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Technology ventures' engagement of external actors in the search for viable market applications: On the relevance of Technology Broadcasting and Systematic Validation



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ABSTRACT

In order to succeed, technology ventures need to find a profitable market application for their technology. Although external market actors may provide important information for the identification and validation of potential technology-market combinations, it remains largely unclear how technology ventures can involve them in this process. Building on insights from organizational search literature, this study follows five university spin-offs trying to commercialize early-stage technologies. We find that ventures are cognitively constrained in proactively identifying and approaching external market actors. Interestingly, the better performing ventures in our sample engage in a previously undocumented market search process we label Technology Broadcasting. They communicate their technological competencies to a broad range of market actors and react to these actors' assessment and spontaneous expressions of interest, thereby overcoming their own cognitive constraints. Resource constraints require filtering these expressions of interest through Systematic Validation with additional market players. These results complement the existing insights on market search by entrepreneurial ventures and advance the literature on organizational search.

Executive summary

A fundamental step in commercializing a new technology is finding a market where its application can create substantial value for a set of end-customers. In order to succeed in this endeavor, technology ventures need to identify a broad range of potential market applications which they then have to test and validate in order to come up with the most promising one. External market actors play a crucial role in this process. As entrepreneurs are typically constrained in terms of their prior experience and knowledge, they need to bring in the knowledge of external advisors to identify more and different markets. Moreover, they have to engage with potential partners and customers to validate these potential market applications.

But while it is clear that external market actors can contribute substantially to the identification and validation of potential market applications for a venture's technology, our understanding of how they are involved in this process is surprisingly limited. The current study therefore wants to investigate (a) the different approaches technology ventures use to involve market actors, and (b) how these

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different approaches impact the identification and validation of potential market applications for their technology.

In order to answer these questions, we use and extend insights from the organizational search literature. This literature starts from the assumption that managers, in our case entrepreneurs, do not have all information *a priori*, and hence need to search for information to make satisfactory decisions. They do so by constructing, evaluating, and implementing alternatives. We study the search process of five U.K. university spin-offs trying to identify a market for their early-stage technology. We follow these spin-offs over a period of five years and analyze the way in which they involve market actors in the identification and validation of potential market applications.

We observe that when the entrepreneurs are limited in terms of knowledge and resources, a more traditional approach, in which the venture proactively identifies specific market segments and tries to contact/convince potential customers and partners in these market segments to validate the market potential (e.g., by developing and testing tailored prototypes), tends to lead to the identification of familiar but suboptimal market applications. In fact, we observe that the better performing ventures in our sample take a far more reactive approach in which they rely on external market actors' assessment of the technology. They show their technological competencies to a broad range of market actors (e.g., through conference presentations and websites) and wait for some of these external market actors to express an interest in the technology. This approach, which we label Technology Broadcasting, allows the ventures in our study to identify a broad range of potential market applications, many of which they had never thought of. We further observe that, in order to use resources efficiently and filter out the most promising market applications, it is best not to use simple rules of thumb like quick returns and cost considerations. Instead, ventures can systematically validate the leads by checking whether additional market actors in that same market segment are equally interested, a process we label Systematic Validation.

These findings enrich previous literature on entrepreneurship by suggesting that different approaches to the identification of and engagement with market actors have different implications for the identification, as well as for the subsequent validation of potential market applications. They also advance the literature on decision-making under uncertainty, which has focused on the benefits and costs of experimentation but has paid little attention to how market actors can be involved in these experiments. More generally, the study contributes to the organizational search literature by focusing on market search (instead of the search for technological solutions), by explicitly distinguishing between the identification and validation phase of the search process, and by showing that not only cognitive but also resource constraints impact organizational search.

1. Introduction

One of the most fundamental steps for entrepreneurial ventures seeking to commercialize a new technology is finding a profitable technology-market combination, or in other words, a market where the application of the technology can maximize value for a set of end-customers (Gruber et al., 2008, 2013). In order to succeed in this endeavor, technology ventures need to *identify* a broad range of potential technology-market combinations which they then need to *test and validate* (Andries and Debackere, 2007; Gruber et al., 2008; Gruber and Tal, 2017). The academic as well as practitioner-oriented literature has emphasized the importance of entrepreneurs' prior knowledge in this respect (Shane, 2000; Fiet, 2007; Patel and Fiet, 2009; Grégoire et al., 2010; Gruber et al., 2013; Gruber and Tal, 2017). In particular, prior specific knowledge can create cost advantages in the systematic search for an opportunity (Fiet, 2007) and allows entrepreneurs to make mental connections, so-called cognitive alignments, between the technology and the market (Grégoire et al., 2010). Both have positive impacts on the founding team's ability to identify a good market opportunity.

However, in many cases, entrepreneurs' prior knowledge will not suffice to *identify* profitable technology-market combinations, and information from external market actors will need to be incorporated (Gruber et al., 2013; Snihur et al., 2016). In particular, entrepreneurs are typically constrained in terms of their prior experience and knowledge, which limits their ability to identify a broad range of technology-market combinations (Fern et al., 2012; Gruber et al., 2008; Shane, 2000). Gruber et al. (2013) explain how the use of external advisors, who bring in their own specific knowledge, can at least partly overcome such knowledge constraints and result in the identification of more and different markets. Even if entrepreneurs are able to identify potential technology-market combinations, these combinations still need to be *tested and (in)validated* with potential partners and customers through, for example, purposeful experimentation (Murray and Tripsas, 2004; Pillai et al., 2020). The need to include external market actors in the identification and validation of potential technology-market combinations is particularly pressing for ventures commercializing early-stage technologies, as many of these technologies' eventual market applications cannot be predicted based on prior knowledge but will only be shaped through the entrepreneurial (inter)actions of different actors (Andries et al., 2013; Alvarez and Barney, 2007; Dutta and Crossan, 2005; Molner et al., 2019).

However, while it is clear that external market actors can contribute substantially to the identification and validation of potential technology-market combinations, our understanding of how they are involved in this process is surprisingly limited. As Shepherd et al. (2021, pp. 31) explain: "we have a rich understanding of an organization's network and the benefits (and constraints) of that network. [But] it seems that we are only starting to gain an understanding of how networks are formed in the first place and how that formation facilitates [...] the identification of a potential opportunity, the formation of a community of inquiry, the enrollment of stakeholders [...]." In particular, it has been demonstrated that technology entrepreneurs are often located in ecosystems which are rich in technology expertise but scarce in access to business advice (Clarysse et al., 2014). How these entrepreneurs then can access the knowledge of relevant market actors remains unclear. The current study wants to improve our understanding of this issue by investigating (a) *the different approaches technology ventures use to involve market actors*, and (b) *how these different approaches impact the identification and validation of potential technology-market applications*.

Starting from and extending insights from the organizational search literature, we study five U.K. university spin-offs trying to identify a market for their early-stage technology. We follow these spin-offs over a period of five years and analyze the way in which they identify and engage with market actors in the identification and validation of potential technology-market combinations. We

observe different approaches and compare the performance outcomes of these approaches for the ventures under study, as contrasting performance levels in general allows to induce more accurate mechanisms (Eisenhardt, 1989).

We identify two broad approaches to the engagement of market actors in the identification of potential technology-market combinations. A first approach, which we label Proactive Market Identification, reflects a more traditional approach to market search in which the venture proactively tries to assess the value of specific market segments and contact/convince potential customers and partners in these market segments. The potential of these market applications is then validated through trial-and-error learning (e.g., through the development and testing of tailored prototypes). We observe in our sample that cognitive and resource constraints tend to limit the venture team in identifying unfamiliar but interesting market actors and corresponding technology-market combinations. A second broad approach to the identification of potential technology-market combinations, which – as far as we know – has not been documented in previous research and which we call Technology Broadcasting, entails broadly exposing the venture's technology to market actors in a wide variety of market segments (e.g., through conference presentations and websites), relying on their assessment of the technology's potential, and reacting to their spontaneous expressions of interest. In analogy to crowdsourcing or “broadcast search” (Afuah and Tucci, 2012; Jeppesen and Lakhani, 2010), this approach is not based on the market experience and knowledge of the founding team nor on its purposeful request for advice from experts it identifies, but relies on (a broad range of) market actors, thereby allowing the venture to overcome its cognitive constraints and identify a large number of less familiar but promising technology-market combinations.

We observe in our sample however that resource-constraints make it impossible to validate all these leads in depth, and we detect that the ventures use two distinct approaches to deal with this challenge. A first group of ventures uses simple rules or heuristics, such as quick returns and cost considerations, to decide which external actors and corresponding technology-market combination to commit its resources to. The ventures in our sample which use these heuristics make suboptimal choices. We identify an alternative approach, whereby the ventures systematically validate and filter the leads by checking whether additional market actors in that same market segment are equally interested. Whereas Technology Broadcasting allows identifying a large number of promising, unfamiliar technology-market combinations, this Systematic Validation– contrary to Heuristics-based Validation– enables the ventures in our sample to improve their assessment of these technology-market combinations' value before committing substantial resources to a selection of them.

This study speaks to the literature on entrepreneurship and decision-making under uncertainty, as well as to organizational search literature. In the domain of entrepreneurship, our findings enrich earlier research that underlines the important role of external market actors in the identification and validation of technology-market combinations. In particular, it suggests that different approaches to the identification of and engagement with market actors have different implications for the identification, as well as for the subsequent validation of potential technology-market combinations. We propose that, when it is impossible to identify a number of promising markets upfront, either because the venture team does not have the necessary market knowledge nor access to experts who have such knowledge or because this information simply does not exist (yet), Technology Broadcasting appears a promising approach, especially when the expressions of interest that then emerge from Technology Broadcasting are filtered through Systematic Validation before committing substantial resources. These insights advance the literature on decision-making under uncertainty, which has focused on the benefits and costs of experimentation but has paid little attention to how market actors can be involved in these experiments. More generally, we contribute to the organizational search literature by focusing on market search (instead of the search for technological solutions), by explicitly distinguishing between the identification and validation phase of the search process, and by showing that not only cognitive but also resource constraints impact organizational search.

In the next section, we review relevant insights from the entrepreneurship and organizational search literature. We then present our empirical approach and findings, and conclude by discussing their implications for research and practice.

