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Keep searching and you'll find: what do we know about variety creation through firms' search activities for innovation?

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This article critically reviews and synthesizes the contributions found in theoretical and empirical studies of firm-level innovation search processes. It explores the advantages and disadvantages of local and non-local search, discusses organizational responses, and identifies potential exogenous triggers for different kinds of search. It argues that the initial focus on local search was a consequence, in part, of the attention in evolutionary economics to path-dependent behavior, but that as localized behavior was increasingly accepted as the standard mode, studies began to question whether local search was the best solution in all cases. More recently, the literature has focused on the trade-offs being created, by firms having to balance local and non-local search. We account also for the apparent "variety paradox" in the stylized fact that organizations within the same industry tend to follow different search strategies, but end up with very similar technological profiles in fast-growing technologies. The article concludes by highlighting what we have learnt from the literature and suggesting some new avenues for research.

JEL classification: O31, O32.

1. Introduction

It is over a century since Alfred Marshall pointed to the importance of diverse business approaches for economic progress:

> Every locality has incidents of its own which affect in various ways the methods of arrangement of every class of business that is carried on in it: and even in the

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> same place and the same trade no two persons pursuing the same aims will adopt exactly the same routes. *The tendency to variation is a chief cause of progress; and the abler are the undertakers in any trade the greater will this tendency be.* (Marshall, 1890/1949: 295, emphasis added).

Later, evolutionary economics and the strategic management of innovation literature stressed the importance of firms' access to a variety of inputs, to produce successful innovations that would affect their competitive advantage (e.g. Nelson and Winter, 1982; Metcalfe, 1994; Cohen and Malerba, 2001; Fleming and Sorenson, 2001; Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Lazonick, 2005; Laursen and Salter, 2006; Yayavaram and Ahuja, 2008). However, given that the level of attention by firms and firm decision makers is restricted (Simon, 1947; Ocasio, 1997), searching for and managing such variety is not an easy task and often involves searching in alien technological domains (Cyert and March, 1963; Katila and Ahuja, 2002).

The search process typically requires firms to work with a variety of non-local individuals (such as scientists) and organizations (such as supplier firms), each with different norms, habits, and rules, which require different organizational practices to make the search process successful (Laursen and Salter, 2006). Empirical research shows that firms predominantly search locally (Pavitt, 1988; Cantwell, 1989; Stuart and Podolny, 1996; Martin and Mitchell, 1998; Tripsas and Gavetti, 2000; Fagerberg et al., 2005) and that firms' observed (*ex post* search) technological profiles in fast-growing technologies—within the same industry—display remarkably little sign of technological variety (Patel and Pavitt, 1997). In other words, there is an inherent trade-off between the advantages to be gained from variety and the degree of variety the firms can manage effectively.[1]

The present article draws on and thematically reviews theoretical and empirical contributions on firm level innovation search processes, and summarizes the historical evolution of this quite substantial literature. A full text search on Business Source Complete reveals 1029 papers published in academic journals between January 1990 and March 2011, containing the words "innovation" and "technology", as well as "local search", or "search process". Thus, this article does not provide an exhaustive review of the literature and is not intended to offer a formal meta-analysis or "unifying" conclusion to the findings in the literature. Rather, the aim is to synthesize and provide a critical overview of a subset of the literature that analyzes the organizational responses evoked by firms that try to overcome local search problems, and the related external contingencies that allow firms to conduct non-local search. The main focus is on how firms perform technological search over technological and organizational boundaries to achieve process and product innovation and the

[1] In evolutionary economics terms, this could be described as a firm-level trade-off between the mechanisms of preservation and transmission (organizational routines) and the mechanisms of variety creation (see Andersen, 1994: 14–15).

literature included is sourced mostly from top management journals, as well as from the leading innovation journals, such as *Research Policy* and *Industrial and Corporate Change*. There are two main reasons for this overview. The first is that because contributions come from an increasing range of research domains, the literature on technological search has become internally disconnected and somewhat incoherent. In our view, a broad framework that combines the insights from earlier research with the prevailing relationships between the most important variables would be useful. The second reason is that technological search is a field of research that is under development with the result that work in the field is concentrated on a few particular areas leaving others under researched. This article identifies some of the gaps within and across different research trajectories and points to new avenues for research.

The article is structured as follows. First, the advantages of local and non-local search are discussed. The empirical evidence on firms' search for a variety of knowledge inputs is critiqued, from the initial work on local search to more recent studies on the trade-offs triggered by firms' efforts to balance local and non-local search. This discussion is followed by a portrayal of the mechanisms, all of which involve division of labor, that can be used to alleviate some of these trade-offs, and identifies potential exogenous triggers for local and non-local search. The so-called "variety paradox" is discussed, that is, the empirical finding that organizations within the same industry tend to follow different search strategies but end up with very similar technological profiles in fast-growing technologies. The final section in the article summarizes the central insights in the literature and makes some suggestions about future research.

2. Variety and local search

2.1 The role of a variety of inputs in the innovation process

According to some (Schumpeter, 1912/1934; Nelson and Winter, 1982; Kogut and Zander, 1992; Fleming and Sorenson, 2004; Fagerberg, 2005), innovation is a result of the novel integration of previously separate bodies of knowledge that has a commercial application. In this definition of innovation, variety is central. Evolutionary economists highlight the role of search in helping organizations to find sources of variety, allowing them to create new combinations of technologies and other knowledge (Nelson and Winter, 1982). Accordingly, a variety of knowledge inputs provides opportunities for firms to choose among different technological paths (Metcalfe, 1994). The more approaches to a given technological objective, the more the possibilities for improvements to the quality and performance of products, or to manufacturing costs (Nelson, 1961; Evenson and Kislev, 1976; Nelson, 1982; Cohen and Malerba, 2001).

2.2 Why is local search (most) often advantageous?

Based on earlier behavioral insights (in particular, Cyert and March, 1963), evolutionary economists, such as Dosi (1982) and Nelson and Winter (1982), argue that search processes are almost always highly localized in that firms search along established trajectories created by past experience, routines, and heuristics (see also, Nelson, 1991; Malerba, 1992). At the technology level, Dosi (1982) advanced the Kuhnian (1970) idea that most of the time (because paradigm shifts are infrequent) technological progress emerges along an established trajectory guided by a technological paradigm. The paradigm embodies strong prescriptions for the directions of technical change that should be pursued or ignored. A technological trajectory is defined as "the pattern of 'normal' problem solving activity on the grounds of a technological paradigm" (Dosi, 1982: 152).

Following Polanyi (1967), Nelson and Winter (1982) make the central assumption that much knowledge is tacit, that is, knowledge embodied in individuals and organizations that is very difficult or even impossible to articulate. The existence of a strong tacit component makes knowledge difficult to transfer from nonproximate contexts: tacit knowledge can be transferred only through personal contacts. At the firm level, Keith Pavitt articulated the idea of localized search, stating that:

> the search process of industrial firms to improve their technology is *not* likely to be one where they survey the whole stock of technological knowledge before making their technical choices. Given its highly differentiated nature, firms will instead seek to improve and to diversify their technology by searching in zones that enable them to use and to build upon their existing technological base. (Pavitt, 1988: 130, original emphasis).

