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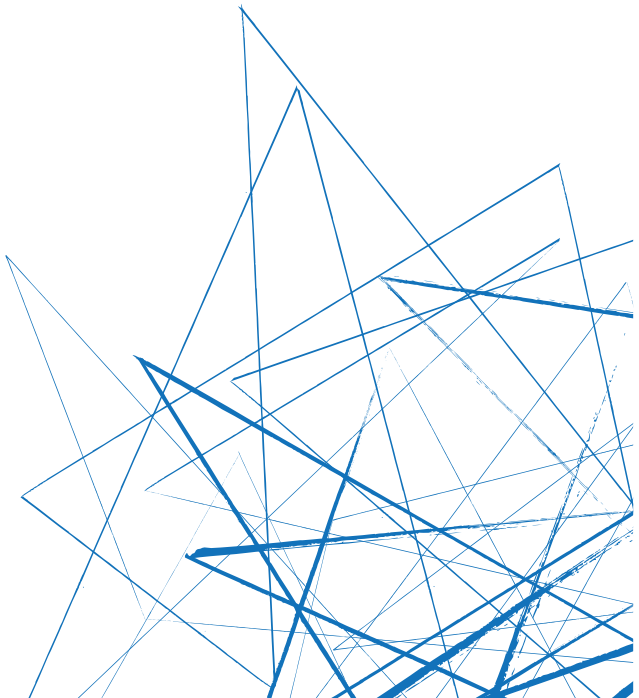

IN SEARCH OF SOLUTIONS INERTIA, KNOWLEDGE SOURCES AND DIVERSITY IN COLLABORATIVE PROBLEM-SOLVING

PhD Series 04-2016

Anders Ørding Olsen

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The PhD School of Economics and Management | **PhD Series 04.2016**

CBS COPENHAGEN BUSINESS SCHOOL
HANDELSHØJSKOLEN

IN SEARCH OF SOLUTIONS

Inertia, Knowledge Sources and Diversity in Collaborative Problem-solving

Anders Ørding Olsen

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The PhD School of Economics and Management
Copenhagen Business School

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ENGLISH SUMMARY

Innovation is at the core of firms' competitiveness. External knowledge is increasingly leveraged in the efforts to increase innovation performance by solving innovation related problems and thereby developing new technology, products or services. Using internal knowledge sources can be beneficial when pursuing minor performance improvements in existing technologies. However, reliance on internal knowledge sources carries a risk of organizational inertia related to problem understanding and solution development in the shape of path-dependencies and preferences for exploitation and reapplication of existing knowledge. Such inertia may imbue innovation processes related to the development of new technologies with reduced novelty and an inability to recognize alternative and potentially more attractive solutions. As a result, over-reliance on internal knowledge sources is likely to inhibit the ability to solve problems and reduce innovation performance related to the development of new technology. In contrast, a growing stream of research shows the positive effect on problem-solving and innovation performance from drawing on diverse knowledge sources outside the firm. Through collaborative efforts involving universities, customers, competitors and suppliers in problem-solving firms can gain complementary perspectives, insights and technological knowledge as they pursue the development of innovative technologies.

The purpose of this dissertation is to contribute to this latter stream of research. This is done by examining how the organization of external knowledge search efforts can improve problem-solving related to the development of new technology. More specifically, the dissertation explores the influence of incumbent firms suffering from organizational inertia, advocacy groups without technological knowledge, and increasing diversity of knowledge domains and experience on problem-solving on external knowledge search efforts. The empirical analyses are based on a database comprising all collaborative applications for funding submitted to the European Commission's 7th Framework Program. This database consists of a number of specific problems that the EU has identified for solving through collaborative efforts. This data is matched with the Orbis database developed by Bureau van Dijk, which provides details on each individual applicant such as patent portfolios, sector and more. Combining these datasets enables the dissertation's three essays to explore how the configuration of participants and their individual characteristics influence the ability of the collaborative efforts to develop solutions to specific problems.

In the first essay I question whether incumbent firms can overcome their inertia related to technologies with competence-destroying effect and threats to their competitiveness by accessing external knowledge sources, and whether the negative effects of their inertia may be overcome by proactive strategies for a reconfiguration of competences to accommodate the technological change. In the second essay I explore whether the development of solutions to technological innovation problems benefit from involving organizations without technological knowledge. More specifically, I analyze how the involvement of advocacy groups such as Greenpeace improves the fundamental understanding of the specific problem prior to developing a solution. In the third and final essay, I examine the benefits and limitations of an increasing diversity of knowledge domains in external knowledge search efforts and the influence of experience among the collaborators. In sum, the dissertation contributes to a more nuanced understanding of the benefits and limitations of accessing external knowledge in the search for solutions to technological problems. This provides important insights into how firms organize problem-solving efforts to increase their innovation performance and thereby their competitiveness.

DANSK SAMMENDRAG

Innovation spiller en afgørende rolle i virksomheders konkurrencedygtighed. For at øge deres innovation anvender virksomheder i stigende grad viden fra eksterne kilder til at løse problemer i forbindelse med udviklingen af nye teknologier, produkter eller services. Anvendelse af interne videnskilder kan være værdifuld i relation til inkrementelle forbedringer af eksisterende teknologi. For stort fokus på interne videnskilder indebærer imidlertid en risiko for inerti relateret til forståelsen af problem og udviklingen af løsninger grundet organisationel stiafhængighed og præferencer for at genanvende eksisterende viden. Denne inerti kan forhindre identificeringen alternative og potentielt mere attraktive løsninger og dermed reducere nytænkningen i innovationsprocesser relateret til udviklingen af nye teknologier. Dermed indebærer en kraftig prioritering af interne videnskilder en risiko for at hæmme evnen til at løse problemer og udvikle nye teknologier. I modsætning til dette viser en stigende mængde af forskning hvordan anvendelsen af eksterne videnskilder har en positiv indvirkning på problemerløsning og innovation. Ved at samarbejde med universiteter, kunder, konkurrenter og leverandører i forbindelse med problemløsninger, kan virksomheder få adgang til komplimentære perspektiver og teknologisk viden i udviklingen af nye innovative teknologier.

Formålet med denne afhandling er at bidrage til forskningen indenfor anvendelsen af ekstern viden og effekterne på virksomheders innovation, ved at undersøge hvordan løsningen af problemer relateret til udviklingen af ny teknologi påvirkes af inerti i enkelte videnskilder, anvendelse af videnskilder uden teknologisk viden, og adgang til forskelligartede vidensdomæner. Den empiriske analyse er baseret på en database bestående af ansøgninger om støtte fra Europa Kommissionens syvende rammeprogram. Denne data består af en række specifikke problemer som Europa Kommissionen har identificeret og ønsker løst gennem innovative samarbejde mellem flere organisationer. Ansøgningerne består dermed af løsninger på spesifikke problemer relateret til teknologisk innovation, udviklet af en ansøger gennem anvendelse af en række eksterne videnskilder. Dataene på disse ansøgninger er kombineret med Orbis databasen fra Bureau van Dijk, som indeholder detaljeret information om blandt andet hver enkelt ansøgers patentportefølje, sektor og omsætning. Ved at kombinere disse datasæt analyserer jeg hvordan konfigurationen af videnskilder og deres individuelle viden og karakteristika påvirker den fælles udvikling af løsninger på specifikke innovationsproblemer.

I det første kapitel undersøger jeg hvorvidt store veletablerede virksomheder kan overkomme deres inerti relateret til nye teknologier, som truer deres konkurrencefordele. Jeg analyserer disse virksomheders anvendelse af eksterne videnskilder og hvorvidt deres inerti kan overvindes ved at de tager initiativet til at imødekomme de teknologiske og konkurrencemæssige forandringer i deres sektor ved at udvikle nye kompetencer. I det andet kapitel analyserer jeg om udviklingen af løsninger på teknologiske problemer kan have gavn af involveringen af organisationer, som ikke besidder teknologisk viden. Nærmere betegnet undersøger jeg, om interesseorganisationer som Greenpeace kan øge forståelsen af det underliggende problem og dermed forbedre udviklingen af løsninger. I det tredje og sidste kapitel undersøger jeg fordele og begrænsninger ved at anvende forskelligartede vidensdomæner og vigtigheden af erfaring med problemløsning blandt videnskilderne. Samlet set bidrager afhandlingen til en øget forståelse af fordelene og begrænsningerne ved at anvende ekstern viden i udviklingen af løsninger på problemer relateret til teknologisk innovation. Dette giver fornyet indsigt i hvordan virksomheder kan forbedre deres innovation og konkurrencedygtighed.

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This dissertation marks the end of a journey which, had I known its course from the beginning, I am not sure I would have had the courage to embark on. However, I am incredibly thankful to this ignorance and the personal and professional development that it allowed me to enter into and enjoy over these past years. Despite a challenging start and an immensely steep learning curve I am grateful to have spent these years in excellent company both intellectually and personally. I am thankful for the many direct, albeit well-meant, pieces of advice and the strong but insightful criticism offered from my colleagues and supervisors, as well as the collaborations with my co-authors. This has taught me more than I thought possible and helped shape my research and raise it to a level it would otherwise never have reached. On a personal level I am grateful to have had the opportunity to meet so many inspiring people and make such good friends during my PhD studies – thank you all.

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inspired me, accelerated my learning and developed me enormously. This dissertation would not exist without you guys. Beyond the professional rewards of these co-authorships I always enjoyed begin around each of my three Germans friends whether this involved decaf Nespresso and melted Ritter Sport in Wolfgang's office, appropriating the last bottle of Spumante with Christoph in Rome, or rescuing overdosing drug addicts in Denver with Jörg. It has truly been a pleasure working with you.

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listen to frustrations and offer advice based on healthy perspectives. Thank you for making me laugh and distracting me from my PhD, both of which were essential to getting through it. Thank you for being great friends for so many years: Mathias, Britt, Søren, Morten, Lasse, Anders, Sune, Astrid, Rasmus, Cathrine, Thor, Christian and Christian, Peter, Jesper and Jesper.

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Anders Ørding Olsen
Frederiksberg, December 2015

CONTENTS

CHAPTER 1: INTRODUCTION

This dissertation consists of three chapters that explore how firms can organize knowledge search to draw on external sources in efforts to solve problems related to technological innovation. Chapter two finds that these efforts are sensitive to the organizational inertia and strategic interests of the individual knowledge sources. Chapter three shows the value of involving knowledge sources without technological knowledge in the development of solutions related to technological innovation. Chapter four shows the benefit of increasing the diversity of the knowledge domains accesses by the external knowledge search efforts and the necessity of previous problem-solving experience. Table 1 provides a brief overview of the three chapters and their main components.

[Insert Table 1 around here]

The dissertation seeks to contribute to the management and strategy literature by increased the understanding of the one of the important factors that improve firms' ability to gain and retain competitive advantage: the development of new technologies that set firms apart from their competitors (Geroski and Machin 1992; Kogut and Zander 1992; Peteraf 1993)[1]. This dissertation focuses on the front-end of technological innovation, i.e. the search for new knowledge required to create solutions to the problems faced when inventing new or improving existing technology (Cyert and March 1963; March 1988). Such efforts are a process of firms identifying problems that would be valuable for them to solve and subsequently organizing the search for, access to and combination of the knowledge required to develop a solution (Nelson and Winter 1982; Nickerson and Zenger 2004; Nickerson et al. 2012). In this dissertation I study such efforts in the context of organizing the search for solutions to problems related to technological innovation. More specifically I explore: (i) How problem-solving is influenced by the organizational inertia of incumbent firms towards technological change with competence destroying effects; (ii) The benefits of accessing sources without technological knowledge to solve technological problems; and (iii) The value of knowledge diversity and problem-solving experience among the knowledge sources combined.

While the locus of problem-solving efforts related to innovation was traditionally argued to be located within closed organizations' internal research and development departments,

[1] While innovation may also relate to new products or services, the focus of this dissertation is on technological innovation

research is increasingly focusing on efforts that combine internal and external knowledge sources. For a recent overview of the literature see e.g. Felin and Zenger (2014), or Laursen (2012). In the traditional closed approach organizations base their problem-solving on prior experience, which entails a myopic focus on the learning from and effectiveness of their past successes, and thus a tendency to disregard new alternative solutions (Levinthal and March 1993). In addition to this firms tend to prioritize exploitation of existing knowledge rather than exploration of new knowledge to develop solutions to problems (March 1991). Firms thereby have a propensity to search for solutions locally in their own or closely related knowledge domains (Helfat 1994; Stuart and Podolny 1996). While local search is efficient in solving problems related to minor performance improvements in existing technologies, it is inefficient for problem-solving efforts targeting more significant advances or development of entirely new technologies such as those studied in the context of this dissertation (Nickerson and Zenger 2004; Sørensen and Stuart 2000). Moving beyond local search and involving external sources in problem-solving allows firms to access knowledge that can enable them to develop more efficient solutions to the latter type of problems (Rosenkopf and Nerkar 2001; Rosenkopf and Almeida 2003). The benefit of external knowledge search in problem-solving is shown by the increase in innovation as firms open towards outside sources (Laursen and Salter 2006; Leiponen and Helfat 2010). However, the challenge that this dissertation studies is how firms can best organize these search efforts to include the knowledge sources that eventually increase the likelihood of solving the specific innovation problem (Nickerson et al. 2012).

Problem-Solving through External Knowledge Search

In this dissertation search is conceptualized as being inherently problem-driven (Cyert and March 1963; March 1988). This entails an understanding of the process of search as initially beginning with the identification of a problem, followed by organizing a search effort to access and collect relevant knowledge, integrate this to develop potential solutions and subsequently evaluate one or more of these based on this process (Maggitti et al. 2013; Nickerson and Zenger 2004). This conceptualization combines the broad search framework with a more specific problem-solving approach proposed by e.g. Nickerson et. al. (2012). In this conceptualization a central question is how leaders of problem-solving efforts can organize search efforts to include external knowledge and sources in order to create efficient solutions to the problems they choose to address

(Nickerson et al. 2012). I address this question by showing how the development of solutions in external knowledge search efforts is influenced by the inclusion of incumbent firms with inertia towards the competence-destruction associated with certain problems, how advocacy groups improve problem-solving despite their lack of technological knowledge, and how the diversity of knowledge and problem-solving experience of the sources involved in external knowledge search efforts influences the development of a solution. To achieve this I draw on literature that focuses on how organizations organize search to access external knowledge sources in the effort to solve specific problems and make technological advances (Felin and Zenger 2014; Nickerson and Zenger 2004).

The locus and characteristics of this knowledge relative to the focal firm is of central importance in the search literature as this is found to influence the ability to and likelihood of solving problems (Katila and Ahuja 2002; Rosenkopf and Nerkar 2001; von Hippel 1994). While early research mainly focused on firms' investments into their own research and development efforts, the internal organizing of knowledge in problem-solving and the resultant innovation, an increasing emphasis has been put on the benefits of spanning organizational boundaries and accessing external knowledge (Laursen 2012). Through the former, localized search efforts, organizations apply existing and/or local knowledge to solve their problems. While this mode of problem-solving is beneficial as the costs and risks involved in developing new knowledge or spanning organizational boundaries to access distant knowledge is avoided, it carries an inherent risk of decreased problem-solving. This is due to the organizational inertia that may prevent them from efficiently understanding and solving problems (e.g. Baer et al. 2013; Nickerson et al. 2012).

The inertia that firms develop over time increases their propensity to search locally and to over-estimate the value and usefulness of their own knowledge and undervalue alternatives (Levinthal and March 1993). This leads to a search for solutions that are related to their existing knowledge and competences rather than exploring radically new and different solutions (Helfat 1994; Nelson and Winter 1982; Rosenkopf and Nerkar 2001). As a result, the willingness and ability to recognize, seek out and apply alternative and potentially more promising solutions is reduced. While this is potentially useful for developing solutions that contribute to incremental improvements to existing products or processes, it is unlikely to result in solutions that create or are part of creating new

technology (Martin and Mitchell 1998; Rosenkopf and Nerkar 2001). As a result, local search efforts related to significant technological problems are at risk of reducing the likelihood of solving the specific problem (Felin and Zenger 2014). Accordingly, research has increasingly focused on the use of external knowledge to overcome this inertia. This approach to problem-solving organizes search efforts to combine internal knowledge with the knowledge and expertise of external sources to create novel solutions to the problems faced in innovation (Cassiman and Veugelers 2006; Katila and Ahuja 2002; Rosenkopf and Almeida 2003). In addition to overcoming inertia firms are also argued to benefit from reducing different costs when their combine internal and external sources to both create and commercialize knowledge (Cassiman and Valentini 2015). In sum, extant research has shown that firms that open up to a broader range of sources of knowledge increase their innovation performance, albeit with upper boundaries due to restrictions on the capacity to absorb new knowledge and effectively utilize this (Laursen and Salter 2006).

Contributions to Extant Research

While research has documented the benefits of external knowledge search in overcoming organizational inertia and the associated local search bias (Rosenkopf and Nerkar 2001), the field of research continues to evolve and aspects related to the dynamics, contingencies and organization of external knowledge search remain underexplored (Laursen 2012). One aspect not yet fully embraced by extant research on search is the notion that individual sources influence each other beyond the objective provision of knowledge (Knudsen and Srikanth 2014). The idea behind this is that the characteristics and incentives of individual participants influence the outcome of collaborative efforts in general (Puranam et al. 2012). In this dissertation I apply this idea to extend extant research by showing that the organizational inertia of individual knowledge sources has negative influences on the problem-solving likelihood of external knowledge search efforts. Furthermore, I show that this can be prevented through proactive commitment of these knowledge sources to overcome their inertia and embrace technological change.

An additional notion that is attracting increasing attention is the understanding of the processual nature of knowledge search and problem-solving efforts (Maggitti et al. 2013). This views search as a process consisting first of understanding the problem and subsequently developing solutions to this problem (Baer et al. 2013; Nickerson et al.

2012). Meanwhile, extant research has shown the benefits of searching different types of knowledge sources for different innovation outcomes (Köhler et al. 2012; Laursen and Salter 2006). Accordingly, I contribute to extant research by arguing for a differentiation between knowledge sources that provide knowledge related to understanding and solving problems respectively, and showing how problem-solving through external knowledge search efforts is influenced by the involvement of the former.

Finally, extant literature has shown that firms benefit from accessing a range of external knowledge sources as this provides input to and complements their internal problem-solving capabilities and efforts (Cassiman and Veugelers 2006). This has shown the benefits of an increasing breadth of types of sources such as suppliers, universities or competitors (Laursen and Salter 2006). I argue that knowledge sources that serve a similar purpose for a firm may represent different knowledge domains. The idea is that a firm organizing and leading an external knowledge search effort may access two distinct knowledge domains by collaborating with two different suppliers since they do not inherently possess the same knowledge although they both are suppliers to the focal firm. The final contribution of the dissertation lies in exploring how organizing external knowledge search efforts to include diverse knowledge domains influences problem-solving and whether lack of experience with managing such diversity influences the collective outcome.

I make the above contributions by answering the following three separate research questions related to problem-solving and external knowledge search:

- How does organizational inertia influence the problem-solving potential of external knowledge search efforts?
- How do knowledge sources with problem-understanding rather than problem-solving knowledge influence the problem-solving potential of external knowledge search efforts?
- How does increasing knowledge diversity and experience in managing the ensuing complexity influence problem-solving potential in external knowledge search efforts?

EMPIRICAL SETTING

I make the above contributions by analyzing a large number of external knowledge search efforts organized to develop solutions to problems related to technological innovation. More specifically I leverage data on proposed solutions submitted to problems put forth by the European Commission in their calls for applications in the 7th Framework Programme. I restrict the sample to cover the Cooperation Programme, which has the objective to "gain leadership in key scientific and technological areas by supporting cooperation between universities, industry, research centers and public authorities" (European Commission 2006). Subsequently I restrict the sample to exclude purely scientific calls to ensure a match between the final sample and the theoretical and conceptual framing in the dissertation.

I use expert evaluations of whether the solutions submitted by consortia of multiple knowledge sources (i.e. external knowledge search efforts) are likely to successfully solve the specific problems they address. Through this I contribute to the literature on search and problem-solving by focusing on three aspects: First, I explore whether the inertia of incumbent firms in the energy sector has negative influences on the likelihood that external knowledge search efforts will develop solutions with a high likelihood of solving problems related to technologies with competence-destroying effects on the incumbent. Subsequently, I explore whether the proactive commitment of incumbents to overcome their inertia and initiate the technological change can mitigate such negative effects. Second, I use qualitative data to argue that advocacy groups such as the Red Cross or World Wildlife Fund are beneficial to achieving a better problem-understanding. Subsequently I investigate the extent to which the inclusion of these groups as a knowledge source has a positive effect on problem-solving by improving the understanding of problems related to Grand Challenges. Third, I analyze the benefits of knowledge diversity through accessing an increasing number of knowledge domains and the importance of problem-solving experience. Extant research has traditionally measured firms' knowledge and representations of their knowledge domains through patent data (e.g. Ahuja and Katila 2004; Katila and Ahuja 2002). Patent offices such as the European Patent Office assign patents to different classes according to the technology that they relate to. An International Patent Classification (IPC) thereby provides information about the knowledge domain that a particular patent is situated within, and thereby about the knowledge that the firm holding this patent possesses. Accordingly, knowledge diversity

is captured by measuring the amount of different IPC classes accessed by external knowledge search efforts and subsequently combined with the effects of collaborating with inexperienced knowledge sources on the likelihood of solving complex environmental problems.

The three empirical essays on external knowledge search leverage a novel and unique dataset containing proposed solutions to problems. More specifically the data consists of all applications for funding from the European Commission's 7th Framework Programme. This enables analyses of how search efforts are organized by leaders to involve several external knowledge sources in the development of solutions to the problems described by the European Commission in their calls for applications, and how variation in the organization of these efforts influences the problem-solving potential of the solutions. These external knowledge search efforts form through a process similar to the conceptualization developed by Nickerson et. al. (2012) and the earlier work of Nickerson and Zenger (2004), which describes the process of problem-solving as consisting of a leader selecting a problem, identifying relevant knowledge to solve it, and subsequently organizing a search effort to include the knowledge domains and sources inside and outside the firm required to jointly develop a solution, and finally evaluate potential solutions.

In line with this conceptualization the applicants interviewed for chapter four and four experts on EU funding interviewed to understand the data described the problem-solving process observed in the data as follows. The leader of an external knowledge search effort identifies one of the problems put forth as calls by the European Commission that is attractive for her to solve, as she believes this will have commercial value. The leader will subsequently identify the knowledge sources she considers relevant to developing an efficient solution to the specific problem and engage these to enroll them in the external knowledge search effort. In an iterative process managed by the leader, these knowledge sources combine their knowledge to first gain a more detailed understanding of the problem and subsequently develop potential solutions. Typically multiple potential solutions are developed and discussed under the direction of the leader before she formulates the final solution to the specific problem based on the iterative search process involving the knowledge sources. This solution description contains details on the solution and exactly what resources and knowledge the individual sources will contribute

to this. It describes what role the resources and knowledge play, as well as the role of each participant. Finally it contains details on how the leader of the problem-solving will manage the process. The leader of these external knowledge search efforts is responsible for the management and leadership, including potential existing or resultant IPR, other legal aspects and the distribution and reporting of finances. While the individual participants contribute knowledge and resources in the problem-solving, the initiative and main legal and financial responsibility rests on the leader (European Parliament and Commission 2006).

The efficiency of the solution in solving the specific problem is evaluated by the independent experts hired by the European Commission. These experts base their evaluation on the degree to which the solution moves beyond the state-of-the-art, draws on competent knowledge sources, outlines a sound management structure and the extent of the commercial potential. A brief description of the formation of external knowledge search efforts and the evaluation process is provided by the European Commission on their participant portal for the Horizon 2020 Programme[2], which followed the 7th Framework Programme, and in more detail in their online manual[3]. Albeit being the successor of FP7, the process of identifying a problem, assembling knowledge sources, developing and solution and submitting this is identical. To ensure the construct validity of the process and the outcome measure as problem-solving potential in relation to the theoretical framing of the dissertation I interviewed four experts on EU funding and application procedures who confirmed both independently of each other.

This data on the specific external knowledge search efforts is combined with organization-level data to explore the effects of a range of characteristics of the search leaders and knowledge sources, as well as providing relevant controls. This includes a classification of firms as industry incumbents, identification of advocacy groups and the diversity of the patent portfolio of the knowledge sources. The influence of these factors on the external knowledge search efforts ability to develop efficient solutions to the specific problems thereby constitutes the core contributions of this dissertation.

[2] https://ec.europa.eu/research/participants/portal/desktop/en/funding/
[3] http://ec.europa.eu/research/participants/docs/h2020-funding-guide/grants/applying-for-funding/find-a-call_en.htm

By analyzing novel and detailed data on the potential of specific solutions rather than traditional firm-level performance outcomes the dissertation answers the call for an increasing use of problem- and solution-level analyses (e.g. Nickerson et al. 2012). As such, the dissertation studies the ability of a joint external knowledge search effort to develop solutions to problems contingent on the involvement of incumbents, advocacy groups and diverse knowledge domains. The use of ex-ante evaluations of specific solutions' problem-solving likelihood as outcome in the empirical work contributes to overcoming a range of largely unobservable influences often associated with traditional measures such as patenting, firm-level innovation or turnover. As such, through the use of a novel dataset and outcome measure the dissertation provides insights into the specific effects on problem-solving in external knowledge search efforts without confounding this with other firm-level R&D activities or changes in firm strategies, prioritizations etc. during the execution of a solution.

STRUCTURE OF DISSERTATION

The following three chapters consist of individual essays, the first of which is single-authored while the remaining two are co-authored with Christoph Grimpe and Wolfgang Sofka. The three draw on the same empirical data although using separate subsamples thereof. Similarly, they share a broad theoretical orientation towards external knowledge search and problem-solving but retain individual empirical foci and make separate albeit complementary theoretical contributions. Furthermore, the papers differentiate by focusing on the influence of individual knowledge sources and the effects of the collective composition of knowledge respectively. Figure 1 provides an outline of the relationships explored in the three chapters and the overlaps and differences in each. Chapter two explores how the knowledge and characteristics of individual knowledge sources contributes to problem-solving contingent on the technological and industry context, and the role of the specific knowledge source in the external knowledge search effort. More specifically, the chapter explores how the inertia of incumbent firms related to competence-destroying technologies in their industry has negative impacts on problem-solving when they participate in external knowledge search efforts. The chapter further explores whether these negative effects are mitigated when incumbents are acting in the role as leaders of the efforts and thereby proactively initiate the technological change and engage in reconfiguring their competences accordingly.

[Insert Figure 1 around here]

As illustrated in Figure 1 above, chapter three explores how the knowledge and characteristics of individual knowledge sources influence problem-solving and includes the contextual contingency of the problem. More specifically the chapter investigates how organizations without technological knowledge can nonetheless be valuable contributors as knowledge sources in external knowledge search efforts related to solving technological problems in the context of Grand Challenges. The chapter explores how advocacy groups such as Greenpeace, World Wildlife Fund or Red Cross increase the likelihood of developing high-potential solutions by increasing the fundamental understanding of the problems faced. It shows that the value of this problem-understanding is particularly relevant in the context of problems associated with societal Grand Challenges. Finally, in the context of complex environmental problems the fourth chapter investigates how the diversity of the combined knowledge of each sources involved in external knowledge search efforts and the inclusion of knowledge sources with no previous experience with related problem-solving influences the problem-solving of external knowledge search efforts. The three chapters are outlined in the following and summarized in Table 1.

