ENVIRONMENTAL CHALLENGES:

COLLABORATIVE SEARCH FOR SOLUTIONS

PRELIMINARY WORKING PAPER.

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INTRODUCTION

Firms are increasingly challenged to generate sustainable innovations which do not just provide economic returns but have simultaneously positive effects on the environment, society or safety (Ketata, Sofka, and Grimpe, 2014). This challenge is oftentimes too large for a firm's existing expertise so that it will need to collaborate with outside partners with promising solutions. Prior research has frequently documented the benefits of integrating external knowledge into firms' innovation processes (e.g., Laursen and Salter, 2006a; 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). Adopting a model of problemistic search, firms develop search strategies that target external knowledge sources in order to find solutions for a problem they are facing (Katila and Ahuja, 2002). When problems are complex, a search strategy may involve relationships with several external partners at the same time in order to collaboratively solve a problem. Several important questions arise if firms' search is carried out collaboratively, which however have so far received little attention in extant research: What is the role of coordination and communication in collaborative search? How does the accumulated knowledge and experience of the partners matter, and does it make a difference how knowledge and experience are distributed among the partners? And finally, how do these characteristics of the search consortium influence its ability to provide promising solutions to complex innovation problems?

Hence in this paper, we aim at developing an understanding of problemistic search which takes into account that the search is collaborative in nature. We argue that each knowledge source provides potential solutions from its particular domain while the problem solving potential of the overall search strategy depends on how well these solutions can be integrated (Knudsen and Srikanth, 2014). In that sense, search strategies do not only differ with respect to the diversity of knowledge that external sources provide but also how well the knowledge sources can be coordinated. Typical coordination activities within a search strategy include the communication of potential solutions, setting priorities for particularly promising ones and assimilating various solutions so that they form a conclusive search strategy. Firms can influence the problem solving potential of their search strategy through coordination or the absence thereof. The latter can create confusion among knowledge sources while too much coordination can limit the potential of the overall search strategy by reducing it to the lowest common denominator among partners (Knudsen and Srikanth, 2014). As a consequence, 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 distribution of both prior knowledge and coordination experience among the partners matters in that the problem solving potential benefits most from a more equal distribution of coordination experience but a less equal distribution of prior knowledge.

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). Firms' innovation activities that target environmental problems are different from solving other innovation related problems for mainly two reasons. First, environmental problems are typically complex and knowledge to solve them is dispersed. In fact, many sustainable innovations are systemic in nature and they originate from complex sets of knowledge which require the involvement of diverse groups of actors (Hall and Vredenburg, 2003). Second, environmental problems are oftentimes not formulated by the firm devising a search strategy itself but rather by the external environment a firm is operating in. This includes stakeholders, NGOs or the 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 topic calls in the environmental area of the European Commission’s 7th Framework Program, a research funding program that ran during the period from 2007 to 2013 with a total budget of more than EUR 50 billion. Project grants can reach a size of several million Euros and the grant application process requires significant investments. Hence, the effort is significant and with a potentially high payoff in terms of funding obtained to implement a search strategy. Grant applications are submitted through consortia of partners. To determine whether a submitted project will receive funding or not, the European Commission relies on ratings of three to five external and independent experts who assess the quality of each grant proposal and assign a quality score based on standardized criteria. 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 putting emphasis on 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, 2006a, 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 more often than not multilateral in nature. As a consequence, coordination among the partners involved becomes a crucial but currently absent factor in most models of knowledge search. Models which focus on collaborative search are oftentimes limited to simulation studies (Knudsen and Srikanth, 2014). On the other hand, prior literature largely ignores that the partners involved in a search consortium differ not only with regard to the knowledge they can provide but also the collaborative experience they bring into the consortium. We suggest that the distribution of these 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, 2006a). 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 which 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 observe also the less successful ones.