Search typically is considered local when it relates to knowledge that is in the neighborhood of the organization's current knowledge base (see e.g. Helfat, 1994; Stuart and Podolny, 1996; Fleming and Sorenson, 2004), for instance, in terms of the types of technologies used by the organization. Exploratory search (generally used synonymously with boundary-spanning or non-local search) can be defined as search behavior that "involve[s] a conscious effort to move away from current organizational routines and knowledge bases" (Katila and Ahuja, 2002: 1184). However, although these general definitions are useful, they are not very precise and, for this reason, it is informative also to look at influential empirical operationalizations of the concepts. Katila and Ahuja (2002) use two search variables: search depth and search scope. The first describes how deeply a firm reuses its existing knowledge, and the second describes how widely a firm explores new knowledge, the former being associated with exploitation and the latter with exploration. Using patent citation data, search depth is measured as the average number of times a firm repeatedly used the citations in the patents it applied for. Search scope is measured as the proportion of previously unused citations in a firm's focal year's list of citations or, more specifically, the share of citations from the focal year's citations that do not appear in that firm's patent citations (Katila and Ahuja, 2002: 1187). Similar measures of local versus non-local search are used in other studies (Benner and Tushman, 2002; Laursen et al., 2010; Phelps, 2010). It should be noted that exploration using this operationalization does not necessarily imply radical deviation from earlier search, in the sense that even were a firm basing its search on a previously unexploited technology, that technology might be related to already familiar ones. Exploration refers only to the fact that the search domain is new to the firm; however, it may not be radically different from what the focal firm is typically engaged in.

Rosenkopf and Nerkar (2001) offer a very useful distinction between technological and organizational boundary spanning (non-local search) that has been used frequently. Empirically they look at patent citations within the optical disc industry. When a focal optical disc firm cites its own patents within optical disc technologies, the authors term this search "local"; when a firm cites its own patents, but outside optical disc technologies, this search is described as "internal boundary-spanning". When the focal firm cites other firms' patents in optical disc technologies this is described as "external boundary-spanning"; if citations refer to non-optical disc technologies, as well as to patents not filed by the focal firm, this is classified as "radical" search (see Section 5 for a critique of Rosenkopf and Nerkar's notion of external boundary-spanning).

It can be noted that some parts of the literature treat exploitative search and explorative search as on a continuum—following March (1991)—within which a "balance" has to be achieved, whereas others—following Tushman and O'Reilly (1996)—examine whether exploitation and exploration can co-exist within the same organization (see, Lavie et al., 2010, for an expansion of this point). Organizations that can manage the two, seemingly conflicting, processes are described as "ambidextrous."

Two fundamental reasons can be proposed for the dominant tendency to conduct local search, given the complexity of technological problem-solving activities (Helfat, 1994). First, people's limited cognitive abilities give rise to bounded rational behavior (Simon, 1982) so that managers and technological problem-solvers are unable to contemplate every possible option to the solution of their problems and are unable to accurately evaluate the future prospects in relation to the performance of potential options (see, Knudsen and Levinthal, 2007, for an elaboration on this point). Second, the accumulated knowledge base facilitates learning related to that knowledge. In this context, and based on the work of Edward Constant II (1980), Vincenti (1990: 7–8) suggests it is useful to distinguish between normal and radical designs (which is also a Kuhnian distinction). Normal designs are designs where the engineer involved knows how the device in questions works and is familiar with its features. In Vincenti's terms, this means that the "operational principle" and the "normal configuration" of a device are known. An operational principle defines how the subcomponents interact with one another to achieve the central purpose of the device. A normal configuration is the general shape or arrangement that has been commonly agreed to best embody the operational principle. When a device is properly designed in line with the given operational principle and related normal configuration, it has a good chance of accomplishing the required task. In other words, engineers can take most of the central features of a design for granted, and experiment with a limited number of new features (typically one at a time).

In the case of a radical design, the protagonists have little to take for granted—how the device should be arranged or how it should work is largely unknown. In this instance, the central problem is to "design something that will function well enough to warrant further development" (Vincenti, 1990: 8). As a consequence, only a normal configuration design realistically can produce a reliable artifact that will have no major failures—at least in the shorter term. For this reason, it is often advised, that initially the members of an organization should search for innovative solutions for new processes, products, and services in areas where the organization already has expertise. Nelson and Winter (1982: 9–10) describe it as organizations are "typically much better at the tasks of self-maintenance in a constant environment than they are at major change, and much better at doing "more of the same" than they are at any other kind of change." In other words, learning is easier if it is restricted to familiar and proximate neighborhoods (Cohen and Levinthal, 1990). Empirically, incremental innovations constitute the lion's share of technological advance (Hollander, 1965; Vincenti, 1990), although they are often enabled only after an initial break-through that is more radical in nature.

Although local search has much lower potential for recombination of more radical knowledge, the costs related to the search for local solutions are frequently much lower if they are within a familiar domain (Rosenkopf and Almeida, 2003). One of the reasons for this is the resistance to communication across knowledge boundaries (Carlile, 2002). In addition, because agents develop an understanding of "local" elements that potentially could be combined, they are better able to invent and, with greater reliability by avoiding elements that did not work in the past (Vincenti, 1990; Fleming and Sorenson, 2004). In sum, there are clear advantages for organizations in conducting local search in their problem-solving activity, including problem solving related to innovation.

3. The need for variety created through boundary-spanning search

3.1 Changed focus in the more recent literature

Although the empirical evidence might suggest that evolutionary economics is right in observing that firms are constrained in their range of choices and that, most often, local search is the most efficient mode due to its reliability and relatively low costs (Pavitt, 1988; Cantwell, 1989; Helfat, 1994; Stuart and Podolny, 1996; Tripsas and

Gavetti, 2000), work based on the seminal contribution of James G. March (1991), highlights the disadvantages of local search which potentially can be damaging and eventually lethal to organizations that become too reliant on this type of search (Levinthal and March, 1993; Gavetti and Levinthal, 2000; Tripsas and Gavetti, 2000; Levinthal and Rerup, 2006).[2]

The downside to too frequent local search is that the knowledge required to solve a new problem is unlikely to coincide with the organization's current knowledge base and may require search beyond the organization's boundaries for complementary knowledge (Postrel, 2002). Local knowledge often lacks the inspiration and variety required for problem solving, and the local environment may not offer enough opportunities for knowledge combination and recombination (Rosenkopf and Nerkar, 2001; Fleming and Sorenson, 2004; Rothaermel and Alexandre, 2009). Too frequent focus on local search can lead to myopic behavior (March, 1991; Levinthal and March, 1993) and cognitive biases, which mean that superior solutions from more distant knowledge domains—often nested in communities beyond the immediate boundary of the focal organization—are systematically overlooked. The widespread "not invented here" syndrome in part reflects these myopic tendencies among teams and managers (Katz and Allen, 1982).

4. Why organizations often get it wrong

Although there are several ways for firms to conduct variety-generating search for innovation, many firms apply dysfunctional search strategies, implying that firms search too much or too little, or conduct too much of one type of search at the expense of other types (see for instance, Katila, 2002; Rosenkopf and Almeida, 2003; He and Wong, 2004; Laursen and Salter, 2006; Yayavaram and Ahuja, 2008). In general, the search processes of firms are constrained by resources, as well as time (Koput, 1997). In particular, in rapidly changing industries, search is often conducted under extreme time pressures that may lead firms to adopt too narrow or too broad search routines (Levinthal and March, 1993). The literature has a number of explanations for these problems. As already mentioned, many firms suffer from cognitive bias against external sources and develop myopic search processes (March, 1991; Levinthal and March, 1993). In the case of too narrow or myopic search processes, the search process may be hampered by lack of resources in the form of funds and skilled personnel to explore different potential combinations. Models of innovative search highlight the limited cognitive abilities of agents and the need for

[2]Whereas the behavioral and evolutionary theoretical approaches have spurred the scientific progress in the innovation search literature, such progress has also been spurred by the provision of large scale datasets in electronic form in terms of patent citation data (Jaffe et al., 1993) and innovation surveys, including the widely used Community Innovation Survey (see, Smith, 2005).

agents to concentrate their attention on a limited range of potential alternatives rather than searching the broad environment or following many different paths simultaneously (Simon, 1947; Ocasio, 1997; Gavetti and Levinthal, 2000). At the same time, the past experience and future expectations of managers in which search strategies are rooted can also lead firms to over-search the external environment with detrimental outcomes as a result.