Chapter 2: Search and Destroy: The Effects of Incumbent Inertia on External Knowledge Search

In the first chapter of the dissertation I explore whether the inertia of incumbent firms towards technologies with competence-destroying effects influences problem-solving on external knowledge search efforts. The chapter questions whether the characteristics of individual knowledge sources influence the joint problem-solving of external knowledge search efforts. I take my point of departure in the literature on the effects of technological change (Tushman and Anderson 1986) and the responses of incumbent firms (e.g. Jiang et al. 2011; Lavie 2006). This is complemented by the research on search and the inertia that firms develop over time (e.g. Levinthal and March 1993), and the mutual influence of collaborators and effects of misaligned incentives (Knudsen and Srikanth 2014; Puranam et al. 2012). The dataset comprises 1,072 external knowledge search efforts in the energy area of the 7th Framework Programme with varying involvement of incumbent firms. Extant research argues that incumbents tend to suffer from inertia towards and face competitive threats from problem-solving in competence-destroying technologies. I

exploit this to determine whether knowledge sources influence external knowledge search efforts differently based on their individual inertia and interests.

The results show that incumbents improve problem-solving related to technologies with competence-enhancing effects. Meanwhile, they reduce problem-solving related to competence-destroying change when taking a reactive role as participants. However, they improve problem-solving in competence-destroying technologies if they have proactively engaged in leading the technological change and reconfiguring their competences. In combination, this indicates that inertia and strategic interests are central factors behind the negative effects observed from their reactive participation in problem-solving related to competence-destroying technologies. By showing the negative effects of incumbent firms I contribute to the literature on external knowledge search by showing that the joint problem-solving of collaborative efforts are influenced by the characteristics and interests of individual knowledge sources. This extends extant theory by the increasing focus on and understanding of contingencies related to the use of external knowledge search and problem-solving (Knudsen and Srikanth 2014; Laursen and Salter 2014; Nickerson et al. 2012). For practitioners I show the importance of considering the characteristics, underlying interests and motivations of potential collaborators and knowledge sources to ensure shared goals and commitments.

Chapter 3: Solving Grand Challenges Starts with Understanding – How Advocacy Groups Improve Problem-Solving

The third chapter of the dissertation examines the specific role of advocacy groups in overcoming the threat of mutual confusion as external knowledge search efforts develop solutions to society's largest problems, i.e. "grand challenges". With my coauthors we consider these grand challenges to be large-scale problems, which require solutions to be developed through external knowledge search efforts due to their interconnectedness and complex nature. We propose that firms can address the individual sub-problems that comprise the grand challenges through external search efforts that draw on multiple knowledge sources. We depart from existing search and problem-solving literature's tendency to confound understanding and solving problems by arguing that the critical first step is to understand the underlying problem. By increasing the understanding, the problem-solving likelihood of a solution will be significantly higher since the risk of mutual confusion among the knowledge sources is reduced (Knudsen and Srikanth 2014).

We argue that the inclusion of advocacy groups as a knowledge source on external knowledge search efforts targeting the development of solutions to technological problems is valuable despite their lack of technological capabilities and knowledge. Based on qualitative interviews with firms using advocacy groups as knowledge sources in their external knowledge search we argue that rather than contributing directly to the development of a technological solution, this source of knowledge contributes to a better understanding of the problem and the applicability of potential solutions, and thus increases the likelihood of developing a solution with high potential.

To test this we examine the influence of advocacy groups on 9,464 external knowledge search efforts' development of solutions to 252 individual sub-problems identified by the European Commission as related to society's Grand Challenges and important to solve in order to overcome these. Consistent with our hypotheses we find that advocacy groups have a positive influence on the likelihood that a problem is solved. By relating this to the explanations of our interviewees, we conclude that this positive effect is a result of advocacy groups increasing an external knowledge search effort's understanding of the problem. These findings contribute to extant literature by showing the importance of disentangling problem-understanding and -solving knowledge as two distinct, albeit interconnected, types required to solve problems. Furthermore, the findings show the value of including non-technological knowledge sources in the effort to solve technological problems, specifically by including advocacy groups to give representation to the stakeholders experiencing the underlying problem.

Chapter 4: Solving Environmental Problems: Knowledge and Coordination in Collaborative Search

The fourth chapter distinguishes itself by focusing on the combined knowledge and experience of all knowledge sources on external knowledge search efforts. This complements the preceding two chapters by showing the value of combining knowledge sources that represent diverse knowledge domains, as well as the importance of problem-solving experience among these knowledge sources. Accessing multiple knowledge sources and domains is argued to be particularly important for developing environmentally related innovations because of the high complexity of the problems (Hall and Vredenburg 2003; Ketata et al. 2015). However, this inherently carries the risk of

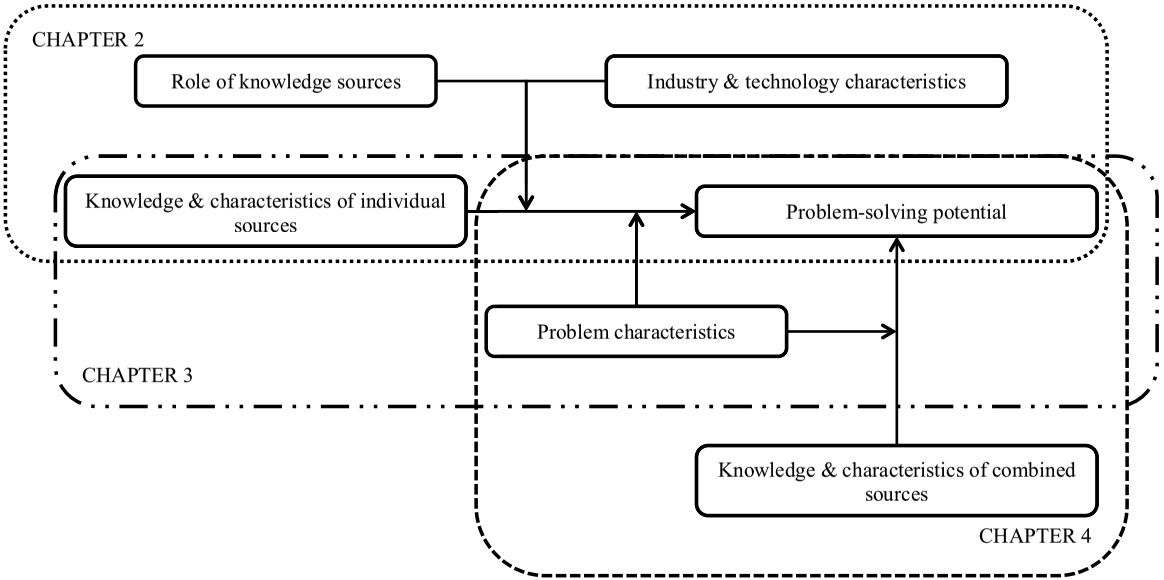
mutual confusion among the collaborators as many interdependent sources pool their knowledge to solve a specific problem (Knudsen and Srikanth 2014).

In addition to expecting diversity of knowledge domains to be an important determinant of problem-solving, we predict that the resultant increase in complexity will make problem-solving experience important to succeed as this helps avoid mutual confusion. We find that the likelihood of solving environmental problems is increased by external knowledge search efforts that include a more diverse set of knowledge domains. Furthermore, the inclusion of first-time problem-solvers is argued to increase the requirement for coordination and the risk of collaboration problems, which results in an observed negative effect from higher shares of such rookies. These findings add to the literature on external knowledge search by further explaining the benefits and drawbacks of increasing knowledge diversity in external search. Furthermore, we make the novel contribution of discussing and investigating the negative consequences of involving inexperienced knowledge sources. In addition to the theoretical implications this provides insights for practitioners and policymakers that are working on designing problem-solving teams that can address the important and pressing environmental challenges faced globally.

Table 1

Chapter	Empirical Setting & Study	Data	Explanatory Variables	Dependent Variable	Method
2	Technological change in the energy sector. Influence of incumbent firms on problem-solving	FP7, Orbis	Incumbent reactive participation; incumbent proactive leadership	Funding approval of solution by experts	Logistic regression with split sample
3	Societal Grand Challenges. Advocacy groups' effect on understanding and solving problems	FP7, Orbis, qualitative interviews	Advocacy groups' share of budget; concentration of sectors represented	Solution rating by experts	OLS with problem fixed-effects and split sample
4	Environmental problems. Effects of diverse knowledge domains and problem-solving experience	FP7, Orbis, patent data	Diversity of IPC classes on effort; share of first-time problem-solvers	Solution rating by experts	OLS with problem fixed-effects

Figure 1


CHAPTER 2
Role of knowledge sources
Industry & technology characteristics
Knowledge & characteristics of individual sources
Problem-solving potential
Problem characteristics
CHAPTER 3
Knowledge & characteristics of combined sources
CHAPTER 4

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CHAPTER 2. SEARCH AND DESTROY: THE EFFECTS OF INCUMBENT INERTIA ON EXTERNAL KNOWLEDGE SEARCH

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ABSTRACT

I analyze the influence of incumbent firms on the problem-solving likelihood of external knowledge search efforts in the context of competence-enhancing and competence-destroying technological change respectively. By analyzing 1,072 external knowledge search efforts I show that incumbents have positive effects on problem-solving related to competence-enhancing technologies. However, organizing such efforts to involve incumbent firms as a knowledge source has a negative effect, which I argue is caused by their inertia related to competence-destroying technologies. Finally, I show that incumbents who proactively lead technological change and engage in reconfiguration of their competences have positive effects in competence-destroying technologies. The findings contribute to extant literature by showing the influence of individual knowledge sources on the problem-solving likelihood of external knowledge search efforts, and the contingencies regarding the organization of these efforts conditional on the commitment of individual knowledge sources to the resultant technological change.

INTRODUCTION

This paper investigates the effects of organizing external knowledge search efforts to include incumbent knowledge sources facing technological change. More specifically, the paper analyzes the effects on the problem-solving likelihood of such efforts contingent on the involvement of incumbent firms and the competence-enhancing or competence-destroying effects respectively. In doing so the paper combines the literature on external knowledge search (e.g. Cassiman and Veugelers 2006; Katila and Ahuja 2002) with the problem-solving perspective (Nickerson et al. 2012) and draws on the topic of incumbent decline in the face of technological change and strategies for survival to understand the influence of individual knowledge sources on the likelihood of solving problems in collaborative external knowledge search efforts.

The topic on incumbent decline has traditionally attracted significant attention in the strategy and management literature (e.g. Eggers 2015; Rothaermel and Boeker 2008; Tripsas 1997). This stream of research builds on the conceptualization of technological change in an industry as having one of two effects: (i) Competence-enhancing effects that increase the value of existing competences in the industry and thereby enables incumbent firms to maintain or improve their competitive advantage; or (ii) competence-destroying effects that undermine the value of incumbent firms' existing competences and competitive advantage (Tushman and Anderson 1986). Incumbents often neglect to adapt to the latter type of technological change despite the high risk of failure from not proactively reconfiguring their competences to accommodate new technologies and business models. Among the prominent examples of such failure is Kodak. Despite playing a significant part in its invention Kodak failed to reconfigure its competences to embrace the emergence of digital photography, and ultimately went bankrupt in 2012 after having been a dominant force in the photography industry for more than a decade (Tripsas and Gavetti 2000). However, incumbents can maintain their competitive advantage despite competence-destroying change by proactively engaging in reconfiguring their competences (Lavie 2006). IBM provides a noteworthy example of an incumbent firm which has continuously adapted to technological changes in their industry, e.g. through reconfiguration their competences from a focus on plasma to LCD technology for flat panel displays (Eggers 2015).

Numerous causes have been argued to underlie the failure of incumbents to embrace and survive competence-destroying technological change. Fundamentally, these firms have shown a tendency to fall victim to their own success as the growth into incumbency results in increasing inertia over time. Several sources have been noted for this inertia, such as the tendency to myopically focus on exploitation of existing competences and out-dated mindsets of managers that reduce proactive embracing of new technology (Levinthal and March 1993; March 1991; Tripsas and Gavetti 2000). Similarly, organizational rigidity caused by routines and structures that delay or even prevent responses to technological change (Henderson and Clark 1990), reluctance to cannibalize on existing business areas and profits by pursing new technology or a lack of sufficient competences to do so (Henderson 1993; Leonard-Barton 1992) may all contribute to the incumbents' inertia (Kraatz and Zajac 2001; Levinthal and March 1993). Combined with the negative effects on the competitive advantage of incumbents from competence-destroying technological change this inertia can render incumbents unable or unwilling to embrace the emergence of technologies that result in the destruction of their competences and subsequent demise (Henderson 1993; Tripsas and Gavetti 2000).

Collaborating with external sources has been noted as a potential solution for incumbents to reconfigure and retain competitive advantage in the face of competence-destroying technological change in the strategy literature (Lavie 2006; Rothaermel and Boeker 2008; Rothaermel and Hill 2005). Similarly, the literature on external knowledge search has shown that accessing external knowledge sources in problem-solving efforts is an important contributor to firms' innovation performance by improving the likelihood of developing solutions to innovation related problems (Katila and Ahuja 2002; Laursen and Salter 2006; Leiponen and Helfat 2010). By drawing on external knowledge sources such as universities, suppliers, users and even competitors, firms can access new knowledge and incumbents can thereby reduce the above-described inertia (Rosenkopf and Nerkar 2001; Rosenkopf and Almeida 2003). In a problem-solving perspective the challenge related to external knowledge search is how to organize these efforts to include the optimum knowledge sources in order to develop efficient solutions to problems (Nickerson and Zenger 2004; Nickerson et al. 2012). In line with this perspective increasing scholarly attention has been directed towards how to organize search efforts in which multiple knowledge sources interact to develop and assemble the appropriate pieces of a larger puzzle to find a solution to an innovation related problem (Baer et al.

2013; Felin and Zenger 2014; Love et al. 2014). The inherently interactive nature of such efforts creates interdependence among the knowledge sources and potential cooperation problems due to the characteristics of the individual sources, which impact the joint outcome (Puranam et al. 2012). However, the effects of the mutual influence of knowledge sources involved in such collaborative problem-solving efforts has not been fully embraced in extant research (Knudsen and Srikanth 2014).

I empirically explore whether external knowledge search efforts are influenced by incumbent firms based on the notion that individual knowledge sources influence their collaborators and thereby the collective effort and its problem-solving likelihood. Specifically I explore whether problem-solving is influenced by incumbents contingent on the nature of the technological change and whether these incumbents are proactively pursuing a reconfiguration of their competences. I predict variation in the ability of external knowledge search efforts to solve innovation problems depending on whether the organization of these involves incumbent firms, the competence-enhancing or competence-destroying nature of the related technological change, as well as the reactiveness or proactiveness of incumbents in leading the change and reconfiguring their competences accordingly. To test the theoretical predictions I use data on external knowledge search efforts related to technologies with competence-enhancing or -destroying effects from the perspective of incumbents. These efforts are organized to have no involvement of incumbents, have incumbent participants or are initiated, organized and led by incumbents. The latter of these variations is interpreted as incumbent proactiveness in reconfiguring their competences and leading the technological change. The analysis draws on 1,072 cases of external knowledge search consisting of jointly formulated solutions to specific innovation problems. The dependent variable captures independent expert reviewers' evaluation of whether the problem-solving likelihood of the proposed solutions are sufficiently high to merit funding from the European Commission 7th Framework Program's energy area, which ran between 2007 and 2013. The energy sector provides a valuable empirical setting since incumbents in this industry have decades of engagement in the established mode of production and distribution of electricity. This has entailed investments into costly large-scale and technology specific assets and development of specialized competences related to these technologies and the established business model. This development results in a high degree of inertia in these firms (Delmas et al. 2007; Smink et al. 2015). This historic development exposes incumbents to

the loss of competitive advantage through competence-destroying technological change in this industry. Such change is represented by the emergence of technologies that facilitate small-scale electricity production, such as solar energy and electricity storage, as well as energy saving technologies. These technologies destroy the value of competences related to and profitability of existing large-scale production facilities, thereby threatening the incumbents. The analysis is focused on problem-solving through external knowledge search efforts related to the competence-enhancing or –destroying technologies respectively. Through this, the paper examines whether the interdependent nature of external knowledge search results in a negative effect of incumbent involvement related to the competence-destroying technologies in opposition to those with competence-enhancing effects, and whether this can be mitigated by incumbent proactiveness towards technological change.

The remainder of the paper is structured as follows. Section two reviews literature on incumbents and technological change before linking this to the literature on collaboration, problem-solving and external knowledge search. Hypotheses are then developed to predict the effects of incumbents on problem-solving in the context of external knowledge search related to competence-enhancing and –destroying change, with a differentiation in the latter between reactive participation and proactive leadership by incumbents. Section three describes the empirical setting and analysis before section four presents the results. Section five provides discussion of the findings and section six concludes with limitations and avenues for future research.

INCUMBENTS AND EXTERNAL KNOWLEDGE SEARCH

Technological Discontinuities: The Rise and Fall of Incumbents

The framework developed by Anderson and Tushman (1986) describes how technological discontinuities initiate cyclical developments that impact the value of firms' competences and the competitive dynamics in an industry. The discontinuities create an era of ferment where experimentation results in crude versions of different technologies, which compete to become the dominant design. The establishment of a dominant design eventually follows as the industry converges on a particular technology and the related mode of problem-solving and value creation, at which stage the firms lacking the competences to establish a competitive position based on this design will exit. In the subsequent era of incremental change innovation efforts target cost reduction and minor differentiations,

and the value of competences related to the dominant technology increases since specialized knowledge is required for problem-solving related to achieving these incremental improvements. Firms are required to become increasingly expert in solving problems related to the dominant technology to excel at exploiting the opportunities in the industry. Possession of competences suited to problem-solving in the dominant technology allow these firms to establish themselves as industry incumbents (Anderson and Tushman 1990; Tushman and Anderson 1986).

Eventually new technological discontinuities will emerge as a result of solving innovation problems related to new technologies (Anderson and Tushman 1990). As the possession of valuable competences is central to establishing or retaining competitiveness following such discontinuity, Tushman and Anderson (1986) differentiate between technological changes with either competence-enhancing or competence-destroying effects. Competence-enhancing effects create new opportunities to exploit current technologies and business models by improving productivity based on existing competences. Thereby, incumbents are in a favorable position to maintain or improve their positions as industry leaders. Competence destroying effects are the result of problem-solving that enables the introduction of new technologies or business models. As a result, the competitive advantage of incumbents is undermined since the value of their existing competences is reduced and competing firms possess the competences to exploit the new opportunities. While incumbents are threatened by competence-destroying technological change, new entrants in an industry are likely to benefit, since they do not suffer from the inertia that stifles incumbents with competences tied to the old technology (Tushman and Anderson 1986).

External Knowledge Search as Incumbent Survival Mechanism

The main cause of incumbent decline in the face of competence-destruction is the lack of innovation and adaptability (Henderson and Clark 1990; Tushman and Anderson 1986; Utterback 1994). This inability to innovate and adapt is largely a consequence of incumbent inertia caused by path-dependency and myopia, which is developed over time through successful exploitation of existing technologies and related competences (Levinthal and March 1993; Rosenbloom and Christensen 1994). However, studies have shown that some incumbents manage to escape this decline and survive competence-destroying change (e.g. Eggers 2015; Hill and Rothaermel 2003). A central caveat related

to the likelihood that incumbents will survive competence-destroying technological change is the extent to which they engage in a dedicated effort to escape incumbent inertia and reconfigure their competences (Lavie 2006). Multiple factors underlie the importance of such commitment: First, the path-dependency that incumbents tend to develop as a result of their preference for exploiting existing competences and the resultant myopia (Levinthal and March 1993; March 1991; Tripsas and Gavetti 2000). Second, the routines and structures that create organizational rigidities and competence traps (Henderson and Clark 1990); and third the inherent reluctance in firms to self-cannibalize (Henderson 1993; Leonard-Barton 1992). These factors create a degree of inertia that renders incumbents unable or unwilling to embrace the emergence of technologies that result in the destruction of their competences (Henderson 1993; Tripsas and Gavetti 2000).

A fruitful strategy for incumbents to survive competence-destruction despite their inertia is to engage in collaborations with external partners (Rothaermel 2001; Rothaermel and Boeker 2008; Rothaermel and Hill 2005). While these findings show that incumbents can benefit from collaborating with external partners it remains unclear if the specific collaborative efforts benefit from the participation of incumbents, or if this is contingent on their commitment to reconfiguring their capabilities. As such, the observed survival of incumbents does not account for whether this survival is caused by embracing or reducing competence-destruction in their industry, and whether the latter carries consequences for the specific collaborations and remaining participants. Furthermore, the studies of incumbent survival have largely focused on technology licensing and well-defined, contract-based strategic alliances. These have a different vulnerability to influence between collaborators than the interactive and iterative problem-solving taking place in external knowledge search efforts at the front end of innovation.

Similarly to e.g. Katila and Ahuja (2002) the theoretical background of the paper rests on the conceptualization of external knowledge search as efforts involving multiple knowledge sources that jointly attempt to develop a solution to technology related innovation problems. This conceptualization recognizes that incumbent firms become path-dependent and myopic over time (Levinthal and March 1993), and that access to distant knowledge from external sources can mitigate the resultant inertia and improve their ability to solve innovation related problems by contributing novel perspectives and solutions (Rosenkopf and Almeida 2003). External search thereby helps firms overcome

the path-dependency of reapplying local knowledge and familiar solutions by combining a variety of different knowledge sources and domains (Rosenkopf and Nerkar 2001). For example Laursen and Salter (2006) show that firms can improve their innovation performance by increasing the breadth and depth of openness towards external knowledge sources. Knowledge sources such as universities or competitors are found to influence the ability of firms to innovate (Köhler et al. 2012), as is the involvement of users (von Hippel 2005). Efficient problem-solving is thereby a matter of organizing search efforts to involve appropriate knowledge sources in order to develop solutions with a high likelihood of solving the specific problem (Felin and Zenger 2014; Nickerson et al. 2012). Similarly, studies of incumbents' survival of technological change have shown how they benefit from leveraging external knowledge (Rothaermel and Boeker 2008; Rothaermel 2001). However, these studies have not explored the potential for negative effects on these efforts from incumbents that suffer from inertia and risk competence-destruction. The following sections elaborate on this by embracing the mutual influence inherent in joint search (Knudsen and Srikanth 2014; Puranam et al. 2012). Hypotheses are developed on positive and negative incumbent influences as a consequence of competence-enhancing or –destroying effects respectively, as well as on the effects of whether incumbents are proactively leading the technological change and engage in reconfiguring their competences.

THEORY AND HYPOTHESES

Competence-Enhancing Change and Incumbents in External Knowledge Search

To explore the influence of incumbents on problem-solving in external knowledge search efforts I define technologies from the incumbents' point of view to capture the competence-enhancing or competence-destroying technological change, which successful solving of the specific innovation problems observed in the analysis would contribute to. Consequently, competence-enhancing technologies are defined as those that maintain or reinforce the value of the incumbents' competences and thus their competitive advantage (Tushman and Anderson 1986). The implications of problem-solving and innovation in these technologies on industry structures, business models and competitive dynamics are traditionally limited and maintain or improves the competitive advantage of incumbents (Afuah and Utterback 1997; Henderson and Clark 1990). For example, problem-solving that improves processes related to existing technologies has the advantage of reduced cost or time, which improves the profitability of incumbents and manifests their industry

position. Advances in these technologies will also enable the integration of related technology, components or similar into existing products or business models, which improves the existing modes of value creation (Tushman and Anderson 1986). Furthermore, improvements in these technologies are likely to raise the expectations for what benefits technologies with competence-destroying effects should provide to convince customers to adopt these (Adner and Zemsky 2005). Consequently, problem-solving in the existing technologies reduce the threat from competence-destroying technologies. As a result, incumbents tend to favor innovation related to these technologies because of the enhancement of the value of existing competences and thus the lack of a threat to their competitive advantage (Cyert and March 1963; March 1991; Tushman and Anderson 1986).

While the tendency to favor these technologies may be motivated by a strategic interest in maintaining competitive advantage, it may similarly be caused by utilization of experience and existing knowledge. Incumbents are likely to have significant experience with the specific innovation problem from several years of activities within the technology following the emergence of a dominant design (Anderson and Tushman 1990; Suárez and Utterback 1995). This experience enables them to provide in-depth knowledge regarding the technological area, which is likely to increase the likelihood of finding a solution with their inputs (Katila and Ahuja 2002). As external knowledge search efforts require provision of valuable knowledge in the joint learning that targets the development of a solution (Felin and Zenger 2014; Nickerson et al. 2012), such efforts within competence-enhancing technologies are likely to benefit from incumbents' expertise and experience in the area.

External knowledge search efforts rely on the interactive contribution and combining of relevant and valuable knowledge from the involved sources to solve the related problem (Garriga et al. 2013; Love et al. 2014). As a result, the knowledge sources are inherently influencing each other as they interact in these iterative processes of solution development (Knudsen and Srikanth 2014). Alignment of incentives between the different sources is important to ensure collaboration in such efforts where the joint problem-solving likelihood is contingent on the contributions from individual participants (Puranam et al. 2012). Therefore successful problem-solving is likely to rely on the alignment of incentives to encourage knowledge sources to contribute knowledge and expertise.

Incumbents' participation in external knowledge search efforts related to competence-enhancing technologies is likely to have a positive effect because of their valuable knowledge and incentives to solve problems related to competence-enhancing technologies. The alignment of incentives and incumbents' possession of important knowledge and experience motivates the first hypothesis of this paper:

Hypothesis 1: *In competence-enhancing technologies incumbents' increases the problem-solving likelihood of external knowledge search efforts*

Competence-Destroying Change and Incumbents in External Knowledge Search

Incumbent Reactiveness through Participation

To the extent that incumbents are not leading the problem-solving and thereby not engaged in a reconfiguration of their capabilities I predict a negative effect on problem-solving likelihood from their involvement in external knowledge search efforts related to competence-destroying technological change. This prediction rests on the knowledge that technologies with radically new features, increased customer benefits or novel applications create dramatic changes in industries' established structures, competitive dynamics and business models (Adner and Zemsky 2005; Chesbrough 2010). Solving problems within these technologies thereby destroys the value of the incumbents' competences and undermines their competitive advantage (Tushman and Anderson 1986). These *"disastrous effects on industry incumbents"* (Henderson and Clark 1990, pp.1) are caused by the historic developments by which these firms grow into incumbency, which involves commitments to capabilities, assets and business models that over time become increasingly tied to the dominant design (Henderson and Clark 1990; Lavie 2006). These commitments increase as competitive advantage is established through increasing efficiency and lower costs, creating a reinforcing path-dependency whereby exploiting existing technologies through incremental innovation is preferred to exploration of potential substitutes (March 1991). The result is incumbent inertia whereby alternatives to the dominant technology are dismissed as inferior or perceived as threats to be avoided.

The economies of scale, price advantages and barriers to entry for competitors created through the investments made by incumbents will suffer from the substitution of the technologies on which these are created (Adner and Zemsky 2005). As new technologies capture market shares and reduce the potential to utilize the full capacity of existing

production facilities, incumbents' profitability and payback times suffer (Panzar and Willig 1977). The sunk costs incurred during decades of establishing competitive advantages based on existing technologies are potentially lost and future profitability is threatened by the lack of the requisite competence to compete following technological change (Adner and Zemsky 2005; Tripsas 1997). Finally, the business models that complement the investments and competences of incumbents may be undermined by technologies that enable significantly different modes of value creation and capture (Chesbrough 2010). The consequence is both a strategic interest of incumbents to avoid this destruction of their competences and the organizational inertia that prevents them from engaging in the pursuit of such technological change.

