A MULTI-LEVEL PERSPECTIVE ON TECHNOLOGY SEARCH AND SELECTION: THREE ESSAYS

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AMIT KUMAR

JURY

Elisa OPERTI	Supervisor	Associate Professor, ESSEC Business School, France
Raymond-Alain THIETART	Chair	Distinguished Emeritus Professor, ESSEC Business School, France
Stefano BRESCHI	Referee	Professor, Bocconi University, Italy
Keld LAURSEN	Referee	Professor, Copenhagen Business School, Denmark
Sen CHAI	Examiner	Associate Professor, ESSEC Business School, France
Corey PHELPS	Examiner	Professor, McGill University, Canada

INTRODUCTION

Motivation and Overview

Since early days in my doctoral studies, I was fascinated to know why certain firms remain technology leaders over a long time whereas others fail miserably. Similarly, why certain regions successfully renew their competence over generations of technologies, while others succumb to such changes. What do the firms, decision-makers, and inventors do, and how do they organize so that certain organizations (firms and knowledge-networks) generate and adopt technological breakthroughs whereas others decline. During my coursework, I became interested in understanding how technology search and selection processes operate at distinct levels of economic organization. Whereas distant search (exploration) generates new technological opportunities (options), efficient internal selection of those opportunities enables an organization to pursue the most adapted trajectories, and thus protects it from external selection. As search and selection processes determine organization's scope, performance, and dynamic adaptability, they constitute important topics in Strategy and Organization research (e.g. Laursen, 2012; Laursen and Salter, 2006; Monteiro, 2015; Phelps, 2010; Piezunka and Dahlander, 2014; Singh, House and Tucker, 1986).

I began my dissertation by studying articles on technology-selection, and more broadly, on firms' opportunity-selection. In the first paper, I reviewed 106 empirical studies on firms' strategic exit. Scholars have studied the topic predominantly from a domain-perspective. Consequently, there evolved three fairly independent streams of literature on firms' exit from industries, economies or markets, and agglomerations. These streams rarely communicate with one-another; indeed while studying firm-exit from one opportunity-domain, such as industries, scholars have ignored firms' simultaneous exits from other domains, e.g. from the relevant markets, technology areas, or agglomerations. This paper conceptualizes exit from a firm's perspective, as a strategic decision taken by organizational actors so that the firm adapts better to its evolving opportunity-space. Accordingly, I focused on empirical studies establishing the antecedents and consequences of firms' decisions of strategic exit. Bringing together studies on strategic exit irrespective of the type of domain or nature of divested/dissolved assets, this paper integrates the literature on exits from industries, economies/markets, and agglomerations. At the end, I underline certain areas to which future research can fruitfully contribute. While reviewing the articles, I learned how high-stake decisions like strategic exit are made, which not only affect firm's scope and identity but also substantially redistribute resources, powers, and payoffs in the organization. Some recent works emphasize the efficiency of selection decisions in studying their performance effects; if firms invest the proceeds from divested assets into growth options, firm-valuation receives a positive shock (e.g. Bates, 2005). Thus, efficient exit decisions are adaptive in nature and lower firms' probability of external selection.

Although scholars have predominantly employed rational choice theories, such as agency, resource-base, and real options etc., to explain strategic exit decisions, one can question such assumptions of rationality in such organizational decision-making. I started asking how firms make their technology choices, especially as these are fraught with environmental and asset-specific uncertainties, and whether they systematically deviate from optimality. The second essay[1] inquires how structural factors predict the incidence of commission and omission errors in firms' selection of technological opportunities. Building upon the theory of organizational cognition, we hypothesize that inventors with cohesive support in firm's co-invention network and geographical proximity to its key decision-makers are more successful in framing contests

[1] Co-authored with Elisa Operti

(Kaplan, 2008). Hence, firms are more likely to make commission errors in selecting technological opportunities produced by such inventors. Symmetrically, opportunities produced by the boundary-spanning and geographically distant inventors are more prone to omission errors. Capturing selection of technological opportunities through patent-renewal, we find support to our hypotheses in empirical context of mobile phone industry (1990-2010). This works underlines that technological opportunities are socio-cognitively constructed by organizational actors, and when competing frames emerge about a certain choice, structural factors determine which inventors will win the framing contests and thus which technologies will be selected.

External selection of less productive organization increases macroeconomic productivity and has welfare effects. Economic crises, technological disruptions, and institutional changes are some shock conditions that induce exit waves. I was interested to know how firms respond to such shocks, and what aggregate-level effects of such responses are. In my third essay[2], we argue that economic crises increase regional exploration. As firms' performance declines during crises, they engage in problemistic and slack search, and tend to explore into emerging technologies to create growth options (Bloom, 2005; Greve, 2003; Nohria and Gulati, 1996). Thus, we witness inventors innovating in those technologies, in which their regional network didn't have prior competence. Additionally, crises have indirect effect on regional exploration, mediated through flattening of regional knowledge networks. Crises induce a reorganization of these networks: firm-failures, layoffs and project-terminations lead to dissolution of existing ties whereas new ones are made between inventors pursuing new technologies. Lower network hierarchy supports exploration, and thus mediates the effects (Lazer and Friedman, 2007). We operationalize

[2] Co-authored with Elisa Operti

regions in terms of MSA (metropolitan statistical areas) in the US, and capture the intensity of crisis through movement of housing price index. Measuring regional exploration through share of patents belonging to USPC main classes new to the region, we find empirical support to our hypotheses. This paper exhibits how firms modify their search processes responding to economic crises, and how the dynamics of the knowledge networks sustain these search processes. Together, these responses have system-level outcomes: the whole region shifts towards emerging and futuristic technologies.

Working on these three essays, I learned that while strategic concerns drive both search and selection processes, their efficiency is determined by the organizational structure. Another insight is: geographical factor determines the efficiency of technology search and selection. It can have both facilitative and constraining effects. This creates a paradox: while firms enter certain distant geographies to improve their search-efficiency, the distance lowers their selection-efficiency, and thus their ability to benefit from such entries (Monteiro, 2015). I also drew substantially upon economic theories of decision-making, social network theory, and behavioral and cognitive theories, which I came across working on all essays. Although each essays makes contributions to specific conversations, my dissertation, overall, is a humble contributions to the literature on technology search and selection, and more broadly to that on R&D strategy and organization.

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FIRM EXIT – TAKING A STRATEGIC DECISION PERSPECTIVE

Amit Kumar

ABSTRACT

Although strategic exit determines firm-scope, it has not received as much attention from the scholars in management and allied disciplines. Further, strategic exit has primarily been studied from the perspective of exited opportunity-domains. Thus, we have fairly independent streams of literature on exits from industries, economies, technologies, and agglomerations. Underlining the need for a coherent conceptualization of exit as a strategic decision problem in an organizational context, I review papers on the antecedents and the consequences of such decisions, from firm's perspectives. Often a corollary of firm's strategic renewal and corporate restructuring, strategic exit decisions span across domains. Hence, I review and integrate the literature on firms' exit from three domains, viz., industries (also underlying technologies), economies, and agglomerations. At the end, I set agenda for future research.

Keywords: Strategic exit, divest*, opportunity-selection decisions.

INTRODUCTION

In 2015, Elfenbein and Knott observed that exit received significantly less attention than entry in both management and economics journals (p 957-958). It is more so with the topic of strategic exit, which is essentially a firm's resource-allocation decision, and often a corollary of its strategic renewal. What stops us, as an academic community, from generating scientific knowledge about exit as a strategic decision problem despite its importance and ubiquity? It is partly because the literature has evolved rather along the type of opportunity-domains exited. Thus, we have quite independent streams of works on corporate divestiture, technology-selection, foreign divestment, and plant-closure, rather than a coherent corpus of work on strategic exit decisions. Each stream studies exits from one type of opportunity-domain, keeping agnostic about firms' possible simultaneous exits from other types of domains. In reality, firms' exit decisions are much more complex and cut across distinct domains. For instance, when STMicroelectronics decided to exit chip-manufacturing and focus sharply on design (de-diversify vertically), it closed down several fabrication sites globally, and ended up exiting countries where it was primarily into manufacturing. Non-manufacturing processes and units, which were too small to carry out independently, were relocated to other locations where STM had bigger establishments (geographical de-diversification). Thus, STM's decision of exiting a value-activity influenced its decisions of exiting certain process technologies, agglomerations, and countries. Comprehending exit as a phenomenon occurring solely in one opportunity-domain obstructs us from conceptualizing it as a decision-problem in the wider context of firm's strategy and organization.

This paper has two objectives. First, to conceptualize exit as a strategic decision from an organizational perspective, irrespective of the type of domains. Although existing works from domain-perspectives have enriched our understanding about exits, it has also inhibited us from conceptualizing strategic exit coherently as a decision problem and approach it with the assumptions of organizational decision-making. The predominant domain-perspective has also created artificial silo between the works studying firm exits from different domains. My second objective is to review the relevant literature on firms' strategic exit decisions. I integrate the empirical findings on firms' strategic exit from distinct domains.