2. Literature review

2.1. Entrepreneurial decision-making under uncertainty

It is generally accepted that new ventures which try to commercialize technologies, are confronted with high degrees of uncertainty. Either the information that is needed to identify the complete set of promising technology-market combinations does not exist (yet), or founders are unable to access it (see above). While earlier work advanced planning and control as mechanisms to deal with uncertainty (Brinckmann et al., 2010; Delmar and Shane, 2003), more recently the insight has emerged that more flexible, adaptive, and collaborative approaches fit better with uncertain decision-making contexts (Alvarez and Parker, 2009; Bingham and Eisenhardt, 2011; Sarasathy, 2001). Uncertainty and risk induce the need for ventures to change their ideas and business models as more information becomes available (Pitt and Kannemeyer, 2000). In particular, “the adaptive entrepreneur allows the business concept to develop over time as he/she gains experience with products, markets, suppliers, employees, and other key variables surrounding the enterprise” (Stoica and Schindehutte, 1999, pp. 1–2).

Experimentation has been advanced as the core component of this adaptive decision-making process. Through experimentation, technology ventures are expected to adapt their initial idea into a viable product-market combination by means of “a series of trial and error changes pursued along various dimensions” (Nicholls-Nixon et al., 2000: 496). By experimenting with a specific technology-market combination and incorporating feedback from the environment, technology ventures adopt an active stance to learning about the environment. If outcomes are negative, the initial idea is adapted and a new experiment is launched (Minniti and Bygrave, 2001), implying ventures will deviate from their initial technology-market combination as they learn about and incorporate information that becomes available during the entrepreneurial trajectory (Gruber et al., 2008). Murray and Tripsas (2004) coined the term

purposeful experimentation to explain how individual firms set up a series of scientific experiments to identify and validate potential product-market combinations, and [Andries et al. \(2013\)](#) propose that ventures should develop a portfolio of parallel technology-market experiments.

External market actors play an important role in these experiments. In particular, research on the “scientific founder” method ([Camuffo et al., 2020](#)), which is inspired upon the more popular “lean startup” movement ([Blank, 2013; Ries, 2011](#)), advocates the *validation* of (assumptions about) potential technology-market combinations through the development and testing of prototypes or minimum viable products with potential users (see e.g., [Felin et al., 2019](#)). Moreover, as [Gruber et al. \(2013\)](#) and [Gruber and Tal \(2017\)](#) explain, external market actors can also contribute substantially to the *identification* of potential technology-market combinations, by contributing knowledge and ideas the entrepreneurial team did not have itself. These insights reflect the more general observation that external knowledge sources play an important role in various types of organizational activities ([Allen, 1977; Chesbrough, 2003; Dixon, 1999; Menon and Pfeffer, 2003; Ozgen and Baron, 2007; Singh, 2000](#)). Below, we advocate that the organizational search literature may provide us with a better understanding of how technology ventures can involve these external market actors in the identification and validation of potential technology-market combinations.

2.2. Insight from organizational search

Whereas an ‘alertness’ perspective has long dominated research on the identification of entrepreneurial ideas, there is increasing evidence that in order to succeed, entrepreneurs need to systematically search their environment for information ([Fiet, 2007; Patel and Fiet, 2009](#)). In a recent study of technology ventures, [Pontikes and Barnett \(2017\)](#) give numerous examples of entrepreneurs and their investors, who engage in extensive and iterative processes of market search before becoming successful. The organizational search literature, which is part of strategy research and is rooted in the behavioral theory of the firm ([Cyert and March, 1963; Katila and Ahuja, 2002; Knudsen and Levinthal, 2007](#)), could provide a theoretical basis for understanding how technology ventures search for information – including information from external market actors – that allows them to develop promising technology-market combinations. This literature starts from the assumption that managers, in our case entrepreneurs, do not have all information *a priori*, and hence need to search for information to make satisfactory decisions. Organizational search is defined as the organizational process of constructing, evaluating, and implementing alternatives ([Knudsen and Levinthal, 2007](#)). Often, these alternatives are represented as different points on an information landscape, with higher points on the landscape representing solutions with a higher pay-off.

Within the organizational search literature, a distinction is made between ‘local’ and ‘distant’ search. Distant searches, in information spaces that are unfamiliar to the focal organization, are the most likely to lead to innovation ([Nerkar and Roberts, 2004](#)). However, decision-makers and organizations have a natural tendency to look for alternatives within the information space that is familiar. Using a *trial-and-error* or experiential search approach, they alter one aspect of their solution at a time, and gather information on its performance ([Levinthal, 1997; Gavetti and Levinthal, 2000](#)). Although [Murray and Tripsas \(2004\)](#) advocate the use of this search approach by entrepreneurial ventures, the dominant view in the organizational search literature is that, in situations of medium or high complexity, organizations that use trial-and-error search tend to get stuck in local or suboptimal peaks on the information landscape, identifying solutions that are superior to other solutions in the immediate neighborhood, but inferior to solutions further away ([Levinthal, 1997](#)).

The organizational search literature has advanced different approaches to overcome this bias. As an alternative to experiential search, [Gavetti and Levinthal \(2000\)](#) advance *cognitive search*, i.e., the selection of actions based on an actor’s simplified representation of, or belief about, the linkage between actions and the consequences of these actions. Based on a simplified representation of the landscape, actors select a promising starting point on the landscape from which they conduct their further search efforts. In contrast to experiential search, where actors learn about the performance of closely related solutions through trial and error, cognitive search allows them to identify superior ‘basins of attraction’, i.e., those points on the information landscape that lead to a common peak through a subsequent process of trial-and-error search ([Kauffman, 1993](#)). It is expected that even when problems are difficult to decompose, cognitive search makes it possible to identify interesting and more remote areas of the information space. [Gavetti et al. \(2005\)](#), on the other hand, put forward *analogical search* processes as an alternative for detecting interesting starting points for organizational search. In their model, the focal organization relies on its experience in different settings. It compares the current problem to a variety of problems it has solved in the past, and starts with the solution that has proven successful in highly similar problem situations. It then refines this solution through trial-and-error learning.

A common critique on these approaches is that, while they theoretically allow decision-makers to search a larger part of the information landscape, they all rely on the decision-makers prior experience and knowledge, which in practice may limit search to a limited number of information channels or solutions. [Fiet \(2007\)](#) and [Patel and Fiet \(2009\)](#) counter this critique by arguing that entrepreneurs who search systematically have a greater chance of making discoveries within a group of information channels that are already known to them, and that offer frequent, low-cost access to information, than when systematically searching the rest of the information landscape. Exploring similar promising ideas in a has a cost advantage as it allows to use prior specific knowledge over and over again ([Fiet, 1996, 2007](#)), while distant search is typically very costly. Acquiring more distant market information from external parties not only requires considerable cognitive effort ([Dahlander et al., 2016; Cohen and Levinthal, 1990](#)), it also entails potential contracting hazards ([Williamson, 2002](#)), and triggers both organizational and transaction costs as the external market information is to be acquired, processed, evaluated, and integrated into the firm ([Cassiman and Valentini, 2016](#)).

Some authors have suggested, however, that it is possible to identify distant information while limiting search costs. In particular, [Jeppesen and Lakhani \(2010\)](#) have argued that, when a focal organization is faced with a concrete problem, it can “broadcast” the details of that problem to a wide range of potential problem solvers and invite the participation of any actor that considers itself

qualified to solve the specific problem. Solvers self-select to try and create a solution, and are rewarded if their efforts are successful. Whereas [Jepesen and Lakhani \(2010\)](#) investigate which external problem solvers are able to come up with successful solutions, [Afuah and Tucci \(2012\)](#) discuss this phenomenon from the perspective of the focal firm, and compare “designated search” processes—which theoretically can take the form of local or distant search—whereby the focal firm tries to identify a suitable subcontractor to solve its technical problems, with “broadcast search” or “search through crowdsourcing”, where the focal firm discloses the details of its problem to the crowd and invites potential subcontractors to advance technical solutions. As explained by [Afuah and Tucci \(2012\)](#), broadcast search transmits the problem over the information landscape so that actors on this landscape can look for a solution in their immediate neighborhood. Only those agents located in the neighborhood of peaks will decide to try and develop a solution for the focal firm. [Afuah and Tucci \(2012\)](#) therefore argue that, for certain technical problems, broadcast search transforms distant search into local search, thereby enabling firms to enjoy the benefits of distant search without having to endure many of its costs.

Although the literature on organizational search has yielded many useful insights, a major problem is that it shows an explicit bias towards technology search (or supply-side search) in large, established companies, while largely overlooking the problem of market search (or demand-side search), i.e. search devoted to the discovery of new insights “regarding market structures and segments, product use and substitution patterns, and customer preferences and needs” ([Sidhu et al., 2007](#), p. 21). The latter is not only imperative for technology commercialization in new ventures ([Gruber et al., 2013](#)) but also poses an important challenge in established companies (see, e.g., [Danneels, 2007](#); [Sidhu et al., 2007](#)). Moreover, we know surprisingly little about how to search for a solution when the problem cannot be formulated upfront ([von Hippel and von Krogh, 2015](#)). This situation is very typical for ventures trying to commercialize early-stage technologies, as many market problems for which a technological solution could be envisaged are not knowable a priori. Our empirical study tends to shed more light on how technology ventures can involve and obtain information from external market actors under these circumstances.

3. Method

We followed the principles of the extended case study method ([Burawoy, 1991](#)), a methodological approach using empirical data gathered through case study to re-conceptualize and extend existing theory ([Danneels, 2007](#)). This approach goes through cycles of confrontation between data and theory, with each iteration directing the analyst to collect additional data and draw on additional concepts and theories.

The setting of our study consists of the spin-off activities at one U.K. university in the period 2009–16. University spin-offs face considerable difficulties in developing their typically early-stage technologies into an appropriate market proposition ([Vohora et al., 2004](#)). In particular, their search for satisfactory technology-market combinations is hindered by their lack of knowledge about how their technology can be applied to serve a residual customer need ([Vohora et al., 2004](#)). In addition, they typically have a good access to technical information sources, but not to external business and market advice (see above). As such, they provide an interesting setting to investigate the different approaches that can be used to involve market actors in the identification and validation of potential

Table 1
Case descriptions.