Regardless of the negative effects incumbents are observed to take part in innovation activities with competence-destroying potential (Jiang et al. 2011). Findings shows that embracing the emergence of competence-destroying technologies can benefit the incumbents in terms of retaining or increasing their competitiveness (Hill and Rothaermel 2003; Lavie 2006). Studies of incumbent survival following competence-destroying change have shown that these firms are likely to benefit from collaborative strategies (Rothaermel and Boeker 2008; Rothaermel 2001). However, the foundation for these findings has been analyses of the incumbents and their survival through formal contract-based collaborations, rather than emergent collaborative problem-solving. As such, extant research has not fully embraced the perspective of external knowledge search targeting joint problem-solving as a unit of analysis, and the extent to which these more interactive, iterative and early stage collaborations may experience different consequences of incumbent involvement. As such, it has not been explored whether the incumbents' overall preservation of competitive advantage potentially comes at the expense of their collaborators as specific efforts are negatively impacted despite the benefits for the incumbent. This consideration is particularly pertinent in the context of this paper – external knowledge search efforts in which knowledge sources mutually influence each other while developing solutions.

While incumbent firms risk losing their competitive advantage following competence-destruction, these technological changes are caused by and result in entrepreneurial activity by pioneering firms (Adner and Zemsky 2005; Anderson and Tushman 1990). As such, contrary to the incumbents' incentives to avoid these developments, other firms

come into existence and base their future competitive advantage and incumbency on the technological change (Anderson and Tushman 1990). Research has shown that these firms may benefit from collaborating with incumbents by accessing complementary assets and valuable industry expertise and networks (Spithoven et al. 2013; Teece 1986). However, these findings are largely based either on technologies with competence-enhancing effects where interests are likely to be aligned, on the perspective of incumbents that have committed to a reconfiguration of their competences to embrace the technological change and subsequent successfully survive competence-destruction, or on less interactive collaboration forms. As a result, the effects on problem-solving on specific external knowledge search efforts from organizing to include incumbent knowledge sources that have not committed to reconfiguration in competence-destroying technological change remain unexplored.

As argued above incumbents potentially have individual interests that diverge from those of the remaining knowledge sources, unless they have committed to a reconfiguration of their capabilities. In their study on industry transitions Smink et. at. (2015) find that incumbents engage in institutional strategies to influence legislation and subsidies in order to intentionally prevent or slow the emergence of competence-destroying technologies. Similarly, incumbent may engage in activities related to competence-destroying technological change to observe and to some extent prevent or delay the emergence of these threats. This creates a misalignment of the incentives of the knowledge sources when incumbents without clear commitment to reconfiguration of their competences are involved. At the level of the individual search efforts the above misalignment of incentives is likely to result in reduction in the provision of knowledge, which has negative effects of joint outcomes from collaborations (Puranam et al. 2012).

In addition the negative effect from misaligned incentives when incumbent participate without commitment to competence-destruction, organizational inertia in incumbents are likely to influence the joint effort's problem-solving likelihood. Organizations tend to develop and learn in an increasingly myopic manner over time as they make ambiguous interpretations of complexity, knowledge and experience based on their previous successes (Argote and Miron-Spektor 2011; Diwas et al. 2013). As a consequence, organizations' understanding of problems and potential solutions becomes increasingly automated based on their existing knowledge, competences and individual

comprehensions of the world (Boeker 1989; Starbuck 1983). This puts successful incumbents increasingly at risk of overestimating their own knowledge and misinterpreting the relationship between problem and solution (Levinthal and March 1993). This inertia is often fund in incumbent firms, and through the interdependent nature of external knowledge search it is likely to influence the problem-solving.

Organizations prioritize drawing on local knowledge and to preserve the value of their existing competences as a consequence of the myopic learning paths and competence traps described above (Haas et al. 2015). This is likely to be particularly pronounced in the development of new technology with competence-destroying effects since this involves distant knowledge with which the incumbent has no previous experience and lacks the competences to exploit. Incumbents are inherently subject to this inertia due to their previous success with the dominant design and development of competences related thereto (Henderson 1993; Tripsas and Gavetti 2000). These internal constraints that incumbents face are critical since the knowledge sources involved in the search for a solution need to collaboratively collect, examine and evaluate knowledge from each of them (Li et al. 2013; Nickerson et al. 2012). This is challenging given the epistemic interdependence in joint efforts (Puranam et al. 2012), which requires both alignment and shared understanding of several different knowledge domains (Baer et al. 2013). This exposes external knowledge search efforts to the risk that individual, powerful participants impose their myopic view of the problem faced and potential solutions on the remaining participants, thereby imposing their inertia and reducing the collective problem-solving likelihood (Knudsen and Srikanth 2014; Levinthal and March 1993). As incumbents are central actors in an industry with power and resources required by the remaining knowledge sources and at risk of being myopic, this potentially increases the negative effects expected from misaligned incentives due to competence-destruction. As such, the second hypothesis of this paper predicts that:

Hypothesis 2: *In competence-destroying technologies incumbents' reactive participation reduces the problem-solving likelihood of external knowledge search efforts*

Incumbent Proactiveness through Leadership

In contrast to the above effect it is expected that incumbents will have a positive effect on external knowledge search efforts related to competence-destroying technological change if they are proactively identifying valuable problems, and organizing and leading the

search for solutions in an effort to reconfigure their competences. This expectation builds on the knowledge that incumbents may successfully engage in and profit from competence-destroying change through the appropriate responses (Hill and Rothaermel 2003; Rothaermel and Hill 2005). Such responses can include the use of external knowledge to respond to technological change by acquiring new and discarding existing competences, by continuously evolving existing competences or by combining the two approaches (Lavie 2006). However, either of these approaches requires incumbents to recognize the need to replace their existing competences and the willingness to do so. Past investments into developing and maintaining competences such as sunk-cost assets, personnel training and similar may create both cognitive and economic barriers to reconfiguration and increase the inertia discusses above, thereby preventing incumbents from reconfiguring their competences. As such, reconfiguring existing competences is challenging to incumbents, but nonetheless remains critical in maintaining competitive advantage after competence-destroying technological change (Lavie 2006; Tushman and Anderson 1986). Indeed, extant research shows that incumbents may retain their competitive advantage despite the destruction of competences by technological change (Eggers 2015; Hill and Rothaermel 2003; Jiang et al. 2011). The use of external knowledge sources is important for incumbents to survive and potentially thrive following competence-destruction (Rothaermel and Boeker 2008; Rothaermel and Hill 2005), as these enable incumbents to overcome the inertia developed over time (Lavie 2006). Furthermore, it increases their ability to identify, develop and commercialize novel solutions from new technologies (Chesbrough 2010; Sydow et al. 2009).

The prerequisite of obtaining these advantages is an initial strategic commitment by the incumbent to reconfigure their competences. As such, incumbents may respond to technological change and competence-destruction beyond the reactive inertia driven behavior related to hypothesis 2. This can either be through continuous development and adaption of existing capabilities, or complete substitution of these with capabilities to retain competitive advantage profit after the breakthrough of radically new technologies (Lavie 2006). Either strategy is inherently dependent on the degree to which incumbents allocate attention towards the emerging technology (Eggers and Kaplan 2009) and perform initial identification of incentives and a strategic commitment to the pursuit of these (Chandy and Tellis 2000). Such identification is captured in the empirical setting of this paper as the leadership of problem-solving efforts related to competence-destruction.

The importance of such commitment is the path-dependency that incumbents tend to develop as a result of their preference for exploiting existing competences and managerial inertia related thereto (Levinthal and March 1993; March 1991; Tripsas and Gavetti 2000), routines and structures that create organizational rigidities (Henderson and Clark 1990) and reluctance to self-cannibalization (Henderson 1993; Leonard-Barton 1992). Combined with the disruptive effects on the competitive advantage of incumbents from competence-destroying technological change (Henderson and Clark 1990; Rosenbloom and Christensen 1994; Tushman and Anderson 1986), this inertia can render incumbents unable or unwilling to embrace the emergence of technologies that result in the destruction of their competences and subsequent demise (Henderson 1993; Tripsas and Gavetti 2000). The caveat is that if incumbents proactively engage in reconfiguration they can in fact overcome the obstacles above and successfully develop the competences needed to survive and benefit from technological changes that destroy their existing competences (Chandy and Tellis 2000; Eggers and Kaplan 2009; Lavie 2006).

Incumbents that have committed to reconfiguring their capabilities to accommodate competence-destroying technological change are likely to be valuable sources for external knowledge search efforts as they contribute valuable knowledge regarding the industry, business model and the limitations of existing technologies that are to be displaced. Incumbents' provision of valuable knowledge and expertise should thereby increase the problem-solving likelihood of the external knowledge search effort. The search efforts involving incumbent sources in competence-destroying problem-solving are thereby predicted to have an increased likelihood of solving innovation problems when incumbents are proactively leading the efforts related to such technological change.

Hypothesis 3: *In competence-destroying technologies incumbents' proactive leadership increases the problem-solving likelihood of external knowledge search efforts*

DATA AND METHOD

Empirical Strategy

The theoretical predictions are tested with logistic regression analysis estimating the likelihood that the solution developed by an external knowledge search effort receives funding from the European Commission. The development of the solutions observed in this data initially begins with the European Commission issuing a call for applications

directed at solving a concrete innovation problem related to a specific technology. Following the publication of these calls, organizations can initiate the development of a solution to the specific problem through an effort involving external knowledge sources. The leader of such efforts subsequently selects and engages the knowledge sources to include them in an interactive and iterative process of developing a solution (European Commission 2006). The successful development of a solution is contingent on the contribution of knowledge from each source regarding both the fundamental problem, the potential ways of solving this and individual components of each, based on their expertise and specific knowledge. This process is well-aligned with the theoretical conceptualization of external knowledge search being a process of problem-solving initiated by a leader that selects a valuable problem, and subsequently organizes a search to include relevant knowledge sources and sets to develop an efficient solution to the specific problem (Nickerson and Zenger 2004; Nickerson et al. 2012).

In the empirical setting of this paper the effectiveness of the solutions developed in the external knowledge search efforts is reflected by the allocation of funding based on the evaluation of independent experts who assess the problem-solving likelihood. As such, the outcome variable takes the value 1 if a search effort develops a solution with a high likelihood of solving the related problem and 0 otherwise. These problems are related to technologies with competence-enhancing or –destroying effects, and the external knowledge searches are organized to either involve incumbent firms as participants, as leaders, or not at all. Each external knowledge search effort is observed in the data through the firm leading the effort, which allows the analysis to control for both leader specific characteristics as well as consortium level aspects. A total 2.35 billion Euros was allotted to solving energy related problems through the solutions proposed. These target the development of commercial technological innovations, creation of growth and development of global business opportunities (European Commission 2006). Allocation of funding is based on the evaluation of external experts, hired by the European Commission based on their expertise within each of the particular areas. These problem areas are represented by calls formulated by the European Commission and considered central to the advancement of the particular technology. The rewards of developing solutions that are approved for funding are substantial, with individual grants of several million Euros. This creates a setting in which significant effort and reward is connected to the formulation of solutions to the innovation problems.

The analysis is performed on the energy theme of the collaboration part of the framework. This allows identification of technologies with competence-enhancing or –destroying effects on the industry, a clear identification of incumbent firms and exclusion of purely scientific collaborations. Technologies are defined from the perspective of incumbent firms to enable a definition of their influence on the joint efforts based on the enhancement or destruction of their competences. In the energy sector the end product is the fully commoditized, homogeneous good of electricity, which functions equally well independent of its technological origin. This enables direct substitution of incumbent technologies by alternatives developed through successful problem-solving. This homogeneity and substitutability of the end product for electricity customers creates an important heterogeneity in terms of the impact that problem-solving has on incumbents. As such, successful problem-solving in competence-destroying technologies will increasingly enable customers to decouple from incumbent firms' energy supply, exclude them from the value chain and undermine their business model (Allen et al. 2008). This creates a suitable setting to analyze the effects of incumbents on problem-solving in external knowledge search efforts. The data on the external knowledge search efforts is supplemented by firm-level data from Bureau van Dijk's Orbis database, which provides the turnover, size, industry and patent portfolios of all participants. The resultant sample consists of 1,072 search efforts, 629 in competence-enhancing technologies and 433 in competence-destroying technologies.

Identifying Incumbents and Competence-Destruction

Incumbents are defined as firms with large sunk costs in and capabilities tied to the existing technologies, modes of value creation and business models (Adner and Zemsky 2005). These commitments result in strong interests in and incentives to retain the status quo rather than face the consequences of competence-destruction. The empirical setting of this paper provides clear identification of incumbent firms through the industry classification code 40.1 covering "*Production and distribution of electricity*". Problem-solving in competence-destroying technologies and resulting increases in distributed energy production lead to the loss of decades of investments in and competences related to large-scale centralized facilities, the dominant technologies and the capabilities used to produce and distribute energy for these incumbent firms (Allen et al. 2008; Watson 2004). Since incumbents are expected to be motivated by the perseverance of their profitability, business model, assets and capabilities, technologies with competence-destroying effects

are defined as those which undermine these after a period of underperformance and initial focus on niche markets (Anderson and Tushman 1990; Tushman and Anderson 1986).

The above conceptualization fits the emergence of distributed electricity generation in the energy sector and technologies with competence-destroying effects are accordingly defined in the data as "*future technologies and novel materials*", fuel cells and hydrogen, electro-chemical storage as well as photovoltaic solar energy. Solving innovation problems within these technologies has resulted in destruction of energy incumbents' competences and profitability due to increasing decentralization of energy production in recent years as described by for example The Economist's study of the European energy sector (2013). Decentralized production at household and small-scale levels was initially a niche market for green consumers. However, advancements in the above technologies coupled with government incentives has resulted in a radical reduction in the costs associated with distributed electricity generation. This has undermined the value of energy incumbents' competences and assets, and as a result their future earning potential, as an increasing number of consumers produce their own electricity. Business models have emerged that enable large customer segments to increasingly purchase or lease solar panels from third parties, which excludes incumbents from the industry value chain. The result of this emergence of these competence-destroying technologies in the energy sector has been losses of more than $550 billion during recent years for incumbents in Europe alone (The Economist 2013). Finally, the definition covers problems related to *energy savings* since significant reductions in the electricity usage of consumers would reduce the value of the incumbents' core competences: the business of producing and selling kilowatt-hours of electricity.

Conversely, problem-solving related to technologies currently dominating incumbents' portfolios preserves or improves the incumbents' competitive advantage, and are accordingly categorized as competence-enhancing. These technologies are defined in the analysis as: wind, biomass, geothermal, large-scale concentrated solar power, ocean power, hydro power, biofuels, smart energy networks, co2 capture and storage technology, and clean coal technologies. These build on or complement the competences of incumbents such as large-scale centralized production or improve the profitability or environmental impact of existing technologies. Problem-solving in these technologies thus serves to enhance the value of incumbents' competences since they help better utilize

and increase the capacity of existing production facilities, to the economic benefit of the incumbents.

Variables

Dependent Variable

The decision to allocate or reject funding to proposed solutions is based on three to five independent experts appointed by the European Commission (EC). These experts evaluate the problem-solving likelihood of the proposals based on the feasibility, innovativeness and commercial potential of the solutions. Each expert carries out an individual evaluation before they all convene to reach a consensual decision in Brussels. This consensus is reached under the guidance of a representative of the EC and an expert in the specific field to ensure that the process includes input from each expert. The dummy variable *Approved* thus captures whether a solution has a sufficiently high likelihood of solving the specific problem it addresses that it is granted funding by the EC based on the expert evaluations. This variable is consistent with similar research using ex-ante measures based on expert evaluations. This includes analyses of the quality of within-firm ideation (Salter et al. 2015), the novelty and potential of proposed innovation projects (Salge et al. 2013), as well as the value of proposals by individuals to solve firms' innovation problems (Poetz and Schreier 2012). The use of an ex-ante measure of the likelihood of solving problems based on the organization of search efforts is beneficial because exogenous factors are likely to influence eventual outcomes (Ring and Van de Ven, Andrew H. 1994). The disentanglement of unobserved exogenous and observed explanatory factors thereby remains a significant challenge in the use of ex-post measurements. Similarly, the process of executing solutions before measuring ex-post outcomes is vulnerable to changing group and individual firm dynamics and conditions. Potential changes are likely to occur in competitive dynamics, as well as in within-group or within-participant factors during execution of a solution (Cronin et al. 2011). These may include shifts in strategies, resource allocations, departure of key employees and similar in individual participants or the group during execution. The use of an ex-ante dependent variable overcomes the measurement challenges caused by such potentially unobserved changes.

Further supporting the use of ex-ante measures is the likelihood that industry or policy level events create higher or lower pressures on firms to solve particular problems during execution (Arino and De La Torre 1998). Such unobserved exogenous influence is likely

to have significant impact on the ex-post outcome. An additional benefit of the ex-ante expert evaluations is the opportunity to avoid the selection bias resulting from studying outcomes of executed problem-solving efforts. This would inherently exclude a large amount of non-realized efforts, which potentially differ from those that are realized. Both approved and rejected proposals should be analyzed to avoid an under-estimation of the factors resulting in rejection, which would create unobserved sample and selection bias (Heckman 1979). To understand how the organization of external knowledge search efforts influence the development of solutions it is therefore beneficial to capture the full variation in these efforts through use of ex-ante measures irrespective of their eventual execution. Finally, the dependent variable provides the opportunity to address the increasing interest in understanding the front-end of innovation processes (Kijkuit and van den Ende 2010; Salter et al. 2015), in particular the early stage of developing solutions to innovation related problems.

Explanatory Variables

The explanatory variables in the analysis capture whether the observed external knowledge search effort is organized to involve an incumbent, which may occur in two different ways. Incumbent firms may be participants, or initiate and lead the search. The dummy variable *Incumbent Participant* takes the value 1 for search efforts that include an incumbent participant and 0 otherwise. This represents instances in which non-incumbent firms in the sample have identified a problem to solve and made the choice of including an incumbent firm in the effort to develop a solution. As such, these are instances in which the incumbent firms have not explicitly identified the solving of the problem as a key strategic goal, but rather participate in a less committed and reactive way. With less commitment to solving the problem the incumbent firms have a larger discretion regarding the extent to which they allocate important resources, reveal key knowledge, contribute valuable insights or otherwise engage fully in the development of a solution, since they are not as explicitly accountable for the success of the problem-solving as the leader (European Parliament and Commission 2006). This allows the incumbents to reactively monitor technological developments and potential threats, while influencing the solutions in a way which serves their strategic goals. In the case of competence destroying technologies incumbent participation is thus interpreted as a sign of reactiveness through a lack of clear commitment to reconfiguring their capabilities.

The dummy variable *Incumbent Leader* captures the influence on search efforts from incumbent sources that have proactively identified a problem to solve, and have initiated and led this effort. The value 1 is thereby interpreted as a reflection of proactive strategic intention from the incumbent, as this shows a commitment to and identification of incentives from solving the innovation problem. This is a signal that the incumbent is actively seeking to solve the problem and has a clear intention of benefitting from the resulting technological changes in the industry, regardless of whether these are competence-enhancing or –destroying. For the competence-destroying technologies this thereby reflects efforts in which incumbents are strategically committed to a reconfiguration of their capabilities according to the technological changes resulting from solving the specific problem. Instances of such proactiveness is likely to involve a greater willingness to allocate resources, share key knowledge etc., as the incumbent is the main organization responsible for the effort, and is reflective of an incumbent firm which is making proactive, intentional strategic efforts to overcoming its inertia and profiting from emergence of competence-destroying technology.

Control Variables

Experience with similar problem-solving and related interactions, coordination and knowledge sharing is likely to influence the ability of firms to develop appropriate solutions (Love et al. 2014). *Leader Experience* therefore controls for whether experience of the search leader is influencing the problem-solving likelihood by capturing the amount of experience within the 7th Framework Program applications prior to the observed search effort. Similarly, the analysis also controls for whether the experience accumulated by all knowledge sources prior to the observed search effort influences the joint ability to coordinate and collaborate through the variable *Participants' Accum. Experience*. Knowledge intense firms may be more likely to solve problems due to a wider range of knowledge and higher absorptive capacity that facilitate the use of external knowledge (Cohen and Levinthal 1990). Following extant literature the count of patents is used to capture the knowledge stock of firms (Ahuja and Katila 2004). As such, the variable *Leader Patent Stock* captures the knowledge stock of the leader of a specific search effort through a count of the number of patents assigned by the European Patent Office. The patents are discounted at an annual rate of 15% to account for whether the knowledge is likely to still remain active and readily available within the firms in the year of the observed efforts (Aerts and Schmidt 2008). Variables are included for the turnover for

individual firms to control for the benefits of available resources that can be committed to the problem-solving. The variation in the turnovers of the observed firms causes skewness and accordingly, the natural logarithm of firms' turnover is included as the variable *Leader Turnover* to control for firms' turnover in the year of the observed effort.

Science-based sources can increase problem-solving and innovation by introducing novel knowledge (Köhler et al. 2012). This is particularly observed in immature technologies where the non-commercial targets of universities, focus on basic research and sharing of the knowledge proves valuable (Cohen et al. 2002; Link and Scott 2005). Consequently, the analysis controls for the influence of universities and research organizations in problem-solving through the variable *University Participant*. The amount of knowledge sources may influence problem-solving positively by increasing the breadth of knowledge inputs (Laursen and Salter 2006). To control for the breadth of the knowledge sources accessed on the problem-solving efforts *Number of Participants* captures the number of participants. The variable *Funding Request* captures the amount of funding requested by the leader in hundred thousand Euros to control for the size of the efforts and any effects from larger or smaller funding requests.

Finally, I control for geographical and industry specific factors of the leader of the external knowledge search efforts. Regional differences are captured by dummy variables that indicating the location of the leader. The regions are defined as *Northern, Eastern, Western, Southern Europe* or *Non-European*, with *Northern Europe* functioning as the reference category. Industry dummies are included to account for industry specific effects (Grimpe and Sofka 2009). The analysis controls for whether the leader belongs to the *High-Medium Tech Manufacturing*, *Medium-Low Tech Manufacturing*, *Knowledge Intense Services*, *Less Knowledge Intense Services* or *Other* categories. The latter serves as reference group in the analysis. The categorization is based on NACE industry classifications and aggregated according to Eurostat's definition of sectors according to knowledge intensity. A further aggregation combines high-tech and medium to high tech sectors in one category, and medium-low tech and low tech manufacturing into one.

RESULTS

Descriptive Results

Table 1 presents the summary statistics for the full sample. The mean of *Incumbent Leader* is .10 across the sample of competence-enhancing and competence-destroying technologies, which shows a low propensity for incumbent firms to initiate and lead external knowledge search efforts. The variable *Incumbent Participant* shows a higher frequency of search efforts organized to include incumbents as participats with a mean of .53. The propensity of incumbents to engage in these efforts as participants rather than leaders would indicate that these firms to indeed focus mainly on existing competences while monitoring future developments, rather than actively engaging in the exploration of new and potentially competence-destroying technology. The use of universities is very high in the combined sample with a mean value of *University Participants* at .91, which is expected given that the problem-solving takes place at early stages of knowledge development and innovation. As such, these efforts are likely to benefit from and involve basic and science based knowledge (Köhler et al. 2012; Link and Scott 2005). While the mean size of the problem-solving efforts is 11 knowledge sources this ranges broadly from 2 to 40, showing a large variation in the breadth of sources accessed by the individual efforts. The firms leading the external knowledge search efforts range broadly in their previous experience. The sample includes firms that are part of this type of effort for the first time, while there are highly experienced leaders with 20 prior search efforts. The majority of participants are based in Northern and Western European countries and represented within knowledge intense services.

----INSERT TABLE 1 AROUND HERE----

Table 2 shows the pairwise correlation of the variables. No high correlations are detected among the variables and a mean variance inflation factor of 1.59 supports the suggestion that the data does not suffer from multicollinearity (Belsley et al. 2005).

----INSERT TABLE 2 AROUND HERE----

Regression Results

Table 3 presents the regression results from the estimation model with a step-wise introduction of the variables and the samples of competence-enhancing technologies represented in left-hand columns under the heading “Enhancing” and the competence-

destroying technologies in the right-hand columns with the heading “Destroying”. Model 1 is the baseline model with the controls at both the level of the firm and search effort respectively. Model 2 includes the first of two explanatory variables *Incumbent Participant*, which takes the value 1 for external knowledge search efforts organized to include an incumbent participant in the problem-solving and 0 otherwise. Finally, Model 3 provides the full estimation including both dummies for incumbent knowledge sources within each category of technologies. The effects remain significant in the full model, supporting the significance of both variables. The significant and positive effect of both explanatory variables in the competence-enhancing technology sample in Model 3 provides support for hypothesis 1. This predicted that external knowledge search efforts experience a positive effect on problem-solving likelihood from including incumbent knowledge sources. The significant and negative effect of *Incumbent Participant* in model three’s competence-destroying sample provides support for hypothesis 2, which predicted that search efforts involving incumbent knowledge sources within these technologies experience a reduced likelihood of solving problems.

----INSERT TABLE 3 AROUND HERE----

Hypothesis 3 predicted that a commitment by incumbents to reconfigure their competences to embrace the competence-destroying technological change would reverse the negative effects predicted in hypothesis 2. To the extent that incumbents engage in a reconfiguration of their capabilities to accommodate competence-destruction, it was predicted that the problem-solving likelihood would benefit from access to their knowledge and resources in the development of solutions. The indicator of such commitment by incumbents is the initiation and leadership of problem-solving. Accordingly, variable *Incumbent Leader* in model 4’s right-hand column captures instances of search efforts in such technologies, which involve incumbent knowledge sources committed to reconfiguring their competences. The predicted positive influence of this alignment on external knowledge search is confirmed by the significant and positive effect of the variable *Incumbent Leader*. No hypothesis was developed for the effects of incumbent leadership in competence-enhancing technologies. However, it could be expected to align with the effects in hypothesis one, which is supported by the positive and significant effect of incumbent leadership in these technologies.

The use of science sources would be expected to have a significant and positive influence (Köhler et al. 2012). However, this was only found in the competence-destroying sample. This may be due to the less explorative nature of the efforts related to the competence-enhancing technologies, where incremental improvements tend to dominate (Anderson and Tushman 1990), which are likely to benefit less from university knowledge (Link and Scott 2005). The number of participants has a positive impact on problem-solving, which likely to reflect the value of knowledge and input from a broad range of sources as described by Laursen and Salter (2006).

Consistency Checks

The appendix presents the results of a number of consistency checks performed to confirm the findings and reject alternative explanations. Table 4 presents the inclusion of dummy variables for each technological field in the sample. These technology fixed-effects are included to confirm that the driver of the results in the two samples is incumbent inertia and competence-destruction in general, rather than only a reluctance towards or prioritization of individual technologies. Table 5 presents the results for a model specification with clustered standard errors at the firm level. This accounts for the occurrence of the same firms as leaders of multiple search efforts in the sample, which could potentially bias results if firm-specific characteristics were driving the problem-solving likelihood of the efforts. The final consistency check in Table 6 seeks to account for the potential alternative explanation that the effects of incumbent participants or leaders is a result of their knowledge and abilities rather than their inertia and reactiveness, or their proactive decision to reconfigure their competences. To control for this alternative explanation I include the variables *Incumbent Destroying Patent Stock* and *Incumbent Enhancing Patent Stock*, which capture the weighted patent stock of any incumbent participants or leaders on specific efforts related to either type of technology according to the European Patent Office's 2nd level of IPC classes. Each of the above alternative specifications provide consistent results to those of the main model.

CONCLUSION AND DISCUSSION

Incumbent firms may face destruction of their competences from technological change, resulting in a loss of competitive advantage (Tushman and Anderson 1986). Extant alliance literature has argued that incumbents can survive these changes through collaborations with external partners (Rothaermel and Boeker 2008; Rothaermel 2001).