This paper is organized along six sections. In the first section, I conceptualize strategic exit from an organizational perspective. In the second, I explain how I selected the articles for review and organized the findings. In the third section, I review the micro (firm)-level antecedents of strategic exit decisions, and in the fourth, I review the macro (environment)-level antecedents that affect firms' exit decisions. In fifth section, I review the findings about performance consequences of firms' exit decisions. At the end, I set an agenda for future research.

CONCEPTUALIZING STRATEGIC EXIT DECISIONS

Entry and exit constitute firms' opportunity-selection and resource-allocation decisions that redefine their strategic scope. A firm strategically exits a domain when it deliberately decides not to pursue opportunities, discontinuing its operations in that domain, and dissolving or divesting (selling off) its assets through which it hitherto pursued those opportunities. Unless firms are pushed to distress-sale of their assets, their exit-decisions are an outcome of their strategic renewal and corporate restructuring (Bowman and Singh, 1993; Feldman, 2014; Karim and Capron, 2016; Vidal and Mitchell, 2015). Efficient exit decisions help firms adapt better to their evolving environment and opportunity-space, and correct their past misallocation decisions (Capron, Mitchell and Swaminathan, 2001; Chang, 1996; Jaef, 2018; Lee and Madhavan, 2010).

Scholars have studied firms' strategic exit decisions along the nature of opportunity-domains exited (Table 1). Consequently, there are quasi-independent streams of literature on firms' exit from industries, economies, and agglomerations. As an opportunity domain, industry refers to the value-activities a firm engages in. A firm's decision to exit an industry redefines its corporate (product-markets) scope. When a firm does so by selling off or dissolving its business unit, it is often referred to as corporate divestiture (Brauer, 2006). Firms operate in an economy either to avail themselves marketing opportunities or to use it as a production-platform. Firm's exit from an economy by the dissolution or selling off the subsidiary or affiliate is termed in the literature as international divestment (Berry, 2010; Mata and Portugal, 2000). It reduces the geographical scope of a firm. An agglomeration offers a firm the opportunities to use its unique productive resources (Alcacer and Chung, 2014; Krafft, 2004). Thus, firms in an agglomeration are competing for certain strategic factors that increase their competitiveness in a given product-market. A firm's decision to close down its establishment and exit an agglomeration may result from both their strategic (scope) and operational (scale)-changes.

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ARTICLE SELECTION AND ORGANIZING FRAMEWORK

This review takes a strategic perspective to firms' exit decisions. Accordingly, I focus on articles examining the antecedents operating at both micro (firm) and macro (environment) levels, and the consequences of such decisions. I included papers examining these decisions across three opportunity-domains: (a) industries (including the underlying technology areas), (b) economies, and (c) agglomerations. Since this paper takes a stock of what we know about strategic exit, it focuses primarily on the empirical works. In this regard, we follow the caution by Phelps, Heidl and Wadhwa (2012): "Including untested theoretical arguments would make it (the review) difficult to compare and contrast studies since some would contain empirical findings regarding particular theoretical arguments while others would not. Moreover, mixing insights from untested theoretical ideas with empirical results could prove misleading as unsubstantiated and possibly incorrect ideas are given equal credence as rigorously tested and replicated empirical results." They also observe that it doesn't diminish the conclusions as the included empirical works do draw theoretical insights from the excluded theoretical and conceptual papers.

To create a sample of articles, I first extracted the list of high-impact peer-reviewed journals (h-5 index and h-5 median; date: December 12, 2016) in management (Strategy, organization, management, international business, and innovation & entrepreneurship) and allied disciplines (economics, finance, economic geography, sociology and decision sciences) from Google Scholar. Subsequently, I searched for the relevant articles on Web of Science (1996-2018) with the following keywords: firm exit (755 articles), divest* (227), plant closure (50), industry exit (433), country exit (169), cluster exit (18), region exit (54), technology exit (117), and strategic exit (150). As one article may enter into our database more than once due to different keywords, I dropped duplicate entries (888), and was left with a total of 1185 articles. Subsequently, I manually removed articles that didn't present empirical evidence about the antecedents or firm-specific consequences of strategic exit decisions. Further, I removed articles dealing with firm-exit through mortality, entrepreneurial exit, or exit of the personnel. I also included a meta-analysis by Lee and Madhavan (2010). Besides, I added some relevant articles from the lists of references (normally older publications) of my chosen articles. Altogether, I collected a database of 106 articles for in-depth review. Table 1 lists these articles along with their source-journals. Figure 1 gives yearly trend of publication, which shows an increasing appreciation of strategic exit decisions as a research-topic in management and allied disciplines.

Apart from the empirical works, I also went through previous reviews on divestitures by Brauer (2006), and on business exits by Decker and Mellewigt (2007). Figure 2 is a diagram of our organizing framework. The rubrics under the antecedents and consequences emerged from the analysis of articles.

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MICRO-LEVEL ANTECEDENTS

Exit decision-making: rational choice model, behavioral and prospect theories

Organizational decision-making about strategic exit and asset-divestiture can be understood by combining behavioral and prospect theories with the rational choice model (Shimizu, 2007). When organizational performance falls below the aspiration levels, decision-makers engage in problemistic search, initially seeking a rather short-term, primarily incremental solution. They tend to avoid uncertainty, largely maintain *status quo,* and take decisions along past experience and rules (Cyert and March, 1963; p. 116-127; Shimizu, 2007; Shimizu and Hitt, 2005). Firms are found to reconfigure majority of their assets, which is a less radical solution, at least once before divesting or dissolving it (Karim, 2006). Underlining the behavioral origins of inertia against strategic exit decisions, Elfenbein, Knott and Croson (2017) argue that equity-stakes distort belief-formation in the decision-makers. In an experimental study, they found that the decision-makers discounted negative information about asset-performance, retained overly optimistic beliefs, and thus delayed exit decisions. Similarly, Sandri, Schade, Musshoff and Odening (2010) discovered in their experiment that decision-makers exhibited “psychological inertia” and held on to their projects longer than the real options reasoning warranted. However, when the shortfall in performance level is substantial and the incremental solutions don’t work, or when they face institutional pressures from the shareholders (control), the organizational decision-makers look for more radical solutions: they redefine the scope of firm through entries and exits (strategic renewal), and alter the organization of firm through development and acquisitions of new assets and divestitures and dissolution of the existing ones (Bowman and Singh, 1993). Normally, decision-makers would avoid risks associated with such options: overweighting the potential losses and underweighting the potential gains (Kahneman and Tversky, 1979). But due to concave utility-functions for the gains and convex for the losses, poorly performing firms exhibit higher risk-taking (Fiegenbaum and Thomas, 1988; Lehner, 2000) and are more likely to engage in strategic exits and asset-divestitures (Berry, 2010; Boeker, Goodstein, Stephan and Murmann, 1997; Chang, 1996; Hoskisson, Johnson and Moesel, 1994; Markides, 1992; Mata and Portugal, 2002; Moliterno and Wiersema, 2007; Vidal and Mitchell, 2015). Financial slack, however, moderates the effects of low performance on firm's intensity of exits and asset-divestitures (Kuusela, Keil and Maula, 2017).

Notably, it is firm-performance in relation to the aspiration levels that triggers the organizational decisions about strategic renewal: entry (search) and exit (selection) (Kuusela, Keil and Maula, 2017). Hence, apart from those with low performance in absolute terms, firms with historically high performance and thus with high aspiration-levels also exhibit a higher propensity to divest assets, when the performance level dips below their aspirations (Hayward and Shimizu, 2006; Kuusela, Keil, and Maula, 2017; Vidal and Mitchell, 2015). Similarly, firms with high opportunity costs, such as multi-unit and multinational firms, have higher aspirations of asset-performance and therefore a higher likelihood of divestitures (Bernard and Jensen, 2007; Berry, 2010; Colombo and Delmastro, 2000; Moel and Tufano, 2002; Procher and Engel, 2018; Wood, 2009). Innovation-led technology firms have higher propensity to undertake strategic renewal and scope-changing restructuring. Even if an asset is profitable in absolute terms, due to their ability to enter new emerging areas and thus high opportunity costs, such firms are more likely to divest the asset. As peer-performance also sets a firm's aspiration levels, technological innovations by rivals also increase such firms' likelihood of divestiture (Kaul, 2012).

Through entries and exits, firms attempt to generate intertemporal economy of scope (Helfat and Eisenhardt, 2004). In this context, their search and selection processes should be viewed as related processes (Chang, 1996; Hudson and Swanton, 2012; Miller and Yang, 2016; Procher and Engel, 2018). New investments increase the likelihood of divestment of firms' existing assets (Berry, 2010; Procher and Engel, 2018). Similarly, firms divesting their assets systematically overinvest in the subsequent periods (Bates, 2005). To improve their knowledge-base and performance vis-à-vis their aspiration, firms engage in directed search and selection – they sequentially enter domains with similar human resources profile and divest those with different profiles (Chang, 1996; Miller and Yang, 2016). In horizontal acquisitions, strategic similarity leads to divestiture of the target assets. When the acquirer and target assets are similar but asymmetrical in resources, firms engage in redeployment of resources from strong to weak assets, and subsequently divest the weak ones (Capron, Mitchell and Swaminathan, 2001).