5. Firms' search for a variety of knowledge inputs: from local to boundary-spanning search

5.1 Local versus non-local search

Table 1 presents an overview of some of the literature on variety generating search for innovation, and especially the subset of contributions based on quantitative empirical research. Table 1 shows the shift in the literature from a focus on local search to a greater focus on how firms can balance the necessity of local search with the less pressing—but nonetheless essential—requirement for boundary-spanning or non-local search. Table 1 also shows a trend towards increased attention to the significant costs associated with search (specifically non-local search). Given the cognitive limitations of managers, organizations can conduct both too little search and also too much search. These shifts in the emphasis in the literature may reflect a better understanding of the multifaceted reality faced by firms and their decision makers. However, it may also reflect an evolution in the search for innovation literature, which initially was based on evolutionary economics (often combined with the resource-based view of the firm and/or behavioral theory). One of the central aims of evolutionary economics was to construct a theory encompassing more "realistic" assumptions that broke with the standard behavioral assumptions of orthodox economics (Nelson and Winter, 1982; Pavitt, 1988; Dosi, 2000). One of the most central assumptions in evolutionary economics is that organizations and their managers are unable to maximize globally. Instead, firms are assumed to base their decisions on past experience and display "satisficing behavior." Such assumptions easily give rise to local search behavior. Thus, some seminal contributions (e.g. Sahal, 1985; Pavitt, 1988; Cantwell, 1989; Burgelman, 1994; Helfat, 1994; Stuart and Podolny, 1996) to the search literature focus on examining the assumptions and predictions made in evolutionary economics and in the related field of strategic management.

As localized behavior was increasingly accepted in the innovation and strategic management literatures, scholars began to question the inevitability of local search in all contexts, both theoretically (e.g. March, 1991; Levinthal and March, 1993; Gavetti and Levinthal, 2000; Levinthal and Rerup, 2006) and empirically (e.g. Tripsas and Gavetti, 2000; Rosenkopf and Nerkar, 2001; Katila and Ahuja, 2002; Rosenkopf and

Table 1 Overview of some key contributions in the innovation search literature

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
Helfat (1994)	R&D intensity	R&D intensity lagged	R&D investments	R&D data	US Petroleum industry	Firms tend both to persist and to differ in the amount of effort they devote to various R&D applications
Stuart and Poldony (1996)	Technological position in comparison with other firms			Patent data	Japanese semiconductor industry	Firms conduct local search. Firms' technological position also depends on the R&D of its competitors
Ahuja and Lampert (2001)	Novel technologies; emerging technologies; pioneering technologies	Citation counts as a reflection of breakthrough inventions	Investment in new technologies	Patent data	The largest firms in the chemicals industry	Experimenting with novel, emerging, and pioneering technologies help established firms create breakthrough inventions
Rosenkopf and Nerkar (2001)	Four types of exploration	The search variable is the department variable	Costs of exploration	Patent data	Optical disk industry	Exploration that does not span organizations, generates lower impact on subsequent technological evolution.
Katila and Ahuja (2002)	Search depth and scope (patent citations)	Number of new product introductions	Through squared terms	Patent data and product announcement data	Robotics industry	Search depth and scope affect the ability to introduce new products, but some firms 'over search'
Katila (2002)	Competitor search age and external search age (age of cited patents)	Number of new product introductions	Through squared terms	Patent data and product announcement data	Robotics industry	Old competitor knowledge hurts, but old extra-industry knowledge promotes innovation
Rosenkopf and Almeida (2003)	Strategic alliances and labor mobility	Knowledge flows (patent citations)	Technological and geographical distance	Patent data	Semiconductor industry	Labor mobility is associated with inter-firm knowledge flows regardless of geographical proximity and the usefulness of alliances improve with geographical distance

(continued)

Table 1 Continued

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
Greve (2003)	R&D intensity (+ innovation launches)	The search variable is the department variable		R&D and product announcement data	Japanese shipbuilding	Problemistic and slack search increase firms' R&D intensity
Nerkar (2003)	Temporal exploitation and exploration ("recency" and spread measures over time, based on patent citations)	Technological impact and performance measured as patent citations	Through a squared term	Patent data	US pharmaceutical market	A balance in combining current knowledge with the knowledge available across large time spans explains the impact of new knowledge
Gibson and Birkinshaw (2004)	Ambidexterity (multiplicative interaction between alignment and adaptability)	The search variable is the department variable	Investments in stretch, discipline, support, and trust	Survey data	Multi-industry, multi-country sample	Ambidexterity is driven by stretch, discipline, support, and trust—and is associated with better performance
He and Wong (2004)	Explorative and exploitative innovation strategies	Percentage of sales from new products + sales growth rate	Investment in explorative and exploitative strategies	Survey data	Manufacturing firms from Singapore and the State of Penang in Malaysia	The interaction between explorative and exploitative innovation strategies is positively related to sales growth rate
Fleming and Sorenson (2004)	'Coupling' among components and cites to science	Citation counts to given patents	-	Patent data	US patents, May and June 1990	Patents drawing from science are likely to increase the likelihood of new combinations when technologies a closely coupled
Nerkar and Roberts (2004)	Proximal and distal technological experience (patent classes)	Sales of new products in the first year in the market	Investments in stocks of technological and product market experience	Patent data	US pharmaceutical industry	New products are more successful when a firm possesses the appropriate stocks of technological and product market experience

(continued)

Table 1 Continued

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
Phene *et al*. (2006)	Technological and geographical distance.	Citation counts as a reflection of breakthrough inventions	Investment in distant technologies + a squared term	Patent data	US biotechnology industry	Technologically distant knowledge of national origin has a curvilinear effect and technologically proximate knowledge of international origin has a positive effect on breakthrough innovation. Technological *and* geographical dimensions are not useful to generating breakthrough innovation
Laursen and Salter (2006)	Search breadth and department among external sources of innovation	Percentage of sales from new products	Through a squared term	Survey data	The UK manufacturing sector	External search breadth and depth leads to higher sales of innovative products, but some firms “over search”
Cassiman and Veugelers (2006)	Internally and externally acquired R&D	Percentage of sales from new products	Investments in R&D	Survey data	The Belgian manufacturing sector	Internal and external search processes are “Edgeworth” complementary
Jansen *et al*. (2006)	Explorative and exploratory innovation	The search variable is the department variable	Investments in organizational design	Survey data	283 organizational units of a single European financial firm	Different types of organizational coordination mechanisms affect explorative and exploratory innovations differently
Sidhu *et al*. (2007)	Innovativeness	Supply-side, demand-side, and geographic search	Costs of different types of search	Survey data	The Dutch metal and electrical engineering sector	Non-local supply-side, demand-side, and geographic search exhibit a positive relationship with innovativeness

(continued)

Table 1 Continued

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
Chen and Miller (2007)	R&D intensity	The search variable is the department variable	R&D investments	R&D data	The US manufacturing sector	Most of the explained variance in R&D intensity is due to firm effects. Slack is a determinant of search investment decisions for outperforming firms with high accumulated slack, but not for outperforming firms with less slack.
Yayavaram and Ahuja (2008)	The coupling between the knowledge elements (proxied by patent classes) of a firm's knowledge base	Usefulness of inventions—patent citations by other firms	Through a squared term	Patent data	The worldwide semiconductor industry.	The usefulness of a firm's inventions is related to the level of decomposability of its knowledge base in an inverted-U-shaped fashion
Fabrizio (2009)	Pace of knowledge exploitation and search quality	The search variable is the department variable	Engagement in basic research and collaboration with university scientists	Patent data	Major firms in the worldwide biotechnology and pharmaceutical industries	Enhanced access to university research enjoyed by firms that engage in basic research and collaborate with university scientists leads to superior search for new inventions
Grimpe and Sofka (2009)	R&D intensity and continuous R&D. Types of innovation sources	Percentage of sales from new products	R&D investments and costs of knowledge sourcing	Survey data	Multi-industry, multi-country sample	Low- and high-technology sectors differ in their search patterns and these mediate the relationship between innovation inputs and outputs
Katila and Chen (2009)	Competitors' search behavior		Competitors' actions	Patent data and product announcement data	Robotics industry	Firms introduce more new products if they search after

