in the network <p>TechnoCenter:</p> <ul style="list-style-type: none"> – 10 actors: suppliers, customers, governmental parties, universities, research institutes – Focal firm role: co-founder of the network <p>COMPO:</p> <ul style="list-style-type: none"> – 9 actors: suppliers, customers, governmental parties, universities and research institutes – Focal firm role: component provider, non-central role
<p>Firm B: Product manufacturer; 200 + employees</p> <p>Interviews: Two interviews with R&D director (industry overview and case interview)</p> <p>Firm C: Material manufacturer; 600 employees</p> <p>Interviews: R&D manager (industry overview); business development manager (case interview)</p>	<p>The company designs and manufactures advanced composite structures for the aircraft and space industry, as well as for other industries. Highly automated manufacturing processes differentiate them from other structure suppliers in the international supply chain.</p> <p>The company is a leading supplier of composite materials for the aerospace and industrial advanced composite industry. The application of the materials ranges from recreational equipment to prosthetics to satellites. Has reached a dominant position in specific technology applications.</p>	<p>ProjectNextGen:</p> <ul style="list-style-type: none"> – 10 actors: universities, research institutes, material suppliers, clients, OEM's, product manufacturers tooling, software companies – Focal firm role: co-founder of the network <p>AviaNetwork:</p> <ul style="list-style-type: none"> – 5 actors: parts manufacturers, research institute, tooling manufacturer – Focal firm role: co-founder of the network, sole provider of the technology, largest member <p>COMPO:</p> <ul style="list-style-type: none"> – 9 actors: suppliers, customers, governmental parties, universities and research institutes – Focal firm role: component provider, non-central role <p>PlasticWing:</p> <ul style="list-style-type: none"> – 4 actors: customer, complementary firm, university – Focal firm role: non-central role, manufacturer of components
<p>Firm D: Manufacturer of components; 25–50 employees</p> <p>Interviews: R&D project leader (case interview)</p>	<p>The company is a custom moulder of continuous fiber reinforced polymer components. Most of their customers can be found in the aerospace industry. Their products are typically small load carrying elements.</p>	<p>COMPO:</p> <ul style="list-style-type: none"> – 9 actors: suppliers, customers, governmental parties, universities and research institutes – Focal firm role: component provider, non-central role
<p>Firm E: Manufacturer of components and material processing; 25–50 employees</p> <p>Interviews: Managing director (case interview); commercial manager (case interview)</p> <p>Firm F: Manufacturer of components; 10–15</p> <p>Interviews: Managing director (case interview)</p>	<p>The company is an SME operating in the aerospace, medical, and automotive industry. They make use of high quality composite materials for their products. The company focuses on the design optimization, engineering, research, and technology development.</p> <p>An innovative developer and manufacturer of thermoplastic composite products and components. They focus improving product performance using the complete range of thermoplastic composite materials for all suitable applications, including aerospace industry and many others.</p>	<p>COMPO:</p> <ul style="list-style-type: none"> – 9 actors: suppliers, customers, governmental parties, universities and research institutes – Focal firm role: non-central role <p>InnoSale:</p> <ul style="list-style-type: none"> – 15 actors: SME's, end users, parts manufacturers, tooling companies, customers – Focal firm role: invited partner <p>TechnoCenter:</p> <ul style="list-style-type: none"> – 10 actors: suppliers, customers, governmental parties, universities, research institutes – Focal firm role: peripheral, with a limited access to relevant knowledge

these interviews to gain a richer contextual understanding, and to help in formulating the interview guide for the second round of interviews.

The second data collection stage was conducted with seven respondents from six different firms (one interview had two informants, others had one). They followed a semi-structured interview guide focusing on understanding the peculiarities of participation in different types of R&D networks. First, general questions were asked about the firm's innovation activities in R&D networks and then respondents were asked to identify R&D networks in which their organization has participated. After that, a list of specific questions about those networks were asked, related to the network actors, duration, company role and position, and products and services developed. This was followed by a set of questions related to the motives, goals, risks, and costs of R&D collaboration. Specifically, the respondents were asked to evaluate any financial, knowledge-related, technological, strategic, and relational motives and/or risks involved in the various networks. The respondents were also asked specific questions about how the involvement of their competitors has influenced their participation in the various networks. During the interviews, as the participants made observations, follow-up questions were asked to extract more information or to learn why those observations were important to the participants (e.g., "Could you give me an example of...?"). In addition, one of the authors has extensive industry experience from the studied industry context, which allows for developing a better understanding of how R&D networks operate, as well as to conducting well-informed follow-up questions in during the interviews. The interviews lasted between 1.5 and 2 h, and all interviews were recorded and transcribed.