Agency problems

Scholars have underlined the problem of agency conflicts in over-diversification of the firms and thereby their poor performance (Elfenbein and Knott, 2015; Markides, 1992). Firms diversify with several objectives: generating synergies between operations (economy of scope), leveraging firm-specific assets, saving transaction costs, increasing market power, harnessing the efficiency of internal capital market (there is higher information asymmetry in external capital market), and generating options value. It also has certain costs in terms of information processing, and governance and control costs for internal capital market. At the optimal level of diversification, firm-performance is the highest. Beyond this level, when a firm perform poorly, we can it overly diversified (Markides, 1992)[3].

Principal-agent agency conflict occurs because of separation between firm's ownership and control, when managerial decisions are not aligned with shareholders' interests. Managers tend to invest in a self-serving manner, and often end up diversifying overly into several unrelated domains in which the firm lacks competence and its competitive positioning is unfavorable (Bates, 2005). Such firms have lower performance. When such firms are put under effective control, such as outsider directors, institutional or blockholder ownership (Bergh and Sharp, 2015; Johnson, Hoskisson and Hitt, 1993; Shimizu and Hitt, 2005), or when managerial interests are aligned with shareholders' through stock-ownership or stock-options (Bergh and Sharp, 2015; Elfenbein and Knott, 2015; Johnson, Hoskisson and Hitt, 1993; Sanders, 2001), the firms de-diversify and exit multiple non-core domains (Bergh and Holbein, 1997; Hoskisson, Johnson and Moesel, 1994; Markides, 1992; Powell and Lim, 2018). The first reduces managers' ability to diversify overly whereas the latter reduces their incentives, thereby leading to divestiture (Bergh and Sharp, 2015; Elfenbein and Knott, 2015; Johnson, Hoskisson and Hitt, 1993; Sanders, 2001; Shimizu and Hitt, 2005). Market for partial corporate control also plays a role in limiting agency costs – activist block purchases of highly diversified firms with poor performance increase the incidence of asset-divestitures (Bethel, Liebeskind and Opler, 1998).

Agency problem may also occur between principals, which can suppress firms' exit and divestiture decisions despite low performance. It is more so in countries with weak legal

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[3] Schommer, Richter and Karna (2018) present a meta-analytical review of diversification and firm-performance.

protection to minority shareholders (Chung and Luo, 2008; Wu, Xu and Phan, 2011). Family firms is a classical case. These firms diversify into unrelated businesses to increase the status, market power and social influence of the dominant family owners, minimize their bankruptcy risks, and increase their family wealth. Despite economic rationale, such firms are less likely to exit businesses and divest assets, especially when they are run by the family-CEOs (Chung and Luo, 2008; Feldman, Amit and Villalonga, 2016). Similarly, Wu, Xu and Phan (2011) found that in China, largest shareholders suppressed corporate divestitures despite a strong economic rationale. Large corporate size made these shareholders effective in pursuing their non-economic objectives, while they could shift the burden of economic inefficiency onto minority shareholders. Thus, their private gains exceeded the losses they incurred due to lower stock-prices.

Characteristics of decision-makers

Characteristics of the decision-makers, especially of the Chief Executive Officers, are known to affect firms' entry (e.g. Eggers and Kaplan, 2009) and exit decisions. In restructuring firms, CEO-succession is related with higher intensity of divestitures (Boeker, Goodstein, Stephan and Murmann, 1997). Outside CEOs successors break the cognitive inertia of the firms: they are more likely to redefine firm's scope and divest poorly performing assets (Shimizu and Hitt, 2005). Lacking in sufficient firm-specific knowledge, such CEOs also find it difficult to affect changes internally in a poorly performing organization. Hence, they are more likely to change firms' scope through asset-divestitures. Inside CEO successors, on the other hand, are more likely to affect scale rather than firms' scope through divestiture (Chiu, Johnson, Hoskisson and Pathak, 2016). Further, when an entry fails and the acquired asset performs poorly, an outside CEO successor who was not involved in the acquisition decision is more likely to divest the asset. Accepting the failure of an entry and acquisition decision is an embarrassment for a CEO or an inside successor who participated in the failed acquisition. However, an outside CEO-successor can attribute the failure to his predecessors and, by divesting the unit, signals that he is in control (Hayward and Shimizu, 2006).

When under pressure to produce strong results, CEO-successors with short tenures can radically change scope of the firm. They are more likely to undertake legacy divestiture. Due to historical reasons, legacy assets generate strong mutual interdependence with other organizational units. Hence, CEO-successors with long tenure – with a long-term view of their organization, are less likely to divest such assets. Similarly, long-terms CEOs, due to their association and attachment to firms' legacy businesses, and their social relationships or political alliances with the personnel from legacy units are less inclined to retrench such assets (Feldman, 2014).

CEOs are more likely to exit the non-familiar domains than the familiar ones. CEOs have a comparative information advantage in familiar segments; for making decisions about a non-familiar domain, they need to depend upon managers from that domain. The familiarity effects are stronger in R&D intensive industries. Similarly, these effects are more pronounced for long-tenured CEOs who have generated sufficient political capital in the organization to select domains of their choice (Ang, de Jong and van der Poel, 2014). Landier, Nair and Wulf (2009) also underline the importance of information and social factors in exit and divestment decisions. They found that in geographically dispersed firms, proximity of a corporate asset to corporate headquarters determined its divestiture: out-of-state assets were divested before those in-state.

Asset characteristics

Certain characteristic of a corporate asset makes it more susceptible to divestiture or dissolution. Such assets are strategically non-core and unrelated to the parent firm in terms of resource-base. They are not well integrated with rest of the organization – other units are mutually less dependent on them (Bergh, 1997; Chang and Singh, 1999; Lien and Klein, 2013; Schlingemann, Stulz, and Walkling, 2002; Xia and Li, 2013). Thus, they do not leverage parent's learning, assets and core competences, and potentially generate negative synergies in the organization (Bergh, 1995, 1998; Berry, 2013; Chang, 1996; Duhaime and Grant, 1984; Li, 1995; Song, 2015).

Divested and dissolved assets are also small (Bergh, 1995, 1998; Colombo and Delmastro, 2000, 2001; Mitchell, 1994; Fortune and Mitchell, 2012; Shimizu and Hitt, 2005; Song, 2015), less resourceful, less competitive (Duhaime and Grant, 1984; Mata and Portugal, 2000; Song, 2015) and hence poorly performing (Bergh, 1998; Berry, 2013; Doms, Dunne and Roberts, 1995; Duhaime and Grant, 1984; Prezas and Simonyan, 2015; Schlingemann, Stulz, and Walkling, 2002; Wood, 2009). They don't have large endowment of human capital (Mata and Portugal, 2000) or subunit power due to external resource access through alliances or acquisitions (Xia and Li, 2013). Firm's sunk costs in such assets are low (e.g. minority holdings) (Colombo and Delmastro, 2001; Doms, Dunne and Roberts, 1995; Mata and Portugal, 2000).

Acquired assets are more likely to be divested. It is due to two reasons. First, the firm might have unsuccessfully attempted to enter a non-related domain through acquisition. Second, internal development generate firm-specific idiosyncratic assets, thus increasing the transaction costs of buyers. An acquired unit is more modular and hence easy to divest for the seller firm and less costly to integrate for the buyer firm (Chang and Singh, 1999). Schlingemann, Stulz, and Walkling (2002) underline the role of liquidity of the market of corporate assets in determining which assets a firm divests. If there is more liquidity in the segment of an asset, the firm is more likely to get better prices and hence to divest it despite relatively higher performance.

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MACRO-LEVEL ANTECEDENTS

Domain-munificence and competition

If an industry or market has low aggregate demand (Berry, 2010, 2013; Harrigan, 1982; Elfenbein and Knott, 2015), excess capacity (Wood, 2009), intense competition (Colantone and Sleuwaegen, 2010; Coucke and Sleuwaegen, 2008; Khanna and Tice, 2001), or incidents of price-wars (Harrigan, 1982), firms are more likely to exit. Institutional changes towards economic integration and globalization increase the competitive pressures on domestic firms. Import-intensity, especially from low-wage economies, international sourcing of intermediate goods within the industry, and entry of multinational firms with global supply chains lead to exits, closure of low-productivity assets, and offshoring of manufacturing (Bernard, Jensen and Schott, 2006a, b; Bowen and Wiersema, 2005; Colantone and Sleuwaegen, 2010; Coucke and Sleuwaegen, 2008; Olley and Pakes, 1996).