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 thus beyond the firm's control, management does have the opportunity to assemble 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 a more equal distribution of such experience among 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 talks about 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 instead of the aggregated firm level. This allows us to develop theory which fits with the nature of sustainable innovation which often times requires search strategies that differ from the average search strategy of a firm (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 problem solving potential of search strategies not just based on the accumulated knowledge of its knowledge sources but also on how well these knowledge sources can be coordinated. The latter factor is largely ignored in existing search theory but 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 (Katila and Ahuja, 2002) and/or knowledge sources (Laursen and Salter, 2006a) which can provide a solution for 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 including 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 (2006a) emphasize the costs for 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 build on the search model of Laursen and Salter (2006a) to the extent that it describes a firm's search strategy as a combination of external organizations, e.g. suppliers, universities, customers, which are supposed to serve as knowledge sources. We deviate from their theoretical model by going beyond the dimension of knowledge diversity and the need for screening. Instead, we envision a search process in which the firm is not a unitary actor which 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 on how well these solutions can be integrated (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 may not only be a result of a firm's own internal research and development (R&D) activities but may also be accessed 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, 2006a; Grimpe and Kaiser, 2010). At the same time, knowledge that the firm possesses performs an important function as 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 collaborative search will increase with the accumulated knowledge of the partners in a consortium for mainly two reasons. First, the higher the stock of knowledge that partners in a consortium have accumulated the higher the chance will be that they can recombine 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, following the absorptive capacity argument, a larger stock of knowledge of the partners involved in collaborative search is likely to facilitate mutual understanding and absorption of knowledge held by each partner. Moreover, such consortia may be able to better access and assimilate knowledge that can be found beyond the individual partners. As a result, our first hypothesis reads as follows:

Hypothesis 1: The problem solving potential of collaborative search increases with the combined 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 the knowledge sources is therefore separate from the diversity of knowledge that external sources provide. Coordination within a search strategy in that sense 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 may 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 firms influence the problem solving potential of their search strategy through coordination. Coordination avoids confusion among knowledge sources providing directions and setting priorities (Knudsen and Srikanth, 2014).

Since collaborative search requires decision making across collaborators, coordination contributes towards 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, 2006a). Love, Roper, and Vahter, 2014 find 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 extend this theoretical argument by arguing that knowledge sources, too, will benefit from such experience effects of engaging repeatedly in the formulation of search strategies. We argue that communication and coordination costs decrease with experience of the partners involved in collaborative search. The higher 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. Hence, our second hypothesis reads:

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

So far we have treated the knowledge stock of the partners in their collaborative search and their collaborative experience as independent factors. This assumption is not likely to hold. Partners in search consortia with large stocks of existing knowledge are especially likely to identify potential solutions to a problem which are novel and distant from existing sets of knowledge. Hence, the need increases to explain the value of these distant solutions to the rest of the search consortium and to allow them to form a consensus on whether the distant solutions are the most promising or cost efficient ones to include in the collaborative search strategy. Accordingly, the need for coordination and communication is especially high. In the absence of collaborative experience, potential solutions may be quickly discarded or narrowly followed up on.

Conversely, search consortia with low knowledge stocks are more likely to consider potential solutions which are simpler and closer to existing knowledge stocks. Such potential solutions are easier to understand and evaluate for the partner in a search consortium. Consequently, they do not benefit as much from the collaborative experience of the partners in a search consortium. We hypothesize:

Hypothesis 3: The problem solving potential of collaborative search increases with the combined knowledge of the partners and this effect is stronger with increasing combined collaborative experience of the partners; i.e. there is a positive interaction effect.

Inherent in the motivation for forming a search consortium is the realization that a partner can make up for deficits in the problem solving space of other partners. University research may for example provide a novel technology for the propulsion system of an environmentally friendly car but expertise is required in logistics and retail for how to provide fuel for the new car, e.g. from an existing network of gas stations. Hence, the partners within a search consortium are necessarily diverse and their distribution becomes an important variable independently from the aggregated sum of knowledge and experience they bring to a collaborative search.

We argue that both a high concentration of knowledge and collaborative experience within a search consortium have negative effects on the problem solving potential of its search strategy but that the negative effect from a high concentration of collaborative experience is stronger. Lower concentration of knowledge among the partners in a search consortium implies that potential solutions from many different domains have to be screened and evaluated. These screening efforts are costly because the management and information processing capacities are limited (Koput, 1997). Within increasing numbers of potential solutions to be screened the average quality of the resulting search strategy will decline.

Lower concentration of collaborative experience, though, ensures that all partners can draw from similar sets of routines for how to communicate and coordinate. The potential for conflict is especially high if very few partners in a search consortium have plenty of collaborative experience, i.e. the latter is highly concentrated. Under such conditions, it is likely that communication will be more likely to occur among partners with collaborative experience. This implies that the search consortium will not reach its full potential because some partners are more integrated than others. In sum, we predict:

Hypothesis 4: Higher concentration of collaborative experience among the partners will have a stronger negative relationship with the problem solving potential of collaborative search than higher concentration of knowledge among the partners.