Case	Founding date and department	Seed funding	Technology	Team experience
Robotico	April 2010 Centre for Ultrasonic Engineering	App. \$ 250 k	Ultrasonic systems, miniature robotic vehicles, embedded electronics and robot positioning	CEO-founder: phd, 2 years of experience in industry CTO-founder: assistant professor, 15 years of experience in technical functions in industry
Microled	July 2010 Institute of Photonics	App. \$ 200 k	Solid-state optical GAN micro-projection systems	CEO-founder: phd, 10 years of experience in high tech companies in optonics Scientific founder (part time): professor, over 10 years of experience developing the technology
Bacterio	February 2010 Institute of Pharmacy and Biomedical Sciences	App. \$ 500 k	Bacteriophages technology	Scientific founder: professor, over 10 years of experience developing the technology Co-founding CEO (part-time): 15 years of experience in biotech directorship positions in different biotech startups Co-founder CFO (part-time): 20 years of experience as a manager in biotech and 13 years in market research for biotechnologies
Biopharm	July 2009 Organic Chemistry Group	App. \$ 2 mio	New class of DNA minor groove binders (MGBs)	Co-founder CBO (Chief Business Officer) (part-time): over 30 years of experience in commercial pharma functions Co-founder CEO: over 30 years of experience managing product development in big pharma Co-founder CTO: 25 years of experience as financial director in big pharma
Diagnostico	July 2009 Institute of Pharmacy and Biomedical Sciences	App. \$ 300k	Innovative assays and diagnostic instrumentation	Co-founder CEO: 15 years of experience as a serial entrepreneur. Co-founder CSO (Chief Scientific Officer): over 30 years of research experience as a professor

technology-market combinations.

Within this setting, we selected five relevant cases with several criteria in common. All ventures in our study were engaged in the commercialization of early-stage technologies developed at a single university. The technologies had been developed at different research units of the university, where it had taken between two and ten years to develop them. Although some ventures had already been officially incorporated while others had not, the university's technology transfer office (and our later interviews with founders; see below) assured us that they were facing similar challenges. All ventures had identified some potential market application for their early-stage technology (e.g. through contract research), but they had not yet validated the actual market potential of these ideas. Moreover, they had difficulties predicting the full set of potential market applications for their technologies upfront. The ventures originated in the same geographical region in the same time period, i.e., between July 2009 and July 2010, and thereby faced a highly similar institutional context. A final selection criterion was that the ventures allowed us to collect detailed information on the market search process. By limiting our selection to ventures that were active in the commercialization of early-stage technologies developed at the same university, originated around the same time in the same geographical region, and benefitted from the same university and government support, we ensure that the observed differences in search processes are not due to contextual or regional differences. **Table 1** summarizes the five cases. It is worth noting that the founding teams of all five ventures had prior industry experience (as this was stimulated by the university and its technology transfer office), and were all able to generate significant amounts of startup funding.

We documented for each venture the period from the initial idea to establish a company up to the point when the venture ceased to exist or became dormant (in the case of Robotico); or to the point when we stopped data collection. We started by analyzing available documents (including company websites, annual accounts, and press articles). Over the period 2011–14, we then repeatedly conducted semi-structured interviews with the (co-)founder; on average ten interviews per case. In the initial interviews, which lasted on average 47 min, we asked founders about their personal experience and background, the venture's founding team and main technological and market activities, and the activities undertaken so far in order to search for a technology-market combination (including but not limited to the involvement of external actors). All ventures had difficulties identifying a satisfactory market application for their technology (as discussed in detail in the findings section). In each follow-up interview, we asked founders which technology-market combinations had been identified, evaluated, pursued, or discontinued in the period that had passed since the last interview. We also asked them why and how this had happened, and what the implications had been. In instances where there had been changes, follow-up interviews lasted up to 86 min. The interviewees provided complementary documents after the interviews (e.g., business plans). When inconsistencies between interviews and documents emerged, these were clarified in consecutive interviews. For each case, interviews and document analysis were performed until a consistent historical timeline of the market and technology search process for each company could be constructed. **Table 2** provides an overview of the data sources used.

3.1. Initial data analysis

In a first step of our analysis, and building on the extended case study approach described by [Danneels \(2002, 2007\)](#), two of the authors read the interview transcripts and documents looking for themes and patterns ([Miles and Huberman, 1994](#)). Critical passages were highlighted and coded, and initial interpretations were recorded in notes. When reading and analyzing transcripts, documents, and scholarly literature, we generated memos, which are pieces of insight that the researcher achieves as he/she proceeds with the analysis ([Strauss, 1987](#)). The two authors jointly matched and contrasted memos to refine theoretical understanding ([McCracken, 1988](#)), and systematically compared the emerging theoretical interpretations in the memos with the evidence ([Eisenhardt, 1989](#)). To ensure that their interpretation was trustworthy, a third author took the role of the “devil's advocate”, challenging the other two authors' interpretations ([Gioia et al., 2013](#)).

Table 2
Overview of data sources.

Company name	Primary data	Secondary data
Robotico	12 interviews with founder (36 transcribed pages)	4 websites 4 press articles 11 internal documents 6 documents from company databases
Microled	9 interviews with founder (45 transcribed pages)	2 websites 5 press articles 26 documents from company databases
Bacterio	14 interviews with founder (66 transcribed pages)	2 websites 10 press articles 3 internal documents 12 documents from company databases
Biopharm	9 interviews with founder (28 transcribed pages)	6 websites 29 press articles 2 internal documents 12 documents from company databases
Diagnostico	10 interviews with founder (41 transcribed pages)	4 websites 5 press articles 14 documents from company databases

Table 3
Constructs.

Concept (definition)	Key references	Key aspects	Exemplary quotes
Cognitive constraints (lack of diversity of mental templates for problem solving)	Baker et al. (2003); Eisenhardt et al. (2010); Furr et al. (2012); Gavetti and Levinthal (2000); Gruber et al. (2008); Sarasvathy (2001); Shane (2000)	<ul style="list-style-type: none"> Ability to search beyond prior knowledge and experience Inability to search beyond existing network 	<ul style="list-style-type: none"> Because you tend to divide... we certainly did, everyone starts out with an idea of what your main fields are going to be, and therapeutics was the obvious thing with an antibacterial substance. In fact, that's proved out to be completely false. It may well be one of the last segments to be developed. (Bacterio) The reason we chose human health is, quite frankly, that that's what the founders of the company's experience and careers had been to date. (Biopharm) Our research was funded by an industrial collaboration called the Research Centre for Non-Destructive Evaluation, and that has members from [...] different sectors, so Airbus, Eon, BP, Shell, I'm sure that there's some petrochemical companies as well, they [i.e. the identified market actors] are all members of this. (Robotico) They were in our network, plus we thought they were more addressable... (Robotico) ...in order to kind of try and optimize our resources, we needed to focus on some sort of key opportunities or markets [...] instead of like moving slowly on loads of fronts, to try and to just optimize the use of resources and deliver on one application. (Robotico) We had more enquiries in different sectors than we first anticipated. So, we're trying to be focused on one sector, but we have now four or five sectors with different customers in those sectors, who are very interested in what we're doing [...] We are actually changing the priority to image capture and then medical. That's where our priorities are. Just because [...] too many things have been asked of us. (Microled) It is the danger. So, you got to focus on one opportunity, but in fact there are a large number of other opportunities [...] In fact we're struggling with... we've got three major, major projects at the moment and we're struggling with manpower. We are recruiting people. We're expanding labs and so on. The danger is we will outgrow our strength...we've got to be a bit realistic about costs and the potential we've got... (Bacterio) We just don't have the capacity. We're a new company, we have to be very careful, otherwise we can overextend
Resource constraints (limited capacity in recombining resources from the environment)	Baker and Nelson (2005); Gans et al. (2019)	<ul style="list-style-type: none"> (Too) many potential applications Limited capacity/resources Need to focus 	<ul style="list-style-type: none"> (continued on next page)

Table 3 (continued)

Concept (definition)	Key references	Key aspects	Exemplary quotes
Proactive Market Identification (proactively identifying and contacting market actors by relying on own assessment)	Afuah and Tucci (2012); Camuffo et al. (2020); Gavetti and Levinthal (2000); Levinthal (1997); McGrath (1997); Ries (2011); Murray and Tripsas (2004)	<ul style="list-style-type: none"> • Proactively contacting market actors • Reliance on own assessment 	<p>ourselves, you know, entirely. (Diagnostic)</p> <ul style="list-style-type: none"> • I was getting a bit sort of fed up going and speaking to people, and they always tell me kind of a similar thing. And then I go and speak with them 6 months later, and they tell me the same thing again. (Robotico) • ...our kind of commercialization effort was to try and speak to them and [...] target them as customers. (Robotico) • So, we thought that was quite an interesting market, actually. But then that really didn't come to anything. (Robotico) • And we decided that nuclear, after this... nuclear and petrochemical. (Robotico) • I do articles in industry magazines or trade magazines every two to three months. (Microled) • And also having a web presence as well. [...] We're not a software company, so our web presence, internet, is not our shop, but is our shop window [...] we're not trading through the internet, but we've got to give the right impression through the internet. (Microled) • With the web, or with the articles, we feel that people become aware of our capabilities. (Microled) • The crescendo happens probably in June, when I'll be attending the Bio International conference in Boston. And I'm going to apply to make a presentation. This is the biggest meeting in the world, actually. It's about 20,000 people who go to this meeting all together. Governments, hubs, investors, pharma, biotech, everything. So, it really is the big stage. (Biopharm) • ...what we're trying to do [on the website] is demonstrate [...] that we have more than one antibiotic [...] As a matter of fact, half an hour before you and I spoke, I went on the website and put in the latest news that we have a... two different approaches now using effectively what would be the same molecule... (Biopharm) • The website would have been designed [...] in quite a technical way, that they would have the information they need [...] (Diagnostic) • In some ways, we're a bit reactive.... (Microled) • We've now had about 60 unique enquiries from companies [...] And we respond to every one of them, and it's not a... we review every one of them... is not a standard reply we give them. We try to engage with them to understand
Technology Broadcasting (showing technological competencies to a broad range of market actors and reacting to their assessment and expression of interest)	Afuah and Tucci (2012); Jeppesen and Lakhani (2010)	<ul style="list-style-type: none"> • Showing technological competencies to a broad audience • Reacting to expressions of interest 	<p>(continued on next page)</p>