Entry of large firms in a domain often disproportionately increases the intensity of competition, and leads to exit of the existing firms. Khanna and Tice, (2001) accounts how many diversified incumbents exited when Wal-Mart expanded in the US discount department store industry between 1975 and 1996. Similarly, when foreign firms enter and expand in a market, many domestic firms exit (Coucke and Sleuwaegen, 2008). In emerging industries, when diversifying entrants participate in battles of dominant design (Suarez, 2004) or setting technical standards (Cusumano and Gawer, 2002), startups are more likely to make technology-exits

(Chen, Qian and Narayanan, 2017). Startups lack organizational legitimacy while entering new markets (Navis and Glynn, 2010), whereas established firms with pre-entry experience enjoy an advantage in not only legitimacy, but also complementary assets (Tripsas, 1997), and integrative capabilities (Helfat and Campo-Rembado, 2016). Competitive forces also drive strategic exit of firms from agglomerations. Technology leaders experience net knowledge outflow in agglomerations. In countries with weak intellectual property protection, such firms are concerned about appropriation of their knowledge-resources by competitors. Hence, while technology laggards tend to collocate with the technology leaders, the latter exit the agglomeration with the increased concentration of other leaders and laggards. Foreign firms also crowd out domestic leaders from agglomerations in the competition for talent (Livanis and Lamin, 2015).

Multi-market competition and dyadic rivalries affect firms' exit decisions. When a firm engages in multi-market competition with its rivals, its likelihood of exiting a market and divesting assets is lower. At high levels of multi-market contacts, firms exhibit mutual forbearance and there is competitive stability. If a firm engages competitors in multiple markets, it can respond to their aggressive behavior in one market by escalating it into other markets (Baum and Korn, 1996; Boeker, Goodstein, Stephan and Murmann, 1997). Baum and Korn (1999) argue that in dyadic competitive interactions, a firm's rate of exit from a competitor's market is related in an inverted U-shaped manner to the level of multimarket contact with the competitor. With limited multi-market competition, the dyad engages into rivalry that might lead to exits both as an outcome or a strategic move. At the moderate level, the rivalry intensifies, and the incidence of exits peaks. However, at the high levels of multi-market competition, the deterrence effects supersede and the incidence of exit is lowered.

Uncertainty and options value

Firms may react to an increase in uncertainties in two diametrically opposite ways: first, by exiting domains with high uncertainty, and second, by creating strategic bets (assets that act as real options). As domain-uncertainty increases the transaction and information processing costs, intermediately and highly diversified firms find it difficult to manage their assets efficiently. During high macro-economic volatility, hence, such firms tend to divest their non-core (unrelated) assets (Bergh, 1998; Bergh and Lawless, 1998).

Less diversified firms, however, acquire more assets during increased uncertainty and divest more during lower uncertainty (Bergh and Lawless, 1998). Continuing the existing operations has options value during periods of uncertainty, especially when the sunk costs of entry and exit are sizable (Damaraju, Barney and Makhija, 2015; Moel and Tufano, 2002; O'Brien and Folta, 2009). In an experimental study, Elfenbein and Knott (2015) found that the decision-makers made rational delays in taking exit decisions during high uncertainty. Empirically, high exchange rate volatility negatively affect multinational firms' divestment of poorly performing subsidiaries (Berry, 2013). During 1997 Asian financial crisis, Thai firms held onto their core assets and became more conservative in churning their business portfolio as the uncertainty increased (Zhou, Li and Svejnar, 2011). As long as manufacturing assets represent growth or switch options under macroeconomic uncertainty, firms don't divest assets despite adverse environmental changes (Belderbos and Zou, 2009). If a multinational firm can fend against environmental uncertainty through production and marketing shifts in its subsidiary network and intra-firm trade, it is less likely to exit an economy with increased wages or adverse demand conditions (Song, 2015). Gaba and Terlaak (2013) however cautions against conflating uncertainty at the firm-level (idiosyncratic) and the industry-level. The former leads to observational learning and inter-organizational imitation in making exit-decisions; however, when there is uncertainty at the industry-level, firms are less likely to exit (Gaba and Terlaak, 2013). But, multinational firms respond to political and regulatory uncertainty by exiting the market and divesting poorly performing assets (Berry, 2013; Sun, Wang and Luo, 2018).

Adaptation challenges and learning

While searching for growth opportunities, firms enter into unrelated domains and face substantial learning and adaptation challenges. This is one reason why non-core assets witness a higher incidence of divestiture. Several international business scholars consider “liability of foreignness” and adaptation challenges as key reasons behind foreign divestment (Barkema, Bell and Pennings, 1996; Kim, Delios and Xu, 2010; Pattnaik and Lee, 2014; Varum, Rocha and da Silva, 2014; Zaheer and Mosakowski, 1997). Cross-national distance (Berry, Guillen and Zhou, 2010) has a positive effect on divestment of foreign assets. When a firm enters a foreign country through joint ventures and acquisitions, it undergoes “double-layered acculturation”. It needs to adapt not only to a new national culture but also to a new organizational culture. Thus, such assets are more at a higher risk of divestiture (Barkema, Bell and Pennings, 1996; Pattnaik and Lee, 2014).

Experiential learning lowers the probability of foreign firms’ subsidiary exits. If a foreign firm had prior experience in the focal industry in the host country, it is less likely to exit. Similarly, firms’ previous experience of entry through acquisition or JV negatively moderates the effects of double-layered acculturation (Barkema, Bell and Pennings, 1996; Kim, Delios and Xu, 2010; Pattnaik and Lee, 2014; Shaver, Mitchell, and Yeung, 1997). Scholars have also underlined the effects of vicarious learning or knowledge spillover in this context. Studying foreign entrants in the USA, Shaver et al (1997) found that if a firm was present in the host country but did not operate in the focal industry, it could benefit from the relevant information spillovers from other foreign entrants in that industry. Hence, greater the presence of other foreign firms (unless that itself had competitive effects) lowered the chances of firm's exit. However, if the firm had no previous experience in the host country, it could not absorb and benefit from the spillovers; hence, its chances of exit remained unrelated to the presence of other foreign firms in the industry. This study also discovered that learning was quite market-specific: experience gained by entering into similar markets (e.g. Europe or Canada), is not easily transitive to the US. Similarly, studying the Japanese multinationals in China, Kim et al (2010) found that a Japanese subsidiary located in the geographical proximity of pre-existing subsidiaries from firm's Japanese industry peers had a lower exit rate. They argue that the cultural and geographical proximity facilitated vicarious learning among the Japanese subsidiaries, and thus helped them adapt in China better.

Some scholars have challenged the notion of "liability of foreignness". Mata and Portugal (2000) reported that the domestic and foreign entrants in Portugal had the same probabilities of exit. Foreign firms did exhibit a higher exit rate than the domestic ones, but primarily because they were intrinsically more volatile and footloose. Empirically, exit of foreign firms increased with age while that of purely domestic firms decreased. If foreignness was a liability, learning effects would decrease the likelihood of exit of the foreign firms over time (Mata and Freitas, 2012). Multi-nationality is one key contributor to foreign firm's footloose-ness as it gives them operational flexibility, efficiency, and thus high opportunity costs. They can shift production from countries and regions, if wages and other costs increase (Berry, 2010; Lee and Song, 2012; Pennings and Sleuwaegen, 2000). However, foreignness itself is a key determinant – Mata and Freitas (2012) found that the exit rates of domestic-based multinationals didn't change significantly with age; they were between those of foreign and purely domestic firms, but closer to the latter.

Technological disruptions also create substantial adaptation challenges, and lead to both firms' strategic exits and mortality (Jovanovic and MacDonald, 1994; Østergaard and Park, 2015). Narula (2002) opines that firms tend to concentrate their R&D in home countries because they are locked-in to and co-evolve with the regional systems of innovation (SI). As long as the technological and institutional elements of the SI maintain firms' competitiveness, the lock-in is efficient. Technological discontinuities shift industry's knowledge-base, necessitating new resources and institutions. However, reorganization of the SI is difficult due to the lock in. Large firms in traditional industries tend to stay in the SI and modify its institutions, whereas firms from science-based industries tend to exit the region, gradually shifting their R&D abroad where they can access relevant knowledge resources (Narula, 2002). Economic geographers have also documented that competence-destroying technological discontinuities alter industry's geography of innovation – incumbent firms phase out their operations from those agglomerations whose comparative advantage has been eroded (Duranton, 2007; Kerr, 2010; Østergaard and Park, 2015).

Experiential learning about asset-divestiture itself determines the intensity of firms' divestiture in the subsequent period. Strategic exit is a complex organizational decision. If a firm previously engaged in the decisions of domain exit and asset divestitures, it is more likely to consider them as a strategic option, and thus has a higher likelihood of asset-divestiture (Peruffo, Marchegiani, and Vicentini, 2018). Previous exit experience also has a positive effect on the implementation of exit decisions. It, therefore, moderates the positive effects of asset-divestiture on firm-performance (Bergh and Lim, 2008).