3.3. Data analysis

The overall aim of the data analysis is to uncover comparative patterns across the firms and R&D networks, in that they help to understand the knowledge search and integration processes within R&D networks and the influence of organizing tensions in them. In the first phase of data analysis, the third author individually conducted a qualitative content analysis. We started our analysis with inductive coding procedures like those suggested by Miles and Huberman, 1994). This phase involved coding sentences or segments of the data depending on their richness. In this phase we tried to remain open to what our material suggested. In the next stage of our analysis, our knowledge of prior theory of R&D collaboration and knowledge sharing processes acted as an analytical lens through which we interpreted and organized the data to gradually raise our level of abstraction. While coding, we took an interrogative approach to the data and tried to detect any processes and actions. The first author was also actively involved in this second phase of our analysis where through discussions and multiple iterations with the data, our initial codes and prior theory, we felt that saturation had been reached. The second author was also involved in the second stage of analysis, questioning the analytical decisions made, and helping to raise the level of abstraction. The overall process allowed for an inductive-deductive iteration cycle between the empirical analysis and the relevant literature (Eisenhardt and Graebner, 2007). Furthermore, the different analytical roles allowed the author team to utilize researcher triangulation, providing a more overarching and diverse set of viewpoints, which we synthesized during the analysis process. Finally, we analyzed the identified tensions against the profile of the focal firm in each network (as is later illustrated in Table 2) as well as the characteristics of each network (as later illustrated in Table 3). The results presented in the following section are an outcome of this analysis process.

4. Findings

Our empirical analyses revealed that there are two types of organizing tensions in R&D networks related to knowledge search and integration processes: dialectical tensions and paradoxical tensions (see Fig. 1).

The dialectical tensions are related to the competing choices that cannot be fully resolved long-term, while paradoxical tensions are related to the persisting variety of contradictory organizing elements within the same context (see Birkinshaw et al., 2016). In our study, we found that dialectical tensions required the firms to make clear choices between specific issues over knowledge search and integration processes, while paradoxical tensions facilitated a more diverse set of behavioral and decision-making dynamics.

As for dialectical tensions, we found two specific types that relate directly to the nature of knowledge search and integration processes. The first tension relates to the openness of the focal firm's 'knowledge boundaries' towards the R&D network, concerning choices over the knowledge being shared to other network members. The second tension relates to the inclusiveness, which refers to the breadth of knowledge sharing across different network members (e.g., sharing with all members or sharing only with some particular members). These tensions can be considered as dialectical, since for a specific act of knowledge search or sharing, firms are required to engage into either-or behavior over the dualities of open/closed and inclusive/selective.

For paradoxical tensions, we have identified three types emerging across the networks: knowledge integration novelty (exploration and exploitation), coopetition (collaboration and competition), and actor interdependence (independence and interdependence). All of these three paradoxical tensions involve two analytically polar opposites which both persist over time, and are perceived in the context of R&D networks by the focal actor. Below, we discuss in detail the tensions found in our field study and how they influence the knowledge search and integration dynamics.

4.1. Dialectical tensions in knowledge search and integration

In the analysis, we have found that firms face a dialectical tension that forces them to conduct decisions of how to search, share, and integrate knowledge. In particular, we found that firms made deliberate decisions with respect to the degree of openness (open vs. closed) and inclusiveness (inclusive vs. selective). Openness characterizes the decision to what and which extent knowledge is exposed to the other R&D network members, while inclusiveness relates to the decisions of either sharing knowledge to all network actors, or by carefully selecting the actors to whom they share knowledge.

In terms of *openness of knowledge sharing behavior*, some of the firms adopted a notably open approach which means that their knowledge exchange within the R&D network was broad and did not typically have clear boundaries. This approach was related to the expected reciprocal benefits of open knowledge sharing, where knowledge shared showcases the firm's technological excellence to other members, providing potentially new customers and use cases. The openness was also seen as beneficial from a relevance perspective: the more knowledge sharing, the better the particular network goals could be achieved. On the other hand, many firms identified a clear risk of proprietary knowledge leakage, which initiated a high dialectical tension and the adoption of a closed approach. In many cases, the firms' core technology is in an advanced commercial stage and usually only developed incrementally in-house. Thus, many companies chose to share only the results and applications to others, while keeping the details and technologies to themselves. Some firms had clearly chosen not to share core knowledge at all. Such closed knowledge sharing behavior was not only identified from the focal firm perspective, but also other R&D network actors were singled out as not sharing knowledge by several respondents.