Table 3 (continued)

Concept (definition)	Key references	Key aspects	Exemplary quotes
Trial-and-Error Validation (validating potential technology-market combinations through trial-and-error testing)	Brown and Eisenhardt (1997); Camuffo et al. (2020); Gavetti and Levinthal (2000); Levinthal (1997); McGrath (1997); Ries (2011); Murray and Tripsas (2004)	<ul style="list-style-type: none"> • Reliance on market actors' assessment • Tailored prototype development and testing • Consultancy 	<p>what sector they're working in. (Microled)</p> <ul style="list-style-type: none"> • We have to be responsive to the market. (Microled) • And we got a phone call from them on the afternoon, saying [...] they want to talk to us. [...] we had several meetings since, and negotiations are proceeding (Bacterio) • The customers came to us. Actually one of them came and [...] we [now] have one person who has been employed to work on this. (Diagnostico) • People will read the articles, and then they will [decide to] come to us. (Microled) • We're relying on people to inform us about the market. (Microled) • The customers who find us... these are the customers who come with two criteria, normally. One, they're very ambitious, so they're searching for new technologies. Or secondly, it's people who are having pain, or problems with what they're presently doing. (Microled) • But if anything, [...] it was customer-led. That's why I started. The customers came to us. (Diagnostico) • The website would have been designed so that [potential customers] would have the information they need to know to be able to decide whether this is interesting – yes or no? (Diagnostico) • basically what these customers are saying is: we like your Listeria, we like your salmonella, but we'd like you even more if you'd supply these other things as well [...] One customer [...] actually phoned up the new CEO and just basically said: if you can show me you can do this by May/June, I'll take 20 thousand of these by the end of the year... (Diagnostico) • I'm very happy to say, we had some very positive feedback at the BioCongress in Washington DC last month from one or two of these players who said: "if you take it to that level, we're very interested". (Biopharm) • Well, we delivered the first [prototype] [...] in three months. And the second one was about a year. So, say January 2010. (Robotico) • So, we've done... did the inspection with them once, but we'll try and do the same inspection over and over. (Robotico) • We've built the prototype and we're just assembling them and testing them. So, assembling, testing, and kind of ironing out all of these little things.(Robotico) • It was more like a sort of a consultancy. They paid for work for us to produce a

(continued on next page)

Table 3 (continued)

Concept (definition)	Key references	Key aspects	Exemplary quotes
Heuristics-based Validation (validating potential technology-market combinations based on heuristics)	Busenitz and Barney (1997); Dunbar (1998); Eisenhardt et al. (2010)	<ul style="list-style-type: none"> • Adjustment of target market through trial-and-error 	<p>system [...] They asked us to build them a bespoke system...(Robotico)</p> <ul style="list-style-type: none"> • Even the product we're developing it's gonna need a bit more trialing and testing, I think, before people will be willing to buy it. So, it's got to begin with consulting. (Robotico) • ... these two [customer segments, and key partners] are a bit in the state of flux. Maybe more the key partners than the customer segments. But [...] we're taking out some, but adding new ones in [...]we're trying to make money from something, and if we don't make money we might try to do it in a different way... (Robotico) • ...we dropped aviation because there wasn't very good fit technically. Wasn't a good technical fit, we had some technical issues that we couldn't really solve for the aviation. ... We would be best trying the easier segments technically, and then coming back to that later.... And then power generation that's, I suppose we weren't making a lot of traction with that... We weren't making very much traction, we weren't having very much success, so we decided to kind of not focus on that. [...] Anyway, so then we got some interest [...] to look at green stores, and problems with corrosion on the roofs of green silos. (Robotico) • We're not yet sure whether we will sell the device, or if we will use our own people to actually deliver the service. So, we're not really sure if it's a product or a service. We'll probably try both ways. (Robotico) • Then wound care... yeah, you can do it in 18 months, veterinary care you're talking 3 to 5 years [...] the horrible industry phrase "low hanging fruit" – you know exactly what I mean [laughs]. What can you do that will give you a return quickly and cheaply, as quickly and cheaply as possible? (Bacterio) • ... they must make a commitment to us: a financial commitment. [...] From our point of view, we insist that the company pay money for the demonstrator. So, we don't give any free samples, irrespective of the size of the company. (Microled) • What's happened with the medical [market application] is we've had long negotiations with that customer, a lot of legal negotiations, whereas in the meantime this one, the negotiations have happened much quicker. So, this one I'm giving more priority to, because

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Table 3 (continued)

Concept (definition)	Key references	Key aspects	Exemplary quotes
Systematic Validation (validating potential technology-market combinations by systematically verifying market needs and size with additional market actors)	Hoornaert et al. (2017); Ozcan and Eisenhardt (2009)	<ul style="list-style-type: none"> Filtering based on cost considerations Systematically contacting additional market actors Verifying market needs Verifying market size 	<p>it's closer to market, closer to happening. (Microled)</p> <ul style="list-style-type: none"> So, to try and reduce our cost there, we try to do things where we will group different segment or products together, and will manufacture things in parallel rather than in series. (Microled) What can you do that will give you a return quickly and cheaply, as quickly and cheaply as possible? (Bacterio) So, we, in particular, one company pursued us. [...]. And they said, we're very interested in this. Can you tell us all about it? So we did. And they said: this is very [interesting]... we have to talk. So, since then I have started to broaden my base, and talk with other animal health groups. (Biopharm) But we will actually be looking very much towards US as well. So, we are actively seeking a partner in the US... (Diagnostico) We already have [contacted them]– it's a very small group of companies, a very, very small group of companies that act in the vet side. We were in touch with all of them – all the significant players. There's probably only [...] about eight now in the whole world of the sort of size that would be useful for us. (Diagnostico) And they are telling us the same thing: this is important, we would like to know more about it. So, I can't ignore that. There's an obvious market interest, a market demand there. (Biopharm) There's enough. There's certainly more than 4 or 5, there's probably about 12 to 15 in total across the world. So, yes there is a healthy club of potential partners for us. (Biopharm)

As the study progressed, we grouped these memos into conceptual clusters of closely related analytic ideas, which we then compared to existing insights from the entrepreneurship and organizational search literature (Danneels, 2002, 2007). As can be seen in **Table 3**, the constructs that emerged from our analysis going back and forth between the strategy and entrepreneurship literatures on the one hand and our empirical data on the other hand reflect two types of *constraints* which have discussed in those literatures namely cognitive constraints (e.g. Eisenhardt et al., 2010) and resource constraints (e.g. Baker and Nelson, 2005), which hinder the ventures' search for satisfactory technology-market combinations, as well as two different *approaches to identification* and three different *approaches to validation* that ventures use to develop a satisfactory technology-market combination (see **Table 3**). Our initial analyses suggested that these identification and validation approaches differed with respect to the engagement of external market actors and the outcome of the search process. In line with recommendations by Burawoy (1991) and Danneels (2007) on the extended case study method, we then collected and analyzed additional data in order to validate our emerging understanding.

3.2. Additional data collection and analysis

As we wanted to better understand whether different search processes indeed were more effective in overcoming the cognitive and resource constraints that appeared to hinder ventures in identifying satisfactory technology-market combinations, we decided to follow the suggestions by Eisenhardt (1989) and contrast the ventures' performance levels in order to induce more accurate mechanisms. In the period 2015–16, we consulted company websites, annual accounts, and press articles, and conducted additional interviews with the founders (which lasted on average 35 min) to obtain performance data on each venture. Relevant performance measures emerged from the interviews. We collected information regarding the number of patents each venture obtained (as patents

reflect an industrial application of a technology), on self-financing (as this reflects whether the venture is able to generate an income from its technology-market combinations), but also on the number of times external actors demonstrated an interest in buying the venture, and the amount of equity and grants obtained (as indicators of external parties' valuation of these technology-market combinations). As more general performance measures, we collected market value and employment data as well as the ventures' self-perception of overall performance and satisfaction with the spin-off process.

We organized the raw data for the different performance indicators in a spreadsheet, and ranked the ventures for each performance indicator using the RANK.EQ function in Microsoft Excel. We then summed these ranks in order to obtain an overall measure of venture performance. The resulting Table 4 displays the ranks for each of the different performance indicators. Due to confidentiality reasons, the raw data are not shown. We find that Robotico displays the lowest performance of the ventures in our sample. This ranking appears to be valid, as Robotico eventually went bankrupt. Microled and Bacterio obtained medium scores, and the top performers were Diagnostico and Biopharm. Using different weights for each of the performance indicators and even excluding either specific or general performance indicators did not yield different rankings.

4. Findings

Our analyses show that the ventures in our study were all unable to identify a clear set of valid technology-market combinations upfront. By contrasting ventures with different performance levels, we observe that they use different approaches to involve external market actors in the identification and validation of potential technology-market combinations, and that these different approaches have a different potential to overcome cognitive and resource constraints, as we will explain in detail below.

4.1. Cognitive and resource constraints

We observe that, as none of the technology ventures in our sample is able to identify a clear set of viable technology-market combinations upfront, they all need to continue searching after founding. The search process is however hindered by two types of constraints. First, we find that ventures' **cognitive constraints** reduce their ability to identify and assess technology-market combinations, as was already well documented in the entrepreneurship and organizational search literature. Cognitive constraints refer to a lack of diversity of mental templates for problem solving that exist in a founding team (e.g., Eisenhardt et al., 2010; Furr et al., 2012). This lack of diversity constrains the problem solving process (Gavetti and Levinthal, 2000). A first type of cognitive constraint we identified, was the **inability to search beyond one's prior knowledge and experience**. For example, the founders of Biopharm and Bacterio explained that they initially had the tendency to build on the knowledge they already had to identify and assess potential technology-market combinations (cfr. Gruber et al., 2008; Shane, 2000), while this knowledge later turned out to be false or incomplete:

The reason we [initially] chose human health is, quite frankly, that that's what the founders of the company's experience and careers had been to date.