Social, political and institutional factors

Apart from the economic and organizational factors, the social, political, and institutional factors operating at the macro level also influence firms' decisions to exit a domain. When under social contestation, media attacks, and institutional pressures, firms are more likely to exit the stigmatized industries (Durand and Vergne, 2015). Similarly, multinational firms divest a host country if people in the home country protest against the host country government. Level of political freedom and transparency of the institutions in the home country positively moderate the effects (Soule, Swaminathan and Tihanyi, 2014; Wright and Ferris, 1997).

In emerging economies, political ties lower the probability of firm-exit (Sun, Wang and Luo, 2018; Zheng, Singh and Chung, 2017). Such economies are characterized by intense market competition and institutional constraints such as regulatory uncertainties, corruption, and underdeveloped capital markets, and an inefficient legal and judicial system. In such conditions, political ties substitute for the institutional voids. Such connections provide the firm governmental contracts, regulatory concessions, access to resources, and superior intelligence about political opportunities. A firm is less likely to divest such adapted assets (Sun, Wang and Luo, 2018) – or divest them through sell-off rather than dissolution (Zheng, Singh and Chung, 2017).

Institutional factors affect strategic exit decisions in an additional way. In many Asian societies, stakeholder-based business systems traditionally predominated over shareholder-based business systems. For instance, institutional investors and domestic shareholders in Japan had a more long-term perspective of returns; employment was considered more a life-long commitment both from firms' and employees' point of view. These institutional aspects of business suppressed the instances of strategic exits and divestitures despite low earnings.

Ahmadjian and Robbins (2005) found that with an increased foreign shareholding, Japanese firms began to adopt asset divestiture and downsizing, which are characteristics of the Anglo-American shareholder economies.

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CONSEQUENCES FOR FIRM PERFORMANCE

Accounting and operational performance.

Retrenchment of non-adapted, loss-making assets normally improves firms' accounting performance (Brauer, Mammen and Luger, 2017; Lee and Madhavan, 2010; Montgomery and Thomas, 1988; Montgomery, Thomas and Kamath, 1984; Prezas and Simonyan, 2015). However, growth conditions at the levels of asset's domain affect the extent and direction of effects on divesting firm's performance. For instance, if the assets belong to a high-growth or a mature industry, characterized by competitive strategic factor market and high liquidity, they can be divested profitably. But, in a declining industry or during industry-level distress, when liquidity in the strategic factor market is low, the sale price is likely to be lower than the discounted present value of the future cash flow (Finlay, Marshall and McColgan, 2016; Morrow, Johnson and Busenitz, 2004; Schlingemann, Stulz, and Walkling, 2002). During increased product-market uncertainty, firms divesting unrelated assets improve their accounting performance more than those divesting their related assets (Bergh, 1998).

Temporality of the exit-decision and strength of the resource-base of firm moderate the effects of strategic exit on firm-performance. When a firm is on a downward spiral of low-performance, it has a limited ability to strengthen its resource-base through restructuring and divestiture. Declining firms improve operating performance, accounting performance, and valuation only if they took the exit and divestiture decisions early (Tangpong, Abebe and Li, 2015). Vidal and Mitchell (2018) argue that asset-retrenchment can exacerbate a firm's weaknesses and reinforce its strengths. High-performing firms tend to invest the proceeds in growth opportunities and existing assets, thus improving their performance. In contrast, divestitures improve the profits of the low-performing firms but inhibit their growth – and thus speed up their exit as independent entities.

Legacy divestiture has negative effects on firm-performance. Firm's other units develop resource-interdependence with the legacy business units over time, which the managers take for granted. However, when the legacy assets are divested, the operating performance of the firm declines for a protracted period, which negatively affects firm's valuation. The effects are stronger when the divested legacy assets are closely related to the existing units of the firm (Feldman, 2014).

Taking and implementing the decisions of strategic exit is complex. Scholars have underlined the importance of learning in this context, and show that firms with previous experience of sell-offs, especially of related assets, have higher post-exit accounting performance, operating incomes, and market performance (Bergh and Lim, 2008; Brauer, Mammen and Luger, 2017). Even vicarious learning positively moderates the relationship between asset sell-off and firm-performance. Thus, involvement of external advisors and the incidence of asset-sell off by industry peers also positively moderates the effects (Brauer et al, 2017).

Valuation

Exit decisions also elicit positive valuation effects (Kumar, 2005; Feldman, Amit and Villalonga, 2016; Lee and Madhavan, 2010; Markides 1992; Meschi, 2005; Mulherin and Boone, 2000; Prezas and Simonyan, 2015; Zuckerman, 2000). Several mechanisms explain these positive effects: opportunity cost, lower negative synergies, focus on core markets and competencies, and decrease in diversification discount. Divesting corporate assets signals that the firm is lowering negative synergies (Lien and Klein, 2013; Mulherin and Boone, 2000) and favoring growth-opportunities at the cost of low-quality opportunities (Bates, 2005), thereby strengthening firm-survival and performance. When a firm de-diversifies and focuses on core industries, markets, and competencies, its competitiveness and hence its market-valuation increases (Kumar, 2005). De-diversification also decreases "diversification discount", and the firm experiences higher investment efficiency for its remaining divisions (Dittmar and Shivdasani, 2003; Zuckerman, 2000). However, if a divestment is perceived as distress-sale or adversely affecting firm's competitiveness, it has negative effects on firm-valuation (Tsetsekos and Gombola, 1992). Similarly, when senior managers take exit decisions due to noneconomic reasons, such as political pressures, the firms experience a negative valuation shock (Wright and Ferris, 1997). If exit decisions are considered an imitative move rather than a rational, calibrated choice, the stock-market returns are low (Brauer and Wiersema, 2012).

As discussed in the previous section, firms often create certain assets as growth options or real options under uncertainty. Such assets are highly valuable during the periods of uncertainty, or when they operates in an emerging domain with only a few firms. When a firm exercises the "option to abandon" its asset and de-diversifies to focus on its core product-market, it receives positive valuation-effects (Bergh, 1998). However, the value-gain is negatively affected by the degree of uncertainty and the extent of concentration in asset's domain (Kumar, 2005).

Positive valuation effects of strategic exit are also contingent upon what firm does with the proceeds (Bates, 2005). Asset sale, often in cash, increases liquidity in a divesting firm. It may pay dividends to its equity-holders, pay its debts to optimize leverage, or retain the proceeds to invest in growth-opportunities. Debt-distribution has a significantly higher announcement period effect returns than the two other decisions as it lowers the agency cost of debt. Firms retaining the proceeds are systematically found to overinvest relative to industry benchmark (Bates, 2005; Borisova and Brown, 2013). This trend can be explained in two ways. First, internal capital market has lower information asymmetry than the external capital market; hence, it can invest in growth opportunities efficiently – returns to retention decisions are positively correlated with the growth opportunities and benchmarked investment. Second, managers can invest the proceeds in a self-serving manner (agency cost). Bates (2005) found the returns to be negatively correlated with the benchmarked investment for firms with poor growth opportunities.

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DISCUSSION AND RESEARCH AGENDA

Exit, along with entry decisions, define the strategic scope of a firm. Exit is complex organizational decision, which may involve cessation of firm's operations across multiple domains, viz. markets, industries, technologies and agglomerations. Existing works mostly miss this complexity and normally focus exit from one specific type of domain. E.g., literature on foreign divestments focuses solely upon firms' decision to exit economies (countries), almost ignoring that these decisions may be intertwined with and affected by firms' simultaneous decisions of exiting industries and technologies. This domain-centric approach has enriched us with deep understanding about specific types of exits; however, it has also created siloes – few studies on firms' exits from industries, economies, agglomerations, and technologies talk with and cite one another. Moreover, it has led to a rather fragmented concept of exit decisions. For instance, scholars studying strategic exit from industries conceptualize it in terms of corporate divestitures, which also includes carve outs, split ups and spinoffs apart from asset sales (Brauer, 2006; Mulherin & Boone, 2000). Whereas those studying strategic exit from economies (countries) conceptualize it in terms of foreign divestment, which includes not only sale and dissolution of subsidiaries but also production shifts from firm's one subsidiary to another (Belderbos & Zou, 2006; Pennings & Sleuwaegen, 2000). This paper reviews the empirical literature across disciplinary boundaries and conceptualizes exit as a strategic option and an organizational decision from firm's perspectives. My submission is that the strategy and organization scholars should approach the occurrence of exit beyond a rather narrow domain perspective. In the literature reviewed, few papers control for firm-exits from other domains while establishing the causation or consequences of exits from one domain. For instance, it is possible that a firm divesting a foreign subsidiary or joint venture may also be simultaneously altering its industry and technology scope, and hence receiving a positive or negative valuation shock. As most works focus solely on firm-exit from only one domain, there are opportunities to conduct multi-domain analyses. How exits in one domain lead to and affect exits in other domains. For instance, it can be interesting to study whether a firm's exit from an industry but a continued presence in the market of underlying technologies affect its reentry.