In terms of *inclusiveness of the knowledge sharing behavior*, we found much evidence of dialectical tensions forcing companies to adopt an inclusive or selective behavioral mode. Inclusive behavior was adopted by several companies who signaled the benefits of broad sharing of information to help to proceed with the R&D network's goals. As for more selective knowledge sharing, many of the firms showed both carefully

crafted approaches within specific networks, as well as total exclusion of specific types of partners. One company commented this quite eloquently by stating that *“So it's open innovation in the sense that you work, and you have all your own expertise, but you're a little careful to lay it all on the street”*. The tension also showed up very strongly up to a point of refusing to collaborate with certain actors based on their geographical background and related uncertainty. Furthermore, some companies pointed out that they might share knowledge to their key clients (who are included in a particular R&D network) in private discussions, but not to other members of the network.

Overall, these types of behavior show that the knowledge search behavior is encountered by dialectical tensions at the firm level, as each firm involved in a network makes independent decisions whether to share certain knowledge and to whom. However, it is also noteworthy that these independent decisions overall determine how knowledge search and integration processes work in the network level.

4.2. Paradoxical tensions in R&D networks

Our analysis reveals three paradoxical R&D network tensions that influence the knowledge sharing dynamics among the members of the networks. These tensions are related to innovation goal alignment, coopetition and actor interdependence, and require constant balancing of the focal firm. This dynamic will be discussed in connection to each of the three paradoxical tensions.

4.2.1. Innovation goal alignment

The actors' innovation goals are an important driver for knowledge search and integration processes in R&D networks. We found that these vary between explorative and exploitative goals, even within particular networks. This tracks back to the classic organizing paradoxes of exploitation and exploration; or in other words, old and new (e.g. Lewis, 2000). The paradoxical tension over exploitative and explorative innovation goals in the R&D networks emerges from the persistence of different pursuits of network participants. The larger the differences between the goals of each actor and the broader network, the higher the goal setting misalignment, and the higher the inter-actor tensions in this regard. In general, we found that the actors often have clear views of their own innovation goals. For instance, in some networks the actors pursue explorative innovation goals, which interviewees indicated quite explicitly: *“...we develop a radical new technology, at this moment those products are not or barely on the market”; “Pretty radical development, we're not optimizing any existing processes.”* In several of such instances, the tensions over goal alignment was deemed rather low, as explorative, open-ended results were in everyone's interest. On the other hand, there were also high tensions regarding the differences and poor visibility over exploitative and explorative goal setting by focal actor vis-à-vis others in the R&D network. Such potential misalignment was identified within even collective goal setting contexts, where other actors were perceived to locally optimizing their own goals, while waiting to see what would emerge from the overall network. Some companies recognized this tension explicitly by highlighting their individually-originated goal setting in the context of the R&D network: *“And it is only the question if we achieve what we set out to achieve”; “If we can earn money with it. That is ultimately what is at stake”*.

When the innovation goal alignment tension is high, i.e. firms' exploration and exploitation goals diverge a lot, the dialectical tensions over knowledge search and integration processes become more pronounced. There could be many reasons for this. For example, participants in several of the R&D networks are simply not willing to share their unique information about a radical new technology, or have different types of goals: *“we are looking for shorter cycles (short term innovation) and flexibility”*. Overall, these types of tensions affect both their innovation goal setting (more exploitative) as well as their knowledge

sharing behavior (closed and selective). On the other hand, when such tensions are low, the knowledge search and integration processes become more pragmatic and flexible: *“We are very open to adopting technological solutions from partners”*.

4.2.2. Coopetition

The tension of simultaneous competition and collaboration (i.e. coopetition) characterizes well the dynamics of R&D collaboration in aerospace industry. In our study, we found that the coopetition tensions can be considered as paradoxical since they are persistent over time, while the tension itself can range from low to high. Low coopetition tensions are found in networks where no or only indirect competitors are involved, whereas medium-high coopetition tensions are present in networks where at least one direct competitor is involved. In any case, the potential of competitive dynamics is present, either indirectly via other firms, or directly due to competitor involvement in the same network. In general, coopetition was perceived to increase complexity of operating in R&D networks. In a network with a lot of members, including one or several competitors, the decision making was perceived as especially difficult. On the other hand, in networks with low coopetition tension, the collaboration with indirect competitors could be more intense. These types of (low-coopetition) networks are also perceived as an opportunity for learning as well as a means for finding a suitable customer segments, improve competitiveness, and getting access to new customers.

We observed clear patterns regarding coopetition tensions and the dialectical choices regarding openness and inclusiveness of knowledge processes. In networks with low coopetition tensions the firms suggested that knowledge sharing was relatively open, often unconstrained and certainly more inclusive, as there were no major concerns regarding knowledge appropriation. In networks with higher coopetition tensions, the knowledge sharing process was more selective, and more careful choices were made on what knowledge was made available in the network, and to which actors.