(Biopharm)

... you tend to divide... we certainly did, everyone starts out with an idea of what your main fields are going to be, and therapeutics was the obvious thing with an antibacterial substance. In fact, that's proved out to be completely false. It may well be one of the last segments to be developed.

(Bacterio)

These cognitive constraints are also reflected in an **inability to search beyond one's pre-existing network**. Robotico, for example, was very much focused on market actors its founders knew from previous research experiences, a process that was called "network bricolage" by Baker et al. (2003), and that is applauded as part of the effectuation logic (Sarasvathy, 2001):

Table 4

Venture performance.

Performance indicators	Robotico	Microled	Bacterio	Biopharm	Diagnostico
Patents granted (in period of data collection)	1	2	3	5	3
Self-financing (in period of data collection)	1	3	2	5	3
Manifestations of interest in buying the venture (in period of data collection)	1	1	1	5	4
Private equity (in period of data collection)	1	3	2	5	3
Grants (in period of data collection)	3	2	1	4	5
Number of employees (beginning of data collection)	1	2	3	4	5
Number of employees (end of data collection)	1	3	2	4	5
Market value (beginning of data collection)	1	2	3	5	4
Market value (end of data collection)	1	3	2	5	4
Self-perception of overall performance (end of data collection)	1	2	3	3	3
Satisfaction with the spin-off process (end of data collection)	1	2	4	4	2
Overall performance rank (SUM)	13	25	26	49	41

1 is lowest and 5 is highest performance.

Our research was funded by an industrial collaboration called the Research Centre for Non-Destructive Evaluation, and that has members from [...] different sectors, so Airbus, Eon, BP, Shell, I'm sure that there's some petrochemical companies as well, they [i.e. the identified market actors] are all members of this.

(Robotico)

In addition, we see that **resource constraints** (in the sense of capacity) make it impossible to test and assess all the potential technology-market combinations that were initially identified or that became apparent later, an issue that has been largely ignored in the literature on organizational search but has received much attention in the entrepreneurship literature (Baker and Nelson, 2005; Gans et al., 2019). We define resource constraint here along the lines of Baker and Nelson (2005) following Penrose's seminal work as the limited capacity that an entrepreneurial firm has in recombining resources from the environment into technology-market combinations. As several founders stressed in the interviews, the **number of potential technology-market combinations was enormous**, and their **limited resources and capacity** forced them to **focus** and narrow down the number of technology-market combinations they could investigate or test in detail:

...we needed to focus on some sort of key opportunities or markets [...] instead of like moving slowly on loads of fronts, to try and to just optimize the use of resources and deliver on one application.

(Robotico)

...we're struggling with manpower. We are recruiting people. We're expanding labs and so on. The danger is we will outgrow our strength...we've got to be a bit realistic about costs and the potential we've got...

(Bacterio)

We just don't have the capacity. We're a new company, we have to be very careful, otherwise we can overextend ourselves, you know, entirely.

(Diagnostico)

Interestingly, we observe that the ventures in our study use different approaches to involve external market actors in the identification and validation of potential technology-market combinations, which differ in the extent to which they allow overcoming cognitive and resource constraints and therefore also in terms of performance outcomes, as explained in the following sections.

4.2. Proactive Market Identification versus Technology Broadcasting

We observe that, although none of the technology ventures in our sample is able to identify a clear set of valid technology-market combinations upfront, they approach this problem in different ways. In particular, we notice a clear difference between how the lowest performing case, Robotico, and the other technology ventures in our study approach the **identification** of potential markets and market actors, as described below.

4.2.1. Proactive Market Identification

A first approach to the identification of external markets and market actors is observed in the case of Robotico, which tries to **proactively contact market players** and convince them of the potential value of the technology. At founding, Robotico takes over the university's research contract with National Nuclear Laboratories, a natural first customer for the startup as they were already making use of the university's services. However, because the contract is at non-commercial terms, it tries to convince National Nuclear Laboratories to alter it into a recurrent commercial contract. To the founder's despair, several months of conversations fail to yield any concrete progress. In the end, the company is not able to convince National Nuclear Laboratories to engage in a recurrent service contract:

I was getting a bit sort of fed up going and speaking to people, and they always tell me kind of a similar thing. And then I go and speak with them 6 months later, and they tell me the same thing again.

(Robotico)

Because the CEO of Robotico thinks that the decision makers at National Nuclear Laboratories really are the problem, he approaches a second customer in that same market, again without success. After failing to make progress in the nuclear market, Robotico turns sequentially to actors in the petrochemical, aviation, power generation, green silo, and non-destructive equipment sectors. It actively contacts these actors and tries to convince them of the value of Robotico's technology.

Now, although they're all in very different markets, they're all requiring inspection solutions, so our kind of commercialization effort was to try and speak to them and [...] target them as customers.

(Robotico)

Robotico **relies on its own assessment** to decide which particular technology-market combinations seem promising enough to investigate further. Unfortunately, this assessment mostly turns out to be incorrect. In fact, most of the actors that were contacted do not see any value in the application of Robotico's technology in their specific sector, as illustrated in the next quote:

... And we decided that nuclear, after this... nuclear and petrochemical.... Anyway, so then we got some interest [...] for a particular application to look at green stores, and problems with corrosion on the roofs of green silos. So, we thought that was quite an interesting

market, actually. But then that really didn't come to anything. So, we decided that wasn't actually a good opportunity. So, we took that one... that one can come out again [laughs].

(Robotico)

We label this approach Proactive Market Identification. It can be defined as a process in which the venture proactively identifies and contacts market actors by relying on its own assessment in order to identify potential technology-market combinations. The specific venture in our study, which uses this approach, looks for a customer that will buy its technology-market combination, or that will at least provide it with valuable information on a potentially viable technology-market combination. This process resembles the concept of designated contracting as described by Afuah and Tucci (2012, pp. 360) in the context of technology search, which "entails evaluating the ability of each potential contractor to deliver the desired solution and then picking the right one."

However, where the validation of the chosen contractor's actual ability to deliver a solution only takes place after the focal firm has closed a contract with him, we see that Robotico tries to **validate** its initial ideas about promising technology-market combinations **by developing and testing tailored prototypes** with the market actors they approach. On the few occasions that a contacted market player shows some minimal interest, Robotico tries to obtain more information on the need of the customer and the possibilities of the technology to respond to that need by engaging in in-depth interactions regarding the functioning and performance of these prototypes:

Well, we delivered the first one [...] in three months. And the second one was about a year. So, say January 2010...

(Robotico)

We've built the prototype and we're just assembling them and testing them. So, assembling, testing, and kind of ironing out all of these little things.

(Robotico)

Also, the company tries to set up **consultancy** services for responsive companies, in order to learn more about their specific needs and requirements:

It was more like a sort of a consultancy. They paid for work for us to produce a system [...] They asked us to build them a bespoke system...

(Robotico)

Even the product we're developing it's gonna need a bit more trialing and testing, I think, before people will be willing to buy it. So, it's got to begin with consulting.

(Robotico)

These findings resonate with insights of Brown and Eisenhardt (1997), who argued that firms wanting to thrive in rapidly changing environments should rely on low-cost probes. As McGrath (1997) already explained, these low-cost experiments will probably not yield accurate estimates of, for example, the market demand for a new product or service, but they may allow the venture to identify whether demand structures are more or less attractive.

Based on the insights obtained from these prototype tests and consulting activities, Robotico constantly **re-adjusts its target market through trial-and-error learning**. Each time the venture finds out that a specific technology-market combination is not satisfactory (i.e., that a specific market actor is not interested), it drops that market and adds a new one. As the founder explained:

I suppose the value proposition stays more or less the same, ... But yeah, these two [customer segments, and key partners] are a bit in the state of flux. Maybe more the key partners than the customer segments. But [...] we're taking out some, but adding new ones in [...] we're trying to make money from something, and if we don't make money we might try to do it in a different way

(Robotico)

...we dropped aviation because there wasn't very good fit technically. Wasn't a good technical fit, we had some technical issues that we couldn't really solve for the aviation. ... We would be best trying the easier segments technically, and then coming back to that later.... And then power generation that's, I suppose we weren't making a lot of traction with that... We weren't making very much traction, we weren't having very much success, so we decided to kind of not focus on that. Anyway, so then we got some interest [...] to look at green stores, and problems with corrosion on the roofs of green silos.

(Robotico)

We're not yet sure whether we will sell the device, or if we will use our own people to actually deliver the service. So, we're not really sure if it's a product or a service. We'll probably try both ways.

(Robotico)

We label this approach, which can be defined as the validation of potential technology-market combinations through trial-and-error testing, Trial-and-Error Validation. The combination of Proactive Market Identification and Trial-and-Error Validation constitutes a search process that is very similar to the experiential search or trial-and-error search approach described in the organizational search literature, with organizations identifying a potentially interesting point on the information landscape, experiencing the performance of that landscape, and (staying there or) making a new move (Levinthal, 1997; Gavetti and Levinthal, 2000). It also reflects entrepreneurship concepts like purposeful experimentation (Murray and Tripsas, 2004), the "scientific founder" method (Camuffo et al., 2020), and the "lean startup" approach (Ries, 2011), where the entrepreneur identifies a market and then engages with actors in

that market to test his/her assumptions and adapt the technology accordingly. For a comprehensive discussion of the lean start-up method, we refer to [Contigiani and Levinthal \(2019:553\)](#), who summarize this method as identifying a product market segment to set up and test explicit hypotheses, being flexible and open to change and making low-commitment investments.

However, our analysis demonstrates that this approach does not perform well in the case of Robotico. The company ceased its activities during our data collection. Despite its efforts, the venture had not been able to identify a satisfactory technology-market combination. Our analysis suggests that this is because the outcome of Proactive Market Identification is heavily affected by the **cognitive constraints** mentioned above and also by **resource constraints**. The cognitive constraints reflect cognitive variety in the founding team and the founding team not being able to bring in knowledgeable experts. In addition to cognitive constraints, also resource constraints also affect their ability to bring in additional employees and externals to increase such cognitive variety. In particular, we observe that to make something with the resources at hand in line with what [Baker and Nelson \(2005\)](#) described, Robotico builds on insights and contacts its founders had previously developed via the university. The venture only targets market actors that were engaged in collaborations with the research center it originated from. When asked why the venture only targeted potential customers from its own contact base, the CEO of Robotico mentioned resource constraints as the primary reason:

...we thought they were more addressable. [...] in order to kind of try and optimize our resources...