However, this stream of research has largely focused on the incumbent perspective and not embraced the idea that incumbents may benefit while their collaborators do not, and has mainly focused on formalized alliances or licensing agreements where mutual influence is limited. The literature on external knowledge search has similarly recognized the value of external knowledge sources and domains for incumbents in their attempts at overcoming their inertia (e.g. Katila and Ahuja 2002; Rosenkopf and Nerkar 2001). However, as argued recently by Knudsen and Srikanth (2014) this has largely conceptualized the search process as unitary, which implies that the searching firm can access and utilize the knowledge of external sources without contingencies related to individual interests, rationalities or similar of those sources. As such, the extant search literature has not yet fully embraced the idea presented by Puranam et. al. (2012) that knowledge sources in collaborative efforts are inherently interdependent and mutually influence each other. In this paper I explore the extent to which this mutual influence may result in negative influences from incumbents due to the threats to their competitive advantage and their inherent inertia. This questions the extent to which external knowledge search is unambiguously an efficient strategy for incumbents and their collaborators to solve problems that create technological change. The results show that incumbents have positive effects on problem-solving related to competence-enhancing technological change, while the opposite is the case for competence-destruction unless the incumbents have initiated such efforts as leaders and thereby taken a proactive approach to the technological change and reconfiguration of their competences. These results contribute to the literature on the use of external knowledge and problem-solving by showing that the benefits of organizing external knowledge search to include incumbents is contingent on the extent to which they are threatened by the resultant change and subsequently whether they have proactively engaged in such change to overcome the inertia characterizing most incumbents.

Extent research has shown that firms may selectively reveal certain knowledge for the purpose of protecting other pieces of critical knowledge or serve specific strategic interests (Alexy et al. 2013; Henkel 2006). As individual sources of knowledge face different consequences of technological change they may leverage knowledge strategically to protect their individual interests, which would be an underlying factor of the negative effects observed in the analysis. Incumbents may reveal and withhold certain knowledge in order to retain the value of their existing competence rather than actively

participate in the destruction or reconfiguration of these. While this strategy may serve the purpose of protecting or maintaining the value of the competences of the incumbent despite technological change, it would most likely reduce development of a solution on an external knowledge search efforts. By retaining key knowledge related to specific problems and solutions incumbents may thus seek to reduce the competence-destroying effects of technological change, despite the negative effects for the joint problem-solving effort. As such, misalignment of interests and inertia may result in selective revealing acting as an underlying mechanism for the reduced likelihood of solving problems when incumbents participate without have proactively committed to and engaged in the technological change. This supports the idea that while individual incumbents may survive technological change through collaborative strategies it does not unambiguously mean that the collaborations they are engaged in benefit from the incumbents participation.

An additional cause of the negative effect from incumbents is likely to be the dependency of collaborations on the allocation of attention and resources by the individual participants (Garriga et al. 2013). Because firms face restrictions in the amount of attention and resources they can allocate to certain efforts due to e.g. limited absorptive capacity (Cohen and Levinthal 1990), prioritization could be a mechanism behind the incumbents' influence. Firms (and their employees) are likely to prioritize their allocation of resources and attention to collaborations based on their own immediate strategic interests, and in a manner which fits within their existing comprehension of which problems are critical and valuable to solve. This is inevitably related to the inertia that incumbents develop over time, which leads them to prioritize incremental improvement of the dominant technologies that leverage their existing competences rather than self-cannibalization through competence-destruction (Henderson 1993; Leonard-Barton 1992; Tushman and Anderson 1986). As such, the negative effect from incumbent participants is potentially a reflection of a lack of allocation of attention and resources, while the positive effect from incumbent leadership would reflect the decision to dedicate both to the reconfiguration of competences.

The epistemic interdependence of individual knowledge sources in the effort to jointly solve a problem has been argued to potentially create coordination problems, which influence the joint outcome (Knudsen and Srikanth 2014; Puranam et al. 2012). This is

likely to be an underlying cause of the negative effect observed in the analysis as the individual sources struggle to develop a shared understanding of the specific problem and developing a suitable solution. Boeker et. al. (1989) explain how different organizations and individuals develop separate conceptions of the world over time, which can subsequently be difficult to reconcile. Incumbents are particularly vulnerable to this due to their past successes with certain technologies and the development of competences related to these. Their history thus makes them increasingly myopic in their learning over time (Levinthal and March 1993). As a result, incumbents develop inertia, which prevents them from interpreting and solving problems beyond the scope of their existing knowledge and conceptualizations (Nelson and Winter 1982; Simon 1955). This inertia is critical because joint efforts require the participants to develop some degree of shared understanding of each individual knowledge domain and how they interconnect, and recognize the value of these in solving the specific problem they face (Puranam et al. 2012). Conflicting understandings may result in powerful participants such as incumbents engaging in "hard bargaining", whereby they impose their perceptions on the remaining participants to reach a consensus (Levinthal and March 1993). However, while the result of this is a shared understanding between knowledge sources, it is likely to produce a suboptimum outcome (Davis and Eisenhardt 2011). As such, the epistemic interdependence of external knowledge search efforts entail the risk that no shared understanding is reached, resulting in mutual confusion about the problem and potential solutions, or joint myopia whereby the bias and incomplete understanding of one participant is forced upon its partners (Knudsen and Srikanth 2014). As incumbents are large and powerful firms in their industries it is likely that they possess the bargaining power to impose their strategic interests or biased understandings on external knowledge search efforts to create joint myopia, or withhold important knowledge to create mutual confusion. However, incumbents that show proactiveness in reconfiguration of their competences have most likely identified the limitations of their current knowledge and competences, and the value from competence-destroying change. As such, these proactive leaders of technological change are more likely to appreciate their own inertia and myopia, and be willing to recognize the value and importance of alternative knowledge domains, problem-understandings and potential solutions. This would account for the positive effect observed from proactive incumbents as well as the negative effects from the more reactive incumbents that have not entirely committed to competence-destroying technological change.

The paper contributes to extant literature on external knowledge search and problem-solving by exploring the important influence of individual knowledge sources. Although the process of joint problem-solving involves interaction and sharing of knowledge and resources (Felin and Zenger 2014; Love et al. 2014; Nickerson et al. 2012) the resultant interdependence has been underexplored in the search literature (Knudsen and Srikanth 2014). This interdependence, the importance of aligned interests and the influence of incumbent inertia on collaborators might be particularly critical in the early stages of innovation where uncertainty about appropriate solutions is high. At this stage there are likely to be many potential understandings of both problems and relevant solutions, which exposes formulation of problems and solutions to the influence of individual knowledge sources (Baer et al. 2013). As such, an important contribution of the paper lies in understanding the impact of individual knowledge sources at the early stages of the innovation process, specifically the influence of incumbent inertia. This contributes to an increasing focus on this stage, which involves different dynamics than later commercialization (Kijkuit and van den Ende 2010; Salter et al. 2015). The results contribute to the debate of incumbents' ability to innovate in competence-destroying technologies (e.g. Jiang et al. 2011), by supporting the idea that incumbents are capable thereof if strategically committed (Lavie 2006). This has implications for the debate of whether non-incumbents should be vary of incumbent firms in their early stage innovation efforts (Diestre and Rajagopalan 2012; Katila et al. 2008; Marx et al. 2014) by showing that non-committed incumbents have negative effects on joint innovation efforts in competence-destroying technologies. Finally, the findings contribute to the problem-solving perspective by Nickerson et. al. (2012) by showing that the organizing of problem-solving should consider not only the knowledge set that a search leader can access through involving external sources, but also the underlying interests of those sources. Organizing problem-solving to include knowledge sources with divergent interests in the solution is suggested as a potential contingency by Baer et. al. (2013), which is further supported by the findings in this paper.

LIMITATIONS AND FURTHER RESEARCH

While the paper benefits from detailed data on the nuances of variation in the organizing of problem-solving efforts and the effects of individual knowledge sources, the data has the drawback of not observing the long-term performance or outcomes of the collaborations. Linking specific external knowledge search and problem-solving efforts

with long-term performance may suffer from unobservable influences. However, it may nevertheless add to the insights in this paper regarding the influence of strategic interests and incumbent inertia on collaborations. Future research may increase the understanding of the long-term effects of misalignment of strategic interests between collaborators on their joint activities. It may be fruitful to investigate new firms' survival rates and performance, since solving individual innovation problems can be decisive to the survival of these firms and they may be particularly susceptible to incumbent influences due to their resource constraints and limited bargaining power.

The findings are based on data on firms choosing to engage in collaborative efforts in application of funding, which is not uncommon for innovative firms. However, a limitation might lie in the choice of firms to refrain from application, remain closed, or open in different ways. Future research might explore different settings or compare effects across settings. The findings draw on data from the energy sector, which is valuable to distinguish technologies and identify incumbents. However, it may also involve different dynamics compared to other industries with other competitive environments, entry barriers or historical contexts. A final limitation exists in the difficulty of distinguishing inertia and strategic intent despite controlling for knowledge and patenting behavior of incumbent firms. While the two may well overlap and interact, they may also represent separate mechanisms empirically. An interesting avenue for future research may be to more explicitly distinguish the interactions between organizational inertia in problem-solving and the specific strategic intent to avoid or delay the solving of certain problems.

TABLES

Table 1: Summary Statistics

Variable:	Mean	S.D.	Min	Max
Approved	.41		0	1
Incumbent Leader	.10		0	1
Incumbent Participant	.53		0	1
University Participants	.91		0	1
Number of Participants	10.98	5.40	2	40
Leader Experience	.79	2.06	0	20
Leader Turnover (logged)	18.10	3.53	8.96	26.38
Leader Patent Stock (hundreds)	.18	1.86	0	36.88
Funding Request (hundred thsnd. Euro)	.93	3.18	0	54.02
Participants' Accum. Experience	3.36	4.45	0	32
Eastern Europe	.08		0	1
Northern Europe	.01		0	1
Southern Europe	.34		0	1
Western Europe	.46		0	1
Med-High Tech Manufacturing	.19		0	1
Knowledge Intense Services	.31		0	1
Less Knowledge Intense Services	.03		0	1
Med-Low Tech Manufacturing	.16		0	1
Mean Variance Inflation Factor (VIF): 1.59				

Table 2: Pairwise Correlations

Variables:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1) Approved	1																	
(2) Incumbent Leader	.13*	1																
(3) Incumbent Participant	.12*	.11*	1															
(4) University Participant	.12*	.02	-.11*	1														
(5) Number of Participants	.20*	.12*	.36*	.05	1													
(6) Leader Experience	.15*	.07*	.13*	.05	.09*	1												
(7) Leader Turnover	.18*	.20*	.32*	.02	.19*	.25*	1											
(8) Leader Patent Stock	.07*	-.03	.01	.02	.05	.02	.16*	1										
(9) Funding Request	.08*	.06*	-.06*	-.00	-.01	.04	.00	-.01	1									
(10) Participants' Accum. Experience	.28*	.11*	.14*	.14*	.33*	.29*	.13*	-.04	.12*	1								
(11) Eastern Europe	-.11*	-.07*	.01	-.06*	-.04	-.08*	-.17*	-.03	-.05*	-.10*	1							
(12) Northern Europe	-.05*	-.04	-.02	.03	.02	-.02	.04	-.01	-.02	.00	-.03	1						
(13) Southern Europe	-.03	.12*	-.04	.06*	-.02	.10*	-.07*	-.06*	.09*	.01	-.21*	-.08*	1					
(14) Western Europe	.07*	-.07*	.05	.00	.04	-.06*	.14*	.08*	-.07*	.10*	-.27*	-.10*	-.66*	1				
(15) Med-High Tech Manufacturing	-.07*	-.10*	-.13*	.02	-.16*	-.13*	-.05*	.01	-.01	-.11*	-.02	.02	-.08*	.04	1			
(16) Knowledge Intense Services	-.01	-.10*	-.06*	-.03	-.00	-.06*	-.36*	.00	-.01	-.06*	.09*	-.03	.06*	-.05*	-.32*	1		
(17) Less Knowledge Intense Services	.01	-.04	.01	-.04	.04	.15*	.07*	-.02	.09*	-.02	-.05	-.02	.06*	-.02	-.08*	-.11*	1	
(18) Med-Low Tech Manufacturing	-.01	-.05*	-.08*	.04	-.05*	-.05*	.11*	.05*	-.03	-.01	.02	-.05	-.07*	.04	-.21*	-.29*	-.07*	1

* Correlation significant at the 10% level

Table 3: Main Model. Logistic regression, outcome: Approval of Funding

	Model 1		Model 2		Model 3	
Variables	Enhancing	Destroying	Enhancing	Destroying	Enhancing	Destroying
Incumbent Leader					0.48*	1.34**
					(0.27)	(0.58)
Incumbent Participant			0.51**	-0.62**	0.53**	-0.57*
			(0.22)	(0.31)	(0.22)	(0.30)
University Participant	-0.06	1.67***	-0.01	1.79***	0.05	1.81***
	(0.45)	(0.38)	(0.46)	(0.41)	(0.46)	(0.41)
Number of Participants	0.04*	0.09***	0.03	0.11***	0.02	0.11***
	(0.02)	(0.03)	(0.02)	(0.03)	(0.02)	(0.03)
Leader Experience	-0.01	0.04	-0.01	0.05	-0.01	0.04
	(0.05)	(0.05)	(0.04)	(0.06)	(0.04)	(0.06)
Leader Turnover	0.11***	0.03	0.09***	0.05	0.08**	0.05
	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)
Leader Patent Stock	0.15*	0.00	0.17	-0.00	0.19	-0.00
	(0.09)	(0.06)	(0.10)	(0.06)	(0.12)	(0.06)
Funding Request	0.03	0.08	0.03	0.11	0.03	0.08
	(0.05)	(0.14)	(0.05)	(0.14)	(0.05)	(0.14)
Participants' Accum. Experience	0.13***	0.00	0.13***	0.01	0.13***	0.01
	(0.04)	(0.03)	(0.04)	(0.03)	(0.04)	(0.03)
Constant	-3.38***	-4.29***	-3.41***	-4.66***	-3.33***	-4.68***
	(0.88)	(0.89)	(0.87)	(0.91)	(0.86)	(0.91)
Year Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Regional Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Industry Dummies	Yes	Yes	Yes	Yes	Yes	Yes
Observations	629	443	629	443	629	443

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

APPENDIX

Table 4: Consistency Check: Logistic regression with technology fixed effects.

Variables	Enhancing	Destroying
Incumbent Leader	0.41	1.15**
	(0.28)	(0.56)
Incumbent Participant	0.52**	-0.53*
	(0.24)	(0.31)
University Participant	0.13	1.84***
	(0.59)	(0.39)
Number of Participants	0.03*	0.12***
	(0.02)	(0.03)
Leader Experience	-0.01	0.04
	(0.04)	(0.05)
Leader Turnover	0.10***	0.05
	(0.03)	(0.04)
Leader Patent Stock	0.18	0.01
	(0.12)	(0.06)
Funding Request	0.04	0.09
	(0.05)	(0.14)
Participants' Accum. Experience	0.14***	-0.01
	(0.04)	(0.04)
Constant	-3.48***	-4.31***
	(1.08)	(0.95)
Technology Dummies	Yes	Yes
Year Dummies	Yes	Yes
Regional Dummies	Yes	Yes
Industry Dummies	Yes	Yes
Observations	629	443

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Consistency Check: Firm clustered standard errors

Variables	Enhancing	Destroying
Incumbent Leader	0.48*	1.34**
	(0.27)	(0.59)
Incumbent Participant	0.53**	-0.57*
	(0.23)	(0.30)
University Participant	0.05	1.81***
	(0.47)	(0.43)
Number of Participants	0.02	0.11***
	(0.02)	(0.03)
Leader Experience	-0.01	0.04
	(0.05)	(0.05)
Leader Turnover	0.08**	0.05
	(0.03)	(0.04)
Leader Patent Stock	0.19	-0.00
	(0.13)	(0.06)
Funding Request	0.03	0.08
	(0.05)	(0.14)
Participants' Accum. Experience	0.13***	0.01
	(0.04)	(0.03)
Constant	-3.33***	-4.68***
	(0.89)	(0.94)
Year Dummies	Yes	Yes
Regional Dummies	Yes	Yes
Industy Dummies	Yes	Yes
Observations	629	443
Number of clusters	502	403

Clustered standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Consistency Check: Incumbent patents in enhancing and destroying technologies

Variables	Enhancing	Destroying
Incumbent Leader	0.45	1.21**
	(0.28)	(0.57)
Incumbent Participant	0.50**	-0.59*
	(0.22)	(0.32)
University Participant	0.03	1.77***
	(0.46)	(0.43)
Number of Participants	0.03	0.11***
	(0.02)	(0.03)
Leader Experience	-0.01	0.04
	(0.05)	(0.06)
Leader Turnover	0.08**	0.06
	(0.03)	(0.04)
Leader Patent Stock	0.20	-0.01
	(0.13)	(0.06)
Funding Request	0.03	0.08
	(0.05)	(0.14)
Participants' Accum. Experience	0.13***	-0.01
	(0.04)	(0.04)
Incumbent Destroying Patent Stock	0.01	0.05**
	(0.01)	(0.02)
Incumbent Enhancing Patent Stock	-0.00	-0.01**
	(0.00)	(0.00)
Constant	-3.30***	-4.76***
	(0.85)	(0.94)
Year Dummies	Yes	Yes
Regional Dummies	Yes	Yes
Industy Dummies	Yes	Yes
Observations	629	443

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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CHAPTER 3. SOLVING GRAND CHALLENGES STARTS WITH UNDERSTANDING: HOW ADVOCACY GROUPS IMPROVE PROBLEM-SOLVING

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ABSTRACT

In this paper we examine the role of advocacy groups in the search for solutions to grand challenges. We view grand challenges as problems that firms can solve collaboratively by accessing external knowledge from a range of domains. We argue that involving advocacy groups in such consortia is important for developing an understanding of the problem and for devising an appropriate search strategy to solve it. Using data on 9,464 efforts to solve problems within 252 different areas, we find that involving advocacy groups increases the problem solving potential of a search strategy because it reduces mutual confusion and joint myopia within consortia. The benefits are particularly high

when problems are more challenging and when multiple knowledge domains are required to address the problems.

INTRODUCTION

Grand challenges represent the most significant, complex and interdependent problems that modern and globally connected societies are facing (Liu et al. 2015). These challenges relate to diverse problem areas such as climate change (Howard-Grenville et al. 2014), mental and physical health (Collins et al. 2011; Varmus et al. 2003), hunger and water shortages (Godfray et al. 2011) and privacy in the digital age (Dodgson et al. 2015; George et al. 2014). While these challenges are highly diverse, they share a need for bold and innovative solutions (Colquitt and George 2011; Omenn 2006). Despite the increasing urgency of addressing these challenges, decades have passed with little progress and even regress in some areas. Examples include escalating climate change (Howard-Grenville et al. 2014), endurance of global health disease issues (Butler 2011), persistence of poverty and hunger (West et al. 2014) and lack of access to clean water in numerous many regions (Griggs et al. 2013).

In this paper, we ask how firms may contribute to solving grand challenges. Our research is anchored in the literature on organizational search for innovation (e.g., Katila, 2002; Katila and Ahuja, 2002; Laursen and Salter, 2006), which has frequently documented the value of external knowledge for firms' innovation processes (e.g., Laursen and Salter, 2006; Leiponen and Helfat, 2010; Garriga, von Krogh, and Spaeth, 2013). However, an implicit yet important assumption in this research is that firms search for solutions to well-understood problems. We argue that this assumption is generally unlikely to hold, and particularly so for grand challenges. To solve complex and interdependent problems, such as grand challenges (Godfray et al. 2011; Omenn 2006), knowledge on the nature, cause and effect of problems is an important complement to the knowledge on how to solve them (Leiblein and Macher 2009; Nickerson and Zenger 2004). Accordingly, we propose that search strategies that aim at solving problems in collaboration with external partners will benefit from the inclusion of partners that hold a deep understanding of the problems rather than knowledge on how to actually solve them. Particularly in the context of grand challenges, we suggest the involvement of advocacy groups (such as Foodwatch, Greenpeace or the Red Cross) in search consortia to facilitate novel or better approaches as well as to reduce frictional losses among the partners.

Our research contributes to the literature in at least two ways. First, we depart from extant search and problem-solving theory in that we do not assume that all knowledge sources necessarily provide expertise directly related to solving the problem. Rather, within our theoretical reasoning, we distinguish between partners that mainly provide knowledge relevant to *solving* a problem, for example universities, suppliers or customers, and partners that mainly provide knowledge relevant to *understanding* the problem, i.e. advocacy groups. Advocacy groups typically do not engage in research and development (R&D) themselves. Rather, they accumulate and aggregate problem-relevant knowledge that they make available to consortium partners. We theorize that they increase the likelihood of the consortium to properly understand and solve problems by eliminating unreasonable or irrelevant solutions and thus to reduce mutual confusion and joint myopia (Knudsen and Srikanth, 2014). In fact, the importance of understanding a problem before devising a search strategy has received little attention in the theoretical literature and virtually no attention in the empirical literature on organizational search (e.g., Felin and Zenger, 2014). However, we argue that the problem definition and understanding will have a considerable effect on the effectiveness of a search strategy. As a result of prior literature's negligence of the importance of partners that mainly facilitate problem definition, we may have considerably overestimated the relative effect of partners providing problem solutions, such as universities.

Second, we show that the benefits of including advocacy groups in search consortia are higher when the efforts to solve problems are increasingly challenging and may ultimately amount to a grand challenge. Moreover, involving advocacy groups is more beneficial when the knowledge accessed to solve a problem is dispersed across multiple domains, as is the case in the context of grand challenges (Godfray et al. 2011). In this regard, our research extends the literature on organizational search and informs managers and policy makers as to how grand challenges may be better addressed by drawing on a variety of knowledge sources and including advocacy groups to provide problem-relevant knowledge and increase the benefits associated with involving multiple knowledge domains. While our research focuses on solutions to grand challenges, advocacy groups, i.e. partners that predominantly help understanding rather than solving a problem, may similarly facilitate firms' innovation performance in many other contexts.

The empirical part of our research is based on unique data on search consortia from the European Commission's Seventh Framework Program for Research and Technological Development (FP7). FP7 was a research-funding program that ran from 2007 to 2013 with a total budget of more than 50 billion Euros. It is specifically dedicated to supporting projects that aim at contributing towards the solution of grand challenges such as climate change, poverty and hunger, privacy in the digital age, and health and disease prevention. Individual project grants can be generous but also require significant effort by the applicants to be obtained. Applications receive a quality score based on standardized criteria from multiple independent experts. We interpret this score as the problem solving potential of a search strategy devised by a consortium, which is comparable across applications within the same problem area. Our sample contains all 9,464 firm-led consortia applying for funding within the 252 calls put forth by the European Commission that define the problem areas. Using this sample we estimate the effect of the inclusion of advocacy groups on the problem solving potential of a search strategy to solve problems within the broader defined grand challenges. We conducted four semi-structured interviews with firm executives acting as leaders of search consortia involving advocacy groups in the FP7 sample. Analyzing these helped inform our hypothesis development by increasing our understanding of the mechanisms through which advocacy groups are selected and how they influence the problem solving potential of search consortia.

The remainder of this paper is organized as follows. The next section describes the theoretical background and derives a set of hypotheses. Data, measures, and the empirical model are outlined in the subsequent section that is followed by the results. We discuss these results subsequently and draw conclusions. The final section addresses the limitations of our research and implications for future research.

THEORY

Our theoretical starting point is to model grand challenges as particular types of problems for which firms search for solutions. Within our setting this search for solutions leads to the formulation of a search strategy, i.e. a choice of technologies (Katila and Ahuja 2002) and/or knowledge sources (Laursen and Salter 2006) that are expected to solve the underlying problem. We focus on collaborative search strategies in which firms collaborate with multiple organizations (Knudsen and Srikanth 2014) because a situation in which a focal firm possesses all relevant knowledge for solving a grand challenge is an

unlikely or extreme assumption. Consequently, we model search strategies as emerging from search consortia in which firms assemble multiple partners who contribute relevant knowledge to understand and solve a problem. Search consortia and their search strategies are assumed to be heterogeneous in nature and will consequently have different potentials to solve the underlying problem (Nickerson and Zenger 2004) . Hence, our overall contribution is to explain the problem-solving potential of search strategies for grand challenges. We will develop a theoretical reasoning for how the involvement of advocacy groups influences the problem-solving potential of the resulting search strategy. We start out by defining central constructs and mechanisms.

The term "grand challenge" has been used in various ways and fields.[4] In this paper we follow the definition by Colquitt and George (2011: 432) which states: "The fundamental principles underlying a grand challenge are the pursuit of bold ideas and the adoption of less conventional approaches to tackling large, unresolved problems". Examples include the definition of Millennium Development Goals of the United Nations for fighting poverty, hunger or diseases worldwide, the 21st Century Grand Challenges formulated by the US Office of Science and Technology on issues such as energy or health[5] as well as the societal challenges of the framework programmes (FP) of the European Union in its most recent form called "Horizon 2020". Private foundations, too, have invited proposals to address grand challenges in global health such as the Bill and Melinda Gates foundation. A grand challenge can thus be understood as a large scale unresolved problem, potentially consisting of multiple sub-problems, which poses a substantial barrier for a variety of stakeholders and encourages innovative and novel solutions, which span boundaries such as disciplines or industries, thereby requiring collaborative efforts.

Following this definition of grand challenges as a particular type of problem with multiple sub-problems, we build our argument on a theoretical lens, which emphasizes problems as the relevant unit of analysis. Nickerson and Zenger (2004) develop a problem-solving perspective within the knowledge-based theory of the firm in which the acquisition of new knowledge in a firm starts with the choice of a valuable problem to address. The

[4] The original "grand challenge" is usually traced back to German mathematician David Hilbert who laid out 23 mathematical challenges in his presentation at the International Congress of Mathematicians at Paris in 1900.
[5] The United States Office of Science and Technology Policy defines the 21st Century Grand Challenges as: "Grand Challenges are ambitious but achievable goals that harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination" (US OSTP, 2015).

value of problems emerges from their potential to lead to important knowledge or capabilities within firms once solved (Leiblein and Macher 2009). Accordingly, the problem choice triggers a process of searching for potential solutions. This search is intended to maximize the probability that the most valuable solution emerges relative to its costs (Nickerson and Zenger 2004). These solutions can be technological in nature, e.g. a new semiconductor design (Macher 2006) or a heuristic (Jeppesen and Lakhani 2010). Grand challenges inherently trigger such search activities (albeit not exclusively in firms) because solutions have large potentials to create economic and social wellbeing (Omenn 2006) and can affect a wide array of industries and economies. George et al. (2014) , for example, provide a discussion on "Big Data" and its application while Kulik et al. (2014) and Howard-Grenville et al. (2014) focus on management challenges from aging populations and climate change, respectively.

Involving Advocacy Groups in Search Strategies

Understanding advocacy group action and its influence on problem solving in search consortia is complicated by the observed heterogeneity of such groups, including political pressure groups, industrial lobbying groups as well as all kinds of environmental, health or other special interest groups. Advocacy groups are typically tied to the absence of satisfactory solutions to a problem, e.g. health or environmental problems from the absence of a clean, renewable source of energy. At first glance, it appears questionable why firms would incorporate advocacy groups in their search consortia since the interactions between firms and advocacy groups often take an adversarial nature. Notable examples include Greenpeace creating media attention vis-à-vis firm misconduct or by directly interfering with firm resources, e.g. by attacking oil platforms (Brugmann and Prahalad 2007) . In this regard, stakeholder theory (Freeman 1984) offers helpful guidance to describe the defining attributes of advocacy groups and how they are related to search. While stakeholders have been characterized in a multitude of ways (Mitchell et al. 1997) we follow Freeman's classic definition – "A stakeholder in an organization is (by definition) any group or individual who can affect or is affected by the achievement of the organization's objectives" (1984: 46) – which is one of the broadest found in the stakeholder literature because a possible stakeholder in an organization may include virtually anyone except those who cannot affect or are not affected by the organization. Based on this definition advocacy groups are regarded as organizations that (a) have a legal, moral or presumed claim on the firm or the ability to influence the firm (Savage et

al. 1991) and (b) are in an existing or potential relationship with the firm (Mitchell et al. 1997). Mitchell et al. (1997) define stakeholders along three attributes. First, they may exert power in their relationship with firms, based on available resources such as problem-relevant knowledge. Second, they are characterized by having a certain degree of legitimacy, defined as "a generalized perception or assumption that the actions of an entity are desirable, proper, or appropriate within some socially constructed system of norms, values, beliefs, and definitions" (Suchman 1995: 574) . The third attribute is described as urgency, which implies a time-sensitive nature or critical importance of the relationship with the firm. Taken together, the three attributes define the degree to which stakeholders are perceived as salient to the firm (Mitchell et al. 1997).