(continued)

Table 1 Continued

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
		Frequency and novelty of new product introductions				their competitors, and they introduce more novel products if they search ahead of competitors
Jansen *et al.* (2009)	Sum of exploitative and explorative learning efforts	The search variable is the department variable	Investments in organizational design	Survey data	Survey data	The direct effect of structural differentiation on ambidexterity operates through senior team social integration and organizational cross-functional interfaces integration mechanisms
Rothaermel and Alexandre (2009)	The ratio of its external technology sourcing over its total technology sourcing	Total number of patents assigned to the firm + financial performance	Through a squared term	Patent and survey data	Multi-industry sample of US manufacturing companies	A curvilinear relationship exists between a firm's technology sourcing mix and its innovation performance
Laursen *et al.* (2010)	Licensing-in and absorptive capacity (monitoring ability and assimilation capacity)	Degree of distance from focal firms' existing patent portfolio	Costs of building absorptive capacity and of licensing-in	Patent and licensing data	A sample of firms with patenting and licensing activity	Licensing-in allows for a stronger effect of monitoring ability on the ability to make distant search
Makri *et al.* (2010)	M&A activity involving complementary scientific and technological knowledge	Postmerger invention performance (higher quality and more novel inventions)	Costs of acquiring businesses	Patent data	M&As from the US drug, chemical, and electronics industries	Complementary scientific knowledge and complementary technological knowledge both contribute to postmerger invention performance
Phelps (2010)	Exploratory innovation as proxied by patent citations	The search variable is the department variable	Costs of setting up strategic alliances	Patent data	The global telecommunications equipment industry	Technological diversity of a firm's alliance partners increases its exploratory

(continued)

Table 1 Continued

Authors	Search variable	Dependent variable	Cost of search	Data type, technology variables	Industry	Main results
						innovation Further, network density among a firm's alliance partners strengthens the influence of diversity
Jiang *et al.* (2011)	Knowledge in novel technology areas as proxied by patent classes	Count of nano patents	Through a squared term	Patent data	Global semiconductor industry	Significant inventions by incumbents outside the existing dominant designs are explained by willingness to search novel areas, explore scientific knowledge in the public domain, and form alliances with a balanced portfolio of partners
Leone and Reichstein (2012)	Licensing-in	Time between firm's inventions	Costs of licensing-in and sharing of property rights in certain cases	Patent and licensing data	A sample of firms with patenting and licensing activity	Firms that licensing-in increase the speed of invention, provided appropriate contractual arrangements

Almeida, 2003; Fleming and Sorenson, 2004; He and Wong, 2004). These more recent contributions are based on the assumption that search continues predominantly to be local but they try to analyze how organizations can avoid the "local search trap" and balance local and non-local search. However, a survey of the literature concludes that, "although near consensus exists on the need for balance, there is considerably less clarity on how this balance can be achieved" (Gupta et al., 2006: 697). In the next section, some of the possibilities for achieving a balance are critically reviewed.

5.2 Organizational responses to the local search problem

5.2.1 Organizational structure

Recent research suggests that although managers may make mistakes for various reasons, it is possible to design organizational structures to increase the likelihood of getting the right trade-off between exploration and exploitation. In this context, Argyres and Silverman (2004) show that centralized R&D at the corporate level generates innovations that have a larger and broader impact on subsequent technological evolution than innovations generated through decentralized research. Somewhat in contrast, Jansen *et al.* (2006) provide evidence indicating that, also in the context of innovation, centralization negatively affects exploration, whereas formalization positively influences exploitation. Social connectedness among individuals within organizational units seems to be an important determinant of both exploration and exploitation. Whereas this research is an extremely helpful starting point, we need to know more about how, when, and why delegation and/or centralization should be applied to balance local and non-local search. We also need more knowledge about which organizational mechanisms and practices managers should apply (or not) (however, see Tushman et al., 2010; Foss et al., 2011).

As mentioned above, firms may often have to allow for the co-existence of exploitative and explorative learning activities within the same firm. The capacity of firms to encompass relatively high levels of both exploitation and exploration has been termed ambidexterity (Tushman and O'Reilly, 1996).[3] The inherent tensions and conflict between the two activities (that can involve inconsistent organizational logics and competencies) may call for the organizational separation of these activities within the firm. Lavie *et al.* (2010) considered three types of separation: (i) *organizational separation*, where exploration and exploitation occur simultaneously, but are situated within distinct organizational units; (ii) *temporal separation*, where exploration and exploitation occur in the same organizational unit but at different points in time, meaning that the organization switches between exploration and exploitation; and (iii) *domain separation*, implying that the organization specializes in either exploration or exploitation in particular organizational domains

[3]For a recent in-depth review of the ambidexterity literature, see Raisch and Birkinshaw (2008).

and balances the activities across domains. In addition, there can be situations of "contextual ambidexterity," which may resolve the tension between exploration and exploitation by enabling the activities to be maintained simultaneously at any given organizational level (Gibson and Birkinshaw, 2004). However, although there seems to be evidence that some firms can manage seemingly ambidextrous activities (see, for instance, Gibson and Birkinshaw, 2004; He and Wong, 2004; Fosfuri and Rønde, 2009; Jansen et al., 2009), there is no indication of which of these organizational models is superior when it comes to introducing product innovation (however, see Tushman et al., 2010 for a first step in this direction).

Also, several papers operationalize exploitative innovation strategies as actions that can be characterized as process innovation and measure explorative innovation as actions closely aligned to product innovation (for instance, He and Wong, 2004; Jansen et al., 2009). However, in many situations, significant product innovation necessitates significant process innovation (Reichstein and Salter, 2006). In these cases, firms may not be confronted by the conflicting demands of exploration and exploitation. In addition, the various ways used to measure ambidexterity are open to question. To obtain variables for ambidexterity, He and Wong (2004) subtract explorative and exploitative search activities from one another; Gibson and Birkinshaw (2004) multiply the two activities, and Jansen *et al.* (2009) added them together. It is not clear that any of these procedures precisely captures the level of overlap between (and hence coexistence of) exploitative and explorative search activities, although, from a conceptual point of view, the first (subtraction) procedure would seem superior to the two other alternatives. Nevertheless, this measure is highly imperfect, given that it takes no account of the absolute level of exploitative and explorative search activities, but only whether or not the levels of two types of search activities are similar or not.

5.2.2 Variety among organizational members

Organizations can employ people with varied backgrounds in the attempt to avoid the local search trap. Research emphasizing the advantages of diversity in human resources stresses flexible adaptation to a changing environment (Priem, 1990; Lyles and Schwenk, 1992; O'Reilly, 1993; Sutton and Hargadon, 1997; Galunic and Rjordan, 1998). As Lyles and Schwenk (1992) assert, "diversity may influence a firm's repertoire of the definitions and understandings of how to handle different situations and events." It may also lead to more comprehensive problem solving and conflict resolution in novel contexts (Priem, 1990; O'Reilly, 1993). An important aspect of diversity is the previous diverse or common company affiliations of organizational members (Rosenkopf and Almeida, 2003; Beckman, 2006). In the context of new firm formation, and drawing on a longitudinal dataset of more than 170 young, high-technology firms in California's Silicon Valley, Beckman (2006) argues and corroborates empirically that, firms whose founding team members were employed in the same company prior to the new firm formation, tend to engage in exploitive behavior (associated with "incremental" firm strategies), because they have shared understandings that allows them to act quickly. New firm founding team members who previously worked at different companies have unique ideas and individual contacts which encourage explorative behavior (associated with "innovator" strategies). Beckman finds also that a balance between exploitation and exploration is desirable: founding teams some of whose members are former colleagues and some with different prior company affiliations bring advantages that allow the firm to grow. Although these are extremely interesting findings, they do not rule out that either certain innovative business niches require more diverse sets of skills and backgrounds, or that diverse set of skills and backgrounds give rise to more innovativeness. In other words, founding team formation may be endogenous (a limitation noted by Beckman).