DATA AND METHODS

Data

Existing research has captured knowledge search strategies 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, 2006a). 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 is identical, (b) that the firm did engage exclusively in the search strategy that was successful and (c) that no external firm factors exist which systematically influence finding but not searching. We argue that these assumptions are too narrow. We envision a search process in which multiple search strategies are devised and compete for funding to execute them based on 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, e.g. competitors engaging in similar or very different search strategies, which are outside of a firm's control but influence the finding performance.

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 7th Framework Program between 2007 and 2013. The program is sizable with 1.89 billion Euros designated to solving problems which 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.[1] Applicants submit proposals to a distinct call put forth by the European Commission, each representing specific and complex environmental problems. 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 solution highly attractive. We restrict our sample to project proposals of firms (not public organizations, universities and non-profit organizations) because their search strategies are at the core of our theoretical logic. Each of these firms assembles a project consortium of various knowledge sources, e.g. universities, which will contribute to the search strategy. Hence, we can observe the composition of a firm's collaborative search strategy. The resulting sample consists of 731 search strategies conducted 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.

To evaluate proposals the European Commission appoints three to five independent experts based on 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 of the potential of the proposal. This process is led by a

[1] Detailed information is available on the European Commission's 7th Framework Program's website: www.ec.europa.eu/research/fp7

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. This provides us with a unique dependent variable to capture the problem solving potential of a firm's problemistic search. A benefit of this ex-ante measure is its exogenous independence from changes in firm, industry or policy factors that influence execution of solutions and thus ex-post measures. We combine the EU data on participants, costs, roles of the organizations and expert evaluations with register data from Bureau van Dijk's Orbis database, which provides patent information of the participants. The resulting dataset is utilized to test our hypotheses.

Dependent variable

We use experts' ratings of the proposed solutions as our dependent variable to analyze the influence of knowledge and experience on the problem solving potential of collaborative search. Ex-ante measures provides unique opportunities to study the front-end of innovation (Salter *et al.*, 2014) through 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.

While ex-ante measures may not capture the final outcome of a specific project they hold advantages over ex-post measures for the purpose of studying mechanisms influencing potential solutions to specific problems. During execution, exogenous factors create contingencies and challenges that influence the execution and outcomes of projects (Ring and van de Ven, 1994). As such, ex-post measures are susceptible to influences from factors unrelated to the specific search strategy and proposed solution. Unobservable firm-specific changes to strategy, allocation of resources, departures of key individuals and similar are likely to occur in the internal organizations of each participant the during execution of the proposed solution, which will influence their contributions and thus impact the outcome beyond the mechanisms of interest to this paper (Bryson, Crosby, and Stone, 2006). Similarly, exogenous events and changes may significantly influence the project during its execution such as increases or decreases in the pressure to perform environmental innovation (Ariño and de la Torre, 1998). The development of new technologies, new knowledge regarding environmental impacts of firms and industries, changes in political landscapes at national or global level and may similarly create such influences. The increased or reduced pressure to focus on environmental aspects is likely to influence the focus and efforts of the participants on a project, thereby creating unobserved influences on the eventual outcome. Understanding the mechanisms influencing the collaborative search for solutions thus requires the ability to differentiate between this search effort and formulation of the identified solution from the management of project execution, in which other mechanisms and factors are influential. We achieve this differentiation through our ex-ante measure based on expert ratings.

Furthermore, the measure enables us to overcome the selection bias related to ex-post measures by analyzing both the approved and rejected proposals. Restricting the analysis to an ex-post measure of approved projects would potentially restrict the variance of the relevant mechanisms, thereby failing to fully capture the value of knowledge and experience. Finally, a small sample of approved proposals could reduce the validity of our analysis by providing an inadequate amount of solutions proposed to the specific problem. 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. We remain confident that this enables us to capture the problem solving potential resulting from the explanatory variables introduced below.

Explanatory variables

Knowledge stock

Following prior literature in the field (Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002), we use the number of patents assigned to the organizations involved in a search consortium as our measure for the accumulated knowledge stock. We calculate patent stocks for each organization with a constant 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 actual application and hence the formation of the search consortium. These stocks are summed up to create our measure. We are aware that patent stocks only capture a part of the knowledge held by organizations. Particularly university knowledge may be better represented by scientific publications. Nevertheless, we believe that the focus on patents allows for a comparable measure that can be aggregated across different organizations.