Existing literature on firms' search strategies largely assumes that firms sufficiently and comprehensively understand the problem to be solved. If this assumption holds search strategies can be reduced to assembling knowledge sources that provide solutions. Such knowledge sources can contribute solutions to problems based on knowledge which the firm would otherwise need to develop itself using time or resources (Fleming and Sorenson 2004) or which enable novel combinations with firm knowledge (Rosenkopf and Nerkar 2001). This stream of research has stressed the importance of involving broad sets of knowledge sources such as universities, customers or suppliers (Garriga et al. 2013; Laursen and Salter 2006; Leiponen and Helfat 2010). Advocacy groups are unlikely to possess in-depth technological knowledge that could similarly contribute to solving the problem at hand. However, they are likely to possess an in-depth understanding of the problem that makes them valuable participants in a search consortium, particularly given the nature of problems related to grand challenges.

The head of research alliances at a large ICT firm underlined the fact that advocacy groups are important to understand the problem but not to solve it:

> "Advocacy groups cannot contribute much to technology development. But by having them on board, we had access to the accumulated knowledge in the entire sector. Without them, our consortium would not have had 30 but rather 60 partners."

In sum, while advocacy groups are unlikely to add solutions to a search strategy, they can provide problem-centric information. Advocacy groups build up repositories of knowledge, which constitute the basis for attaining both power and legitimacy. These repositories of problem-centric knowledge can advance a search strategy in two ways. First, knowledge repositories constitute a source of utilitarian power (Etzioni 1964) if advocacy groups are able to offer resources as incentives in the relationship with firms. Second, advocacy groups are perceived as legitimate when their problem-relevant knowledge is considered accurate and appropriate (Suchman 1995) . Both aspects increase the problem-solving potential of a search strategy. First, advocacy groups accumulate knowledge from the stakeholders that they represent about how the problem affects these stakeholders. They have superior access to such stakeholders because of legitimacy effects and can condense information about the effects of a problem, i.e. channels, magnitudes, interactions. Accordingly, search consortia involving advocacy groups possess an increasingly comprehensive representation of the problem to be solved. Second and related to the first point, advocacy groups legitimize a search consortium vis-à-vis stakeholder groups by conveying a sense of importance and urgency to their concerns. Hence, advocacy groups can transfer their own legitimacy concerning a particular problem to the search consortium. Moreover, as the executive from the ICT firm pointed out, involving advocacy groups increases the likelihood that, in the end, solutions are more likely to be adopted because they address the "right" problem:

> "If we know what the requirements are, we can look for solutions that really fit. It is clear that those [solutions] will have much higher impact."

As a consequence, our first hypothesis reads:

Hypothesis 1: *The problem-solving potential of a search strategy increases with the involvement of advocacy groups*.

Advocacy Groups and Problem Challenge

There is no absolute reference point when the challenge originating from a problem becomes "grand". However, many definitions of grand challenges have in common that they consider existing search trajectories for solutions as insufficient, slow or fragmented (Colquitt and George, 2011). Hence, a problem is more challenging and in the extreme a

grand challenge if it has certain characteristics. Drawing from problem solving theory we emphasize in particular problem complexity, problem structure and the visibility of relevant knowledge of grand challenges. These dimensions have been highlighted by recent research as important determinants of the specific search strategy chosen (Felin and Zenger 2014; Macher 2006; Nickerson and Zenger 2004). The higher the complexity of a problem, the less known and more dispersed are the relevant knowledge sources for solving the problem. Structured problems are based on clearly defined initial states and a consensus on how relevant knowledge-sets interact (Macher 2006) , while ill-structured problems lack these properties. The visibility of knowledge sources for solving a problem relates to the limitations of searching actors to identify all promising pieces of relevant knowledge and their carriers (Fernandes and Simon 1999) . Structure and complexity are dimensions of the problem that relate to interdependencies of knowledge domains. Problem complexity implies that relevant knowledge sets interact and that the search for solutions cannot be decomposed and compartmentalized because changes to one piece of a part of a solution would affect the others (Nickerson and Zenger 2004) . As such, the number of individual knowledge domains involved in the search strategy increases and such domains are of increasing comparative importance as complexity increases.

Within our setting, a problem is considered more challenging when it is more complex, ill-structured and suffering from hidden knowledge. Problems with these properties are unlikely to benefit from a directional search strategy that continuously improves individual aspects of a solution through experimentation in an iterative process (Nickerson and Zenger 2004). Solutions resulting from such approaches are likely to be incomplete or suffer from unintended interactions. Many interdependent knowledge domains are required to interact in order to first understand and subsequently solve the problem, thereby creating a high level of complexity. One example of these aspects is provided by (George et al. 2014) on the interaction between data sharing, privacy and ethics when discussing the grand challenge of “Big Data”. Hence, solving complex problems requires a more theory-driven search strategy (Nickerson and Zenger 2004) . Such search efforts develop an initial theoretical understanding about cause and effect relationships (Leiblein and Macher 2009) .

A theoretical understanding of cause and effect is valuable because it allows search consortia to simulate and predict how potential solutions would eventually affect a

problem. A search consortium will eventually choose the search strategy with the best prediction for solving the problem. However, an inadequate theory of a problem is likely to lead to biased predictions, resulting in adverse choices of search strategies. Inadequate theory can for example originate from omissions of important factors (e.g. the availability of infrastructure) or outcomes as well as interactions between them. It can identify boundaries and avoid generalizations from selective settings or experiences. Particularly when evaluating solutions to challenging problems, which are ill-structured, complex and draw from diverse knowledge sources, firms are unlikely to have comprehensive theories about the effects of potential solutions. While advocacy groups may have very limited potential to provide solutions, e.g. new technologies, they have a very precise understanding about how a problem affects their stakeholders which can be condensed into a more adequate theory on how potential solutions solve a problem.

As noted previously, advocacy groups can legitimize a search consortium and provide access to relevant stakeholders that can reduce the effects from hidden knowledge in the search strategy of a consortium. An innovation manager from a leading manufacturing firm told us for example about her consortium with an advocacy group:

> "We did not learn anything from working with them technologically but they had a network of relevant decision makers in politics which allowed us to have presentations with key individuals. Our own networks would not have reached so far or some decision makers would not have been willing to listen to a large corporation such as ours."

In sum, our second hypothesis reads:

Hypothesis 2: *The problem-solving potential of a search strategy increases with the involvement of advocacy groups and this positive effect is stronger for increasingly challenging problems.*

Indirect Problem Solving Effects from Advocacy Group Involvement

Finally, we develop arguments for how advocacy groups can increase the effectiveness of other knowledge sources within a search consortium. Grand challenges are particularly likely to involve multiple organizations with dispersed knowledge encompassing various

industries or technological domains due to their interdependent and complex nature. Developing a shared theory and understanding of a problem among collaborators involved in a search process requires the collection, examination and evaluation of knowledge from multiple sources (Li et al. 2013) and requires alignment and shared understanding of multiple domains (Baer et al. 2013). However, such coordinated exploration between multiple organizations is inherently sensitive to the risk of mutual confusion and joint myopia (Knudsen and Srikanth 2014). We argue that an improved theoretical understanding of the underlying problem based on advocacy groups has the potential to alleviate these adverse effects of collaborative search.

Mutual confusion is caused by the myopic nature of organizational learning. Organizations tend to base their learning on inferences from previous problem solving as they interpret complexity and create knowledge based on individual, ambiguous experiences (Argote and Miron-Spektor 2011) and previous successes (Diwas et al. 2013). However, even the most capable organizations are likely to misperceive the causal relationship between problems and solutions in complex contexts. This is caused by the tendency to base interpretations on small samples of ambiguous experience and overestimating the value of own capabilities and knowledge (Levinthal and March 1993). Problem understanding and solving is increasingly automated based on existing knowledge and capabilities (Starbuck 1983) and individually comprehensible worlds (Boeker 1989). As a result, the bounded rationality of organizations prevents them from interpreting and solving problems beyond the scope of their existing knowledge (Nelson and Winter 1982; Simon 1955). This produces biased and incomplete interpretations of problems and solutions that disregard alternatives (Levinthal and March 1993), and organizations prioritize drawing on local knowledge to preserve the value of existing capabilities (Haas et al. 2014). Collaborative search is beneficial to firms in the effort to overcome such organizational myopia (Katila and Ahuja 2002; Rosenkopf and Nerkar 2001). However, it simultaneously carries the risk of mutual confusion among the collaborating organizations due to the propensity of organizations to perceive their own interpretation of problems and proposed solutions as superior (Knudsen and Srikanth 2014).

In high-complexity settings, the interdependence of organizations is particularly high since problem solving requires integration of multiple knowledge domains (Puranam et al.

2012). The risk of mutual confusion in joint problem solving increases with interdependence as the knowledge and learning of individual actors is increasingly embedded in the knowledge and simultaneous learning of other collaborators (Knudsen and Srikanth 2014). The risk of mutual confusion is further increased in highly complex problems because of the difficulty in distinguishing which knowledge in- or decreases the problem solving likelihood (Puranam and Swamy 2012). As a result, the understanding of the core problem and appropriate solution strategies remains ambiguous among actors and results in mutual confusion since each actor myopically believes in the superiority of their interpretation and proposed solution (Knudsen and Srikanth 2014). With the importance of understanding all aspects of problems of high complexity, establishing a strong initial theory and understanding of the problem, and comparative importance of all knowledge domains, the negative effects of mutual confusion are particularly strong in the context of grand challenges. We argue that advocacy groups improve the theoretical understanding of the problem underlying a grand challenge and thereby alleviate problems from mutual confusion within a search consortium.

Traditional approaches to avoiding mutual confusion within search consortia tend to increase the risk that the lowest common denominator dictates the search, resulting in lower value in outcomes (Davis and Eisenhardt 2011). The negative consequences of such satisficing are increasingly pronounced in complex problems because the need for an in-depth and accurate understanding of each component of the problem is increasingly high, and as a result the interdependence of the knowledge domains increases (Miller and Lin 2014). As each individual actor's understanding and acceptance is prioritized, the larger problem risks to remain unsolved because the organizations pursue solutions that are acceptable to the others rather than maximizing the solution potential of their individual contribution (Knudsen and Srikanth 2014). In doing so they neglect the more rewarding outcomes created by understanding the fundamental and overall problem, and as a result fail to develop a strategy focused on the knowledge and capabilities that best address this problem (Levinthal and March 1993).

As an alternative to such satisficing a collaborator may engage in "hard bargaining". This tactic seeks to impose the organization's perception of problem and best solution on the remaining collaborators and is likely to be successful when utilized by powerful organizations (Levinthal and March 1993). However, similarly to compromising this is

prone to reducing the problem solving potential as the myopia of the powerful organization is proliferated at the consortium level (Davis and Eisenhardt 2011). We argue that advocacy groups have the potential to reduce the risk for mutual confusion and joint myopia within a search consortium. This is based on their provision of a theoretical understanding for which factors are relevant for solving a particular problem, cause and effect relationships, as well as insights into the effectiveness of proposed solutions. Based on this theoretical understanding, opportunities arise for modularizing search efforts among partners as well as identifying and prioritizing potentially promising options early in the process. Finally, through their legitimacy and distance from commercial interest the advocacy groups are in a position to promote critical views and responses to potential hard bargaining tactics by powerful organizations in search consortia. The innovation manager of a manufacturing firm leading a research consortium involving an advocacy group explained to us:

> "Our consortium involved a diverse group of partners like OEMs [original equipment manufacturers], gas station chains, municipalities, universities, etc. The advocacy group could calm down internal exchanges and bring a sense of neutrality to discussions."

In addition, a consortium coordinator from an electronics firm noted:

> "The advocacy group made sure that the slightly potty ideas did not get through and that people were respectful with each other. They [the advocacy group] facilitated convergence of the search strategy, leading to a consistent concept."

In sum, we propose:

Hypothesis 3: *The problem-solving potential of a search strategy increases with involvement of advocacy groups and this positive effect is stronger if the partners in the search consortium have increasingly dispersed knowledge domains.*

DATA AND METHODS

Data

To support our theoretical arguments and hypotheses we conducted four semi-structured interviews with firm executives acting as leaders of consortia in our sample involving advocacy groups. The interviewees represented consortia in the areas energy, health and ICT, which provided insight into separate areas to confirm similar roles for the advocacy groups in each. The interviewees all had previous experience with these consortia, which provided them with a valuable frame of reference for the benefits and drawbacks of including advocacy groups or not. As contact to rejected applicants is restricted we were limited to speaking to leaders of consortia which received funding. As such, our hypothesis development is informed by firms that seem to have understood the benefits of including advocacy groups as knowledge sources. Since our subsequent quantitative analysis is oriented towards determining whether such advantages influence solution potential, we do not consider this to create a problematic bias.

The analysis of this qualitative data improved our understanding of the data, the construct validity of our measures, informed the hypothesis development and provided support to our interpretation of the mechanisms by which advocacy groups influence problem solving.

The hypotheses were tested using a dataset developed based on all applications submitted to the FP7, the European Commission's Seventh Framework Program for Research and Technological Development. We restrict our sample to the "Cooperation" part of the programme that is dedicated to funding collaborative efforts to develop new technological solutions and to areas that address grand challenges. As such, we focus on efforts that formulate search strategies to solve problems related to one of the following themes: Food and Agriculture, Health, Information and Communication Technologies, Nano Technologies, Energy, the Environment, Transportation, Security, and Socio-economic and Humanities-related issues. Within each of these areas the European Commission announced multiple calls in the seven-year period from 2007 to 2013. Each call relates to a specific problem area and resulted in a total funding allocation of over 50 billion Euros. Consistent with our theoretical focus on the search strategies of firms, we further restrict our sample to only include firm-led efforts that include multiple organizations. Our final

sample consists of 9,464 firm-led efforts that address 252 problems by drawing on external knowledge sources.

This empirical setting has multiple advantages. First, we theorize at the problem-level. The dataset reflects that. Firm- or invention-level (e.g. patent level) information is likely to suffer from biases due to aggregation of information. Second, we theorize on the effects of heterogeneous search strategies. The dataset allows us to capture multiple search strategies for problems, which are exogenously defined by the European Commission for all participating firms alike. Third, we capture all firm-level search strategies submitted to FP7. Hence, the potential for selection biases originating from capturing only successful search strategies is minimized. Finally, the European Commission defines problems in its calls for project applications that differ in how challenging they are. This provides us with the opportunity to distinguish between more and less challenging problems.

We extend the application information using VAT numbers and firm names. We identify the organizations involved in the search efforts in Bureau von Dijk's Orbis database. From this we collect data on the patent portfolios of the organizations, financial data for publicly listed companies, and use NAICS codes to identify advocacy groups based on the activities in which the organizations are engaged. Specifically, we define organizations as potential advocacy groups if these are registered in one of the groups that cover "*Religious, Grant-making, Civic, Professional, and Similar Organizations*". Subsequently we manually check and code the organizations to remove false positives. Finally, we remove any "*Business, Professional, Labor, Political, and Similar Organizations*" from the identified advocacy groups as these are likely to be oriented towards more professional and commercial interests than our theoretical setup seeks to explore. Our sample of advocacy groups thereby covers the following definitions: "*Religious Organizations*", "*Grant-making Foundations*", "*Voluntary Health Organizations*", "*Human Rights Organizations*", "*Environment, Conservation and Wildlife Organizations*", and "*Civic and Social Organizations*".

Variables

Dependent variable

Our dependent variable is the problem solving potential of a search strategy. To evaluate the problem solving potential we utilize the score assigned to each funding application by

three to five independent experts. These are hired by the European Commission based on their expertise within the particular problem area, and initially evaluate the proposals individually before subsequently meeting in Brussels to determine the final scoring of the search strategy outlined by the applicants. This meeting is moderated by a representative of the European Commission and an additional independent expert to ensure full consideration of the input of all experts. Our dependent variable is thus the final score ranging from zero to 100, assigned by experts based on whether the proposed search strategy is likely to solve the underlying problem along the dimensions of innovativeness, competence of the partners, feasibility of the solution, global impact and move beyond the state-of-the art.

Consistent with our theoretical setup we use a measure of the problem solving potential of the search strategy rather than the outcome. This has the advantage of isolating and analyzing the effect of advocacy groups without unobserved influences. Such influences from exogenous factors are likely to occur during the execution phase, creating contingencies and issues that affect the outcome of a search strategy (Ring and Van de Ven, Andrew H. 1994). This would reduce the ability to capture the influence of the variables of interest as this could be confounded with a range of alternative explanations. The use of ex-post measures to analyze the influence of e.g. advocacy groups on search strategies to solve problems is thus susceptible to unobserved influence such as changing resource allocations, departure of key individuals from the joint effort, shifting firm strategies or political priorities, unstable industry dynamics and the like. Such exogenous changes are likely to significantly impact the execution of projects (Arino and De La Torre 1998), such as those observed in our data, and to reduce the ability to identify the effects of advocacy groups on knowledge search. The ability to observe approved and rejected applications is an additional benefit from the use of ex-ante measures. Ex-post measures inherently suffer from selection bias since the rejected search strategies remain unobserved in the analysis. Relying on ex-post measures of approved applications would thus bias the data and potentially reduce the ability to observe the full variation in explanatory variables. Furthermore, our outcome is consistent with recent research using the ex-ante evaluations of expert reviewers as a reliable measure in the study of innovation and collaborative efforts (Franke et al. 2013; Poetz and Schreier 2012) and addresses the call for an increased focus on the front end of innovation efforts (Kijkuit and van den Ende 2010) by studying the initial formulation of search processes.

Explanatory Variables

Advocacy Group Involvement: To test the hypothesized effect of advocacy groups' influence on the problem solving potential we measure how much of the share of funding requested from the European Commission is allocated to advocacy groups. We assume that the influence of members of a search consortium increases with the share of funding allocated to a specific consortium member. A higher allocation of funding for advocacy groups in a search consortium implies thus that a search strategy relies comparatively more intensively on advocacy groups. Accordingly, the variable *Advocacy Group Involvement* captures the share of total funding requested from the European Commission allocated to advocacy groups in a search consortium. We perform consistency checks using the share of advocacy groups relative to the total number of sources used, which produces consistent results.

Problem challenge: The challenge of a problem is difficult to assess consistently across problem areas. Our dataset allows us to derive a comparative measure reflecting the priorities for each problem as reflected in the budget allocation of the European Commission, i.e. the authority that defines all problems.[6] Hence, we assume that problems with small budget allocations are unlikely to address a challenging problem or even a grand challenge and vice versa. More precisely, we use the total amount of funding allocated by the European Commission to each of the 2,217 specific problems nested in the 252 problem areas in our sample. A problem area can be associated with e.g. health, while the more specific problem is defined as related to e.g. Ebola. If the amount of funding allocated to a specific problem is above the mean funding allocation in the problem area we define the corresponding problem as challenging. While it is unlikely that the challenge of a problem and its budget appropriation are perfectly correlated in a linear manner, the creation of a dummy variable for problems which have higher than average budget allocations is likely to capture the priorities of the European Commission for how large the challenge underlying the problem is.

Knowledge dispersion: To test the interaction between advocacy group involvement and knowledge dispersion among multiple domains we use a Herfindahl index to calculate the concentration of NAICS codes represented in each search effort. The Herfindahl index

[6] While the European Commission formally defines all problems to be funded in FP7, this definition is based on extensive consultation with all stakeholders in Europe prior to the launch of calls for applications.

captures the concentration of a measure within a group that ranges from 0 to 1, reflecting equal distribution or full concentration of one single parameter (Hirschman 1964) . For ease of interpretation we reverse the signs of the calculated index and let 0 represent high concentration of NAICS codes, i.e. low dispersion of knowledge, and 1 represent low concentration among the participants, i.e. high dispersion of knowledge. An increase in our concentration variable thus reflects increasing dispersion of knowledge in a search effort.

Control Variables

To control for alternative explanations to the problem solving potential of the search strategies we include a number of controls at the firm and consortium levels. At the firm level we include controls for specific firm characteristics. Firms with high knowledge levels may be better able to identify relevant knowledge domains and sources in order to develop a search strategy to solve problems. Likewise, firms with high knowledge levels may have higher absorptive capacity and thereby have an increased ability to identify, utilize and combine the knowledge from external sources (Cohen and Levinthal 1990; Zahra and George 2002). To control for whether the problem solving potential of the search strategy is driven by high knowledge levels we include the *Firm Patent Stock* of the consortium leader. We depreciate this measure at an annual rate of 15 per cent between the time of patenting and the application to FP7 to account for the depreciation of knowledge over time. Furthermore, we expect that learning and acquiring routines related to joint efforts are likely to increase the ability to develop solutions of high potential (Love et al. 2013) . Accordingly, we include *Firm Experience* to capture the number of times the leader of the consortium has previously participated in applications within both the Sixth and Seventh Framework Programmes, either as a leader or a participant. This provides a measure of the learning effects related to the management and integration of knowledge from multiple sources in a related context (Love et al. 2013). We include the Sixth Framework Programme to capture as much relevant learning from similar efforts as possible, thereby extending the period in which experience is accumulated to 2002 until 2013. As the data on Sixth Framework Programme efforts is restricted to approved applications, which may underestimate the learning effects in our data, we conducted robustness checks using only experience in the Seventh Framework Programme and found stable results.

We include regional dummies regarding the location of the leading firm (Eastern, Western and Southern Europe, Non-European, leaving out Northern Europe as the reference category) to account for firms' geographical locations and to control for whether related differences influence search strategies. We include industry dummies in accordance with the aggregation of sectors based on NACE codes developed by Eurostat, the Statistical Office of the European Union (Eurostat 2013) to control for the industry affiliation of the leading firm. Finally, we include the dummy variable *SME*, which takes the value 1 for firms that meet the European Commissions' definition of small to medium sized enterprises: (i) a turnover below 50 million Euros; (ii) less than 250 employees; and (iii) assets less than 43 million Euros. This variable is provided in the data on FP7 and allows us to control for firm size. We conduct robustness checks using detailed turnover data from the Orbis database available for a reduced sample of publicly listed firms, which produces consistent results.

At the level of the search consortium we control for the total size of the application through the *Number of Participants* since increasing the number of knowledge sources may increase the ability to develop a solution of high potential, and including too many may hamper this. Similarly, variation in the number of different types of knowledge sources has been shown to influence innovation performance of firms (Laursen and Salter 2006). Accordingly, we include the variable *Breadth* to capture the number of different knowledge sources involved in the search strategies. This measure is constructed using NAICS codes to define the industry of each source, with each industry registered as a separate source of knowledge. As universities are found to be particularly valuable for search strategies in early stages of innovation (Kotha et al. 2013; Mindruta 2013) we include the dummy *University Participant*, which takes the value 1 for search consortia involving a university. A high joint absorptive capacity on the project level may hold potential advantages comparative to those present at the firm level. Accordingly, we control for the *Participants' Total Patent Stock* in a consortium with an annual 15 per cent depreciation. Similarly to our expectation of positive effects from experience at the firm level we expect that the joint experience of collaborators will have a positive effect, which is why we include the control variable *Participants' Total Experience*. Finally, a larger application in terms of funding sought may increase the likelihood of solving a problem. Hence, we include the total *Project Costs* in millions of Euros.

Statistical Method

We use a fixed-effects ordinary least squares model with robust standard errors to estimate the effects of advocacy groups on the problem solving potential of collaborative search strategies using expert evaluations. Our data covers 252 problem areas nested within the broader themes described above. It is plausible that the knowledge of advocacy groups has different value when solving challenges related to one specific problem area rather than another. To account for this data structure and ensure that search strategies with different levels of involving advocacy groups are compared to strategies directed at similar problems, we estimate our models with fixed-effects at the level of the 252 problem areas. This holds the potential influence from unobserved heterogeneity between these areas fixed, which may otherwise in- or decrease the value of advocacy groups. We thereby analyze how advocacy groups influence the problem solving potential of firms' search strategies by testing our hypotheses on different problem areas.

In addition to the fixed-effects at the level of problem areas we include dummy variables to capture the industry and region of the firm as described above, and include dummies to capture the specific funding instrument within the European Commission to which the application is submitted. As the different funding authorities may differ in their evaluation and selection criteria and hire different expert evaluators we include these fixed-effects to ensure that our analysis remains exogenous to such potential influence on the outcome.

We conduct a number of consistency checks to ensure the robustness of our analysis. First, we include the average score of the firm leader to check whether the development of search strategies with high problem solving potential is a result of its ability rather than our explanatory variables. The average score is calculated using all previous applications involving the firm in the sample, whether as leader or participant. Second, the use of detailed financial data is restricted by limitations in the Orbis database, which does not provide more than five years historical financial data for private firms. As a consequence we are unable to obtain financial data for all firms in the sample and estimate our main model using alternative controls as described below. Table 4 presents checks using turnover data in a reduced sample where this is available as well as the average score of search leaders. As a final consistency check we substitute our explanatory variables with the share of advocacy groups of the total number of participating organizations in the

observed efforts. The results remain consistent in this alternative specification and are available upon request from the authors.

RESULTS

Table 1 reports summary statistics and Table 2 reports correlations and the variance inflation factor (VIF) for the variables used in our model. A low correlation between the variables and a mean VIF of 2.51 suggests that our data do not suffer from multicollinearity issues (Belsley et al. 2005). As we would expect from these research and development efforts university sources are involved in the majority of the applications and the majority of firms are from knowledge intensive services and high tech manufacturing. In our sample the inclusion of advocacy groups in search efforts occurs in 459 observations of the full sample of 9,464 efforts, indicating that this is not yet common practice among firms, potentially due to the low exploration of the value contributed by these organizations. The low involvement of advocacy groups is reflected in our explanatory variable, which captures the share of funding allocated to advocacy groups as the influence of these on the search effort. The mean allocation of funding is 0.4% in the full sample of search efforts, although this increases to 9.4% in the sample of efforts including advocacy groups. The Herfindahl index of NAICS codes captures knowledge dispersion in the sample ranging from zero to one. At a mean of 0.157 this indicates a tendency to avoid over-searching of too many dispersed knowledge domains, which is supported by the mean breadth at 3.8 out of 13 possible sources of knowledge. This would indicate that firms are aware of the risk of mutual confusion as expected in our hypotheses and accordingly avoid over-searching. This is potentially critical to solving grand challenges since these inherently require the involvement of multiple and often dispersed knowledge domains (Godfray et al. 2011). As discussed in the following, it seems advocacy groups are beneficial to overcoming this difficulty, albeit, as described above, many firms do not yet exploit this opportunity.

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

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

Table 3 presents the results of our main model. A baseline model including only control variables is presented in Model 1. We include the involvement of advocacy groups in

Model 2 for testing our first hypothesis predicting a positive relationship between the degree to which advocacy groups are involved in search consortia and the problem solving potential of search strategies. The coefficient is positive and significant at the 99% level. Hence, Hypothesis 1 receives support.