Educational diversity among knowledge workers may also be important because, education categories may represent different bodies of knowledge within firms (Jacobsson and Oskarsson, 1995; Carlile, 2002). Different types of education may provide people with different basic concepts and models for problem solving, and may be seen steering individuals toward particular communities of practice, encompassing different institutional norms, habits, and rules (Brown and Duguid, 1991; Brown and Duguid, 2001). In this context, Brown and Duguid (2001: 202) describe how the striking differences in the outlooks of different professions with apparently closely related job functions, may be explained by the existence of communities of practice. Whereas other types of diversity, such as gender, race, and geographic origin may provide different perspectives on problem solving, educational diversity may do something more fundamental, since it introduces the possibility of (re)combining different bodies of knowledge (Sutton and Hargadon, 1997; Galunic and Rjordan, 1998).

However, educational variety—and other types of variety in firms' human capital—may incur costs. Grant (1996: 116) asserts that: "if two people have identical knowledge there is no gain from integration, yet, if the individuals have entirely separate knowledge bases, then integration cannot occur beyond the most primitive level." In other words, increasing educational diversity may incur a performance penalty if the costs of diversity outweigh its benefits. For example, a highly diverse pool of human resources can undermine organizational capabilities, if the individuals do not possess the right level of shared knowledge (Buckley and Carter, 2004). This can lead to uncoordinated actions, delayed decisions, and high communication costs (Hambrick et al., 1996; Casson, 1998). Diversity in perspectives might also create a basis for harmful conflict and misunderstandings. In particular, when there are time pressures, conflicting views provoke haggling and unconstructive bargaining. Another harmful impact of educational diversity is information overload, which in combination with decision delays can prevent the integration of individual skills in the pursuit of organizational efficiency (March, 1991). However, while there is empirical evidence on the diversity in the backgrounds of top management teams and its possible effect on firm performance (e.g. Hambrick et al., 1996),[4] little theoretical and empirical research has been conducted on the issue of organizational members' different educational background (however, see Dahlin et al., 2006; Østergaard et al., 2011).

5.2.3 External sources of variety for innovation

Organizations have a number of options for dealing with the trade-off between local and non-local search, all of which involve different interorganizational division of labor. Katila and Ahuja (2002) investigate the impact of search depth and scope (defined earlier in this article) along a technological trajectory on innovative performance. They use the number of product introductions by firms in the robotics industry as their dependent variable and find firms that search little ("under search") and firms that search very much ("over search") tend to introduce fewer new products than those who conduct medium-level search (especially when they perform local search). In other words, a medium-level of search is associated with the highest level of new product introductions.

It has long been recognized that interaction with organizations external to the focal firm is often central to innovation success (Nelson, 1959; Rothwell et al., 1974; von Hippel, 1976, 1988; Rothwell, 1994; Powell et al., 1996; Chesbrough, 2003). Cassiman and Veugelers (2006) find that internal research and development (R&D) and externally acquired R&D are complementary in their effect on innovative performance (see also, Lokshin et al., 2008). Laursen *et al.* (2012) find that being located in a geographical area characterized by a high degree of localized social capital, positively moderates the effectiveness of externally acquired R&D on the focal firms' propensity to innovate. Laursen and Salter (2006) find that greater breadth and depth of external search in terms of external sources of innovation—such as competitors, customers, suppliers, and universities—lead to higher sales of innovative products, but that very high levels of breadth and depth lead to lower sales of innovative products (i.e. over search). They explain this as due to the substantial costs associated with working with many types of external partners. In other words, it is beneficial to conduct boundary spanning search but, given the associated costs, too much of this kind of search can be harmful. These findings are generally corroborated and further qualified by Tether and Tajar (2008), Grimpe and Sofka (2009), Vega-Jurado *et al.* (2009), and Leiponen and Helfat (2010).

A more specific organizational response involves how established firms interact with users to increase innovation performance (e.g. Lundvall, 1988; Urban and von

[4]Hambrick *et al.* find a positive relation between various measures of top-management team heterogeneity—including educational background—and performance. Although interesting, this result does not rule out endogeneity in the diversity of the firms' human capital so that the best firms tend to select better teams, while also performing better.

Hippel, 1988; Lilien et al., 2002).[5] Indeed, a classical result in innovation studies established that attention to user's needs is a precondition for successful innovation (Rothwell et al., 1974). However, Christensen (1997) argues that when incumbent firms fail as innovators, it is because they are constrained by existing customers who require them to follow established technological trajectories, even when novel and clearly better opportunities emerge. From this point of view, learning across organizational boundaries does not always imply explorative search and learning as is often assumed (Rosenkopf and Nerkar, 2001; Rothaermel and Alexandre, 2009). Certainly—and as pointed out by Lavie *et al.* (2010)—even interorganizational R&D alliances may involve varying degrees of basic research and incremental development. This can apply in many other interorganizational contexts, including user–producer relationships: The nature of the organizational boundary spanning is of crucial importance.

In this context, von Hippel and colleagues focus on lead users, that is, users who perceive needs at an earlier stage in time than other users, and also are positioned to benefit considerably by achieving a solution. These "ahead of the trend users" are much less likely to trap innovating firms in established patterns of behavior and empirically have been found to be of crucial importance when it comes to introducing innovative ideas (Urban and von Hippel, 1988; Lilien et al., 2002) and in the process of sharing knowledge within a larger community (Jeppesen and Laursen, 2009). Obviously, in this context, the central challenge for firms is to indentify lead users *ex ante*; something that in reality may be very difficult in many settings. A recent trend involves direct engagement of innovating firms in on-line communities with the aim of learning from users, but also of stimulating users to innovate for the organization (at relatively low cost). There is evidence to suggest that this is happening in the software industry (Dahlander and Wallin, 2006; Jeppesen and Frederiksen, 2006). Yet, we still need to know whether this model is also applicable in other industrial contexts.

Another type of specific technological search occurs through formal licensing-in activities. Laursen *et al.* (2010) show that in-licensing activity allows firms to perform technological searches in terrain more distant from the technological core of the focal firm, whereas Leone and Reichstein (2012) show that licensing-in can speed up the firm's rate of invention, especially when the licensing contract is specified so that the licensee and the licensor's incentives are aligned.

Rosenkopf and Almeida (2003) showed that inter-firm collaboration through alliances, combined with inter-firm labor mobility may help overcome the local search problem. They argue and substantiate empirically that alliances and the mobility of inventors can serve as bridges to distant contexts and enable firms to overcome the constraints of contextually localized search (for other analyses of the issue

[5]For an excellent overview of the user-innovation literature, see Bogers *et al.* (2010).

of innovation and labor mobility, see for instance, Wezel et al., 2006; Kaiser et al., 2008; Corredoira and Rosenkopf, 2010). In related work, Phelps (2010) showed that the technological diversity of a firm's alliance partners increases its exploratory innovation[6] and that network density among a firm's alliance partners further strengthens the influence of diversity. The search for innovation can also be achieved through merger and acquisition activities. In this context, Makri *et al.* (2010) found that complementary scientific knowledge and complementary technological knowledge improve postmerger innovation through the production of higher quality and more novel inventions.

Multinational corporations have an array of possibilities for technological search and can exploit subsidiaries in different geographical locations to tap into local sources of knowledge (see for instance, White and Poynter, 1984; Bartlett and Ghoshal, 1988; Frost, 2001; Cantwell and Mudambi, 2005). Among a huge body of literature, in the context of search and knowledge sourcing, Cantwell and Janne (1999) showed that subsidiaries whose parent companies come from geographical centers that can be characterized as being "lower-order", tend to undertake technological activity that reflects this lower level technological ability ("exploitation"), and those subsidiaries whose multinational firms are headquartered in "higher-order" centers tend to undertake different technological activities ("exploration").