Experience stock

The second main explanatory variable captures the accumulated experience of the participants in a search consortium that we assume to facilitate coordination and communication among the partners. We count the number of participations in search consortia within the 7th Framework Program 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 for a reliable identification of experience with relation and relevance to the search efforts observed. Moreover, we acknowledge that our measure cannot capture an organization's participation in earlier Framework Programs.

Concentration of knowledge and experience

The variables "knowledge concentration" and "experience concentration" are constructed by calculating the Herfindahl indices of the knowledge and experience stocks, respectively, of the partners in a search consortium. Herfindahl indices are calculations of the concentration of a measure within a population or group. They range from 0 to 1, reflecting equal distribution among all participants or full concentration of knowledge or experience within one single partner. An increase in our concentration variables thus reflects increasing concentration of knowledge or experience.

Control variables

To control for factors that may influence the problem solving potential beyond our hypothesized effects, our analysis includes a number of variables related to the characteristics of the firm leading the search effort, as well as the specific search effort. 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 NACE classification system to control for industry effects. 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.

To control for the size and resources of the firms we include a dummy variable indicating whether the leading firm is a small and medium enterprise (SME). This captures whether a firm meets the three EU criteria for 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. At the level of the search consortium we control for the project cost in millions of Euros. To control for the number of partners involved in the consortium we include the count of participants. Finally, previous research has shown the importance of a broad search strategy that includes targets several different external sources of knowledge such as suppliers, universities, users or competitors (Laursen and Salter, 2006a). Therefore we include a variable called breadth to control for the number of different sources involved in effort search consortium, measured as the count of different industries in which the partners are active.

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 and experience on the problem solving potential of a search strategy across the 25 different calls in our dataset. We perform robustness checks using robust standard errors, as well as using the natural logarithm of our dependent variable to account for minor skewness in its distribution with consistent results.

RESULTS

Descriptive findings

Table 1 shows the summary statistics of the variables under study. 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. The majority of the firms leading the search consortium to solve environmental problems is 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. As these sectors have significant direct or indirect environmental impacts, knowledge about the causes and implications of these impacts, and not least about potential solutions, is not surprising. Furthermore, knowledge-intense firms are likely to identify value from engaging in early-stage innovation activities to develop solutions that can be commercialized subsequently. 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. About 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.

[Table 1 about here]

Table 2 shows the pairwise correlations. We do not detect an alarming correlation among the explanatory variables. Moreover, we calculate the variance inflation factors for our explanatory variables to test for collinearity problems (e.g., Belsley, Kuh, and Welsh, 1980). Our mean variance inflation factor for the main explanatory variables is 1.08 and 2.74 for our explanatory variables and control variables combined, which suggests that our data does not suffer from collinearity.

[Table 2 about here]

Regression results

The results of our regression models are presented in table 3, which shows the step-wise introduction of our explanatory variables. As previously described we use a fixed-effects estimation to allow analysis of the influence of knowledge and experience on the solution potential of search efforts across the 25 EU calls representing problems in our data. In Model I only control variables are include, while Model II tests our first two hypotheses. Our control variables show a consistently positive effect of increasing the breadth of sources in external search processes as expected from extant literature (Laursen and Salter, 2006a). This confirms the positive effects of involving a variety of sources in the search efforts, such as universities, customers and similar. Similarly we see a small and significant effect of increasing the number of participants in the search effort. While more diverse sources and an increasing amount of participants contribute positively, we would eventually expect absorptive capacity limits to restrict the ability to take in, process and apply more knowledge (Cohen and Levinthal, 1989, 1990) and create decreasing returns. Similarly we interpret the negative SME effect as being related to absorptive capacity. This indicates the effects of a higher ability of larger firms to invest in the education of their employees, which is previously found to positively influence absorptive capacity (Ketata *et al.*, 2014). We see a small negative effect of increasing project costs, counted as million Euros. This could indicate that the experts are attentive to inflated project cost, although the size of the effect suggests that very exuberate costs are required for any negative 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 search efforts. 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.

[Table 3 about here]

As seen from the positive and significant effect of "*Knowledge Stock*" in Model II the solution potential is raised by an increase in the combined knowledge of the partners. Similarly, the positive and significant effect of "*Experience Stock*" provides evidence that the solution potential increased as the combined experience of the partners grows. We thereby find support for both hypothesis 1 and 2 in Model II. Our third hypothesis expected a positive interaction effect between knowledge and experience. However, as seen from the lack of significance in the variable "*Knowledge*Experience*", we do not find support for this hypothesis. We argue that the lack of significance is a reflection of the different and non-substitutional nature of knowledge and experience. In Model IV we introduce the measures of knowledge and experience concentration, constructed by taking the Herfindahl indices of the knowledge and experience among the partners of each search effort. We find support for our fourth hypothesis on the stronger negative effect of high experience concentration than high knowledge concentration from the significant and positive and negative effects of the variables "*Knowledge Concentration*" and "*Experience Concentration*" respectively. We in fact see a positive effect of a concentration of knowledge, indicating an advantageous effect of some degree of knowledge concentration among the partners rather than an entirely equal distribution. Finally, in Model V we run the full model with all explanatory variables included and find that our results remain robust.