Most works on strategic exit assume rationality of actors and their choices, employing theories such as agency, real options, information asymmetry, and resource-based view. Although these theories powerfully explain firms' strategic exit behavior, the scholarship will gain immensely by integrating insights from behavioral and social-cognitive theories of organizational decision-making[4]. Exit decisions may substantially alter firm's scope and identity, and radically redistribute organizational resources and power in the firm. Adner and Levinthal (2004) have underlined the limitations of applying the concept of real options in organizations. For many decision makers, the question – "Should the firm exit a specific domain?" translates into "Should the firm exit the domain in which I specialize?" or "What do I gain if the firm exits this specific domain?" Under uncertainties, evaluation about the quality of competing opportunities, their fit to firm's scope, and resource-strength of the existing assets are highly contested in organizations. These evaluations affect actors' career in the firm, and they actively engage into framing contests, championing their causes, and political negotiations (Burgelman, 1983; Cyert and March, 1963, Kaplan, 2008; Monteiro, 2015). Indeed, Ang, de Jong and van der Poel (2014) suggested that firms are more likely to exit domains that are non-familiar to CEOs, especially in technology-intensive industries. Patterns of socialization among actors (Nerkar and Paruchuri, 2005), allocation of organizational attention (Ocasio, 1997), and bottom-up strategic actions by managers (Burgelman, 1994) deeply affect these processes and outcomes. Future research may fruitfully inquire in depth about these processes and how they might affect the quality of firms' opportunity selection decisions (Csaszar, 2012; Sah and Stiglitz, 1986).

Although the literature comprehensively establishes the micro (firm) and macro (environment) level antecedents of firm-exit, it ignores the network-level characteristics and processes. Collaboration, socialization and information networks act as both facilitators and constraints for organizational actors, and deeply influence their cognitive frames and decision

[4] Indeed, some recent studies have approaches firm-exit from behavioral perspectives (e.g. Shimizu, 2007) and showed how cognitive biases affect decision-making about project termination at individual level (e.g. Elfenbein and Knott, 2015; Elfenbein, Knott and Croson, 2017).

choices. Characteristics of firm's inventor-network determine not only its innovation performance but also technology areas it commits itself to (Nerkar and Paruchuri, 2005). Similarly, an asset's and inventors' embeddedness into the regional or industrial ecosystems can not only bolster their resource-base and performance but also which opportunities they pursue (Kerr, 2010; Narula, 2002; Xia and Li, 2013). Firm's embeddedness in alliance network has similar effects. None of these areas have been probed in context of firm's strategic exit decisions. These can be promising avenues of future research.

Another promising area of inquiry is the political and institutional antecedents of firms' strategic exit decisions. Some studies have documented how political and institutional pressures push firms to exit certain markets (Soule, Swaminathan and Tihanyi, 2014; Wright and Ferris, 1997). Similarly, some recent articles have pointed how firms' political ties lower their exit from emerging economies deficient in high-quality institutions (Sun, Wang and Luo, 2018; Zheng, Singh and Chung, 2017). As asset-divestiture is consequential for knowledge-flow (e.g. proposed acquisition of power and grid business of Alstom by GE, 2015) and dissolution has spatially concentrated human costs (e.g. Nokia's closure of mobile phone manufacturing plant at Bochum, 2008), even governments in developed, market economies interfere with firms' exit decisions. In Alstom case, the French government interfered whereas in Nokia's case, the German and N. Rhine-Westphalian governments put pressures to stall exit decision. This area is under-investigated, with a lot of promise for both strategy and policy. Future research can fruitfully investigate how firms respond to such factors, and to what consequences.

Acknowledging the contributions made by studies focusing on firm-exit from a domain perspective, I posit that approaching it as a strategic decision problem from firm's perspective will be immensely helpful for the strategy and organization scholars. It helps us, as an academic community, to comprehend firms' strategic exit across domains more holistically and comprehensively, and develop hypotheses employing organizational assumptions. Further, it opens the avenues to inquire relationships and interdependence of entry and exit decisions across domains.

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FIGURES

Figure 1: Empirical papers on strategic firm exit in high-impact journals: management and allied disciplines

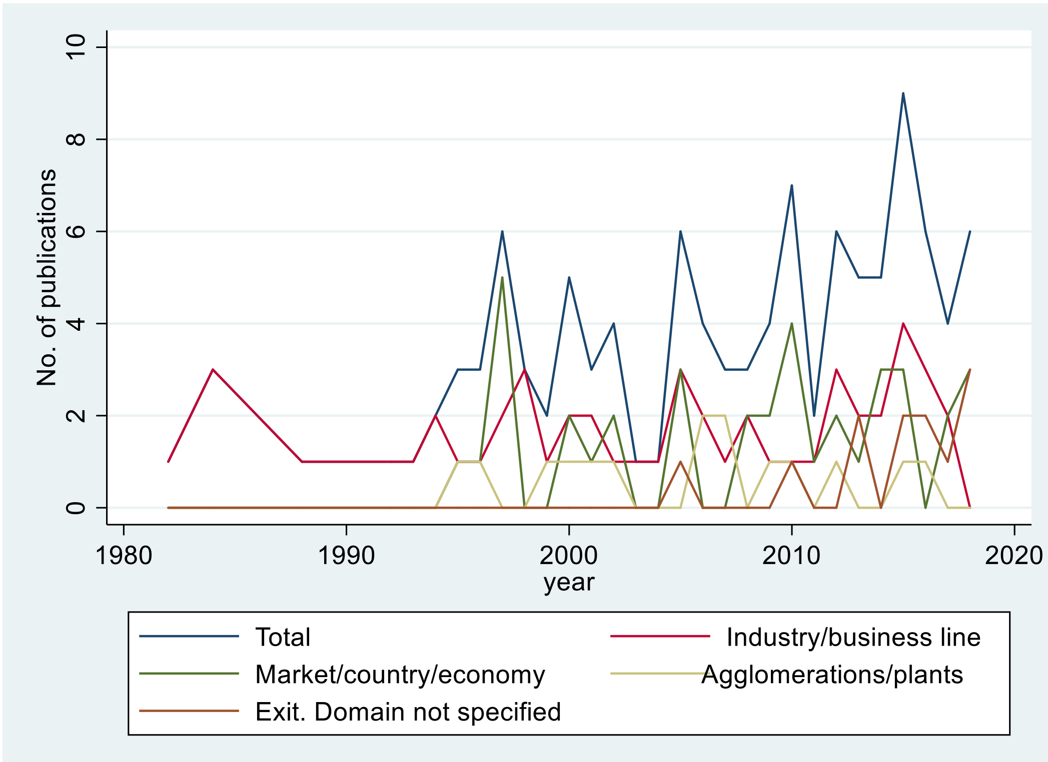
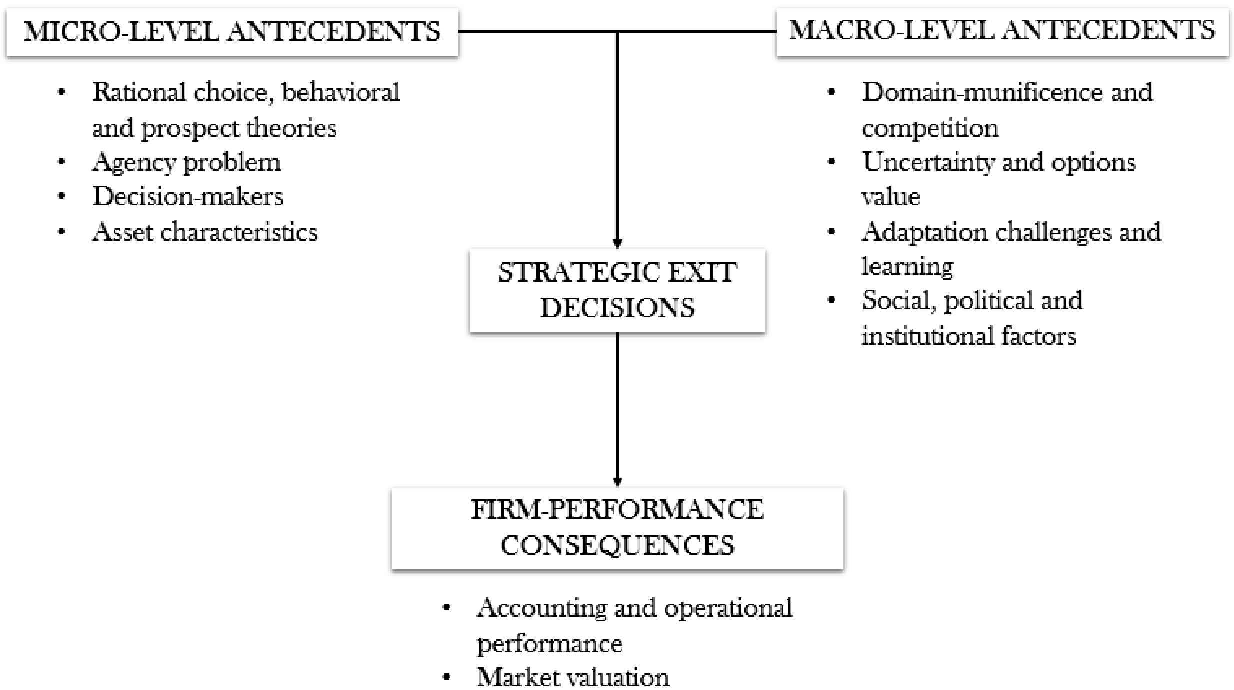


Figure 2: Organizing framework for the literature review



TABLES

Table 1. Firms' strategic exit by type of domains

Opportunity-domain	Industries	Economies (countries)	Agglomerations
Change	Firm's corporate scope	Firm's geographical scope	Firm's scale/scope of production
Mode	Sell-off or dissolution of business unit or division	Sell-off or dissolution of subsidiary, joint venture or affiliates	Closure of establishment or change in its ownership
Literature	Strategy & organization, economics, and finance (performance)	International strategy & organization, economics, and finance (performance)	Economics, innovation studies, and economic geography

Table 2: Articles used for review, along with their source journals.