---------- Insert Table 3 about here ----------

Models 3 and 4 of Table 3 show the results for Hypothesis 2. To test whether advocacy groups are increasingly beneficial to the problem solving potential of search strategies when problems are more challenging, we split our sample along the defined dummy variable. Model 4 represents the sample for more challenging problems (above average), while Model 3 represents the comparatively less challenging problems (below average). Consistent with our prediction in hypothesis 2 we find significant and positive effects in both sub-samples with a stronger effect in the sample of risky problems. We test whether the coefficients of the explanatory variable are statistically different across the two samples to confirm the presence of a stronger effect for more challenging problems. The two-sided test is significant at the 0.05% level, confirming that the difference is indeed different from zero. We furthermore use the Chow test to establish whether the definition of high- and low-challenge problems creates a significant overall difference in the two samples based on the coefficients in the two groups (Chow 1960) , which is confirmed at the 0.01% level. Hence, Hypothesis 2 is supported.

Our third hypothesis predicts an increasingly positive effect of advocacy groups as the dispersion of knowledge within a search consortium increases. This is confirmed by the positive and significant effect of interacting advocacy group involvement and concentration of knowledge in Model 5. Hence, Hypothesis 3 is supported.

All control variables have the expected signs and are only discussed briefly below. The baseline model indicates that increasing *Breadth* is beneficial to problem solving, consistent with e.g. Laursen and Salter (2006). Similarly, we see a positive effect from increasing the *Number of Participants*. We also find a significant and positive effect of the *University Participant* dummy, confirming the expectation and controlling for the ability of universities to improve the solving of complex problems (Kotha et al. 2013; Mindruta 2013) such as those related to grand challenges. We find a positive and

significant effect of a *Firm's Experience* and the joint experience captured by *Participants' Total Experience* confirming the positive effects of learning routines related to coordinating and managing knowledge in joint efforts (Love et al. 2013) . Finally, we see a significant and negative effect from the *SME* dummy, indicating that leading the efforts to solve complex problems is potentially beyond the ability and scope of small- and medium-sized firms.

Table 4 provides the results of the consistency check estimations. Our results remain consistent in the reduced sample that excludes those firms lacking financial data from the Orbis database due to restrictions on historical financial data on privately held firms. In this consistency check we also include the average score of the observed firm leader to control for ability as a driver of solution potential. Similar to the turnover variable the average score is insignificant with a marginally sized coefficient, indicating that neither is significant in explaining the solution potential of the observed efforts. As a result we rely on our main models including a larger number of observations and excluding these variables. We perform an additional consistency check in which we omit the SME variable, which is originally included to capture firm size effects, while including turnover data. Finally we performed consistency check including only average scores and turnover data respectively. The results of these additional checks are consistent to those reported in Table 4.

---------- Insert Table 4 about here ----------

DISCUSSION

We conduct this study to elucidate our understanding how firms' search strategies may contribute to solving grand challenges. We argue theoretically that such challenges benefit particularly from a more refined and complete understanding of the underlying problem. Hence, within our model search strategies lead to more promising solutions if they are not merely collections of potential solution providers, e.g. from science, but also include partners with in-depth knowledge about the problem. We argue that advocacy groups can provide the latter. We find empirical support for this hypothesis and show that the effect is stronger the more challenging the problem to solve and the more diverse the search consortium is.

These findings have several implications. First, our research extends the model of problemistic search particularly in collaborative search efforts. Within our theoretical reasoning a problem can trigger search strategies within firms without the assumption that the firm understands the problem comprehensively. Instead, the theorizing about cause and effect relationships underlying the initial problem becomes part of a firm's search strategy. The latter can therefore encompass both knowledge providers about the particular problem as well as potential solution providers. Second, we find that the improved theoretical understanding of a problem is particularly valuable if the underlying problem is more challenging. In our theoretical reasoning we trance this back to the nature and structure of more challenging problems in which isolated, directional search strategies are likely to lead to insufficient results. Besides, advocacy groups can legitimize search strategies and provide access to relevant knowledge sources. Third, we find that advocacy groups increase the effectiveness of collaborative search processes involving partners from highly different knowledge domains. We attribute this effect to the advocacy groups' ability to reduce mutual confusion and joint myopia among the partners in a search consortium (Knudsen and Srikanth 2014)

For management practice these findings imply that firms should include advocacy groups in their search strategies for solving grand challenges. They have the potential to redefine a problem so that new and promising technological solutions emerge. The particular benefits are especially strong when firms plan to work with diverse knowledge sources. The search for advocacy group partners is likely to require different sets of expertise than choosing partners merely based on technological excellence. Firms can benefit from establishing personal networks with advocacy groups, which can be activated when grand challenges emerge.

Academically, our findings provide new opportunities for the literature on organizational search. First, our search model does not assume that all knowledge sources necessarily provide expertise directly related to solving the problem, which represents a significant departure from extant search and problem-solving theory. We put emphasis on those partners that mainly provide knowledge relevant to *understanding* the problem, such as advocacy groups. This provides new opportunities for research on how to organize firms' search that is not exclusively centered around acquiring solutions (Felin and Zenger 2014) . Second, prior literature that neglects the importance of partners that mainly facilitate

problem definition may thus have considerably overestimated the effect of partners providing problem solutions, such as universities or suppliers (e.g. Laursen and Salter 2006; Leiponen and Helfat 2010). Empirical findings are likely to be biased. Third, existing literature on advocacy or stakeholder groups is currently largely separated from firms' search and innovation processes. Our research indicates that advocacy groups have incentives, too, to get engaged with firms to finding new or technologically advanced solutions which increase the potential to solve grand challenges.

CONCLUSION

While conducting this research we have become aware of further promising pathways for further research. First, while we observe the problem solving potential score that independent experts assign to a proposed search strategy, we do not have information on how well the search strategy actually performed in finding a solution to a concrete problem. While this on the one hand helps clearly separating the effects from searching and finding, it would be desirable to mirror the problem solving potential with the actual problem solving outcome from a search strategy using ex-ante measures and controlling for exogenous factors. Moreover, future research may shed more light on further contingencies under which the involvement of advocacy groups is particularly beneficial for a search strategy to become effective.

Second, our qualitative interviews with firm managers hint towards potential frictions and the need to manage the interaction with advocacy groups. Different advocacy groups may compete to promote their individual agendas, thereby increasing rather than decreasing mutual confusion in search consortia. Furthermore, certain characteristics of advocacy groups such as size, power or public attention may moderate or mediate their influence on search strategies. Relatedly, some respondents hinted towards the particular network positions that advocacy groups possess which facilitate the flow of information or legitimacy. Dedicated studies drawing on network theory and data may find a fruitful path for identifying further heterogeneity among advocacy groups. In sum, there is much to be gained from a more fine-grained understanding of the micro-mechanisms underlying our results.

TABLES

Table 1: Summary Statistics

Variables	Mean	S.D.	Min	Max
Problem Solving Potential	31.847	30.46	0	100
Advocacy Group Involvement	0.04	0.03	0	1
NAICS Herfindahl Index	0.157	0.10	0	1
Firm's Experience	18.038	46.06	0	598
Firm's Patent Stock	1.884	17.23	0	3241
SME	0.555		0	1
University Participant	0.885		0	1
Number of Participants	9.647	6.02	2	96
Breadth	3.897	1.56	1	13
Project Cost €Mio	6.152	15.84	0	605.81
Participants Total Patent Stock	11.494	44.64	0	5812
Participants' Total Experience	9.033	14.21	0	2235
High-Medium Tech Manufacturing	0.113		0	1
Knowledge Intense Services	0.723		0	1
Low Knowledge Intense Services	0.014		0	1
Medium-Low Tech Manufacturing	0.118		0	1
Other Industry	0.032		0	1
Eastern Europe	0.385		0	1
Not European	0.473		0	1
Southern Europe	0.055		0	1
Western Europe	0.045		0	1
Mean Variance Inflation Factor (VIF):	2.51			

Table 2: Pairwise Correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
(1) Problem Solving Potential	1																			
(2) Advocacy Group Involvement	.06	1																		
(3) NAICS Herfindahl Index	.00	-.03	1																	
(4) Firm's Experience	-.00	.02	.07	1																
(5) Firm's Patent Stock	-.02	-.00	.04	.14	1															
(6) SME	-.01	.02	-.18	-.25	-.12	1														
(7) University Participant	-.02	-.08	.42	.05	.02	-.07	1													
(8) Number of Participants	.16	-.00	.64	.09	.06	-.22	.24	1												
(9) Breadth	.21	-.00	.51	.07	.05	-.21	.25	.64	1											
(10) Project Cost €Mio	.05	-.02	.15	.03	.05	-.13	.04	.32	.21	1										
(11) Participants Total Patent Stock	-.00	-.02	.13	.11	.42	-.14	.05	.24	.18	.14	1									
(12) Participants' Total Experience	.10	-.02	.25	.27	.03	-.11	.16	.36	.23	.14	.14	1								
(13) High-Medium Tech Manuf.	.15	-.00	-.06	-.03	.12	-.14	-.04	.05	.12	.03	.07	-.01	1							
(14) Knowledge Intense Services	-.15	.03	.05	-.00	-.13	.24	.02	-.10	-.24	-.12	-.12	-.05	-.58	1						
(15) Low Knowl. Intense Services	.07	.01	.03	.00	-.01	-.07	-.00	.04	.10	.01	-.01	.02	-.04	-.19	1					
(16) Medium-Low Tech Manuf.	.02	-.04	.03	.06	.07	-.14	.04	.07	.13	.10	.10	.08	-.13	-.59	-.04	1				
(17) Other Industry	.03	-.00	-.09	-.05	-.02	-.03	-.04	.01	.07	.07	.00	-.01	-.07	-.30	-.02	-.07	1			
(18) Eastern Europe	-.00	.04	.03	.09	-.08	-.04	.00	-.01	.02	-.04	-.09	-.00	-.05	.11	.03	-.10	-.01	1		
(19) Not European	.05	-.02	-.01	-.04	.10	.01	-.03	.05	.03	.05	.11	.03	.07	-.12	-.05	.12	-.02	-.75	1	
(20) Southern Europe	-.01	-.01	.01	-.06	-.02	-.01	.01	.00	-.02	.04	.00	-.01	.01	-.01	.02	-.02	.01	-.19	-.23	1
(21) Western Europe	-.04	-.00	-.04	-.06	-.02	.08	.01	-.06	-.08	-.03	-.04	-.06	-.04	.04	.04	-.04	-.00	-.17	-.21	-.05

Table 3: Main Model

Variables	(1) Controls	(2) Main Effect	(3) Low Challenge	(4) High Challenge	(5) Full Model
Advocacy Group Involvement		17.99***	16.53**	29.63***	36.16***
		(5.98)	(6.53)	(10.70)	(9.56)
NAICS Herfindahl Index					23.48***
					(5.16)
Advocacy Group Involvement *NAICS Herfindahl Index					66.10** (27.61)
Firm's Experience	0.01**	0.01**	0.01**	0.04***	0.01**
	(0.00)	(0.00)	(0.00)	(0.01)	(0.00)
Firm's Patent Stock	-0.77	-0.79	-0.81	-1.65**	-0.96
	(0.74)	(0.74)	(0.88)	(0.75)	(0.75)
SME	-2.01***	-2.02***	-1.80***	-2.78***	-1.86***
	(0.48)	(0.48)	(0.54)	(0.93)	(0.47)
University Participant	2.64***	2.75***	2.34***	4.09**	1.68***
	(0.66)	(0.66)	(0.63)	(1.77)	(0.61)
Number of Participants	0.37***	0.36***	0.35***	0.38***	0.18***
	(0.06)	(0.06)	(0.07)	(0.10)	(0.06)
Breadth	0.65***	0.65***	0.68***	0.33	0.52***
	(0.20)	(0.20)	(0.22)	(0.30)	(0.19)
Project Cost €Mio	-0.00	0.00	0.01	-0.02	0.01
	(0.01)	(0.01)	(0.01)	(0.03)	(0.01)
Participants Total Patent Stock	-0.14	-0.13	-0.40	0.71	-0.01
	(0.35)	(0.35)	(0.44)	(0.52)	(0.35)
Participants' Total Experience	5.78***	5.93***	3.87**	10.77***	5.35***
	(2.01)	(2.01)	(1.89)	(3.73)	(1.96)
Constant	13.78	12.77	1.72	43.88***	19.96*
	(12.28)	(11.99)	(12.22)	(5.12)	(11.50)
Industry Dummies	Y	Y	Y	Y	Y
Regional Dummies	Y	Y	Y	Y	Y
Funding Source Dummies	Y	Y	Y	Y	Y
Observations	9,464	9,464	6,613	2,851	9,464
R-squared	0.06	0.06	0.06	0.10	0.07
Number of Problem Areas	252	252	206	46	252

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 4: Consistency Check Estimations

Variables	(1) Controls	(2) Main Effect	(3) Low Challenge	(4) High Challenge	(5) Full Model
Advocacy Group Involvement		14.33**	13.67*	23.44*	31.27***
		(6.79)	(7.54)	(13.07)	(10.79)
NAICS Herfindahl Index					18.92***
					(4.88)
Advocacy Group Involvement *NAICS Herfindahl Index					57.88**
					(28.04)
Firm's Experience	0.01*	0.01*	0.01*	0.04**	0.01*
	(0.01)	(0.01)	(0.00)	(0.01)	(0.01)
Firm's Patent Stock	-1.33	-1.38	-1.91	-1.84*	-1.54
	(0.99)	(0.99)	(1.19)	(1.08)	(1.00)
SME	-2.08***	-2.08***	-1.96***	-2.46***	-1.93***
	(0.49)	(0.49)	(0.58)	(0.81)	(0.47)
University Participant	2.58***	2.68***	2.28***	3.89**	1.98***
	(0.69)	(0.70)	(0.72)	(1.72)	(0.68)
Number of Participants	0.35***	0.35***	0.31***	0.41***	0.20***
	(0.07)	(0.07)	(0.08)	(0.11)	(0.07)
Breadth	0.73***	0.73***	0.77***	0.34	0.62***
	(0.22)	(0.22)	(0.26)	(0.29)	(0.21)
Project Cost €Mio	-0.01	-0.01	0.04	-0.06	0.00
	(0.03)	(0.03)	(0.05)	(0.04)	(0.03)
Participants Total Patent Stock	-0.09	-0.08	-0.26	0.75	0.00
	(0.35)	(0.35)	(0.42)	(0.57)	(0.34)
Participants' Total Experience	3.99**	4.10**	1.70	8.75**	3.69*
	(2.01)	(2.00)	(1.86)	(4.20)	(1.96)
Turnover	0.00	0.00	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Average Score	0.00	0.00	0.01	-0.01	0.01
	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Constant	25.68***	24.72***	13.03	45.57***	29.59***
	(9.57)	(9.37)	(10.18)	(6.34)	(9.06)
Industry Dummies	Y	Y	Y	Y	Y
Regional Dummies	Y	Y	Y	Y	Y
Funding Source Dummies	Y	Y	Y	Y	Y
Observations	7,288	7,288	5,127	2,161	7,288
R-squared	0.06	0.06	0.06	0.10	0.06
Number of Problem Areas	240	240	197	43	240

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

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CHAPTER 4. SOLVING ENVIRONMENTAL PROBLEMS: KNOWLEDGE AND COORDINATION IN COLLABORATIVE SEARCH

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ABSTRACT

Recent innovation and strategy research emphasizes the importance of firm's search for external knowledge to improve innovation performance. We focus on such search strategies within the domain of sustainable innovation in which problems are inherently complex and the relevant knowledge is widely dispersed. Hence, firms need to collaborate. We shed new light on collaborative search strategies led by firms in general and for solving environmental problems in particular. Both topics are largely absent in the extant open innovation literature. Using data from the European Seventh Framework Program for Research and Technological Development (FP7), our results indicate that the problem-solving potential of a search strategy increases with the diversity of existing knowledge of the partners in a consortium and with the experience of the partners involved. Moreover, we identify a substantial negative effect from involving partners in a search consortium who collaborate for the first time. Our findings have implications for both the literature on firms' search and the creation of sustainable innovation.

INTRODUCTION

Firms are increasingly challenged to generate sustainable innovations that provide economic returns and simultaneously have positive effects by solving environmental or societal problems (Ketata, Sofka, and Grimpe, 2014). Such challenges are often beyond the expertise of individual firms and require collaboration with outside partners to jointly develop promising solutions. Prior research has frequently documented the benefits of integrating external knowledge into firms' innovation processes (e.g., Laursen and Salter, 2006; Leiponen and Helfat, 2010; Garriga, von Krogh, and Spaeth, 2013). Connecting with external sources of knowledge, such as universities, customers, or suppliers, allows firms to access contextually different knowledge that they can recombine with internal knowledge to improve their innovation outcomes (Chesbrough, 2003).

Firms develop search strategies that target external knowledge sources in order to find solutions to a problem they are facing (Katila and Ahuja, 2002). When problems are complex, a search strategy is likely to involve relationships with several external partners at the same time in order to collaboratively solve a problem. However, the particularities of collaborative search strategies have received little attention so far in extant research (exceptions include the simulation studies of Knudsen and Srikanth, 2014). We develop a theoretical understanding of problemistic search that takes into account the fact that the search is collaborative in nature. We argue that each partner in a consortium contributes knowledge to potential solutions from its particular domain, while the problem-solving potential of the overall search strategy depends on how well these contributions can be integrated (Knudsen and Srikanth, 2014). In that sense, search strategies do not only differ with respect to the diversity of knowledge provided by external sources but also how well these sources and their contributions can be coordinated.

We predict that both the prior knowledge of partners involved in a search strategy and their experience with coordination in collaborative search will positively influence the problem-solving potential of the search strategy. Moreover, we argue that the problem-solving potential of a search consortium decreases if it includes partners who participate for the first time.

The empirical context of our paper is the domain of sustainable innovation. More specifically, we focus on solving environmental problems – one of the core elements of

the sustainability agenda (Siegel, 2009; Ketata *et al.*, 2014). Innovation activities that target environmental problems are different from solving other innovation related problems for two main reasons. First, environmental problems are typically complex and the knowledge to solve them is dispersed. In fact, many sustainable innovations are systemic in nature and they originate from complex sets of knowledge that require the involvement of diverse groups of actors (Hall and Vredenburg, 2003). Second, environmental problems are rarely formulated by the firm devising a search strategy but rather by the external setting the firm is operating in. This includes stakeholders, NGOs, and society more generally, which demand solutions to the problems they have defined in a discursive way (Devinney, 2009). Both complexity and the limited ability to define the problem at hand make coordination within a search strategy a particularly salient issue (Felin and Zenger, 2014).

Testing our hypotheses requires a research design in which many firms search for comparable solutions to environmental problems by assembling search consortia of different partners. We have the unique opportunity to study such a setting by accessing all 731 firm-led project applications submitted to 25 different collaborative topic calls in the environmental area of the European Commission's Seventh Framework Program for Research and Technological Development (FP7), a research funding program that ran during the period of 2007 to 2013 with a total budget of more than 50 billion Euros, of which 1.89 billion Euros were allocated to the environmental area. Individual project grants can reach budgets of several million Euros and the grant application process requires significant investments by the applicants. Hence, the effort is significant and there is a potentially high payoff in terms of funding obtained to execute the proposed solution. Grant applications are submitted through consortia of partners and receive a quality score based on standardized criteria from multiple independent experts. This provides us with a unique dependent variable to measure the problem-solving potential of a search strategy, which is exogenous to the firm and comparable across applications within the same topic area.

Our research contributes to the literature in three ways. First, by emphasizing the coordination effort required in search consortia, we look both theoretically and empirically at an understudied area in the literature on external knowledge search (e.g., Laursen and Salter, 2006, Leiponen and Helfat, 2010). On the one hand, prior literature

treats external search, at least implicitly, as independent, bilateral arrangements, controlled by a focal firm that seeks to solve a problem. We suggest that this assumption is too narrow and biases the results. Instead, search strategies are oftentimes multilateral in nature. As a consequence, coordination among the partners involved becomes a crucial factor, currently absent in most models of knowledge search. Research that focusses on collaborative search is often limited to simulation studies (Knudsen and Srikanth, 2014). On the other hand, prior literature largely ignores the fact that the partners involved in a search consortium differ with regard to not only the knowledge they can provide but also the collaborative experience they bring into the consortium. We suggest that the distribution of both knowledge and experience among the partners matters for the problem-solving potential of a search strategy.

Second, by focusing on the problem-solving potential of a search strategy we are able to observe the likelihood with which a search strategy will be successful. Prior research has typically looked at the outcomes of a firm's search strategy, for example, the number of patents or innovative products generated subsequently or the sales achieved with such new products (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Laursen and Salter, 2006). These outcomes, however, are hard to trace back to a firm's original search strategy since they easily confound searching with finding. The latter is likely to be only a narrow snapshot of the search strategies that were originally developed. Instead, the problem-solving potential isolates the likely effectiveness of a search strategy. What is more, it reflects the more likely scenario within firms in which different search strategies compete for resources to be enacted. We have the unique opportunity to also observe the less successful strategies while previous studies fail to distinguish innovative firms which have searched but not found.

Third, our research provides direct implications for management practice in the area of sustainable innovation. While the problems in this area are typically formulated outside the firm's boundaries and are thus beyond the firm's control, management does have the opportunity to configure and manage a search consortium that is likely to solve the formulated problem. In that regard, our research suggests that coordination experience is important and that a consortium benefits from the accumulated experience of the partners in order to tackle the complexities of sustainable innovation.

The remainder of this paper is structured as follows. The following section describes the theoretical background and derives a set of hypotheses. Data, measures, and the empirical model are outlined in the subsequent section followed by the results. Subsequently, we discuss these results and draw conclusions. The final section addresses the limitations of our research and implications for future research.

THEORY AND HYPOTHESES

Problemistic search for sustainable innovation

Within the model of problemistic search firms develop search strategies to find solutions for a problem they are facing (Katila and Ahuja, 2002). Accordingly, we investigate search strategies at the problem level rather than at the aggregated firm level. This allows us to develop theory to match the nature of sustainable innovation, which often requires search strategies that differ from the overall search strategy formulated at the firm level (Ketata *et al.*, 2014). We will develop theoretical predictions for why certain search strategies have a higher potential to solve sustainable innovation problems than others. We will explain these differences in the problem-solving potential of different search strategies based on both the accumulated knowledge of a search consortium and how well the consortium partners and their knowledge can be coordinated. The latter factor is largely ignored in existing search theory but is especially relevant for sustainable innovation because of its inherent complexities and the dispersion of relevant knowledge. We start out by defining central constructs and mechanisms.

Firms develop search strategies by defining a set of technologies or technological areas (Katila and Ahuja, 2002) and/or knowledge sources (Laursen and Salter, 2006) that can provide a solution to a problem. Firms have been found to benefit from including external knowledge sources, such as universities, for two primary reasons. First, firms can find more novel and hence unique solutions if they combine existing firm knowledge with outside expertise (Rosenkopf and Nerkar, 2001). Second, access to external knowledge enables firms to increase the speed with which they can find solutions because they do not have to develop all relevant knowledge internally (Fleming and Sorenson, 2004).

While many empirical studies find that search strategies that include external knowledge sources increase the innovation performance of firms, there is also consistent evidence that firms struggle with extracting the maximum value of their search strategies, i.e., they

search too narrowly or too broadly (for a recent review see Laursen, 2012). Existing theoretical explanations center on the nature of the knowledge encompassed in a search strategy. Katila and Ahuja (2002) suggest that firms will increasingly exhaust the valuable pools of external knowledge and search strategies may therefore suffer from decreasing returns. Laursen and Salter (2006) emphasize the costs of screening external knowledge from various sources vis-à-vis its benefits. They conclude that the screening costs can outweigh the advantages of a search strategy.

We define collaborative search by drawing on the search model of Laursen and Salter (2006) who describe a firm's search strategy as encompassing several external organizations, e.g., suppliers, universities, and customers. We will refer to the group of organizations involved in a collaborative search strategy as a firm's search consortium. Furthermore, we assume that all partners of a search consortium suggest potential solutions to the overall problem that the consortium wants to solve. However, the consortium will eventually formulate only a single search strategy. This implies that the search strategy of the consortium is the outcome of communication and coordination processes within the consortium in which the partners identify, screen and integrate the potential solutions provided by each partner (Knudsen and Srikanth, 2014). We further assume that a resource controlling authority which has solicited search strategies to a particular problem in the first place compares and ranks search consortia based on the problem-solving potential of their respective search strategies.

Our model deviates from existing theoretical models of knowledge search by going beyond the dimension of knowledge diversity and the need for screening of the searching firm. Instead, we envision a search process in which the firm is not a unitary actor that merely collects knowledge from various sources. We suggest a model of collaborative search in which the problem-solving potential of the overall search strategy depends at least partially on the interaction of partners within a search consortium (Knudsen and Srikanth, 2014). The following section will outline our hypotheses.

Hypotheses

Unique knowledge is among a firm's most valuable assets for achieving competitive advantage (Grant, 1996; Liebeskind, 1996). The open innovation perspective has highlighted that unique knowledge is not only a result of a firm's own internal research

and development (R&D) activities but can also stem from external sources (Chesbrough, 2003). The recombination of internal and external knowledge has been shown to improve a firm's innovation performance (e.g., Laursen and Salter, 2006; Grimpe and Kaiser, 2010). At the same time, knowledge that the firm possesses performs an important function in determining its absorptive capacity (Cohen and Levinthal, 1989, 1990). The idea behind absorptive capacity is that external sources of knowledge need to be identified, activated, and managed for successful integration into the firm's innovation process (Todorova and Durisin, 2007). In that sense, absorptive capacity provides firms with a richer set of diverse knowledge, allowing them more options for solving problems and reacting to change in the environment. As a result, firms may predict future developments more accurately (Cohen and Levinthal, 1994) and refocus their knowledge base through iterative learning processes (Szulanski, 1996; Zahra and George, 2002).

While this line of research implicitly adopts the perspective of a firm searching for knowledge from an external source on a bilateral basis, we can transfer the reasoning on firms' knowledge and absorptive capacity into a model of collaborative search. In the following, we will therefore suggest that the problem-solving potential of a collaborative search strategy will increase with the diversity of accumulated knowledge of the partners in a consortium for two main reasons. First, the diversity of knowledge in a search consortium increases the chance that partners can recombine existing knowledge elements in a way that solves the problem. Knowledge stocks from different organizations within a search consortium allow novel knowledge combinations through collaborative search, which will then be more distant, spanning various organizational boundaries (Rosenkopf and Nerkar, 2001). Second, the absorptive capacity argument suggests that firms benefit from prior related knowledge when identifying, assimilating and exploiting external knowledge (Cohen and Levinthal, 1989). While each individual firm may be bound by its own prior knowledge when searching for external knowledge, a consortium of firms can overcome this limitation. Firms with increasingly diverse prior related knowledge will be more likely to explore potential solutions from a variety of fields. Consequently the pool of potential solutions to a problem within the search consortium becomes broader and more diverse, compared to a situation in which all firms in a consortium draw from the same pool of existing knowledge to guide their search. As a consequence, consortia with diverse pools of prior knowledge are more likely to access and assimilate knowledge that

can be found beyond the individual partners.[7] As a result, our first hypothesis reads as follows:

Hypothesis 1: *The problem-solving potential of a collaborative search strategy increases with the diversity of existing knowledge of the partners.*

While each knowledge source provides potential solutions from its particular domain, our next hypothesis will argue that the problem-solving potential of the overall search strategy depends on how well these solutions can be integrated (Knudsen and Srikanth, 2014). The ability to effectively coordinate partners within a search consortium is therefore separate from the diversity of knowledge that the partners provide. Coordination within a search consortium typically refers to communicating potential solutions, setting priorities for particularly promising ones, and assimilating various solutions so that they form a conclusive search strategy. This is all the more important the higher the complexity of the problem to solve and the lower the ability to actually define the problem (Felin and Zenger, 2014).