DISCUSSION

We conduct this study to explain how firms arrive at especially promising solutions to environmental problems. The latter is highly likely to require knowledge from more than one firm. Search strategies for addressing environmental problems are therefore especially likely to be collaborative in nature, i.e. requiring collaboration between multiple often times diverse sets of partners. To solve this question we draw on search theory and collaborative search. We predict that under conditions of collaborative search for solutions to complex problems, such as environmental ones, the accumulated prior knowledge of the partners in the search consortium can only partly explain the search strategy's problem solving potential.

We develop theoretical arguments for why the distribution of partners in the search consortium matters as well as how well the partners have learned to collaborate, i.e. their collaboration experience. We find that the latter is even more important for the problem solving potential of a collaborative search then the accumulated knowledge of the partners. Interestingly, there is no significant interaction between accumulated knowledge and collaboration experience within a search consortium. Apparently, strength in one aspect cannot make up for weaknesses in another one. However, we do find important distribution effects. While concentrated knowledge within a search consortium increases its problem solving potential, concentrated collaboration experience hurts it. Hence, our findings emphasize the importance of collaboration experience within collaborative search as well as the importance of many partners sharing it. These findings have relevance for academic theory and practice.

For academic research we provide new insights in two research streams. For research in sustainable innovation we provide a more detailed understanding for how firms can form promising search strategies which go beyond breadth and depth measures of partners (e.g. Ketata *et al.*, 2014). The insights have important 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 with partners interact and need to be coordinated. Second, we show that the problem solving potential of a search strategy is strictly determined by the screening capacities (Laursen and Salter, 2006b) or search routines (Love *et al.*, 2014) of the searching firm. Instead, the collaboration experience of the partners has an importance impact as well as its distribution. Hence, we provide a way for future research to conceptualize the search for external knowledge as a much more interactive process than merely the collection 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 which led to "finding" may severely underestimate the diversity of a firm's search.

For management practice and policy making we find that promising search strategies for sustainable innovation originate from search consortia in which many partners have collaboration experience. Prior knowledge is important but can be highly concentrated within the search consortia. Managers should consider the implicit penalty from including partners without collaboration experience. Policy makers, though, may want to encourage potential partners to develop and display their experience in collaborating with external partners to become more promising knowledge sources.

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TABLES

Table 1: Summary statistics

Variables	Mean	S.D.	Min	Max
Problem solving potential	63.37	18.33	0	100
Knowledge stock	-.18	.98	-.48	14.64
Experience stock	-.29	.45	-.45	4.32
Knowledge concentration	.51	.43	0	1
Experience concentration	.55	.34	.04	1
Breadth	1.18	.99	1	5
Participant count	9.87	5.84	2	55
Project costs	4.10	3.09	0	23.50
SME	.55	.50	0	1
Eastern Europe	.08	.28	0	1
Northern Europe	.50	.22	0	1
Southern Europe	.36	.48	0	1
Western Europe	.48	.50	0	1
Non-European	.03	.16	0	1
Medium-high and high tech manufacturing	.08	.27	0	1
Knowledge-intense services	.73	.45	0	1
Less knowledge-intense services	.04	.19	0	1
Medium-low and low tech manufacturing	.03	.17	0	1
Other industry	.13	.33	0	1