4.2.3. Actor interdependence

Actor interdependence reflects to what extent the actors are interdependent on each other when technological solutions are developed. If the actors are highly interdependent, the success of their technological development is based on the activities of other actors in the network, while when the actors are highly independent, their success is mainly in their own hands. However, any R&D network setting always involves a persisting tension between a certain level of interdependence between network members, and a certain level of independence and autonomy.

In the studied R&D networks, it became clear that no firm alone has all the necessary expertise and capabilities to reach its technological goals. However, the level of interdependence between actors in R&D networks can vary from low to high depending on issues such as the position of the firm in the value chain, how central the new technology is for their business, and their motivation for being part of a network. When firms do not develop core technology in the network, regard the network as a means of networking, and/or make themselves and their products visible to potential customers, the level of interdependence is pretty low. In these type of networks, even if the network goals are not met at the end, the networking can still be of value for other (commercial) objectives of the firm. On the other hand, networks with high levels of synergy make firms more dependent on each other, in order to achieve ambitious innovation goals. Each firm still needs to develop their own technology, but they highly complement each other, while not performing similar tasks. This dependence can become a major source of risk and tension if one or more companies are not functioning properly or do not have the capabilities needed to deliver their part: *“...it is often just somebody who volunteers, who may have never done that before and that damages us in the end.”* Also, some respondents find the long terms-commitment related to actor

interdependence difficult to master: “...seven years ago we did not know what we are going to do today... We think, this is not going to be it. Then it is very difficult for us to commit ourselves to fix it [the long-term project dependence]”.

In some networks, the level of actor interdependence was clearly lower and thus firms are more capable of executing tasks independently of one another. This had a direct effect on the knowledge processes. Specifically, the main type of knowledge shared is non-core knowledge. This type of knowledge which is not directly related to firm-specific technologies, is most useful when shared in a broader industry-context since it can be scaled effectively for many types of uses for different types of actors. The focus on more generic knowledge types, so that no core IP needs to be shared, was indicated explicitly by one interviewee: “We try to develop general process knowledge..., so both parties can profit from that”. On the other hand, as the level of actor interdependence goes down, some partners recognize that it affects the collective knowledge integration efforts in a negative way: “... there is less innovation together in my opinion. Then the more we all do our own thing, and we just try to get something else done as soon as possible or as cheaply as possible.”

4.3. Focal firm role and tension in R&D networks

Firms are usually not equal in their position and power in R&D and innovation networks, which often follows a structure with both central and peripheral players (Ritala and Huizingh, 2014). In line with this, we found that the industry profile, and further, the role of the focal firm in the network, had an effect on how the tensions were perceived. In this regard, we identified firms that stood out from the data having a central profile in the R&D network, as opposed to firms with a distinctively more peripheral profile. In portraying firms with such roles, we focused not only on the number of linkages of actors (i.e. the network-theoretic centrality), but also on the centrality in terms of access to valuable network resources and related influence. This reflects the suggestion that a focal or “hub” role in R&D and innovation is related to access to information, resources, and increased bargaining power (e.g. Dhanaraj and Parkhe, 2006; Nambisan and Sawhney, 2011).

Table 2 provides a set of representative quotes related to the focal firm profile in a particular R&D network, and the related tensions for both knowledge exchange and network coordination. The results suggest that firms with a distinctively central profile enjoy the virtues of a

Table 2

Focal firm tensions and profile within R&D networks: illustration.