Fleming and Sorenson (2004) point to the helpful role of scientific thinking for performing technological search. They show that patents are more frequently cited if they contain references to scientific papers in conjunction with high frequencies of patent subclasses appearing in combinations with other subclasses on other patents (the authors refer to the latter as "coupling").[7] In other words, the benefits for subsequent citations appear to increase with coupling. The authors posit that in the case of combinations of relatively independent knowledge components, search can produce fruitful recombinations relatively simply. However, when knowledge components are coupled (i.e. already used in other combinations/systems) it is more difficult to foresee fruitful recombinations due to the implied complexity. In this case, Fleming and Sorenson argue that scientific knowledge and methods may serve as a "map" that helps structure the search process in a more systematic fashion. In

[6]According to Benner and Tushman (2003: 243), innovations are exploratory, when they require new knowledge or departures from focal firms' existing skills. It can be noted that this terminology is not in line with March's (1991) idea of exploration being a process, whereas an innovation is the result of such a process.

[7]A substantial part of the innovation search literature uses patent citations to other patents and to scientific publications, to analyze firms' and individuals' search behaviors. Using patent citations introduces a methodological problem related to the fact that inventors may not be familiar with the patent and scientific publications cited in their patents, because patent examiners are responsible for 63% of the citations in an average patent (Alcácer and Gittelman, 2006). This is not addressed further in this article but readers are referred to the excellent paper by Alcácer and Gittelman (2006).

other words, when knowledge is systemic, there is strong complementarity between technological and scientific knowledge in producing new combinations (see also, Dougherty, 2007 for a discussion of the need to treat technological and scientific knowledge as complements). Fabrizio (2009) provides additional empirical support for this claim. An alternative and possibly complementary explanation might be that technologies that appear in numerous patents are more of the general purpose technology (GPT) type. If the GPTs (e.g. IT, software, biotechnology) are science-based and the GPT patents are more often cited than other patents, this might explain some of the co-variation.

5.3 Exogenous triggers of changes in the level and direction of search behavior

5.3.1 The individual level: the way engineers work

In his account of the history of the "turbojet revolution," Constant II (1980) proposed the concept of *presumptive anomaly* as a trigger for radical advances in technology: "Presumptive anomaly occurs in technology, not when the conventional system fails in any absolute sense, but when assumptions derived from science indicate either under some future condition the conventional system will fail (or function badly) or that a radically different technology will do a better job." (Constant II, 1980: 15).

Thus, in the case of the turbojet, insights derived from aerodynamic theory[8] in the 1920s created a presumption among (some) aircraft engineers that, over the longer term, fundamental constraints would be encountered in the performance of aircraft employing the conventional propeller system. Aerodynamic theory, in particular, suggested that aircrafts would be able to travel faster than the speed of sound but that conventional piston propellers would not be able to secure the necessary level of thrust. Constant II documents how this presumption was central in stimulating the turbojet revolution. In addition to presumptive anomalies, and based on the work of Laudan (1984), Vincenti (1990: 47) conjectured that the search for radical design solutions is also promoted by *actual* functional failures, which occur when a technology is subject to increasingly greater demands or is applied in new situations. According to Vincenti, the failure in the 1930s of the traditional airfoil to provide propellers with satisfactory aerodynamic characteristics at high speeds, led scientists and engineers to search for and subsequently develop high speed airfoil designs.[9]

[8]Ruttan (2008) points out that it is not necessary for the insights that give rise to a presumptive anomaly to be derived from science.

[9]In similar vein, Rosenberg (1969) points out to how bottlenecks and imbalances in technological progress induce and shape technological search, although not necessarily in a radical direction. Reichstein and Salter (2006) highlight the complementary nature of product and process innovation, i.e. that product innovation can lead to the search for process innovation (and vice-versa).

5.3.2 The firm level: idiosyncratic situations, "problemistic" and slack search

Ahuja and Katila (2004) posit that "idiosyncratic situations" may encourage firms to invest in path breaking search. These situations include, in particular, technological exhaustion and expansion beyond national markets. The authors show that US-based chemical firms conduct more searches that draw on science when they face high levels of technological exhaustion. The authors also showed that changes in firms' product market presence may initiate changes to these firms' international research presence. In a very interesting paper, Katila and Chen (2009), using longitudinal data on 124 robotics firms, show that competitors' actions also influence the search activity of firms. In particular, they showed that firms which search after competitors, introduce more new products, whereas firms that search ahead of competitors introduce more innovative new products. Most innovative firms combine these out-of-sync approaches, but avoid synchronized searching.

However, at a more general level, the behavioral theory of the firm (Cyert and March, 1963) posits that one of the central types of search performed by firms is "problemistic search" (i.e. search triggered by a problem). Problemistic search is initiated when decision makers recognize that organizational performance is below perceived aspirations, a level that in part is a function of prior performance. Consequently, if an organization is under competitive pressure (especially price competition or rival innovations), the search for innovation may increase if managers decide that upgrading processes and products could resolve performance problems (Greve and Taylor, 2000; Greve, 2003). For instance, organizations with declining profits may enter the R&D race in an attempt to restore profitability (Kamien and Schwarz, 1982; Antonelli, 1989). Building on Bolton's (1993) work, Greve (2003) argues and demonstrates empirically that performance below aspiration level not only makes decision makers search for solutions, it also makes them more likely to try inherently risky solutions, such as those involving more spending on R&D activities.

Although we know something about the factors that can affect the level of search activities, the literature says little about how problemistic search affects the search for variety and the outcome in terms of the degree of radicalness of the innovation. Nevertheless, theory and evidence provide some of the building blocks to begin establishing a theory in that direction. For example, firms facing rival innovations or increased price competition have incentives to change their internal routines and to unlock innovation potential that may have been constrained by risk aversion or day-to-day business practices (McDermott and O'Connor, 2002).

The selection of a strategy to meet an immediate threat to the firm's profits is not random, however, and short-term incentives are not the only drivers of radical innovation. Substantial resources are also required, resources that may not be available to firms that are under external pressure. Cost efficiency considerations and commitment to certain types of products, processes, or business practices may induce companies to choose not to engage in radical changes. In other words, inertia may be widespread in firms' reactions to these competitive pressures (Tripsas and Gavetti, 2000; Gilbert, 2005). In response to a rapid decline in firm profits, managers may not be able to orchestrate large-scale R&D to develop radical combinations and recombinations of technologies and other kinds of knowledge. Many companies will search for a less challenging road out of the competitive situation by attempting to innovate incrementally, that is, to recombine existing knowledge. Put differently, in a situation of extreme competitive pressure, firms can be expected to focus on incrementally updating existing products and processes based on the exploitation of existing ideas, rather than undertaking the exploration associated with radical innovation (March, 1991), which may require long-term investment in order to be successful in the market. However, future research should examine whether these expectations are valid empirically and develop these ideas theoretically.

Another firm-level driver of the search for variety is organizational slack (Cyert and March, 1963; Thompson, 1967). Organizational slack refers to "those resources, which an organization has acquired which are not committed to a necessary expenditure. In essence these are resources which can be used in a discretionary manner" (Dimick and Murray, 1978: 616). Nohria and Gulati (1996) argued that in the context of innovation, some slack is needed to be innovative because slack allows for the pursuit of innovative projects associated with high levels of uncertainty but a potentially high pay-off. In contrast, too much slack could lead to inefficiencies. It seems reasonable to suggest that in order for a firm to act on a presumptive anomaly as discussed above, a degree of slack is required. Slack search would also allow search that does not seem immediately justifiable, given the current demand. Although such projects often fail, they sometimes (accidentally) yield benefits that are of great value to the firm.