Table 2: Pairwise correlations

	Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
(1)	Problem solving potential	1																	
(2)	Knowledge stock	.15	1																
(3)	Experience stock	.15	.15	1															
(4)	Knowledge concentration	.22	.25	.08	1														
(5)	Experience concentration	-.27	-.17	-.07	-.26	1													
(6)	Breadth	.21	.20	.24	.17	-.45	1												
(7)	Participant count	.26	.19	.28	.19	-.44	.45	1											
(8)	Project costs	-.01	.05	.17	-.00	.09	.14	.35	1										
(9)	SME	-.16	-.03	.03	-.17	.09	-.00	-.09	-.12	1									
(10)	Eastern Europe	-.18	-.06	-.07	-.08	.10	-.13	-.12	-.04	.10	1								
(11)	Northern Europe	-.07	-.02	-.01	-.01	-.03	.01	.04	.03	-.06	-.07	1							
(12)	Southern Europe	-.12	-.04	.02	-.05	.19	-.06	-.10	-.06	-.02	-.22	-.17	1						
(13)	Western Europe	.27	.09	.02	.11	-.21	.12	.15	.05	-.02	-.29	-.22	-.72	1					
(14)	Non-European	-.07	-.03	.01	-.04	-.03	.01	-.02	.04	.03	-.05	-.04	-.12	-.16	1				
(15)	Medium-high and high tech manuf.	.06	.07	-.07	.03	.13	.04	-.06	.10	-.01	-.03	.03	.05	-.03	-.02	1			
(16)	Knowledge-intense services	-.04	-.00	-.03	-.03	-.21	-.10	.07	-.12	.16	.05	.03	-.11	.07	-.01	-.48	1		
(17)	Less knowledge-intense services	-.05	.00	-.01	.03	.10	.07	-.03	-.02	-.12	.02	-.01	.15	-.16	.06	-.06	-.32	1	
(18)	Medium-low and low tech manuf.	-.03	-.05	-.04	-.04	.12	.02	-.08	.10	-.01	-.05	-.00	.02	-.00	.02	-.05	-.28	-.03	1
(19)	Other industry	.05	-.03	.13	.02	.06	.05	.00	.04	-.13	-.02	-.05	.01	.03	-.01	-.11	-.62	-.08	-.07
	Mean Variance Influence Factor (VIF):	2.74																	

Table 3: Fixed-effects estimations for the problem solving potential

Variables	**Model I**	**Model II**	**Model III**	**Model IV**	**Model V**
Knowledge stock		1.77**	1.78**		1.34*
		(0.74)	(0.74)		(0.74)
Experience stock		6.03***	6.03***		5.45***
		(1.60)	(1.60)		(1.59)
Knowledge * experience			0.03		
			(1.27)		
Knowledge concentration				4.73***	3.75**
				(1.52)	(1.54)
Experience concentration				-10.28***	-9.42***
				(3.13)	(3.11)
Breadth	3.30***	2.75***	2.75***	2.17***	1.83**
	(0.78)	(0.78)	(0.79)	(0.82)	(0.82)
Participant count	0.65***	0.49***	0.49***	0.51***	0.38***
	(0.13)	(0.14)	(0.14)	(0.14)	(0.14)
Project costs	-0.85***	-0.88***	-0.88***	-0.77***	-0.81***
	(0.23)	(0.23)	(0.23)	(0.23)	(0.23)
SME	-6.08***	-6.34***	-6.34***	-5.23***	-5.60***
	(1.31)	(1.30)	(1.30)	(1.31)	(1.30)
Eastern Europe	-3.03	-2.34	-2.34	-3.21	-2.51
	(4.41)	(4.35)	(4.36)	(4.35)	(4.31)
Northern Europe	-2.02	-1.21	-1.21	-2.18	-1.42
	(4.76)	(4.70)	(4.70)	(4.70)	(4.65)
Southern Europe	3.34	3.63	3.63	3.11	3.49
	(3.98)	(3.93)	(3.93)	(3.93)	(3.89)
Western Europe	10.36***	10.74***	10.73***	9.34**	9.88**
	(3.96)	(3.91)	(3.91)	(3.91)	(3.87)
Medium-high and high tech manufacturing	3.83	4.96*	4.96*	3.59	4.73*
	(2.85)	(2.84)	(2.84)	(2.81)	(2.81)
Knowledge-intense services	-0.92	-0.31	-0.31	-1.20	-0.64
	(1.98)	(1.96)	(1.96)	(1.95)	(1.94)
Less knowledge-intense services	-5.51	-4.79	-4.80	-5.44	-4.73
	(3.71)	(3.66)	(3.66)	(3.66)	(3.63)
Medium-low and low tech manufacturing	-3.43	-1.86	-1.87	-2.45	-1.21
	(4.14)	(4.09)	(4.10)	(4.08)	(4.05)
Constant	52.38***	56.34***	56.34***	59.15***	62.14***
	(4.51)	(4.53)	(4.53)	(5.18)	(5.19)
Observations	731	731	731	731	731
R-squared	0.20	0.23	0.23	0.23	0.25
Number of calls	25	25	25	25	25

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