Tension type	Central profile in the R&D network	Peripheral profile in the R&D network
<i>Knowledge exchange tensions (dialectical)</i>		
Openness	<p>“It is always a risk [knowledge spill over] that is there, but we don't really act on it.” (Firm A, a dominant player in that network)</p> <p>“We often develop the product in-house and bring the result into a consortium. If changes have to be made we bring it back to our facility, apply changes, and bring the result back to the consortium partners again” (Firm C, with a dominant role as a sole provider of technology)</p>	<p>“And all the details how it has been made, the tooling you used, that stays in-house. But the results are being presented to the outside world.” “We don't share core knowledge. Good luck copying our products”. (Firm A, with a peripheral role in an international network)</p> <p>When we are collaborating with [company name] we don't exactly tell how we do everything. We usually don't share all information, that's not how we work. (Firm F, with a low-access role to a highly competitive network)</p>
Inclusiveness	<p>“We are very open as participants, if we get stuck other members are quickly informed.”; “We want to get the most out of a program (project), and that's when you start sharing knowledge. Because the more you contribute, the more you can achieve.” (Firm C, with a dominant role as a sole provider of technology)</p>	<p>“It is easy to see by looking at the deliverables in some projects. The reports that are being handed in. By looking at the role of certain companies in a project. Some are just looking at what is going on.” (Firm A, with a peripheral role in an international network, referring to non-inclusive knowledge sharing by some network actors)</p> <p>“So if you are ahead in a certain area it's not always interesting to put your knowledge into that consortium. Maybe in the long term, but not in the short term. That's the hard part with open innovation, where to secure your IP rights.” (Firm F, related an R&D network with several competing actors interested in same technology)</p>
<i>Network coordination tensions (paradoxical)</i>		
Innovation goal alignment	<p>“Because of the consortium it is easier to guide the development of technologies as a whole.” (Firm A, commenting their position as a founding member of the R&D Network)</p>	<p>“...the project is defined with multiple parties. It has to fit within your strategic goals... my experience is that everybody is concerned with their own focus.” (Firm A, with a peripheral role in an international network)</p> <p>“They probably won't tell you or don't want to tell you, but you have to go out of your way to find out their intentions”. (Firm D, a non-influential member of an international network)</p>
Coopetition	<p>“This does not pose a direct problem”</p> <p>“In aerospace a competitor can quickly become a customer. Due to the long technology cycle it can be quicker and easier to buy parts from your competitor than to develop and master the technology to make those parts yourself”</p> <p>“There is always a risk of losing knowledge to a competitor. But we don't always act on it. Everybody is welcome to try and copy our products, most times they fail” (Firm A, representing a large firm with lot of internal IP)</p> <p>“We are both [with a direct competitor] operating in that consortium...and we have divided the research tasks with them very openly. These are your tasks, these are our tasks”. (Firm C, with a dominant role as a sole provider of technology)</p>	<p>“It is not always easy to identify a competitor. Some parties use different technologies to manufacture competitive parts.” (Firm D, related to larger players in the networks)</p> <p>“The more companies a consortium contain, the more complex that situation gets, especially when there are competitors present.” (Firm F, with a very peripheral role in the network)</p> <p>“We will manage our knowledge in that [R&D network including competitors] very differently, compared to an [R&D network] with only suppliers and clients.” (Firm F, with a very peripheral role in the network)</p>
Actor interdependence	<p>“...we want to obtain commercial programs. The client wants something, and we attach the companies and specialization. We create a demonstration, pre-production. We are now currently, with a partner, working out a factory and calculations for future serial production.” (Firm C, with a dominant role as a sole provider of technology)</p>	<p>“The only real risk for us is technology failure due to failure of consortium partners</p> <p>“...if one of the previous parties fails at producing the part, or delivers the part with a bad surface quality, which makes [our part] impossible. That is something we encounter all the time. ...our dependency to the people making parts is very big” (Firm E, with a non-central role dependent on other network actors)</p>

hub firm (e.g. [Dhanaraj and Parkhe, 2006](#)), in that they are able to affect how the network is coordinated and how mutual goals are set. In addition, these central firms also seem to perceive quite little tension related to knowledge sharing openness and inclusiveness, and rather see knowledge sharing as a vehicle to push forward their agenda in the network. On the other hand, firms with a more peripheral profile in the network perceive stronger tensions (in a negative sense). This means that they are far more protective regarding their core knowledge, and tend to withhold their core knowledge from the network members. These peripheral actors also feel tensions related to difficulties in goal alignment, coopetition, and interdependency risks in the network.

4.4. Tension-resolving mechanisms in different types of R&D networks

In addition to the firms' perceptions of tensions, our data also allowed us to examine the characteristics of seven R&D networks and analyze what types of tension-resolving mechanisms were applied (see [Table 3](#) for summary and representative quotes). This type of

analysis follows the recent suggestions in the literature to focus on paradoxes and tensions in R&D relationships and networks, as well as the mechanisms of how such tensions can be resolved ([Fernandez and Chiambaretto, 2016](#); [Järvenpää and Wernick, 2011](#)).

The core issue studied relates to the *proximity* between the actors in a network. [Biggiero and Sammarra \(2010\)](#) found that geographical proximity between actors in the Italian aerospace cluster increases the amount of relevant knowledge transferred. In a study of Dutch aviation industry, [Broekel and Boschma \(2012\)](#) found that various types of proximity – including geographical, organizational, cognitive and social – explain the formation of an inter-organizational knowledge network and increase the amount of knowledge shared. In the absence of quantifiable measures, we pursued to identify the *knowledge proximity*, which relates to the actors' perceptions of the knowledge familiarity across the network (see [Breschi et al., 2003](#)). As such, knowledge proximity could be affected by a number of the aforementioned proximity dimensions. For instance, we found that the knowledge proximity seemed to be in sync with geographical proximity, where the national consortia

Table 3
Knowledge characteristics and tension-resolving mechanisms in R&D networks.