On the other hand, slack can have negative effects because, it can be misused by organizational members for personal gain. The existence of slack resources may lead decision makers to fund R&D projects that advantage certain groups or individuals within the firm rather than the whole firm. In sum, slack search entails benefits and costs. Also, empirical research does not agree on the positive effect on innovation outcomes (see e.g. Zajac et al., 1991; Majumdar and Venkataraman, 1993). Given the benefits and costs of slack search, Nohria and Gulati (1996) hypothesize and substantiate empirically that that there is an inverted U-shaped relationship between functional departments' levels of slack and their perceived innovativeness; in other words, there is an optimal level of slack associated with innovativeness.

However, as in the case of problemistic search, no work has been published on the type of innovation that slack search may lead to. Theory and historical evidence would suggest that slack search should lead to more radical innovations (such as the incidental discovery of the Post-it note at 3M). The argument is as follows. In examining declining organizations, Wiseman and Bromily (1996: 524) showed that the relationship between risk taking behavior and performance can be expressed as "a cyclical process with positive feedback in which decline and the loss of certain slack resources increases risk which in turn reduces performance and results in further organizational shrinkage. Thus, firms facing decline fall into a trap of taking unprofitable risks that ultimately exacerbates the decline."[10] Regarding innovation, unprofitable risk may often encompass a focus on producing incremental innovation rather than radical innovation, because radical innovation requires slack to allow for the more broad and explorative search needed to produce this type of innovation (Knight, 1967; Özcan, 2005). An organization needs a certain amount of slack to be able to pursue new combinations of knowledge more radically, by searching broadly among a variety of possible inputs because the technological and market outcomes of these innovations remain unpredictable due to the high levels of uncertainty (Vincenti, 1990; Pavitt, 2005).

5.3.3 The system level: new technological opportunities

Technological opportunities are the set of possibilities for technological advance and can be measured as returns to R&D taking account of the demand conditions, current level of technology, and appropriability regime (Malerba and Orsenigo, 1993; Klevorick et al., 1995). Arguably, new technological opportunities allow more variety in the possibilities for combining and recombining knowledge elements through technological search. As resources are devoted to R&D and projects are completed, the pool of opportunities may become depleted and the possibilities for combining and recombining knowledge more limited. However, the pool of opportunities can be replenished from the sources of opportunity, including advances in scientific understanding; technological advance originating outside the industry; and new possibilities opened up by feedback from current innovations (Klevorick et al., 1995: 189). As the pool of opportunities is restocked, this implies that a period of incremental change is being replaced by a period of ferment, in which radical innovations materialize (Tushman and Anderson, 1986), possibly to the extent that a new technological paradigm emerges (Dosi, 1982).

The theory of recombinant invention (Utterback, 1994; Hargadon and Sutton, 1997; Fleming, 2001) provides another related argument for why new technological opportunities may lead to recombinations of a variety of more radical inputs. According to this theory, inventors' experimentation over combinations of new components and configurations of previously combined components, leads to less technological success on average but increases the variability that can lead to technological breakthroughs associated with radical innovation (Fleming, 2001). However,

[10]Note that the tension between problemistic and slack search is an unresolved issue in the literature. On the one hand it is argued that organizational problems can lead to more (problemistic) search; on the other hand, organizational problems lead to less slack, which should result in less search (see for instance, Greve, 2003). One could speculate that at least part of the resolution to this apparent contradiction lies in the possibility of problemistic and slack search leading to different *types* of search.

as technologies mature, the likelihood that high-utility combinations of technological elements have not been tried or exploited already must eventually decline (Ahuja and Lampert, 2001). As a result, new technological opportunities offer the possibility of radical combinations and recombinations. In other words, new technological opportunities may allow hitherto separate technologies to be combined in new, complex, and valuable ways.

In many cases, advances in basic scientific research have led to new, radical combinations, particularly in science-based industries (Nelson, 1959; Klevorick et al., 1995) (however, see Pavitt, 2005, on the nonlinear relationship between scientific theory and technological practice—and on scientific theory very often being a poor guide to practice). Although basic scientific research eventually may lead to technological breakthrough, it is fundamentally uncertain when and where the results of basic research should be applied (Nelson, 1959; Pavitt, 1993). Nelson (1959: 300) says that: "Moving from the applied-science end of the spectrum to the basic-science end, the degree of uncertainty about the result of specific research projects increases, and the goals become less clearly defined and less closely tied to the solution of a specific practical problem or the creation of a practical object." The reason why basic science often leads to radical breakthroughs is thus connected to the observation that basic research addresses fundamental questions that are not necessarily constrained only by the solution to a practical problem (see Nightingale, 1998, for a discussion of the differences between technological and scientific search processes). The results of the research are, moreover, fully and freely disseminated to a large community, so the potential sources of new ideas are numerous and varied (Dasgupta and David, 1994; Fleming and Sorenson, 2004).

5.4 Search over time and in different contexts

The subsections above suggest that the intensity, direction, and type of search are not evenly spread across contexts and time. Indeed, Jansen *et al.* (2006) show empirically that exploration in the context of innovation is more effective in dynamic environments, whereas exploitative behavior related to innovation is more advantageous to an organizational unit's financial performance in more competitive environments. Similarly, using cross-sectional data from a range of manufacturing industries, Sidhu *et al.* (2007) suggest that the value of so-called supply-side, demand-side, and spatial exploration and exploitation is contingent on the (self-reported) "dynamism" of the industry in which the firm competes. In particular, non-local supply-side search (involving awareness of technological developments within the given industry) is found to be positively associated with innovation in more dynamic industries, whereas such exploration seems to hamper innovation in less dynamic industries. Conversely, while boundary-spanning demand-side search (aiming at understanding customers' needs) is found to be positively associated with innovation in less dynamic industries, it appears to be harmful to innovation in more dynamic contexts.

Spatial boundary-spanning search (knowledge of opportunities inside and outside of the home region), however, seems to contribute to innovation in dynamic and in less dynamic industries.

These studies constitute an important first step towards improving our understanding of how and why different types of search occur in different contexts. However, their limitation is that these studies are cross-sectional. Cross-sectional analyses often suffer from problems related to unobserved heterogeneity, and by definition, cannot say much about how relationships change over time. Indeed, the majority of the papers in the innovation search literature are cross-sectional, and if they involve a time-series dimension, they exploit variation over time but most often do not look at how search patterns can change over time (however, see Katila and Chen, 2009, discussed earlier)

6. Search and (the lack of) technological diversity among firms: the "variety paradox"

The search literature shows that there are differences in the way firms go about conducting technological search in terms of explorative and exploitative search activities, which gives rise to variations in firms' innovation performance (for instance, Katila and Ahuja, 2002; Leone and Reichstein, 2012). Despite what we know about the diverse ways in which organizations search for variety in order to achieve innovations, however, firms within the same industry have been shown to display little technological diversity in search activities related to fast-growing technologies (Patel and Pavitt, 1997).[11] Patel and Pavitt demonstrate that each firm's patenting activity in the period 1985–1990, in five broad fields of technology (chemicals, mechanical, electrical–electronic, transport, and other), is strongly correlated with the prior distribution of its total patenting in the same fields in the period 1969–1984. The five correlations range between 0.55 and 0.91. In other words, firms patenting predominantly in mechanical technology exploit fast-growing opportunities mainly within the mechanical field, and the same logic applies to the other fields. This is an apparent paradox, given the findings in the search literature.

Patel and Pavitt (1997) suggest that the variety that causes heterogeneous performance among firms comes from the relative difficulty for firms to turn that technology, understood as know-how, into profitable products (see also Pavitt, 1998, on this point). Patel and Pavitt posit also that some of the difficulties involved in turning technologies into products lies in the fact that products are often complex because they encompass many distinct technologies (for instance, a car uses

[11]Note that Patel and Pavitt find that the *rate* of technological search differs markedly among firms within the same broad field of expertise. They conclude that managers have more scope for choice in relation to the rate as opposed to the *direction* of change.

transport, electronics, and chemical technologies). They suggest that some firms are better at investing in the firm-specific learning processes that enable the transformation of technologies into products. This contrasts strongly with the traditional evolutionary view that firms' outputs differ because their technologies differ. Patel and Pavitt argue instead that firms within the same industry have, more or less, the same technologies but differ internally in relation to how they can turn those technologies into successful products in the market.