(Robotico)

In other words, Robotico's Proactive Market Identification is limited to local search efforts because of cognitive as well as resource constraints; and these local search efforts make it difficult for the venture to involve interested external market actors and identify viable technology-market combinations. Based on the evidence from this one case, combined with initial insights from the entrepreneurship and organizational search literature, we propose that Proactive Market Identification (combined with Trial-and-Error Validation) may result in suboptimal technology-market combinations when founders are bound by cognitive and resource constraints.

4.2.2. Technology Broadcasting

In the four other cases—Microled, Bacterio, Diagnostico, and Biopharm—we identify a different process to identify relevant market actors and markets. We see that these ventures are **showing their technological competencies to a broad audience**, via their respective websites, presentations at conferences, and press interviews, to make them aware of the potential of their technology.

We have not had an active marketing strategy, but [...] I do articles in industry magazines or trade magazines every two to three months.

(Microled)

And also having a web presence as well. [...] We're not a software company, so our web presence, internet, is not our shop, but is our shop window [...] we're not trading through the internet, but we've got to give the right impression through the internet.

(Microled)

With the web, or with the articles, we feel that people become aware of our capabilities.

(Microled)

...what we're trying to do [on the website] is demonstrate [...] that we have more than one antibiotic [...] As a matter of fact, half an hour before you and I spoke, I went on the website and put in the latest news that we have a... two different approaches now using effectively what would be the same molecule....

(Biopharm)

The crescendo happens probably in June, when I'll be attending the Bio International conference in Boston. And I'm going to apply to make a presentation. This is the biggest meeting in the world, actually. It's about 20,000 people who go to this meeting all together. Governments, hubs, investors, pharma, biotech, everything. So, it really is the big stage. And that's when I'm hoping we will have great data, and generate some big excitement.

(Biopharm)

We further observe that Microled and Bacterio (medium performers), as well as Diagnostico and Biopharm (top performers) do not take a proactive approach like Bacterio, but instead put their effort into **reacting to expressions of interest** from market actors that have heard about their technology:

In some ways, we're a bit reactive...

(Microled)

We've now had about 60 unique enquiries from companies [...] And we respond to every one of them, and it's not a... we review every one of them... is not a standard reply we give them. We try to engage with them to understand what sector they're working in.

(Microled)

We launched our website on the 1st of August, [...] And we got a phone call from them on the afternoon, saying they booked a flight, they want to talk to us. [...] we had several meetings since, and negotiations are proceeding.

(Bacterio)

In particular, the case of Diagnostico shows several concrete examples of how the company reacted to expressions of interest from external market actors. In particular, Diagnostico's website attracts the attention of a small ISO9001 certified supplier of laboratory

diagnostic test systems, which was in 2011 in financial trouble through the sudden drop of the Pound against the Euro which made its European technology supplier too expensive. The company approaches Diagnostico and the newly formed joint venture follows up on this expression of interest and starts to compete with food diagnostic companies itself and sell end product kits. Shortly after Diagnostico had started to sell end product kits, the scientific founder told us the company was planning to expand into China as a reaction on an expression of interest. He explained that a Chinese producer had contacted them for mycotoxins, a component they had not been focusing on but did have access to via a license with the university, and that as a result they were now developing this component for the Chinese market:

The customers came to us. Actually one of them came and [...] we [now] have one person who has been employed to work on this.
 (Diagnostico)

Contrary to Robotico, all these ventures **rely on assessments by external market actors** in order to identify potential technology-market combinations. By presenting information on their website, on conferences, and in press articles, the ventures enable external actors to assess the value of the technology for their respective markets:

The website would have been designed so that [potential customers] would have the information they need to know to be able to decide whether this is interesting – yes or no?
 (Diagnostico)

Instead of having to assess the potential of different markets themselves, ventures can infer the value of these market by the expressions of interest from the market actors:

We're relying on people to inform us about the market.
 (Microled)

The customers who find us... these are the customers who come with two criteria, normally. One, they're very ambitious, so they're searching for new technologies. Or secondly, it's people who are having pain, or problems with what they're presently doing.
 (Microled)

...basically what these customers are saying is: we like your Listeria, we like your salmonella, but we'd like you even more if you'd supply these other things as well [...] One customer [...] actually phoned up the new CEO and just basically said: if you can show me you can do this by May/June, I'll take 20 thousand of these by the end of the year...
 (Diagnostico)

We label this second approach Technology Broadcasting, in analogy to the term “broadcast search” that Afuah and Tucci (2012) and Jeppesen and Lakhani (2010) use to describe how organizations crowdsource technical solutions to problems they encounter. Whereas Afuah and Tucci (2012) discuss the concept of broadcasting for solving a technological problem, the ventures in our study use it to identify a market problem. They present their technology and company in an “un-designated” way to a broad range of market actors. Instead of the ventures having to convince these potential partners or customers of the potential value of their technology, they are contacted by actors who, based on their own knowledge and capabilities, consider the technology a potential solution to their problems. Based on our findings, we therefore define Technology Broadcasting as the process in which a venture shows its technological competencies to a broad range of market actors and reacts to their assessment and expression of interest in order to identify potential technology-market combinations.

We find that – contrary to Proactive Market Identification – Technology Broadcasting allows the ventures in our sample to **overcome their cognitive constraints**. A first issue that was frequently mentioned in the interviews was the ability to identify satisfactory technology-market combinations which the venture itself had not been able to foresee upfront. For instance, the companies that contacted Bacterio and Microled came from a broad range of markets outside the ventures' existing network and extend the ventures' knowledge base. When the founder of Bacterio was asked to recount the interest the company received in wound care applications of its technology, he said:

Simply honest, we never thought of them [i.e. wounds as an application].
 (Bacterio)

In addition, the expressions of interest from the chemical industry bring the venture entirely new knowledge and insights:

There's been a lot more interaction with chemical industries, which we didn't anticipate, because until you actually get involved with the people down here, you don't know what this supply chain is. And how relevant it is. And how much interest there is at this level.
 (Bacterio)

As explained above, Diagnostico starts to develop mycotoxins because potential customers start asking for them. Even though their CSO has links to a research institute that is specialized in mycotoxins, the venture had not realized that they represent a viable technology-market combination:

Actually one of [the lead customers] came and said: “Oh, your CSO in Solus is [affiliated to Research Institute X, which] is famous for mycotoxins”.
 (Diagnostico)

Similarly, the commercialization of product kits is a technology-market combination that Diagnostico had not thought about initially. It is only because it was contacted by a supplier of laboratory diagnostic test systems, that the viability of this technology-market became apparent, and that the company starts to compete with food diagnostic companies by selling end product kits.

It's entirely different customers, with a different support, because we support the production ourselves. But it's the same item [...] Originally we would be selling the technology basically to the big food diagnostic companies. [...] Now we're selling the end product to the end user. So, instead of the profit being diluted all the way through, we get the whole profit.

(Diagnostico)

The venture describes some of its new insights as the spotting of “*a very large [...] surprising gap*”.

It hence appears that as Technology Broadcasting relies not on the knowledge of the focal venture, but on that of external market actors which spontaneously approach it, the venture is able to identify a large variety of potential technology-market combinations it was unable to foresee itself.

However, while Technology Broadcasting allows Microled, Bacterio, Diagnostico, and Biopharm to identify interesting technology-market combinations they never had thought of, we observe that the approach still creates difficulties with respect to **resource constraints**. The founders of Microled, Bacterio, and Diagnostico all mentioned explicitly that their ventures had too few resources to engage in in-depth conversations and collaborative developments with all interested external actors, and therefore were unable to assess which technology-market combinations were the most promising ones. As the founder of Microled explained:

We had more enquiries in different sectors than we first anticipated. So, we're trying to be focused on one sector, but we have now four or five sectors with different customers in those sectors, who are very interested in what we're doing [...] We are actually changing the priority to image capture and then medical. That's where our priorities are. Just because [...] too many things have been asked of us.

(Microled)

As we will discuss in the next section, we observe that the medium performers (Microled and Bacterio) and the top performers (Diagnostico and Biopharm) in our sample differ in how they deal with this plethora of interested market actors and potential technology-market combinations that are identified through Technology Broadcasting.

4.3. Heuristics-based versus Systematic Validation

4.3.1. Heuristics-based validation

In line with previous work pointing to the frequent use of heuristics (Dunbar, 1998) in resource-constrained firms (e.g., Busenitz and Barney, 1997; Eisenhardt et al., 2010), we observe that medium performers Microled and Bacterio resort to some simple “rules of thumb” to prioritize the numerous expressions of interest from external market actors. Bacterio, for example, **filters** those technology-market combinations **based on cost considerations and the potential to generate quick returns**:

The shift [...] was primary financially driven, that the cost of setting up a vet company, as I said, is substantially more than setting up a wound care company. Also the wound care we had more evidence closer to market, so it was, if you like, an economic reality check, how do we get to the business, quickly. Then wound care... yeah, you can do it in 18 months, veterinary care you're talking 3 to 5 years [...] the horrible industry phrase “low hanging fruit” – you know exactly what I mean [laughs]. What can you do that will give you a return quickly and cheaply, as quickly and cheaply as possible?

(Bacterio)

Microled's approach is similar, in that only engages in developments for those specific market actors (or: customers) that are willing to pay for it:

We try to engage with [market actors that showed interest] to understand what sector they're working in. And then from that, we then go through this model of... they must make a commitment to us: a financial commitment. [...] From our point of view, we insist that the company pay money for the demonstrator. So, we don't give any free samples, irrespective of the size of the company.

(Microled)

In fact, they focus their attention on those technology-market combinations where such a financial commitment is reached quickly:

What's happened with the medical [market application] is we've had long negotiations with that customer, a lot of legal negotiations, whereas in the meantime this one, the negotiations have happened much quicker. So, this one I'm giving more priority to, because it's closer to market, closer to happening.

(Microled)

Just like Bacterio, Microled combines this rule of thumb on quick gains, with a concern for cost reduction. The venture selects technology-market combinations that have synergies amongst each other:

So, to try and reduce our cost there, we try to do things where we will group different segment or products together, and will manufacture things in parallel rather than in series. So, we do things that try to limit those costs.