R&D network	Knowledge characteristics of the network	Tension-resolving mechanisms in knowledge exchange	Tension-resolving mechanisms in R&D network coordination
COMPO	Knowledge proximity between actors is low, national R&D network involving all the major actors developing components, with incremental development around a shared key technology.	Choosing inclusiveness and openness in foreground knowledge sharing, while keeping core IPs in-house “The consortium partners know very well how innovative companies are and what they work on. If you show that openly that also has its advantages”	Actor interdependence tensions are balanced by separating own technology and joint development “In a consortium it is most important to create synergy, where everybody needs to develop their own technology. We have to do activities in which we complement each other and not do the same thing. That's why a good functioning consortium like [COMPO] covers the whole supply chain” Coopetition tension avoidance via positioning far-away from markets “We try to develop low technology-readiness-level technologies, technologies which are not our core IP, in [this type of] competitive consortia”
TechnoCenter	Knowledge proximity between actors is low; national partners developing mutually interesting technology.	Choosing to open only certain technologies “...we can take conscious decisions about what technology and demonstrators to give to the consortium.”	Innovation goal alignment is made sure by involving enough resources “...the beauty is that all partners have a lot of interest in gaining that information. Everybody submits a certain amount of money and then something that you couldn't do is possible” Interdependence risks are externalized to 3rd party “...there is an independent institute over which the partners have influence. About what their steps will be. And when all partners agree on those steps, they will be executed.”
AviaNetwork	Knowledge proximity between actors is low; national partners incrementally developing and marketing technologies towards an international recognition in a specific segment.	Choosing to be inclusive in sharing the internal developments across the network “We are very open as participants, if we get stuck other members are quickly informed.”	Resolving coopetition tensions via exclusive roles “we made a matrix of disciplines which we require in the consortium. So those disciplines we want to fill up. So companies are selected and invited to join. It is not an open membership. If you bring in a discipline which none of the existing members do, you can enter.” Lowering actor interdependence risks via ensuring commitment by yearly cost of participation “fee is intentional so you will only get very serious partners”
InnoSale	Knowledge proximity between actors is low; national R&D network involving development and commercialization goals.	Choosing inclusiveness for all newly emerging knowledge across the network “Those results become available for the consortium members. We also get the result, but we don't really care about that and I think that it works the same the other way around.”	Securing goal alignment via sub-project structure within the larger network “Once a project is defined, a number of companies in the consortium is put on that project. Then that project group takes the project and the risk, not the entire consortium. They make a contract with the client.” Lowering actor interdependence tension via small joint part, and large individual responsibilities “We are loosely collaborating with the other partners. There is a common component in that project for research and an individual part. The individual part is bigger.”

Table 3 (continued)

R&D network	Knowledge characteristics of the network	Tension-resolving mechanisms in knowledge exchange	Tension-resolving mechanisms in R&D network coordination
ProjectNextGen	Knowledge proximity between actors is high; international R&D network involving a goal to open up a new market.	Choosing to open up only results and not core knowledge “you only present results from technological development and don't research core business with other partners.”	Lowering coopetition tension by focus on pre-competitive research that is distant from markets “developing knowledge. Opening the market... That's why we still encounter competitors there” Resolving goal alignment via externalizing the lead of R&D to a third party “the focus is on networking. Developing new technology happens at the [research institute]”
PlasticWing	Knowledge proximity between actors is high; international R&D network involving both industry and university actors, and uncertain radical innovation goals.	Choosing to close down the communication about internal processes “the trick is in the details of the process and in the flexibility of applying the technology to make many different parts. So what we exactly do there we keep to ourselves.”	Coopetition tension low, since only one firm per a specific field is involved “...consortium [without overlapping fields] has been formed very deliberately”
AeroEffect	Knowledge proximity between actors is high; international R&D network involving early-stage technology with lot of uncertainty.	Choosing to include only prospective client as a receiver of sensitive information “It raises many questions when you bring a new technology, so those questions have to be supported. A project like that gives you the means to support your new technology and it is possible to send this information only to [potential client for that technology].” Choosing to open up application knowledge and not in-house IP “...you are able to develop products, very innovative. But the IP that you generate, what the tooling looks like and how you develop/design tooling, that is a part nobody sees. ... In the consortium it is possible to test an assembly.”	Coopetition as pragmatics “So we work together, not against each other...In the aerospace a competitor can also be a client. It is also possible for us to deliver parts to [competitor 1] or [competitor 2].” Innovation goal alignment determined via joint client: “...you have a client, the make requirements for a specific part. And targets, high level targets for that part to meet. Everybody has to meet those targets with their parts. But everybody does it in their own way.”

involving only Dutch parties were perceived to have low knowledge proximity. This is in line with Broekel and Boschma (2012), who found geographical proximity to be a major explanation for knowledge network formation in the Dutch aviation industry. Furthermore, we found that when knowledge proximity was low, the networks tended

to engage more incremental and application oriented goals, whereas high-proximity, international networks pursued more radical and uncertain goals. Thus, increasing proximity seems to go hand-in-hand with uncertainty and higher-radicalness goals, which is in line with research suggesting the merits of distant knowledge search in networks aiming for really new developments (e.g. Phelps, 2010).