Problems in the area of sustainable innovation are likely to be more complex because they require the involvement of diverse groups of actors (Hall and Vredenburg, 2003). Ketata et al. (2014) show that sustainable innovation benefits more from a broader involvement of knowledge sources such as suppliers or customers, which in turn need to be coordinated. We therefore argue that the problem-solving potential of a consortium's search strategy depends on how well it can be coordinated internally. Coordination avoids confusion among partners by providing directions and setting priorities (Knudsen and Srikanth, 2014).

Since collaborative search requires decision making across partners, coordination contributes to defining a shared language, criteria, and decision rules with respect to the combination of knowledge elements, which should eventually improve the understanding of the problem and the solution potential. In that sense, coordination prevents the search strategy from becoming too narrow (Knudsen and Srikanth, 2014) or too broad (Laursen and Salter, 2006). Powell, Koput and Smith-Doerr (1996) find that firms do not just

[7] Prior literature has frequently made a distinction between search breadth and depth (e.g., Laursen and Salter, 2006). Our context is characterized by a rather high degree of search depth, i.e. intensive collaboration with selected partners. For that reason, we focus our arguments on the diversity of knowledge, i.e. on search breadth.

acquire knowledge when collaborating with other firms but that they also develop capabilities to function within a context that spans firm boundaries. Love, Roper and Vahter (2014) extend this argument to the search context and show that the effectiveness of firms' search strategies increases if firms search repeatedly. They explain this improvement in a firm's search with the creation of routines and management systems for coordinating the search. We combine these theoretical arguments by arguing that all partners in a search consortium will benefit from such experience effects of engaging repeatedly in the formulation of search strategies. We argue that communication and coordination costs decrease with the experience of the partners involved in collaborative search. The greater their experience, the better the partners are presumably able to draw on effective tools and vocabularies, making the assimilation of partner knowledge more efficient. As a result, experience also decreases the degree to which management attention is required for coordination efforts (Ocasio, 1997) since experience is likely to generate routines that facilitate collaboration.

Relatedly, having experience in the formulation of collaborative search strategies will likely also benefit the overall structuring, content and configuration of partners involved. These management skills of the firm leading the search consortium and the partners develop through experience and represent a separate mechanism, independent of the benefits that experience has for coordination. Since search consortia require resources in order to implement the devised search strategy, partners involved in a consortium have an interest in structuring and describing the search strategy in a way that is clear and convincing to both internal and external providers of resources and funding. As a result, not only will the perception of the problem-solving potential increase, but a clear and convincing search strategy will also have positive repercussions for the partners involved. They will benefit from a more structured approach and will find it easier to identify key requirements and common objectives while the search strategy is being implemented. Taking the two mechanisms together, our second hypothesis reads as follows:

Hypothesis 2: *The problem-solving potential of a collaborative search strategy increases with the combined collaborative experience of the partners.*

Inherent in our elaborations on collaborative experience is the notion that a search consortium creates an inter-organizational context in which potential solutions are

identified, evaluated and integrated. Rules and procedures for how to operate efficiently within this context are rarely codified. As a consequence, relevant capabilities need to be developed in practice over time (Powell *et al.*, 1996). Following this logic, we explore the particular situation of consortium partners which participate for the first time, i.e. have no collaborative experience. We develop a line of reasoning that draws a distinction between an overall absence of experience and the otherwise gradually accumulated level of experience laid out in hypothesis 2.

There are two primary reasons for why collaboration rules in a search consortium cannot be sufficiently laid out in handbooks, contracts or manuals. First, the nature of the content underlying the inter-organizational agreement to search for solutions to a problem within a consortium is necessarily novel, untested and fluid. Partners can hardly foresee ex-ante which search strategy will emerge and which particular resources are required to provide it. Hence, every contractual agreement or manual is necessarily abstract and incomplete. Second, contractual agreements capture necessarily only a fraction of the actual exchanges between partners in inter-firm research activities (Powell *et al.*, 1996). Relevant interactions between organizations for new knowledge occur mostly through inter-personal exchange among scientists and engineers from various organizations. Large parts of their exchanges produce a shared knowledge which is tacit in nature since it requires personal interaction (Agrawal, 2006).

Given the absence of codified rules and manuals, partners without prior collaborative experience are likely to increase the costs for communication and coordination within a search consortium because they are necessarily ill-prepared for the particular context. Contributions of such first-time search partners are more likely to be misaligned with shared language conventions and procedures of a consortium. This makes their contributions harder to absorb and evaluate for the rest of the consortium. Similarly, first-time search partners are more likely to be a source of conflict within a consortium because they are less likely to understand the full set of mechanisms through which a consortium can deal with diverging priorities and incentives. Moreover, considerable investments are required in order to prepare the organization for the collaborative effort (including the hiring of specialized personnel for project management and accounting, provisions against unintended knowledge leakage, etc.) that consume and re-direct management attention (Ocasio, 1997) that cannot be dedicated to solving the actual problem. We hypothesize

that the sum of these effects will have a detrimental effect on the problem-solving potential of the search strategy of the consortium as a whole:

Hypothesis 3: *The problem-solving potential of a collaborative search strategy decreases with the share of partners who participate in a search consortium for the first time.*

DATA AND METHODS

Data

We test our theoretical predictions by using collaborative search strategies of firms formulated as grant applications for project research. This approach differs from existing research, which has captured knowledge search strategies by relying on three primary types of data sources: patent statistics (e.g., Katila and Ahuja, 2002), firm alliance data (e.g., Rosenkopf and Almeida, 2003), and innovation surveys (e.g., Laursen and Salter, 2006). All of these data sources have in common that they capture search strategies in which firms have actually found knowledge. These approaches assume, at least implicitly, that (a) what the firm was searching for and what it found were identical, (b) that the firm engaged exclusively in the successful search strategy, and (c) that no external firm factors exist that systematically influence finding but not searching. We argue that these assumptions are too narrow. We observe search processes in which firms devise multiple search strategies and compete for funding to execute them on the basis of their problem solving potential. Firms can improve the formulation of their search strategies because the search process is under their control. The subsequent finding stage, though, may be subject to a multitude of outside factors.

We investigate search strategies and their problem solving potential in a setting in which firms formulate search strategies for comparable problems by assembling consortia, i.e., engaging in collaborative search for comparable problems. We utilize data on joint applications for funding submitted to the environmental area of the European Commission's Seventh Framework Program (FP7) between 2007 and 2013. The program is sizable, with 1.89 billion Euros designated to solving problems that directly relate to sustainable innovation. The explicit goal of the program is to solicit potential solutions related to challenges caused by the increasing pressure on the environment with a commercial target of developing environmental technologies to create growth and

business opportunities globally.[8] Applicants submit proposals to a distinct call put forth by the European Commission, each representing specific and complex environmental problems. In Appendix 1 we provide examples of calls which are part of our empirical setting, which target the development of new technology for transforming waste to useable resources, and monitoring and management of water and flood risks respectively. All environmental calls can be found on the European Commission's Cordis website in the "Cooperation" section[9].

Successful applicants receive funding to cover part of the project costs, amounting to several million Euros, making the rewards of investing time and effort into the joint development of a search strategy highly attractive. Within our dataset all calls are directed at environmental challenges. These calls provide an abstract description of the problem, which is supposed to be solved, and the respective goals. Examples of the calls included in our analysis are requests for proposals to develop technologies that improve the safety of buildings in case of flooding, proposals that address the adaption of water supply systems to cope with climate change, or the development of green infrastructure or organic materials. Firms and other organizations collaboratively develop search strategies within a particular call. The call also describes the application and evaluation procedures.

We believe that funding applications within FP7 are suitable to study the theoretical predictions of our hypotheses for several reasons. The FP7 explicitly aims at facilitating collaborative research projects that seek to develop novel solutions and technologies and not just apply existing knowledge to new problems. In that sense, FP7-funded projects resemble very closely firm-funded collaborative research activities, particularly because a firm's R&D also needs to secure internal funding that will only be released if projects promise to actually solve problems that the firm experiences in its innovation activities. Our data emerges from the application stage, which provides a unique view on the formation and configuration of the search consortium that otherwise cannot be easily observed. Hence, we argue that grant applications, provided that the funding program is actually geared towards technological novelty like FP7, may very well complement existing types of data sources to study organizational search strategies.

[8] Detailed information is available on the website of the European Commission's Seventh Framework Program: www.ec.europa.eu/research/fp7
[9] http://cordis.europa.eu/fp7

We restrict our sample to project proposals from private firms because their search strategies are at the core of our theoretical logic. Each of these firms assembles a project consortium of various partners, e.g., universities, which will contribute to the search strategy. Hence, we can observe the composition of a firm's collaborative search strategy. The search consortium and its collaborative search strategy is the unit of analysis in our empirical tests. The resulting sample consists of 731 search strategies from all search consortia led by private firms, each submitted to one of 25 different calls, which are analyzed to estimate the effects of knowledge and experience on problem solving potential.

We add data on successful applications in the Sixth EU Framework Program to our data on the FP7. This extends our measure of experience to cover activities in these programs in the period from 2002 to 2013. The data on applications, experience and expert evaluations are combined with register data from Bureau van Dijk's Orbis database, which provides patent information on the participants.

Dependent variable

We use experts' ratings of the proposed search strategies as our dependent variable to analyze the influence of knowledge and experience on the problem-solving potential of collaborative search. To evaluate proposals, the European Commission appoints three to five independent experts on the basis of their level of expertise within the specific proposal area. Each expert prepares an individual evaluation before the team of experts assigned to a specific proposal convenes in Brussels to reach a consensus on the potential of the proposal. This process is led by a representative from the European Commission and overseen by an additional expert to ensure an unbiased process that considers the input of each individual expert. A score ranging from 0 to 100 reflects the final evaluation of the problem-solving potential of a proposal.

Three overall criteria are evaluated in assigning these scores: First, the technological and scientific excellence of the proposal is evaluated based on whether it contains a sound concept with high-quality objectives, whether the methodology is effective and the extent to which the proposed solution moves beyond the state-of-the-art. Second, the quality and efficiency of the implementation and management is evaluated, which considers the structures and procedures for execution, the competences of the participants related to

carrying out their individual tasks, the quality of the consortium and whether the requisite resources are made available by the participants. Third, the impact of the solution is evaluated based on the potential and exploitation of the commercial results and dissemination of the scientific outputs. This provides us with a unique dependent variable to capture the problem-solving potential of a firm's problemistic search.[10]

Ex-ante measures provide unique opportunities to study the front-end of innovation (Salter, Ter Wal, Criscuolo, and Alexy, 2014) by isolating the mechanisms influencing the problem-solving potential of a search strategy without the risk of confounding it with effects originating from the finding stage. As such, our measure responds to the call for an increasing focus on early-stage innovation activities (Kijkuit and van den Ende, 2010). The process of assigning scores consists of initial individual evaluation by the experts and subsequent consensus creation. By relying on multiple independent experts the likelihood of biased perceptions of the solution potential is reduced, as is the risk of individuals overlooking important caveats in the proposals. The presence of a representative of the European Commission and of an additional expert to lead the consensus building increases the reliability of the measure by ensuring that all valid and relevant aspects are heard and considered in the final score. Our dependent variable "problem solving potential" thereby captures the experts' rating of both approved and rejected applications, reflected by a score between 0 and 100.

Explanatory variables

Knowledge diversity

Following prior literature in the field (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002), we use patents assigned by the European Patent Office to the organizations involved in a search consortium to construct our measure knowledge diversity. Patents are a widely used measure of knowledge because the patent application process is costly and patent offices require a degree of novelty ("inventive step") for a patent to be granted (Encaoua, Guellec, and Martinez, 2006). Patents are therefore valid representations of knowledge following a shared quality standard across organizations.

[10] Prior research has frequently made a distinction between more radical and incremental innovations (e.g., Laursen and Salter, 2006). In our context, solutions to problems sought within FP7 are unlikely to be incremental. In fact, FP7 explicitly facilitates joint technology development and basic research that not least due to competitive reasons has to be distant from actual application. The problem-solving potential hence focuses on problems that are rather radical.

We calculate the diversity of a search consortium's existing knowledge by counting the number of different patent classes (IPC) in which the partners of a search consortium have patented. Technology classifications of patents are assigned by patent offices and grouped according to their respective bodies of knowledge and technologies. We measure the patent portfolios of the partners at the aggregate organization level, meaning that for a firm with multiple business units or divisions we count the aggregate number of patents at the level of the overall organization. Ideally, we would register patents at department, unit or team levels. However, given the diversity of organizations in our empirical setting, this is not systematically possible. Consequently, we conduct several consistency checks to test the sensitivity of estimation results to this aggregation of patents, all of which are robust. Counts of technology classes are widely applied to account for the breadth or scope of technologies within organizations (Katila and Ahuja, 2002). Based on the IPC classification of separate overall bodies of knowledge our variable for knowledge diversity ranges from zero to a maximum of eight for consortia that cover all the different 1st level classes used in the IPC. Higher values of the variable indicate that the organizations in a consortium have knowledge from more diverse knowledge domains which can contribute to the consortium's collaborative problem-solving. We standardize the variable by rescaling it to a mean of zero and a standard deviation of one, which enables a comparison of the magnitude of effects between this and our other explanatory variables.

Collaborative experience

The second explanatory variable captures the accumulated experience of the participants in a search consortium, which we assume will facilitate coordination and communication among the partners. Repetition of search activities, even with varying partners, has been found to facilitate the development of search routines and management systems (Love *et al.*, 2014). Accordingly, we count the number of participations in search consortia within the Sixth and Seventh Framework Programs prior to the focal search consortium as our proxy of search experience. While this excludes us from observing collaborative search experience outside our dataset, it is directly applicable to reliably identifying experience with relation and relevance to the search efforts observed. Incorporating the Sixth Framework Program for the calculation of experience allows us to capture an organization's participation in Framework Programs over a long period between 2002 and 2013 as well as the most relevant and related setting. Analogous to our measure for

knowledge diversity, we standardize the experience stock to enable a comparative interpretation of the measures.

Share of first-time participants
We construct a variable on first-time participants as the share of partners in a search consortium without prior experience in collaborative search in either the Sixth or Seventh Framework Program. Increasing values of the variable thus indicate an increasing share of participants with no prior experience with related search activities. Again, we standardize this measure for comparison of effect sizes in our estimation models.

Control variables
To control for factors that may influence the problem-solving potential beyond our hypothesized effects, our analysis includes variables related to the characteristics of the firm leading the search consortium, as well as the specific search strategy. First, since previous research has shown the importance the breadth of external search strategies (Laursen and Salter, 2006), we include a variable that controls for the number of different sources involved in each search consortium, measured as the count of different sectors represented by the consortium's partners. To account for the size of the search consortium we incorporate the overall count of partners as well as the reported costs of executing the project in millions of Euros.

To control for the size and resources of the firms leading a consortium, we include a dummy variable indicating whether the firm is a small or medium sized enterprise (SME). This captures whether a firm meets the three EU criteria for the SME definition: (i) having less than 250 employees, (ii) having an annual turnover below 50 million Euros, and (iii) having a positive balance sheet of less than 43 million Euros.

Finally, we address geographical and industry differences. To account for the influence of regional differences we include dummy variables for the geographical area in which the firm leading the consortium is located (Northern, Eastern, Western, and Southern Europe, as well as non-European locations). We include industry dummies for the leading firm based on the NACE industry classification system to control for industry effects (e.g., Grimpe and Sofka, 2009). These dummies are defined in accordance with the Eurostat aggregation of sectors according to knowledge intensity, with a further aggregation made

by combining high-tech and medium-high-tech manufacturing into one category, and similarly combining medium-low-tech and low-tech manufacturing.

ESTIMATION MODEL

To test our hypotheses we apply a fixed-effects ordinary least squares model with within-call fixed effects. This approach allows us to estimate the influence of knowledge diversity, collaborative experience and searching with inexperienced partners on the problem-solving potential of a search strategy across the 25 different calls for funding applications in our dataset. The fixed effect allows us to ensure that our analysis is conducted on firms search for solutions to the same problems (represented by the calls) on the basis of the same problem descriptions and processes. By estimating our model with call-fixed effects we avoid analyzing across problems, which would compare e.g. the influence of knowledge diversity on solutions to highly complex problems to the influence of knowledge diversity on solutions to less complex problems. As such, we estimate the following equation:

$$Y_{ic} = \alpha_c + \beta_1 X_{1,ic} + \beta_2 X_{2,ic} + \beta_3 X_{3,ic} + Z_{ic}{}'\beta_4 + u_{ic}$$

Where α_c are the call fixed effects and u_{ic} is the error term. X_1, X_2 and X_3 represent the three independent variables *knowledge diversity*, *collaborative experience* and *share of first time participants* and Z represents our control variables. β represents the respective coefficients of the explanatory and control variables, and Y the dependent variable *problem-solving potential*.

Additionally, we conduct several consistency and sensitivity estimations to demonstrate the stability of our empirical findings.

RESULTS

Descriptive findings

Table 1 shows the summary statistics of the variables in our sample. The mean problem-solving potential is 63 out of 100 with a rather low standard deviation, indicating that most submitted proposals receive a rather moderate evaluation score. We standardize the measures of knowledge diversity and experience by rescaling the means to zero and standard deviations to 1 to enable a comparative interpretation of their influence on the

problem-solving potential of the search consortia. In Table 2 we provide descriptive statistics for the non-standardized versions of the explanatory variables, which show that the mean of the unstandardized knowledge diversity is 5.25, showing that the typical search strategy involves five different IPC classes. The knowledge diversity ranges from low where no IPC classes are represented in the consortia to high where eight IPC classes are represented, and the standard deviation of 2.6 shows a rather high variation of diversity within the range possible. The unstandardized means of accumulated collaborative experience and the share of first time participants are 166.77 and 0.40 respectively. We observe consortia that consist solely of first-time participants, as well as consortia with none of these inexperienced partners. As such, the accumulated collaborative experience has a minimum value of zero, which represents consortia consisting solely of first-time participants. The maximum value of combined experience is 1,659, which represents the case of a consortium where the most experienced individual organizations in our sample collaborate on a consortium.

The majority of the firms leading a search consortium to solve environmental problems are in knowledge-intensive services. This category covers activities within transport, real estate, and sewage, as well as a range of business and service activities such as engineering and architecture. The category "other industry" includes the primary sector and utilities, both of which also have significant impacts on the environment, which explains the representation of this sector as the second largest in our sample. Approximately half of the 731 search consortia in our sample are led by SMEs, and most consortia are led by firms located in Northern and Western Europe. A majority of 59 percent of the consortia involve university participants, which would be expected given the novel research required to solve a number of the problems.

[Table 1 about here]

[Table 2 about here]

Table 3 shows the pairwise correlations. We do not detect high correlations among the explanatory variables. Moreover, we calculate the variance inflation factors for our explanatory variables to test for issues arising from multicollinearity (e.g., Belsley, Kuh, and Welsh, 1980). The mean variance inflation factor for our main explanatory variables

is 1.37 and 2.89 for our explanatory variables and control variables combined, which suggests that the data do not suffer from collinearity by any conventionally applied standard.

[Table 3 about here]

Regression results

The results of our regression models are presented in Table 4, in which we introduce our explanatory variables stepwise. Model I is the baseline model including only control variables. Model II tests our first two hypotheses. We find a positive and significant effect of knowledge diversity on the problem-solving potential. Similarly, the positive and significant effect of collaborative experience provides evidence that the problem solving potential increases with the combined experience of the partners. Thus, hypotheses 1 and 2 receive support. On the basis of a linear estimation model and standardized variables, we can compare effect sizes. We test whether the coefficients of our explanatory variables are equal, which would suggest that a comparative analysis of these is not possible. With a significant test score at the one percent level we can reject this and compare the effect sizes of the three variables.

While a one standard deviation increase in the knowledge diversity of a search consortium raises the experts' evaluation of the problem-solving potential by 2.88, the corresponding increase in combined collaborative experience results in an increase of 2.46. This provides evidence of a similarly strong influence on the problem-solving potential of a search strategy from increasing the combined collaborative experience and diversity of knowledge involved in the search. With the rather low standard deviation of experts' evaluation of problem solving potential, the effects of increasing knowledge breadth and experience stock both substantially influence the potential of search strategies for solving problems.

In Model IV we introduce the share of first time participants to the model. We find that when increasing the share of first time participants by one standard deviation the experts' rating of the problem solving potential of the search strategy decreases by 3.42. This provides evidence that collaborative search suffers from the involvement of novice partners without prior collaboration experience, thereby providing support for hypothesis

3. Finally, model V provides the full model with all explanatory variables. All estimated effects remain stable.

[Table 4 about here]

We do not develop hypotheses for our control variables but they show the expected signs throughout the estimation models. We find a consistently positive effect of increasing the breadth of different knowledge sources, as expected from extant literature (Laursen and Salter, 2006). This confirms the positive effects of involving a variety of sources in the search efforts, such as universities, customers, and others. Similarly, we see a small and significant effect of increasing the number of participants in the search effort. We interpret the negative SME effect as being due to a lack of resource availability. Larger firms have been found to invest more in the training of their employees, which has previously been found to positively influence absorptive capacity (Ketata *et al.*, 2014). We also observe a small negative effect of increasing project costs. This could indicate that the experts are attentive to inflated project costs. In terms of industry effects, we find a significant positive effect from the medium-high and high tech sector dummy, which is to be expected given the technological focus of the industry. Finally, a positive and significant effect is found for firms located in Western Europe. This is likely caused by the nature of firms located in this geographical area and the tradition of focusing on environmental technologies and innovation in such countries.

Consistency and sensitivity estimations

We conduct several additional estimations to test the stability of our findings and rule out alternative explanations. All estimation results are available from the authors upon request if not explicitly referenced. In Appendix 2 we provide tests for potential bias from university participation and the consistency of our results to alternative specifications of the knowledge diversity measure. In Model V we estimate the main model with the inclusion of a dummy variable indicating the participation of a university, as scientific knowledge is potentially particularly valuable in innovation efforts. 59 percent of the consortia involve a university participant, and while this has the significant and positive effect that would be expected, the effects of our explanatory variables remain consistent. As a result we conclude that our main results are not biased by the participation of universities in certain consortia.

Furthermore, Appendix 2 introduces a number of consistency checks to ensure the validity of our knowledge diversity measure and the validity of our findings regarding its importance to problem-solving. Our measure is based on patent information at the level of the organizations, which entails an assumption of access to knowledge across organizational units. This assumption could be particularly strong in the case of universities, which are often in possession of highly dispersed knowledge in departments with highly diverse scientific foci. As our measure of knowledge diversity could potentially be inflated by this characteristic of university knowledge Model VI provides a consistency check with a knowledge diversity measure, which excludes university patents. Similarly, Model VII provides a consistency check using a knowledge diversity measure that is exclusively based on firm-held patents since non-firm organizations' motivations for and use of patenting is likely to vary from that of commercial firms.

Additionally, we acknowledge that the use of patents as proxies of knowledge have been subject to debate in the literature. While there is largely the consensus that patents remain the best proxy for knowledge, we conduct a consistency check in Model VIII that uses the number of industries represented in the consortia by counting the number of difference NACE codes on a consortium rather than the patents' IPC classes. This alternative measure of knowledge diversity captures industry specific knowledge, rather than technology specific knowledge as is the case with patent classes. These alternative specifications of knowledge diversity produce consistent results to those in our main model, which shows that our hypothesized relations are not sensitive to alternative definitions.

In Appendix 3 we conduct five additional consistency checks to ensure that our results are not the result of misspecifications. First, we estimate our model using robust standard errors to account for potential outliers and heteroskedasticity in our data. Model IX presents the results, which are consistent with those of our main estimation model. Second, we construct our measure for knowledge diversity from patent statistics. We want to rule out that the effect is merely driven by the number of patents. We calculate patent stocks for each partner in a search consortium using a constant annual depreciation rate of 15 percent, as is standard in the literature (e.g., Hall, Jaffe, and Trajtenberg, 2005), covering the period up to the year of the formation of the search consortium. These stocks are summed up for each consortium and included in Model X. All hypothesized

effects remain stable. Since the patent stock variable increases the level of multicollinearity in our estimation models we include it only as a consistency check. Third, larger firms may have more resources available to manage and coordinate their consortia. To test whether this factor influences the estimation results we restrict the model to search consortia led by SMEs. Model XI in the appendix shows the results of the SME sample, which are fully aligned with our main results.

Fourth, approximately 12% of our sample consists of consortia in which none of the participants hold patents. As a result our main model contains observations that are registered with zero in the knowledge diversity measure. Arguably this speaks to the limitations of patents as a proxy for knowledge as described above. Strictly speaking our measure thus ascribes no knowledge diversity to these consortia, which is likely to be an oversimplification. In addition to utilizing NACE codes in the alternative measure of knowledge diversity as described earlier, we provide an additional consistency check in Model XII by excludes all consortia that have no participants with patents. Restricting our sample in this way ensure that our results are not driven by the zeroes assigned to consortia without any patents among the partners. The results of our consistency check on this restricted sample are aligned with those found in our full sample.

Fifth, we investigate to what degree the selection of partners into a consortium influences the estimation results for the effects on problem solving potential. For this purpose we estimate a Heckman selection model (Heckman, 1979) using all organizations who have participated in applications in FP7 as the population of partners which the firms in our sample could have selected as partners (32,967 organizations in total). We initially estimate the likelihood of being selected based on our explanatory variables and calculate the inverse mills ratio from this model to subsequently include in our main estimation model (Heckman, 1979). The results are reported in Model XIII in Appendix 3 and show that our results remain robust to those of our main model after inclusion of the control for potential selection bias. Additionally, we estimate a two-step selection model by using the geographical proximity of firms and potential partners as an instrumental variable, which provides stable effects to that of the main model in terms of sign and significance. As a final consistency check we perform our analysis using the 2nd level of IPC classes for the knowledge diversity measure rather than the 1st level used in the results provided in the paper. This increases the granularity of the knowledge measure and thereby the number of

distinct knowledge domains registered. This increasing granularity is however likely to register knowledge domains which are likely highly overlapping as being separate. This creates a risk of inflating the diversity measure, which is particularly critical in the empirical setting of environmental problems and innovation, where knowledge from distinctively diverse domains is required. We nonetheless test whether our results are stable to this alternative specification of knowledge diversity and find consistent results to those reported in the paper.

DISCUSSION

We conduct this study to answer the question of how firms develop promising strategies to solve environmental problems, which typically requires knowledge from multiple firms or organizations. Search strategies for addressing environmental problems are therefore particularly likely to be collaborative in nature, i.e., requiring the collaborative effort of diverse sets of partners. To answer our question we draw on collaborative and problemistic search theory. We predict that under conditions of collaborative search for solutions to complex problems, such as environmental ones, the diversity of prior knowledge of the partners in a search consortium can only partly explain the ability to jointly develop a search strategy with a high problem-solving potential.

We develop theoretical arguments for why it matters how well the partners have learned to collaborate, i.e., their collaborative experience, and why there is a price to pay for including first-time partners. We find that collaborative experience is equally important as the diversity of the existing knowledge of the partners for the problem-solving potential of collaborative search. Moreover, we find that first-time participants in a search consortium reduce its problem-solving potential significantly.

For academic research we provide new insights in two research streams. For research in sustainable innovation we provide a more detailed understanding of how firms can form promising search strategies that go beyond breadth and depth measures of knowledge sources (e.g., Ketata *et al.*, 2014). We find that sustainable innovation requires not only collaborative efforts that span existing fields of expertise, but also partners who can communicate and coordinate effectively. What is more, we find that involving a novice partner is costly. These findings provide important new variables for theorizing on how the search for solutions to important societal challenges can best be addressed.