Although this view likely has explanatory power, it is not the only plausible explanation. While most researchers would agree that there are strong technological imperatives in technological search processes, given the firms' end-products ["if you want to design and make automobiles, you must know (amongst other things) about mechanics" (Patel and Pavitt, 1997: 155)], the limits imposed by these imperatives may be wide—at least wide enough to explain a significant proportion of firm-level variation in innovation performance. There are at least three complementary explanations. First, there is likely to be an intertemporal aspect to technological search. A leading firm may perform explorative search and subsequently enter new technologies, thus gaining a temporary technological advantage over competitors. However, advanced rival organizations do not only rely on their own research in the development of innovations; they also use the innovations of leading competing organizations as inputs to their own innovation processes through various forms of imitation mediated by industrial intelligence activities (Mansfield et al., 1981; Levin et al., 1987; Cassiman and Veugelers, 2002; Ziedonis, 2004). In this sense, organizations' search directions are somewhat interdependent (see also, Katila and Chen, 2009). This tends also to lead to more similar technological profiles among firms in the same industry despite their searching in different ways at any given point in time. It should also be noted that although Patel and Pavitt focus on search outcomes in terms of patent classes, more recent search literature focuses on the search process as reflected in patent citations.

Second, explorative search activities are unlikely to constitute the majority of search in successful organizations, given the high costs involved but, at the same time, firms often need to master emerging technological opportunities in order to identify potential contributions to future business opportunities. Patel and Pavitt (1997: 148) describe it as: "at least in the early stages, emerging fields will be *marginal* in the total technological portfolio of the firm, but this will change as a function of the richness of the stream of potential opportunities that are identified" (original emphasis). In other words, if firms fail to explore the technological space in emerging fields, they may miss important future business opportunities with extremely damaging consequential effects on the organization.

Third, technological profiles across patent classes of firms are observed after the search process. Firms *ex ante* search for knowledge components may be of different intensity and conducted in different ways; it may be directed towards solutions to similar problems, given the shared industrial context and technological imperatives

(Teece, 1988; Patel and Pavitt, 1997). These solutions to similar problems are likely to be classified in the same broad patent classes (recall that Patel and Pavitt use five broad classes), although they may be far from identical.

Whereas there is an apparent contradiction between Patel and Pavitt's (1997) results and the findings in the search literature, the pieces of the jigsaw puzzle do fit in one particular corner. The search literature shows that firms with the highest level of explorative activities for innovation in new technological (Katila and Ahuja, 2002), or organizational (Laursen and Salter, 2006) domains are penalized in the sense that they are responsible for lower levels of product innovation compared with firms that do less explorative search. In other words, there is a broad agreement that the search for variety is rather strongly constrained. In any case, the "variety paradox" raises a number of research questions (see Section 8 below).

7. What we think we know about search, variety and innovation

The theoretical and empirical literature on variety generation through the search for knowledge components is very informative. The innovation search literature demonstrates that firms vary in the way they search for new combinations and the intensity with which they do so, and moreover in their ability to handle the trade-offs involved in having to balance local and non-local search. Whereas early contributions in the literature focused on establishing local search as the default and most "realistic" search behavior of firms, later contributions acknowledge the central importance of local search but also explore its disadvantages. Local search on its own is cheaper and less risky but is also less rewarding than a combination of local and non-local search. The literature also highlights the non-trivial costs associated with search, and that given the cognitive limitations of decision makers, organizations may be performing not only too little search but in some cases, too much search (of various kinds). In addition, the literature shows that the resulting resource heterogeneity of firm-specific search processes often leads to variations in organizational performance. In other words, search matters.

We have seen that firms have to balance local and non-local search and have demonstrated that certain factors may help firms to avoid the local search trap, although we do not have a perfect understanding of the extent to which these factors should be applied to avoid the local search trap without over-searching (this is obviously an important limitation). Factors such as a diverse set of employee education and skills, labor mobility (hiring), markets for technology, formal collaboration, informal knowledge exchange, licensing-in, user networks, science, and working with external knowledge sources, in general, are all important contributors to the avoidance of this trap. There is evidence to suggest that when the right balance between local and non-local search is achieved, the relation between the two search types is complementary (see for instance, Katila and Ahuja, 2002).[12] Another area about which much more is now known is related to the frequent inability of firms to make the right decisions concerning the direction of search. We know also that the search is often triggered by engineers' actual and perceived design constraints, competitors' actions, organizational problems (problemistic search), and in other situations through a degree of organizational slack and based on the set of technological opportunities the firm faces in its search process. An understanding that organizational structure matters for the effectiveness of search for innovations also emerges.

8. What we still need to know about search, variety, and innovation

Whereas the innovation search literature provides the answers to several important questions and deepens our understanding of the innovative process, it has some limitations. One is related to the generalizability of some of the results, given that the empirical studies are conducted in particular contexts and in specific industries which may be unlike any other industries. Also, the focus on specific geographical locations could be a concern. Another limitation is related to the fact that several of the papers reviewed here suffer from endogeneity problems related to unobserved heterogeneity and the possibility of reverse causality. These problems lead to overestimation of the hypothesized effects (Hamilton and Nickerson, 2003). Survivor bias may also be affecting the results (Fleming and Sorenson, 2004, for instance, acknowledge this explicitly), because most recombinations are so ineffective that they are not executed (as Schumpeter originally suggested) even if the direction of the effect of this bias is not evident *a priori* in a regression setup. These empirical problems may be difficult to overcome but need to be noted.

Other limitations to the studies in the literature, represent puzzles that give rise to whole new sets of research questions. One such is related to the "variety paradox" discussed above. In this context, we need an empirical examination of whether or not firms' innovative performance is determined by the ability to turn technology into products or by the ability to develop technologies through search for variety (or both). Although the mechanisms involved are not easy to disentangle empirically, this is a vital question for future research.

Another issue involves the role of the organizational structures that could facilitate local and boundary-spanning search. Attention in the literature to this issue is recent. However, as noted above, we need to learn more about how, when, and why delegation and/or centralization should be applied to balance local and non-local

[12]However, note that Laursen and Salter, (2006) find that firms with relatively large R&D departments and much external search have difficulties in translating these efforts into innovations. This implies that heavy investment in local search may hinder effective non-local search.

search and we need to know more about which organizational mechanisms and practices the managers need to utilize to make innovation search more effective. In relation to organizational ambidexterity, we need measures that better reflect the theoretical notion of ambidexterity and some large-scale quantitative studies that examine which organizational designs work best for ambidextrous search activities, and under what circumstances.

Another somewhat under-researched issue concerns the type of search to which organizational problems give rise. Prior empirical research focuses on search intensity (Greve, 2003; Chen and Miller, 2007) but not on the type and direction of search. For example, does slack search produce more radical innovations? Does problemistic search produce more incremental changes? In cross-sectional studies, changes in search behavior over time are most often inferred. However, more studies are needed that place the time dimension at the center of the analysis (at the same time there is more to be learnt from cross-sectional and case studies). The difficulty involved should not be underestimated and some of the innovation-related changes discussed in this article are of a long-run nature. We need more studies over longer time periods.

There are also some other questions that require research. One is related to the role of appropriability when conducting search for innovation. For instance, how can firms engage in knowledge search in the external environment without losing too much essential knowledge? What is the role of appropriability conditions in this context? Another important question is how firms prioritize their search efforts for new combinations, given the opportunity costs compared with other investments. We know little about how organizational decision makers prioritize scarce resources for search and other essential activities in the bid to achieve the best performance outcomes.

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