As for tension-resolving mechanisms, networks with high knowledge proximity seemed to be using rather clear mechanisms for knowledge exchange to resolve the high tensions related to the uncertain contexts (for illustration, see Table 3). These involved closing down the internal IP and processes from the network members, or including only key clients as recipients of relevant knowledge. Mostly applications and use cases were shared within networks of this type. This was especially highlighted in networks with radical aims and a lot of uncertainty (especially the last two networks listed in the Table 3). For low-proximity networks, the knowledge sharing was more active and inclusive, involving e.g. active dissemination of new developments within the network. However, also in many of these networks the internal IP was preferred to be kept in-house. This might echo the higher probabilities of knowledge transfer in low-proximity networks (Biggiero and Sammarra, 2010; Broekel and Boschma, 2012).

Also for network coordination mechanisms, some patterns were observed. In high-proximity networks, network coordination issues were resolved by externalizing the lead for a third party (in one case an institution, a client on another). Coopetition tensions were mostly resolved by pragmatic approaches, where competitors were seen as the ‘necessary evil’ related to international technology collaboration, or as prospective clients. For low proximity-networks, the tension-resolving mechanisms involved a lot of variety, with some general patterns. Particularly observable mechanisms were utilized to lower coopetition tensions. The close proximity was taken into account in pursuing solutions that enable avoiding coopetition by focusing on early-stage development, or by forming the networks initially via complementary rather than overlapping roles. Furthermore, interdependency risks were resolved in several cases by providing enough resources, and functionally

Fig. 1. Knowledge search and integration dynamics and tensions in R&D networks.

separating project tasks at the network-level from the individual firm ones.

5. Discussion and implications

The aim of this study was to examine the knowledge search and integration processes in R&D networks and the role of perceived tensions in these processes. Building on studies arguing that knowledge search and integration in networks is a process full of tensions and frictions (e.g. Järvenpää and Wernick, 2011; Alexy et al., 2013; Ghosh and Rosenkopf, 2014; Järvenpää and Majchrzak, 2016), and studies that discuss the role of strategic dualities, dialectics and paradoxes (Lewis, 2000; Birkinshaw et al., 2016), we find that actors' behaviour related to the knowledge processes strongly depends on the perceived dialectical and paradoxical tensions. We also found that the network role of the firm (central or peripheral), as well as the characteristics of the network (especially knowledge proximity) affect how tensions are perceived and what kind of solutions and mechanisms are adopted to resolve those tensions. The findings of this study extend current research on R&D networks by providing new evidence about the tension and knowledge dynamics within such structures. The following sections discuss the implications of our study in detail.

5.1. Theoretical implications

This study contributes to three broad streams of literature: 1) knowledge search and integration literature, 2) R&D and innovation networks literature, and 3) inter-organizational tension and paradox literature.

For the knowledge search and integration literature, our study provides insights regarding the factors that influence the complex processes of searching and integrating knowledge in the context of R&D networks. In line with previous knowledge search studies (e.g. West and Bogers, 2014), we find that the main motivation behind a firm's participation in R&D networks is to search for valuable external knowledge, and to integrate and combine knowledge with other network actors in order to reach their innovation goals. Within this context, our particular contribution is showing how different types of tensions emerge and affect each other. Recent studies suggest that a lot of complexity is involved in knowledge processes between firms in R&D relationships (e.g. Järvenpää and Wernick, 2011; Järvenpää and Majchrzak, 2016) and that there are inherent risks involved (e.g. Ritala et al., 2015). Our study empirically explores these processes and provides an in-depth analysis of different types of tensions. Dialectical tensions force firms to make deliberate choices whether specific knowledge is exposed or shared and with whom, while paradoxical tensions provide better understanding of the context characteristics that affect knowledge processes in R&D networks. We believe these findings can serve as a useful starting point for further research to understand the in-built tensions in knowledge search and integration in the inter-organizational network context.