Our findings are not limited to sustainable innovation and have significant implications for the broader research streams on knowledge search and open innovation. First, we conceptualize a firm's search strategy as a multilateral process in which partners interact and need to be coordinated. Second, we show that the problem-solving potential of a search strategy is not strictly determined by the screening capacities (Laursen and Salter, 2006) or search routines (Love *et al.*, 2014) of the searching firm. Rather, collaborative experience of the partners has an important impact on the ability to collaboratively develop solutions. This is supported by the finding that engaging with inexperienced collaborators can have significant negative effects for the problem-solving potential because first-time participants need to develop routines and collaborative capabilities. Hence, we provide a way for future research to conceptualize the search for external knowledge as a more interactive process than the simplistic collection and combination of external knowledge by a searching firm. Finally, we show that firms are heterogeneous in the problem-solving potential of the search strategies that they devise and that focusing exclusively on successful search strategies that led to "finding" may severely underestimate the diversity and complexity of a firm's search.

Our results also have immediate relevance for management practice and policy making. We develop a profile of search consortia that are likely to provide promising solutions to environmental challenges and result in sustainable innovations. Firms should strive to collaborate with partners with diverse knowledge and collaborative experience, while novice partners should be avoided. Especially the latter finding may be challenging for policy makers. On the one hand, many organizations should be encouraged to participate in the search for sustainable innovation, including start-ups with little if any collaborative experience. On the other hand, search consortia including first-time participants develop search strategies with less potential. Our results suggest that for generating search strategies for sustainable innovation, policy support is best directed at strengthening the collaborative experience of existing search consortia and their partners. This can, for example, be achieved by organizing networking events for experienced partners. Inexperienced organizations interested in joining search consortia need opportunities to develop collaboration capabilities prior to collaborations taking place. Such efforts are likely to benefit both collaborators and society through search strategies with higher problem-solving potential.

CONCLUDING REMARKS

We have discovered several unresolved research opportunities while conducting this study. First, we cannot observe the detailed interactions between partners in a search consortium prior to their search strategy. We suspect that the quality and quantity of personal interactions as well as the use of digital tools may influence the development of a search strategy. Studying these intra-consortium interactions would require a dedicated research design that goes beyond our current setting. Relatedly, observing interactions in a more detailed fashion would also allow constructing a measure for particularly deep search effort with certain partners (Laursen and Salter, 2006). Second, collaboration experience can originate from a variety of sources and manifest itself in multiple ways, e.g., employee mobility between organizations. While our study focuses on a particular source of collaboration experience, dedicated studies may collect primary data on broader sets of collaboration experience and how they influence search strategies. This would also allow disentangling the two mechanisms we have outlined through which experience benefits the problem-solving potential, currently a limitation to our study. Similarly, diversity of knowledge can also be captured in various ways. We rely on patent statistics since they provide us with countable representations based on a shared standard. It could be very interesting to see how our measures correlate with alternative operationalizations, e.g. based on scientific publications. Third, future studies may want to analyze the content of the search strategy documents themselves. Such analyses could reveal information at the level of the grant proposal, e.g. how search strategies are structured or integrated. Given the advances of automated content analysis tools, this could be a fruitful path for a dedicated project. Finally, we focus on collaborative search strategies, which are likely to be among the most important and longest running ones of participating firms because of the large budgets and intensive collaboration. It is not obvious that our theoretical logic would be equally applicable in settings where firms can more easily dissolve search partnerships or switch partners in more routine search efforts. In a similar vein, it would be interesting to study the differences that emerge when problems to be solved only lead to incremental innovations and not radical ones. In this sense, the current study opens up many new pathways for studying the interaction between firms and their external knowledge sources, particularly in the early stages of formulating strategies to solve problems.

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TABLES

Table 1: Summary statistics

Variable	Mean	S.D.	Min	Max
Problem-solving potential	63.370	18.334	0	100
Knowledge diversity	0	1	-1.980	1.110
Collaborative experience	0	1	-0.638	5.709
Share of first-time participants	0	1	-1.445	2.169
Breadth	1.893	.985	1	5
Participant count	9.865	5.837	2	55
Project costs	4.099	3.089	0	23.500
SME	.546		0	1
Eastern EU	.082		0	1
Northern EU	.049		0	1
Southern EU	.361		0	1
Western EU	.482		0	1
Non-European	.026		0	1
Medium & high tech	.081		0	1
Knowledge intense services	.725		0	1
Less knowledge intense services	.038		0	1
Low & medium tech	.029		0	1
Other industries	.127		0	1

Table 2: Summary statistics for non-standardized explanatory variables

Variable	Mean	S.D.	Min	Max
Knowledge diversity (non-standardized)	5.126	2.588	0	8
Collaborative experience (non-standardized)	166.774	261.399	0	1659
Share of first-time participants (non-standardized)	0.400	0.277	0	1

Table 3: Pairwise correlations

Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
(1) Problem-solving potential	1																
(2) Knowledge diversity	.31	1															
(3) Collaborative experience	.24	.46	1														
(4) Share of first-time participants	.01	.38	.01	1													
(5) Breadth	.21	.48	.26	.48	1												
(6) Participant count	.26	.43	.40	.23	.45	1											
(7) Project costs	-.01	.03	.13	-.09	.14	.35	1										
(8) SME	-.16	-.11	-.06	.02	-.01	-.09	-.12	1									
(9) Eastern EU	-.18	-.11	-.12	-.06	-.13	-.12	-.04	.10	1								
(10) Northern EU	-.07	-.01	.07	.03	.01	.04	.03	-.06	-.07	1							
(11) Southern EU	-.12	-.12	-.04	-.08	-.07	-.10	-.06	-.02	-.22	-.17	1						
(12) Western EU	.27	.18	.08	.07	.13	.15	.05	-.02	-.29	-.22	-.72	1					
(13) Non-European	-.07	-.01	-.03	.08	.01	-.02	.04	.03	-.05	-.04	-.12	-.16	1				
(14) Medium & high tech	.06	-.07	-.11	-.03	.04	-.06	.10	-.01	-.03	.03	.05	-.03	-.02	1			
(15) Knowledge intense services	-.04	.05	.06	.07	-.10	.07	-.12	.16	.05	.03	-.11	.07	-.01	-.48	1		
(16) Less knowledge intense services	-.05	-.02	-.03	-.02	.07	-.03	-.02	-.12	.02	-.01	.15	-.16	.06	-.06	-.32	1	
(17) Low & medium tech	-.03	-.06	-.08	-.04	.02	-.08	.10	-.01	-.05	-.00	.02	-.00	.02	-.05	-.28	-.03	1
(18) Other industries	.05	.03	.06	.03	.05	.00	.04	-.13	-.02	-.05	.01	.03	-.01	-.11	-.62	-.08	-.07
Mean variance inflation factor (VIF):	2.89																

Table 4: Fixed-effects estimations for problem-solving potential

Variable	Model I	Model II	Model III	Model IV
Knowledge diversity		2.88***		3.03***
		(0.85)		(0.84)
Collaborative experience		2.46***		1.99***
		(0.74)		(0.74)
Share of first-time participants			-3.42***	-2.93***
			(0.87)	(0.87)
Breadth	3.25***	2.23***	4.70***	3.45***
	(0.79)	(0.81)	(0.86)	(0.88)
Participant count	0.65***	0.42***	0.60***	0.40***
	(0.13)	(0.14)	(0.13)	(0.14)
Project costs	-0.85***	-0.88***	-0.89***	-0.91***
	(0.23)	(0.23)	(0.23)	(0.23)
SME	-6.05***	-5.53***	-5.86***	-5.35***
	(1.31)	(1.29)	(1.30)	(1.28)
Eastern EU	-3.03	-3.02	-3.37	-3.40
	(4.41)	(4.32)	(4.37)	(4.29)
Northern EU	-2.01	-2.65	-2.19	-2.69
	(4.77)	(4.66)	(4.72)	(4.63)
Southern EU	3.35	2.68	2.74	2.17
	(3.98)	(3.89)	(3.95)	(3.87)
Western EU	10.36***	9.26**	9.73**	8.72**
	(3.96)	(3.88)	(3.92)	(3.85)
Medium & high tech	3.84	5.10*	3.87	4.99*
	(2.85)	(2.80)	(2.82)	(2.78)
Knowledge-intense services	-0.93	-0.44	-1.15	-0.66
	(1.98)	(1.93)	(1.96)	(1.92)
Less knowledge-intense services	-5.49	-4.50	-5.65	-4.72
	(3.71)	(3.63)	(3.67)	(3.60)
Low & medium tech	-3.42	-1.90	-3.42	-2.01
	(4.14)	(4.05)	(4.10)	(4.02)
Constant	52.41***	56.72***	50.94***	55.29***
	(4.52)	(4.48)	(4.49)	(4.47)
Observations	731	731	731	731
R-squared	0.20	0.24	0.22	0.25
Number of calls	25	25	25	25

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Reference categories: Non-European location; Other industry

APPENDIXES

Appendix 1: Examples of calls

Call number: ENV.2013.6.3-1

Title: Turning waste into a resource through innovative technologies, processes and services

Description: The overall objective of this topic is to reduce environmental impacts through innovative, breakthrough solutions that lead to a reduced demand for raw materials and contribute to more efficient use of materials generally, thus supporting important EU policy commitments reflected in the Roadmap to a Resource-Efficient Europe and helping to create a bridge with future Horizon 2020 activities on 'Climate action, resource efficiency and raw materials'. Proposals must focus on solid waste management (including existing industrial and urban waste dumps) and address one of the following two sub-topics:

a) Valorization of urban solid waste. Research should focus on the development of innovative solutions which aim for a radical change in the way of collecting, handling, separating, processing, upcycling or transforming urban solid wastes and/or the development of new added-value products and services with good market potential based on recycled urban waste. This activity should contribute to more efficient and cost-effective urban mining and to a more circular economy.
b) Recovery of valuable raw materials from industrial waste. Research should address new, radical, different and sustainable solutions for the collection, recovery and preparation for reuse of raw materials (like e.g. critical metals and minerals as defined in the context of the Raw Materials initiative40) from waste from key industrial sectors such as construction, chemicals, aerospace, machinery and equipment, automotive or ICT. New business models and reuse-oriented services to enable an efficient management of raw materials should be also considered. This topic complements related activities to be supported under Theme 4 Nanosciences, Nanotechnologies, Materials and New Production Technologies. In both cases, proposals should demonstrate how the research foreseen will contribute to improving the environment, including how it will promote the development of new economic opportunities, improve resource efficiency and boost

competitiveness. Proposals should also demonstrate that the proposed solutions have the potential to be substantially more sustainable, from a life cycle perspective, than current practice, should consider both direct and indirect, both positive and adverse impacts and, where appropriate, contribute to the standardization process. Pilot trials at an appropriate scale should be envisaged to facilitate future market uptake.

Expected impact: Breakthrough innovation in novel technologies, products or services with high potential to achieve a more green economy. More sustainable consumption and production patterns. Improved resource efficiency and reduced environmental impacts. Reduced waste production and pressure on raw materials. New business models, industrial symbiosis, and cradle-to-cradle approaches. Substantial contribution towards the sustainable supply of raw materials of economic importance in Europe. Improved communication and transfer of knowledge to policy making, business and to the general public.

Call number: ENV.2013.6.2-1

Title: Water resources management under complex, multi-stressor conditions

Description: The challenge is to underpin decision making, risk assessment and management of water systems under complex multiple stress conditions (combination of organic and in organic pollution, flow and morphology alteration, surface and groundwater abstraction, land use change, climate variability and change, invasive species, pathogens, etc.). Research should have a clear user perspective and aim to enhance our understanding of stressors interactions, species interactions, species-stressor-relationships and impacts on the ecological functioning, stability and resilience of the aquatic ecosystems. Based on innovative methodologies, research should develop holistic approaches and tools to diagnose changes in the ecological, quantitative and chemical status of water bodies, as defined in the Water Framework directive (WFD)16, and in water availability, in relation to multiple stress conditions, identify the relevant stressors which are responsible for their deterioration, and forecast and predict the ecosystem responses and ecological recovery as a consequence of alternative management measures on different spatial scales.

It should also aim at the development of integrated impact assessment tools, coupling biophysical with socio-economic assessment of impacts (provision of ecosystem services) to improve water resource protection and management, including water related extreme event prevention and management, at EU and river basin levels.

Expected impact: Improved water status and availability of clean water, better implementation of water policy and optimal decision making in water resources management under complex multiple stress conditions, with the aim of achieving sustainable resource use and flood risk reduction. Development of more cost-effective Programmes of Measures (POMs) to improve the ecological status of surface water bodies from the local to the river basin scale and improve the groundwater body status – also in the context of ecosystem goods and services – in line with the EU Water Framework Directive.

Appendix 2: Consistency checks

Variable	Model V	Model VI	Model VII	Model VIII
Knowledge diversity	2.57***			
	(0.86)			
Collaborative experience	1.48*	1.46*	2.01***	2.79***
	(0.77)	(0.77)	(0.74)	(0.71)
Share of first-time participants	-3.05***	-3.10***	-3.19***	
	(0.87)	(0.87)	(0.87)	
University participant	4.60**			
	(1.83)			
Knowledge diversity (excl. university patents)		2.19***		
		(0.79)		
Knowledge diversity (firm patents only)			1.75**	
			(0.72)	
Industry diversity				6.34***
				(1.95)
Breadth	3.08***	3.06***	3.21***	2.20***
	(0.89)	(0.89)	(0.89)	(0.81)
Participant count	0.37***	0.37***	0.36***	-0.31
	(0.14)	(0.14)	(0.14)	(0.27)
Project costs	-0.88***	-0.88***	-0.89***	-0.95***
	(0.22)	(0.23)	(0.23)	(0.23)
SME	-5.55***	-5.64***	-5.57***	-5.85***
	(1.28)	(1.28)	(1.28)	(1.28)
Constant	53.45***	52.88***	52.61***	65.41***
	(4.51)	(4.49)	(4.49)	(5.53)
Location dummies	Y	Y	Y	Y
Industry dummies	Y	Y	Y	Y
Observations	731	731	731	731
R-squared	0.26	0.26	0.26	0.24
Number of calls	25	25	25	25

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Reference categories: Non-European location; Other industry

Appendix 3: Consistency checks

Variable	Model IX	Model X	Model XI	Model XII	Model XIII
Knowledge diversity	3.03***	2.89***	2.85**	3.08***	2.79***
	(0.70)	(0.86)	(1.12)	(1.14)	(0.84)
Collaborative experience	1.99*	1.81**	2.88***	1.92**	4.12***
	(1.04)	(0.77)	(1.09)	(0.75)	(1.10)
Share of first-time participants	-2.93***	-2.94***	-3.30***	-2.56***	-2.81***
	(0.96)	(0.87)	(1.20)	(0.91)	(0.87)
Consortium patent stock		0.70			
		(0.76)			
Breadth	3.45***	3.39***	3.92***	3.23***	4.21***
	(1.01)	(0.88)	(1.21)	(0.89)	(0.92)
Participant count	0.40***	0.40***	0.33*	0.45***	0.50***
	(0.14)	(0.14)	(0.17)	(0.14)	(0.14)
Project costs	-0.91***	-0.91***	-1.23***	-1.00***	-0.85***
	(0.20)	(0.23)	(0.32)	(0.25)	(0.23)
SME	-5.35***	-5.35***		-5.16***	-7.40***
	(1.37)	(1.28)		(1.36)	(1.49)
Inverse mills ratio					-8.82***
					(3.36)
Constant	55.29***	55.53***	61.24***	54.35***	60.25***
	(3.50)	(4.47)	(6.09)	(4.62)	(4.83)
Location dummies	Y	Y	Y	Y	Y
Industry dummies	Y	Y	Y	Y	Y
Observations	731	731	399	641	731
R-squared	0.25	0.25	0.25	0.24	0.26
Number of calls	25	25	22	25	25

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1
Reference categories: Non-European location; Other industry

CHAPTER5. CONCLUSION AND CONTRIBUTIONS

In this dissertation I contribute to extant research on external knowledge search and the problem-solving perspective. The dissertation contributes to increasing the understanding of how problems related to technological innovation can be solved through external knowledge search efforts. More specifically I leverage a unique and novel dataset to answer the research questions regarding the organizing of external knowledge search: (i) How does organizational inertia of individual knowledge sources influence problem-solving on external knowledge search efforts? (ii) How do knowledge sources with problem-understanding rather than problem-solving knowledge influence problem-solving on external knowledge search efforts? (iii) How does increasing knowledge diversity and experience in managing the ensuing complexity influence problem-solving potential on external knowledge search efforts? The findings provided by answering these questions can benefit firms and other organizations through an improved understanding of how to organize external knowledge search efforts to solve innovation problems contingent on the characteristics of the individual sources, the combination of these and the problems faced. The dissertation also contributes to extant research through an empirical focus on specific collaborative efforts. Extant research has largely focused on firm-level analyses of openness and external knowledge search, albeit with some noteworthy exceptions using project-level analyses (e.g. Cassiman et al. 2009; Cassiman et al. 2010; Salge et al. 2013). An increasing focus on the project-level of specific efforts provides a relevant test of firm-level findings as this is the typical level of execution for firm-level strategies in most firms. Furthermore, given the empirical setting of the research, an improvement in problem-solving in the specific empirical fields will be particularly valuable to solving energy and environmental related problems, as well as addressing global society's grand challenges, which are of increasing interest to global policy makers and society at large.

Inertia, Interdependence and Joint Problem-solving

In chapter two of the dissertation I show how individual knowledge sources involved in external knowledge search efforts can negatively influence the joint problem-solving likelihood. The inertia of individual sources related to or misaligned strategic interests due to potential loss of competitive advantage from problem-solving is shown to influence the development of efficient solutions. I argued and showed that if the technological change resulting from the problem-solving has competence-destroying potential, this led to a negative effect from incumbent collaborators due to their inertia and strategic interests in

maintaining their competitive advantage. However, I also show the benefits of incumbent knowledge sources on problem-solving related to competence-enhancing technology or to competence-destroying technologies to the extent that the incumbents have proactively initiated the technological change and engage in reconfiguring their competences. This supports the idea that individual incentives will influence joint outcomes in collaborative efforts (Puranam et al. 2012), and more broadly the argument that individual knowledge sources are interdependent and mutually influence each other as well as their joint outcome (Knudsen and Srikanth 2014). It suggest an important contingency in understanding knowledge sources as more than providers of knowledge, but also as agents of individual interests and agendas.

Since incumbents are at risk of losing their competitive advantage as a consequence of problem-solving related to innovation in competence-destroying technologies, their interests are likely to differ from those of the remaining participants on the external knowledge search effort. Incumbent firms are likely to hold an interest in reducing the innovativeness of the solution or the pace at which the problem is solved, and thus the speed at which change occurs. Similar behavior to influence technological change has been observed by incumbent firms in the context of institutional strategies and policy development (Smink et al. 2015) but has remained unexplored at the level of specific collaborations. As such, I show that the inertia of individual sources and the misalignment of strategic interests between knowledge sources has negative impacts on the likelihood of developing efficient solutions to problems through external knowledge search efforts. This is likely to apply to settings beyond specific problem-solving efforts and those of incumbents and their interests. It is likely that other causes of collaboration problems can act to reduce the ability of collaborators to reach an optimum joint outcome since this can potentially be in conflict with individual strategic interests. This calls attention to an important caveat in both the external knowledge search and problem-solving literatures, as well as other literatures of inter-firm collaborations such as strategic alliances, joint ventures and similar: the question of whether the individual collaborators share a common strategic interest in solving the concrete problem in a similar manner.

The findings contribute to research by combining the related external knowledge search literature (e.g. Katila and Ahuja 2002) and problem-solving perspective (Nickerson et al. 2012) to understand the influence of path-dependencies in organizational learning (e.g.

Levinthal and March 1993) and organizational impacts of technological discontinuities (Tushman and Anderson 1986) on the ability of mutually dependent collaborators (Puranam et al. 2012) to develop an attractive joint outcome. This extends the literature on external knowledge search and problem-solving by suggesting that individual underlying strategic interests and competitive dynamics form an important influence on the outcomes of such efforts. This also provides a broader implication in providing empirical support for the notion that search should increasingly be considered as an interdependent rather than unitary process (Knudsen and Srikanth 2014). For management this has implications for the selection and organizing of collaborators and composition of knowledge sources in problem-solving efforts. The underlying strategic interests of potential partners is an important criterion to consider when organizing external knowledge search efforts and problem-solving. While incumbents or other collaborators might offer expertise, resources and commercialization opportunities, these benefits might not outweigh the collaboration problems arising from a misalignment of strategic interests. While the hampering of collaborations might be a consequence of inertia and inability rather than an intentional defensive mechanism, it is nonetheless crucial to ensure that all knowledge sources are dedicated to reconfiguring their capabilities and strategies according to the outcome expected from an external knowledge search effort.

Problem-understanding as Prelude to Problem-solving

The dissertation explored how advocacy groups contribute knowledge relevant to understanding rather than directly solving problems in external knowledge search efforts, and what the effects thereof is on overall problem-solving potential. Using qualitative data from interviews I develop hypotheses related to why and how advocacy groups are beneficial to solving technologically related problems despite their lack of technological knowledge and expertise. I show that as the size and complexity of the problems grow to become increasingly important to solving "Grand Challenges", the need for more in-depth understanding of the problems increases. I find that the problem-understanding knowledge that advocacy groups hold due to close stakeholder relations and exposure to the specific problem provide external knowledge search effort with insights that eventually increase the likelihood of developing solutions with high potential. The findings show that as problems increase in size and complexity, the importance of initially developing a fundamental understanding of such problems rises.

These findings contribute by studying the benefits of a previously underexplored knowledge sources and by exploring the extent to and circumstances under which the use of knowledge without direct problem-solving relevance will eventually increase the likelihood of developing solutions with high potential. This contributes to an appreciation of these two different types of knowledge by separating problem-understanding and problem-solving relevant knowledge, and by showing the importance of involving both when organizing search efforts, particularly so when problems increase in size and complexity. The findings also contribute by supporting the notion that the process of search and problem-solving should be understood as separate, initially developing an understanding a problem, and subsequently solving it (Maggitti et al. 2013; Nickerson et al. 2012). This suggests that both theory and practice would benefit from increasingly understanding which knowledge sources are capable of providing relevant insights at each stage, and how organizing search efforts to include these at different times influences the overall likelihood of solving problems.

Benefits of Knowledge Diversity and Importance of Experience

The dissertation contributes to extant research's exploration of the effects of accessing different domains of knowledge on the ability to solve problems (Nickerson et al. 2012). More specifically it increases the understanding of the influence of accessing increasingly diverse knowledge domains through external knowledge search, and the importance of collaborative experience with related problem-solving efforts. The value of breadth of knowledge sources has previously been subject to study by researchers in the field (Laursen and Salter 2006; Leiponen and Helfat 2010; Love et al. 2014). This shows how firms benefit from complementing their internal knowledge with that of external knowledge sources (Cassiman and Veugelers 2006). I extend these findings by embracing the idea that diversity of knowledge sources and the diversity of their knowledge domains are distinctly different. I argue that this disentanglement is relevant since it can be expected that while two organizations may be of the same type, e.g. firms, they may still possess significantly different knowledge. For instance, two firms engaged in distinctively different industries are likely to have significantly different knowledge to contribute to problem-solving efforts through external knowledge search. Based on this I captured the knowledge domains of an individual organization according to their patenting activities in the different categories of the International Patent Classifications. I then combined the knowledge of the sources involved in an external knowledge search

effort to measure the diversity of knowledge available and capture the effects on the development of solutions to specific problems. Finally I expected that with increasing diversity of knowledge, experience will be increasingly important. As such, I argued that with more complexity, the lack of previous experience with combining knowledge and managing the relationship with other sources among individual participants would reduce the collective's ability to effectively combine knowledge and develop a solution with high potential. This was confirmed by measuring the share of knowledge sources on each external knowledge search effort that did not have prior experience with similar efforts in our data and analyzing the effects of this on problem-solving.

The dissertation contributes by showing the importance of involving diverse knowledge areas to solve problems related to the environmental field where complexity is high. While prior literature has shown the benefit of search breadth, I contribute by differentiating breadth of sources and breadth of knowledge. In doing so I contribute to extant literature by arguing and showing the importance of a distinction between these two constructs. This focuses on the effects of the characteristics of the collective search effort through the combined knowledge diversity and the share of inexperienced participants, rather than focusing on the effects of individual knowledge sources. I contribute by showing the benefits of organizing search to span diverse knowledge domains and the negative effects of increasing inclusion of inexperienced problem solvers. This finding opens an interesting discussion and consideration of the trade-off between novel input from entrepreneurial knowledge sources in problem-solving and the difficulties involved in collaborating with partners that have little or no prior experience with such efforts. The importance of diversity and the need to ensure that partners are capable of engaging effectively in collaborative efforts both have managerial implications for the selection of partners and design of collaboration processes and tools. Furthermore, policy makers may consider increasing efforts to educate inexperienced knowledge sources in effective collaborative problem-solving and provide well-designed tools for or management of such efforts to ensure valuable outcomes.

LIMITATIONS AND FUTURE RESEARCH DIRECTIONS

I combine the literature on external knowledge search with the problem-solving perspective through a problem-centered empirical approach to understanding the benefits and contingencies of using external knowledge sources with varying characteristics and

knowledge in the development of efficient solutions to technology related innovation problems. While I show the negative effects of incumbent inertia on specific external knowledge search efforts, future research could contribute additional insights by exploring the firm-level effects of engaging with incumbent firms threatened by competence-destruction. As such, the perspective of non-incumbents in these collaborations remains underexplored relative to the perspective of the incumbents that benefit from external knowledge. While my findings show important contingencies related to whether incumbent collaborators on specific problem-solving efforts are proactively engaged in reconfiguring their competences, the long-term effects of different modes of collaboration with incumbents suffering from inertia merits further empirical exploration. Similarly, future research could make an important extension to the work in this thesis by disentangling the underlying mechanisms behind the negative effects of incumbent firms. As such, the data applied in my empirical analysis did not allow an explicit disentanglement of incumbent inertia (i.e. limited ability) and strategic interests (i.e. intentional strategizing) as sources of their negative effects on joint problem-solving. An increasingly detailed disentanglement of which specific mechanisms are driving the effects as well as comparative studies of their effects and potential mitigation would be an attractive avenue for future research.

Furthermore, the findings support the importance of recognizing the value of separating the knowledge search process into problem-understanding and problem-solving respectively. It further increases the understanding of the knowledge domains and sources that contribute to either and their composition in organizing problem-solving (Nickerson et al. 2012). A relevant extension on this would be to empirically test the implications of more or less efficient problem-understanding on subsequent problem-solving in a more explicitly processes oriented setting. Similarly, an interesting extension on the findings of this dissertation would be to further explore the influence of diversity in the knowledge domains involve in external knowledge search efforts on understanding and solving problems respectively. It may be expected that increasing breadth of knowledge diversity is valuable to understanding a problem, while solving it requires more in depth in the specific knowledge domain or domains that hold the potential solutions. Finally, as the empirical setting of this dissertation focuses on the front-end of innovation I have not studied the outbound flow of knowledge, e.g. commercialization of the solutions. In- and outbound flows of knowledge are argued to be complementary despite so far lacking clear

empirical evidence (Cassiman and Valentini 2015). A relevant extension of the research in this dissertation would be to empirically study which role the knowledge sources involved in the creation of the solutions subsequently play in their commercialization. As the collaborative efforts receiving funding come to an end in the coming years it would be an attractive opportunity for future research to study the subsequent commercialization of the solutions through patents that allocate commercial value to few or more of the knowledge sources involved.

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