(Microled)

Other technology-market combinations or customers which do not offer such short-term synergies, are not pursued, even though

they might in fact be more viable in the long-term.

In sum, we observe that the ventures that are medium performers in our sample use Technology Broadcasting to generate a wide variety of interested market actors and corresponding technology-market combinations, and then use Heuristics-based Validation, which we define as the validation of potential technology-market combinations based on heuristics or simple rules of thumb, to select which specific market actors and combinations to commit resources to.

4.3.2. Systematic Validation

On the contrary, those ventures in our sample that we identified as the top performers, Diagnostico and Biopharm, use a different process to prioritize the large number of market actors and corresponding technology-market combinations identified through Technology Broadcasting. For example, Biopharm's communication about its technology in conferences, press articles, and online sources leads to several potential customers approaching the venture. The venture engages in several telephone and face-to-face conversations with these potential customers. However, instead of starting to develop a potential prototype or product for these specific customers, it first *systematically contacts other actors active in the same markets*. In other words, it develops a thought-through step by step approach to verify whether the general market interest in the venture's technology is substantial enough to start up an experiment or partnership with a specific customer:

So, we, in particular, one company pursued us. [...]. And they said, we're very interested in this. Can you tell us all about it? So we did. And they said: this is very [interesting]... we have to talk. So, since then I have started to broaden my base, and talk with other animal health groups.

(Biopharm)

Similarly, Diagnostico, which observed an interest from several European players in mycotoxins, contacts potential distributors for these products in other continents, including the U.S. and Asia, to check whether they are also interested. Only after the venture finds that there is sufficient interest across a number of countries and continents, it takes the final decision to enter that market. When we asked about their plans to go ahead with the mycotoxins, a founder told us:

But we will actually be looking very much towards US as well. So, we are actively seeking a partner in the US...

(Diagnostico)

In addition to the mycotoxin market, Diagnostico also had been approached by a customer with whom they got a 1.5 mio £ joint research grant to automate the testing in abattoirs (i.e., slaughter houses). However, before deciding to go for this market, they checked as well with other vet companies whether there was enough interest in this market to continue exploring it:

We already have [contacted them] – it's a very small group of companies, a very, very small group of companies that act in the vet side. We were in touch with all of them – all the significant players. There's probably only [...] about eight now in the whole world of the sort of size that would be useful for us.

(Diagnostico)

These contacts enable Biopharm and Diagnostico to verify the information they receive from the initial lead customer. They do this *to better understand the needs or demands of the market*, as well as to obtain an assessment of *the size of the market* (which, according to Gruber and Tal, 2017, are important aspects of the validation phase). As the CEO of Biopharm explains, he was able to establish that the market interest in animal health applications was not restricted to one single customer, but broadly supported by a large number of animal health groups:

And they are telling us the same thing: this is important, we would like to know more about it. So, I can't ignore that. There's an obvious market interest, a market demand there.

(Biopharm)

We label this approach Systematic Validation, which can be defined as validating potential technology-market combinations by systematically verifying the market needs and size with other market actors. This process replaces the heuristics the medium performers in our sample use to prioritize different technology-market combinations. The process shows some similarities with findings by Hoornaert et al. (2017). They observe that the performance of ideas generated by a crowd of consumers can be predicted by looking not only at the characteristics of the idea and the specific consumer that contributed this idea, but also at the reactions of other consumer in the crowd to that specific idea (e.g., through online voting systems). Diagnostico and Biopharm are not active in the consumer market, but they also try to validate an idea launched by one specific market actor by obtaining feedback on this idea from additional market actors. More generally, the process also shows some similarities to insights of Ozcan and Eisenhardt (2009), who show that the best performing ventures in the wireless gaming industry are able to make cognitive representations of the industry and how their alliance portfolio should look like instead of using their resources at hand to build up alliances, one after the other.

In sum, our observations suggest that whereas Technology Broadcasting enables the venture to involve a broad range of external market actors and identify various potentially interesting initially unforeseen market segments, Systematic Validation allows it to improve its assessment of the size and value of these markets before committing to (some of) them. For the ventures in our sample, where the costs of setting up experiments are quite high and/or the variety of different parties that are interested is very broad, the latter selection approach appears to be more interesting than Heuristics-based Validation (such as filtering based on the possibility to limit costs or generate quick returns).

5. Discussion

This study intended to investigate the different approaches technology ventures use to involve external market actors, and how these different approaches impact the identification and validation of potential technology-market combinations. We identify two broad approaches to the engagement of market actors in the identification of potential technology-market combinations. A first approach, which we label Proactive Market Identification, reflects a more traditional approach to market search in which the venture proactively tries to identify and contact external market actors by relying on its own assessment of potential technology-market combinations. The potential of these combinations is then validated through trial-and-error learning, using consultancy and the development and testing of tailored prototypes with customers. We observe that the cognitive and resource constraints of the venture team unfortunately limit the potential of this approach in identifying unfamiliar but interesting market actors and corresponding technology-market combinations.

A second broad approach to the identification of potential technology-market combinations, which – as far as we know – has not been documented in previous research and which we call Technology Broadcasting, entails showing the venture's technological competencies to a broad range of market actors (e.g., through conference presentations and websites) and reacting to their spontaneous expressions of interest. As this approach is not based on the market experience and knowledge of the venture, but on that of (a broad range of) market actors, it allows the venture to overcome its cognitive constraints and identify a large number of less familiar but promising external market actors and corresponding technology-market combinations.

We observe however that resource-constraints make it difficult to validate all these leads in depth, and we detect two distinct approaches to deal with this challenge. A first group of ventures uses Heuristics-based Validation to decide which external actors and corresponding technology-market combinations to commit its resources to, but this approach tends to lead to suboptimal choices for the ventures in our study. A second group of ventures uses an alternative approach, which we label Systematic Validation, whereby the venture validates the leads stemming from Technology Broadcasting by systematically obtaining information on market needs and size from additional market actors. Whereas Technology Broadcasting allows identifying a large number of promising, unfamiliar technology-market combinations, Systematic Validation enables the venture to filter out the most promising technology-market combinations.

These findings, which are graphically represented in Fig. 1, have several theoretical implications and speak to scholars in the field of entrepreneurship and in the domain of organizational search. We discuss in the next sections how we contribute to ongoing conversations in both literature streams.

5.1. Theoretical contributions to the entrepreneurship literature

The entrepreneurship literature has paid substantial attention to the commercialization of new technologies. Several conceptual and empirical papers have been written on the topic, and valuable tools have been developed that assist practitioners in investigating whether and how an optimal technological solution can be developed for a given market (Camuffo et al., 2020; Ries, 2011), and in prioritizing a range of potential technology-market combinations (Gruber and Tal, 2017; Shepherd and Gruber, 2020). This literature has emphasized the importance of experimentation and adaptation in this respect (Andries et al., 2013; Minniti and Bygrave, 2001; Murray and Tripsas, 2004) and has pointed to the important role external market actors can play in both the identification and validation of potential technology-market combinations (Gruber and Tal, 2017; Gruber et al., 2013).

In this study, we advance our understanding of how technology ventures can involve relevant external market actors in these identification and validation processes. First, we show that a more traditional approach, in which ventures proactively identify and

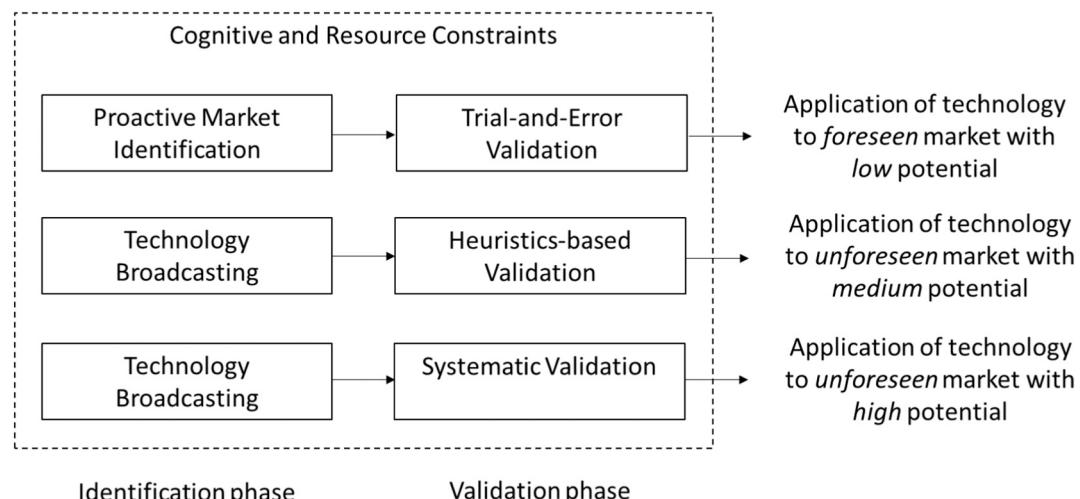


Fig. 1. Conceptual model.

contact external market actors, suffers from cognitive and resource constraints, which are well known in the entrepreneurship literature (Baker and Nelson, 2005; Gans et al., 2019). In line with ideas on network bricolage (Baker et al., 2003), ventures tend to identify and approach market actors from their pre-existing network. While such Proactive Market Identification may work well for entrepreneurs who already have a relatively clear idea of the customer needs, such as the Garage holders in Baker et al.'s (2003, 2005) studies or, more generally, the demand driven entrepreneurs (Agarwal and Shah, 2014), it leads the technology-driven venture in our sample to investigate only low-potential technology-market combinations that are closely related to its prior market experience and knowledge.