For the R&D and innovation networks literature our study provides new implications related to the role of the actor in the network, and the characteristics of the network itself. From an actor perspective, our results suggest that occupying a central network and power position in the network provides the actor a context which involves less tension, and provides more opportunities to share knowledge across the network and to affect future development trajectories. These benefits support the suggestions in the network literature that argue a central position provides access to not only knowledge and resources, but also brings influence (Dhanaraj and Parkhe, 2006; Gnyawali and Madhavan, 2001). On the other hand, our results showed how peripheral actors were suffering from the lack of influence and control, effectively increasing the perceived tensions, and making them to adopt protective solutions. Furthermore, we examined the network characteristics especially from a proximity perspective (Biggiero and Sammarra,

2010; Broekel and Boschma, 2012). We focused on knowledge proximity, i.e. the closeness and familiarity of knowledge (e.g. Breschi et al., 2003) between actors in the network, and found that high-proximity networks differ from those with low-proximity. In particular, in high proximity networks the tensions were highlighted and more strict tension-resolving mechanisms were put in place. On the other hand, in low proximity networks the knowledge search and integration processes were more effective and flexible, supporting the results of earlier studies such as Biggiero and Sammarra (2010).

Finally, for the inter-organizational tension and paradox-literature, our study provides a much needed network-facing perspective, since most literature involves dyadic, or firm-strategy levels of analysis (e.g. Tidström, 2014; van Fenema and Loebbecke, 2014). While several more specific research streams, such as the coopetition literature, have examined inter-organizational tensions and paradoxes and their implications to knowledge processes (Fernandez and Chiambaretto, 2016; Gnyawali et al., 2016), research on R&D networks has not provided comprehensive understanding on this context. By studying the focal firm's tension perceptions embedded within the larger (R&D) network fabric, the analysis can take into account the broader context within which knowledge search and integration behaviour is often situated in practice. Overall, our findings show that actors perceive various types of dialectical and paradoxical tensions in R&D networks, which affect their behaviour in a network. Furthermore, we identify several types of tension-resolving mechanisms both for knowledge exchange and for network coordination (as summarized in Table 3). These results contribute to the so far sparse literature examining the paradoxes and their management in R&D and innovation networks (e.g. Järvenpää and Wernick, 2011). In particular, our study provides a detailed account of the dialectical and paradoxical tensions that affect knowledge search and integration behaviour, showing the diversity of tension and resolution alternatives, as well as the highly perceptual nature of those.

5.2. Managerial and policy implications

Our study identifies several important issues firms should consider when joining an R&D network, and for the actors that are organizing and designing such networks. For actors that consider joining an R&D network, our results suggest that goal congruence and competitive dynamics are likely sources of tension that need to be considered explicitly when making decisions whether to join. When designing the coordination and management mechanisms of R&D networks, the typical sources of tensions need to be identified and accounted for on beforehand. For instance, designing contractual and relational governance within the network in such way that these promote reciprocity, openness, and individual actor's value capture opportunities would be a good starting point.

For instance, in terms of knowledge sharing processes, our results regarding the dialectical tensions show how "selective revealing" of knowledge (see Alexy et al., 2013; Henkel, 2006) takes place in R&D networks. This implies that the choices over knowledge sharing are made often from an actor perspective, and this has implications not only for participating firms, but also for firms orchestrating R&D collaborations and other networks. Furthermore, the paradoxical tensions over innovation goal setting, coopetition, and actor interdependence show that network design matters for how actors perceive the opportunities and risks involved. Thus, sensitivity for such issues is warranted when designing R&D networks in order to achieve the desired level of knowledge exchange needed to reach the innovation goals of the network (Dhanaraj and Parkhe, 2006).

As policy implications, our results suggest that policy tools could be utilized to lower some of the tensions involved in R&D networks. For instance, having R&D funding programmes which would provide clearer mechanisms for participants to share specific knowledge would help to overcome some of the tensions, especially in high-proximity networks. Further, providing a clear intellectual property infrastructure

would be helpful to lower the tensions related to core knowledge exposure and openness.

5.3. Limitations and future research directions

Our results can be considered as exploratory, early phase insights into tensions in R&D networks and their impact of actors' knowledge processes. Therefore, our study has inherent limitations related to the generalizability and breadth of evidence. In particular, as our focus was on focal actors' perceptions on tensions and the resulting knowledge search and integration behaviour, we did not analyse in detail the particular linkages between actors in dyad nor network level. Future studies could therefore focus more on the inter-organizational knowledge processes and tensions within a specific R&D network, and provide additional insights on the issues identified in the current study. For instance, research designs with a whole network perspective (see Provan et al., 2007) would be helpful to understand the particularities of knowledge flows and tensions within the overall network. Furthermore, studies adopting a longitudinal perspective to knowledge search and integration behaviour could provide a perspective on how tensions affect actors' behaviour over time.

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