For entrepreneurs who start a venture based on a fungible technology, we suggest an alternative approach to identify relevant market actors and corresponding technology-market combinations, which we label Technology Broadcasting. This approach does not solely rely on the network nor knowledge of the founding team, but on that of (a broad range of) market actors, thereby allowing the venture to overcome its cognitive constraints and identify a large number of less familiar but promising technology-market combinations. Second, whereas ventures are typically resource-constrained and cannot investigate all these leads resulting from Technology Broadcasting, we propose that systematically validating these leads with other market actors is highly valuable to filter out the most promising technology-market combinations. In sum, our study indicates that, rather than seizing opportunities which arise from existing contacts as the entrepreneurship literatures on bricolage (Baker and Nelson, 2005; Baker et al., 2003) and effectuation (Sarasvathy, 2001) propose, technology ventures can benefit from broadening their search to include actors from unfamiliar markets and systematically verify the needs and size of these markets in order to develop unforeseen but highly promising technology-market combinations. This approach seems to be particularly useful when the entrepreneur starts with a technology at hand which is fungible or multi-purpose, akin to academic entrepreneurs (Agarwal and Shah, 2014).

Our insights propose that the combination of Technology Broadcasting and Systematic Validation form a fruitful approach to overcome the cognitive and resource limitations of entrepreneurs. As Gans et al. (2019, pp. 751) argue, "ranking alternative viable strategies requires knowledge that can only be gained through experimentation, but experimentation to resolve uncertainty ultimately results in some level of commitment that can foreclose particular strategic options." The authors therefore predict that entrepreneurs will not search for the optimal strategy to commercialize their idea, but instead will stop searching when two equally viable options are identified. Referring to similar constraints, Fiet (2007) and Patel and Fiet (2009) propose that nascent entrepreneurs who systematically search information channels that are already known to them have a greater chance of identifying potential applications than when systematically searching the rest of the information landscape, as such local search requires far less cognitive effort than distant search. Based on our study, we propose that while these limitations certainly characterize the Proactive Market Identification process, they can be overcome through Technology Broadcasting and Systematic Validation, which jointly allow entrepreneurs to engage in distant market search without having to develop in-depth knowledge of these unfamiliar markets. While Ozcan and Eisenhardt (2009) showed that the best performing ventures are those able to make cognitive representations of how their overall alliance portfolio should look like instead of building up alliances one by one, our study shows that Technology Broadcasting and Systematic Validation may be highly relevant to come to such a broad understanding.

Whereas our findings do not invalidate previous insights on the importance of purposeful experimentation under conditions of uncertainty (cfr. Murray and Tripsas, 2004), they do imply the need to carefully consider which external market actors to involve in these experiments and how. In particular, our study warns against the proactive identification of potentially interested market actors by the founders of the ventures if these have limited experience or do not have access to a large network of mentors who could provide a wide variety of insights (Cohen et al., 2019). Surprisingly, a venture's reliance on simple rules of thumb or heuristics to select partners, as suggested by the entrepreneurial strategy literature (Eisenhardt et al., 2010), appears to lead to inferior results in comparison to a Systematic Validation approach when there is an overload of potential applications in markets in which the entrepreneurs have no experience and resource constraints make it impossible to set up experiments in each of them.

In sum, we provide an alternative approach to the mainstream view in the entrepreneurship literature which advocates processes of bricolage and effectuation to overcome resource and cognitive constraints. We show that reliance on input from a broader set of less familiar market actors in combination with a systematic validation process provides better results for new ventures that face uncertainty while being constrained in terms of resources and/or cognition.

5.2. Theoretical contributions to the search literature

Our study builds on insight from the organizational search literature, which – as already mentioned above – has predominantly focused on the search for technological solutions. By investigating the search of technology ventures for potential market applications, we extend existing insights to better understand the concept of market search. While our findings show similarities to concepts previously advanced in the context of technology search or supply side search, we observe also important differences. For example, the concept of Technology Broadcasting shows similarities to the phenomenon of "broadcast search" or "search through crowdsourcing" which Afuah and Tucci (2012) discuss in the context of a focal firm's search for a technological solution. However, while the assessment of a potential subcontractor's actual ability only takes place after a contractual agreement has been made and the subcontractor has delivered a solution, we see that in market search, validation is done before an actual commitment of the focal firm towards an interested market actor. As such, contrary to most work on organizational search (for an exception, see Knudsen and Levithal, 2007), our study explicitly distinguishes between the identification and validation of solutions, and shows that both aspects or phases require careful attention.

In particular, our study shows that Technology Broadcasting poses challenges in terms of resource constraints, as not all the need-solution pairs that market actors advance can be investigated in-depth by the focal venture. While Afuah and Tucci (2012), in their

conceptual study on broadcasting, do not consider how to deal with information overload and the eventual selection of ideas to pursue further, other work on organizational search has pointed to the evaluators as a potential weak spot, as they may tend to select solutions based upon familiarity, localness or personal networking (Boudreau et al., 2016; Piezunka and Dahlander, 2018). We advance these insights by identifying two different approaches to validating the numerous expressions of interest by external actors. We propose that filtering on the basis of simple rules of thumb or heuristics, such as quick wins or cost savings, leads to suboptimal choices. We advance Systematic Validation, a process in which the focal organization filters the leads by checking whether similar actors in that same market segment are equally interested, as a promising way to prioritize expressions of interest.

More generally, we enrich the organizational search literature by showing that not only cognitive limitations, but also resource constraints hinder organizational search processes and their results. These resource constraints reflect the concerns of innovation management scholars on the costs of open innovation. Numerous studies (e.g., Faems et al., 2008, 2010; Gerwin, 2004), stress that collaborative innovation requires substantial monitoring and control efforts. In particular, as the diversity of partners increases, firms increasingly need dedicated alliance functions in order to manage potential synergies and conflicts between the different alliances (Hoffmann, 2007; Kale et al., 2002; Parise and Casher, 2003). With regards to the use of multiple information sources (and in particular with respect to using information from the “crowd”), Alexy et al. (2012), Hoornaert et al. (2017), and Kornish and Ulrich (2011) point to the challenges in assessing the quality of a large number of ideas. Google, for example, received 150,000 proposals in its 2008 Project 10^100 contest—a general call for ideas—and devoted 3000 employees for processing them (Blohm et al., 2013). Even though the ventures in our study that used Technology Broadcasting did this at a much smaller scale than typical crowdsourcing campaigns of large established companies, their resource constraints do hinder them in assessing the expressions of interests received. Given the huge variation in potential technology-market combinations, these resource constraints may hence play a much bigger role than generally envisaged in the organizational search literature.

5.3. Practical implications

Our findings have implications for technology-driven organizations as well as for the coaches and investors supporting them. First, our study clearly suggests that instead of trying to proactively approach and convince potential customers, technology-driven organizations should open up to a broad audience of potential partners and customers, via their website, conference participations, and press publications, and react to the assessments and expressions of interest of these market actors. By doing so, they may discover opportunities in market segments they had never imagined. Moreover, in order to select the most promising technology-market combinations amongst all the generated expressions of interest, they should refrain from relying on simple rules of thumb, like cost savings or quick returns for deciding which ideas to commit their resources to. Instead, they should first validate the general market interest in these technology-market combinations by approaching additional actors in the same market, and filter out those technology-market combinations with the largest potential. These insights on Technology Broadcasting and Systematic Validation can be integrated with existing tools such as the lean start-up method (Ries, 2011) and the Market Opportunity Navigator (Gruber and Tal, 2017) to guide the identification and validation process.

6. Limitations and suggestions for future research

Although our study makes several contributions to theory, it also has a number of limitations which future research may try to overcome. First, whereas our qualitative evidence allows us to discern between different market search processes and identify cognitive and resource constraints as important boundary conditions affecting their appropriateness, the performance implications observed in this study should clearly be validated through larger-scale, quantitative work. This would of course require the development of measurement scales for Proactive Market Identification, Technology Broadcasting, Trial-and-error Validation, Heuristics-based Validation, and Systematic Validation. Such future quantitative studies should carefully investigate to which extent the performance impact of these different search processes is moderated by a venture's financial resources as well as the human capital or cognitive styles of its founders. Also, they may want to investigate the specific characteristics of the technology-market combinations that result from these search approaches. In particular, as Technology Broadcasting combined with Systematic Validation builds on the shared interest of a range of market actors, they can be expected to result in technology-market combinations that improve the competitive position of these actors. This sheds doubt on the potential of Technology Broadcasting and Systematic Validation to generate disruptive innovations, an issue that is worth investigating further.

Moreover, all the ventures under study were academic spin-offs of which intellectual property (IP) was protected through complexity of the technology and the long period of time the university had been conducting research on the topic. Future research should take into account that the appropriability regime in which ventures operate is not always as tight (Katila et al., 2008) and should investigate how IP appropriability affects the performance implications of Technology Broadcasting in particular. Whereas technological complexity may protect the venture from imitation and thereby improve the outcomes of Technology Broadcasting, it may at the same time hinder external market actors to assess the technology and evaluate whether or not it may be of value to them. Finally, our research focuses on a very specific set of organizations, namely technology ventures that spun out of the university. While such a focus increases the internal validity of our findings, it also puts constraints on the degree to which we can generalize the results. It would be interesting for future research to validate our findings in technology ventures that do not originate from an academic environment.

7. Conclusion

The current study investigated how technology ventures can involve external market actors in the identification and validation of potential technology-market combinations. We identify two broad approaches to identification, each with a different potential to engage external market actors and overcome ventures' cognitive and resource constraints. First, we observe that, Proactive Market Identification, a more traditional approach whereby ventures proactively try to convince potential customers and partners in a specific market segment is intrinsically limited by cognitive constraints as well as by resource constraints, and is therefore likely to result in a local and suboptimal technology-market combination. Ventures can overcome their cognitive constraints through Technology Broadcasting, which implies that they broadly expose their technology to potential customers and partners in a wide variety of market segments (e.g., through conference presentations and websites). Instead of having to identify and convince potential customers about their technology's potential, they can rely on and react to the assessment and expressions of interest of a broad range of actors from markets they had not imagined. However, ventures typically do not have the necessary resources to follow-up on all these expressions of interest through in-depth investigations and collaborative developments. We propose that instead of using heuristics to select certain technology-market combinations, they should validate these expressions of interests with additional actors in the same market in order to filter out the most promising ones for further development.

CRediT authorship contribution statement

Petra Andries: Conceptualization, Methodology, Formal analysis, Writing - original draft; Writing - review & editing. **Bart Clarysse:** Conceptualization, Methodology, Formal analysis, Writing - original draft; Writing - review & editing. **Sergio Costa:** Conceptualization, Methodology, Investigation, Formal analysis.

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