Name of the Journal	Articles*
American Sociological Review	Ahmadjian and Robbins, 2005 (Z)
American Economic Review	Duranton, 2007 (C)
Econometrica	Olley and Pakes, 1996 (C)
Economics Letters	Colombo and Delmastro, 2000 (C); Pennings and Sleuwaegen, 2000 (B)
Journal of Economic Behavior & Organization	Sandri et al, 2010 (Z)
Journal of International Economics	Bernard et al, 2006a (C)
Journal of Monetary Economics	Bernard et al, 2006b (C)
The Review of Economics and Statistics	Bernard and Jensen, 2007 (C)
Journal of Economic Geography	Kim et al, 2010 (B)
European Urban and Regional Studies	Hudson and Swanton, 2012 (C)

Journal of Urban Economics	Kerr, 2010 (C)
Regional Studies	Østergaard and Park, 2015 (C)
Journal of Political Economy	Jovanovic and MacDonald, 1994 (A)
Industrial and Corporate Change	O'Brien and Folta, 2009 (A)
Research Policy	Colombo and Delmastro, 2001 (C); Livanis and Lamin, 2016 (C); Narula, 2002 (B)
Financial Management	Gombola and Tsetsekos, 1999 (C)
Journal of Banking & Finance	Borisova and Brown, 2013 (Z)
Journal of Corporate Finance	Ang et al, 2014 (A); Finlay et al, 2018 (Z); Mulherin and Boone, 2000 (A); Prezas and Simonyan, 2015 (A); Zhou et al, 2011 (B).
Journal of Financial Economics	Schlingemann et al, 2002 (A)
The Journal of Finance	Bates, 2005 (B); Bethel et al, 1998 (A); Dittmar and Shivdasani, 2003 (A)
The Review of Financial Studies	Landlier et al, 2009 (B); Moel and Tufano, 2002 (C)
Academy of Management Journal	Baum and Korn, 1996 (B); Brauer and Wiersema, 2012 (A); Harrigan, 1982 (A); Hoskisson et al, 1984 (A); Markides, 1992 (A); Montgomery, Thomas and Kamath, 1984 (A); Sanders, 2001 (A); Shimizu, 2007 (A)
Administrative Science Quarterly	Mitchell, 1994 (A); Zuckerman, 2000 (A)
Asia Pacific Business Review	Pattnaik and Lee, 2014 (B)
Asia Pacific Journal of Management	Wu et al, 2011 (A)
International Business Review	Procher and Engel, 2018 (B); Sun et al, 2018 (B); Varum et al, 2014 (B)
International Journal of Industrial Organization	Doms et al, 1995 (C)
Journal of Business Research	Powell and Lim, 2018 (B)
Journal of International Business Studies	Belderbos and Zou, 2009 (B); Berry and Zhou, 2010 (B); Colantone and Sleuwaegen, 2010 (B); Coucke and Sleuwaegen, 2008 (B); Mata and Freitas, 2012 (B); Meschi, 2005 (B)
Journal of Knowledge Management	Peruffo et al, 2018 (Z)
Journal of Management	Bergh, 1998 (A); Bergh and Sharp, 2015 (Z); Brauer et al, 2017 (Z); Lee and Madhavan, 2010 (A); Morrow et al, 2004 (A); Shimizu and Hitt, 2005 (A); Zheng

	et al, 2017 (B)
Journal of Management Studies	Tangpong et al, 2015 (A/B)
Journal of World Business	Song, 2015 (B)
Organization Science	Bergh and Lawless, 1998 (A); Berry, 2010 (B), 2013 (B); Boeker et al, 1997 (B); Chung and Luo, 2008 (A); Feldman, 2014 (A); Gaba and Terlaak, 2013 (Z); Lien and Klein, 2013 (A); Vidal and Mitchell, 2015 (Z)
Strategic Management Journal	Barkema et al, 1996 (B); Baum and Korn, 1999 (B); Bergh, 1995 (A), 1997 (A); Bergh and Holbein, 1997(A/B); Bergh and Lim, 2008 (A/B); Bower and Wiersema, 2005 (A); Capron et al, 2001 (A/B); Chang, 1996 (A); Chang and Singh, 1999 (A); Chen et al, 2017 (T); Damaraju et al, 2015 (A); Duhaime and Grant, 1984 (A); Durand and Vergne, 2015 (A); Elfenbein and Knott, 2015 (B); Feldman et al, 2016 (Z); Fortune and Mitchell, 2012 (A); Hayward and Shimizu, 2006 (A); Johnson et al, 1993 (A); Karim, 2006 (A); Karim and Capron, 2016 (A); Kaul, 2012 (A); Kumar, 2005 (A/B); Kuusela et al, 2017 (A/B); Lee and Song, 2012 (B); Li, 1995 (B); Mata and Portugal, 2000 (B), 2002 (B); Miller and Yang, 2016 (A); Moliterno and Wiersema, 2016 (Z); Montgomery and Thomas, 1988 (A); Shaver et al, 1997 (B); Soule et al, 2014 (B); Vidal and Mitchell, 2018 (Z); Wood, 2009 (C); Wright and Ferris, 1997 (B); Xia and Li, 2013 (A); Zaheer and Mosakowski, 1997 (B)
The Leadership Quarterly	Chiu et al, 2016 (A)

*A = Exit from industry, product market, or business line; divestiture or dissolution of business units. B = Exit from geographical market, or country; divestiture or dissolution of international subsidiary. C = Exit from agglomerations; divestiture or dissolution of plants, or establishments. T = Exit from technology area. Z = Domain/asset-type not specified.

Table 3. Micro (firm) level antecedents of firms' strategic exit decisions

Mechanism	Variables, moderators, and references
Rational choice, behavioral and prospect theories	• Firm performance vis-à-vis aspirations (-): Berry, 2010; Boeker et al, 1997; Hoskisson et al, 1994; Kaul, 2012; Markides, 1992; Mata and Portugal, 2002; Moliterno and Wiersema, 2007; Vidal and Mitchell, 2015 Moderator: o Financial slack: Kuusela, Keil and Maula, 2017 • Opportunity costs (+): Bernard and Jensen, 2007; Berry, 2010; Colombo and Delmastro, 2000; Moel and Tufano, 2002; Procher and Engel, 2018; Wood, 2009 • Innovation-led strategy (+): Kaul, 2012 • Intensity of search/entries (+): Berry, 2010; Chang, 1996; Miller and Yang, 2016; Procher and Engel, 2018 Moderator: o Relatedness of the entered domain: Chang, 1996; Miller and Yang, 2016 o Relatedness of acquired assets in horizontal M&A: Capron et al, 2001
Agency problem	• Over-diversification (+): Bergh and Holbein, 1997; Hoskisson et al, 1994; Markides, 1992; Powell and Lim, 2018 Moderators: o Effective control, e.g. outside directors, institutional or blockholder ownership: Bergh and Sharp, 2015; Johnson et al, 1993; Shimizu and Hitt, 2005 o Alignment of managerial interests with shareholders', e.g. stock ownership or options: Bergh and Sharp, 2015; Elfenbein and Knott, 2015; Johnson et al, 1993; Sanders, 2001 • Large shareholders (-): Wu and Phan, 2011 • Family-ownership (-): Chung and Luo, 2008; Feldman et al, 2016
Decision-makers	• CEO-succession (+): Boeker et al, 1997; Chiu et al, 2016; Hayward and Shimizu, 2006; Shimizu and Hitt, 2005; Moderators:

	○ Outside or inside CEO successor: Chiu et al, 2016; Hayward and Shimizu, 2006; Shimizu and Hitt, 2005 ○ CEO-tenure: Feldman, 2014 • Domain-familiarity; information about assets (-): Ang et al, 2014; Landlier et al, 2009
Asset characteristics	• Strategic core-ness; organizational integration; relatedness to parent's resource-base (-): Bergh, 1997; Chang and Singh, 1999; Lien and Klein, 2013; Schlingemann et al, 2002; Xia and Li, 2013 • Synergies; leverage of parent's learning, competences (-): Bergh, 1995, 1998; Berry, 2013; Chang, 1996; Duhaime and Grant, 1984; Li, 1995; Song, 2015 • Size (-): Bergh, 1995, 1998; Colombo and Delmastro, 2000, 2001; Mitchell, 1994; Fortune and Mitchell, 2012; Shimizu and Hitt, 2005; Song, 2015 • Resourcefulness; competitiveness (-): Duhaime and Grant, 1984; Mata and Portugal, 2000; Song, 2015 • Performance (-): Bergh, 1998; Berry, 2013; Doms et al, 1995; Duhaime and Grant, 1984; Prezas and Simonyan, 2015; Schlingemann et al, 2002; Wood, 2009 • Sunk costs (-): Colombo and Delmastro, 2001; Doms et al, 1995; Mata and Portugal, 2000 • Subunit power/external resources-access (-): Xia and Li, 2013 • Acquired (+): Chang and Singh, 1999 • Option value (-): Belderbos and Zou, 2009; Song, 2015

Table 4. Macro (environment) level antecedents of firms' strategic exit decisions

Mechanism	**Variables, moderators, and references**
Domain munificence and competition	• Adverse demand conditions (+): Berry, 2010, 2013; Harrigan, 1982; Elfenbein and Knott, 2015 • Excess capacity and price wars (+): Harrigan, 1982; Wood, 2009 • Import-intensity and foreign firms (+): Bernard et al, 2006a, b; Bowen and Wiersema, 2005; Colantone and Sleuwaegen, 2010; Coucke and Sleuwaegen, 2008; Olley and Pakes, 1996 • Entry of large, established firms (+): Khanna and Tice, 2001; Chen et al, 2017

	• Threat of resource-expropriation (+):Livanis and Lamin, 2015 • Multimarket competition (-): Baum and Korn, 1996, 1999; Boeker, Goodstein, Stephan and Murmann, 1997 Moderator: o Level of dyadic rivalry: Baum and Korn, 1999
Uncertainty and options value	• Marco-economic uncertainty (-): Berry, 2013; Elfenbein and Knott, 2015; Zhou et al, 2011 Moderators: o Level of diversification: Bergh, 1998; Bergh and Lawless, 1998 o Sunk costs of exit and entry: Damaraju et al, 2015; Moel and Tufano, 2002; O'Brien and Folta, 2009 o Growth or switch option of the asset: Belderbos and Zou, 2009; Song, 2015 o Idiosyncratic or industry-level uncertainty: Gaba and Terlaak, 2013 • Political and regulatory uncertainty (+): Berry, 2013; Sun et al, 2018
Adaptation challenges and learning	• Relatedness of industrial/technological domain (-): Bergh, 1995, 1998; Berry, 2013; Chang, 1996; Duhaime & Grant, 1984; Li, 1995; Song 2014. • Foreignness in an economy (+): Barkema et al, 1996; Kim et al, 2010; Pattnaik and Lee, 2014; Varum et al, 2014; Zaheer and Mosakowski, 1997 Moderators: o Cross national distance between firm's home and host country: Berry, Guillen and Zhou, 2010 o Mode of entry: Barkema et al, 1996; Pattnaik and Lee, 2014 o Experiential learning: Barkema et al, 1996; Kim et al, 2010; Pattnaik and Lee, 2014; Shaver et al, 1997 o Vicarious learning: Kim et al, 2014; Shaver et al, 1997 • Technological disruptions: Duranton, 2007; Jovanovic and MacDonald, 1994; Kerr, 2010; Narula, 2002; Østergaard and Park, 2015
Social, political and institutional factors	• Social contestation, political protests and institutional pressures (+): Durand and Vergne, 2015; Soule et al, 2014; Wright and Ferris, 1997 Moderator: o Political freedom and transparency of the institutions: Soule et al, 2014

- Political ties (-): Sun et al, 2018; Zheng et al, 2017
- Stakeholder-based business system (-):Ahmadjian and Robbins, 2005

Table 5. Performance-consequences of firms' strategic exit decisions

Variables, mechanism, moderators, and references
• Accounting and operational performance (+) Mechanism: o Sale of loss-making assets: Brauer et al, 2017; Lee and Madhavan, 2010; Montgomery and Thomas, 1988; Prezas and Simonyan, 2015 Moderators: o Growth-rate and liquidity of asset's industry: Finlay, Marshall and McColgan, 2016; Morrow, Johnson and Busenitz, 2004; Schlingemann, Stulz, and Walkling, 2002 o Product-market uncertainty and asset's relatedness: Bergh, 1998 o Firm's pre-exit performance: Tangpong et al, 2015; Vidal and Mitchell, 2018 o Legacy assets: Feldman, 2014 o Learning – experiential and vicarious: Bergh and Lim, 2008; Brauer et al, 2017 • Market valuation (+) Mechanism: o Favoring growth-opportunities: Bates, 2005 o Lowering negative synergies: Lien and Klein, 2013; Mulherin and Boone, 2000 o Focus on core markets and competencies: Kumar, 2005 o Decrease in diversification discount: Dittmar and Shivdasani, 2003; Zuckerman, 2000 Moderators: o Distress sale of valuable assets: Tsetsekos and Gombola, 1992 o Non-economic reasons: Wright and Ferris, 1997 o Imitative decision: Brauer and Wiersema, 2012

- De-diversification: Bergh, 1998
- Abandoning assets with option value under uncertainty and concentration in asset’s domain: Kumar, 2005
- Utilization of proceeds – dividends, debt-repayment, investment in growth options: Bates, 2005

MISSED CHANCES AND UNFULFILLED HOPES: WHY DO FIRMS MAKE ERRORS WHEN SELECTING TECHNOLOGICAL OPPORTUNITIES?

Amit Kumar and Elisa Operti

ABSTRACT

Why do firms sometimes dismiss high-quality technological opportunities and retain low-quality ones? We propose that the social and geographical locus where an opportunity originated affects the likelihood of error (omission or commission) in its selection. Inventors embedded in cohesive networks or positioned in core locations can shape the shared cognitive frames, which decision-makers use to assess technological opportunities. Hence, the opportunities they generate are often selected, even if they are of lower quality. In contrast, inventors that span boundaries are less capable of influencing the shared frames used to evaluate technologies. Thus, the technological opportunities they generate are likely to be dismissed. Our results, based on the data of the mobile phone and personal development agenda industry between 1990 and 2010, corroborate our hypotheses.

Keywords: Opportunity selection; cognitive frames; boundary spanning; patent renewal

INTRODUCTION

The value of novel technologies is difficult to predict *ex ante*, especially in the industries characterized by rapid technological changes (Tripsas, 1997a, 1997b; Tripsas & Gavetti, 2000; Benner & Tripsas, 2012). To keep abreast of competition, firms must continually reconfigure their technological portfolios, entering emerging technologies within the "window of learning," allowing an exit for obsolete ones (Tripsas & Gavetti, 2000; Eggers, 2012, 2016). However, firms often make errors in evaluating technologies. For example, Motorola Mobile developed cameras for mobile phones earlier than any other competitor. However, the top management did not see value in having a camera on a phone and they asked the chief architect and lead engineer working on the project in Phoenix to leave the firm and pursue their project elsewhere.[5] Nokia kept committing significant investments in Symbian even when top and middle managers were aware of its inferiority to iOS and Android (Vuori & Huy, 2015: 18).

These examples illustrate that omission errors (i.e., dismissing a high-quality technological opportunity) and commission errors (i.e., retaining a low-quality one) are quite common in fast-changing, uncertain industries (Garud, Nayyar & Shapira, 1997; Csaszar, 2012). However, why do such errors occur? Scholars have approached this question using both a structural and a cognitive perspective. The first avenue of research (Sah & Stiglitz, 1986; Ocasio, 1997; Knudsen and Levinthal 2007; Csaszar, 2012) explored how the formal structure of the organization – e.g., its degree of hierarchical control – affects information aggregation in an organization, thereby prompting biases in decision-making. This stream of research demonstrated that hierarchies maximize omission errors, while less centralized structures maximize commission errors (Sah & Stiglitz,1986; Csaszar, 2012). Scholarly work adopting a cognitive lens (Tripsas & Gavetti, 2000; Kaplan & Tripsas, 2008; Eggers &

[5] The episode was reported by Andrea Cuomo (Executive Vice President at STMicroelectronics) during his keynote speech at the SMS special Conference in Rome in 2016.

Kaplan, 2009) focused on how information about opportunities is interpreted in an organization. According to this view, the cognitive frames of the organizational actors determine which issues (problems, opportunities, and threats) they enact as relevant and how they conceptualize the value and relevance of an option in the context of their organization (Daft & Weick, 1984; Ocasio, 1997). Thus, commission and omission errors reflect the inaccuracies of the predominant cognitive frames in an organization used by organizational members to evaluate technological opportunities (Burgelman, 1994; Kaplan & Tripsas, 2008).

While both approaches advanced our understanding of the sources of selection errors, they have their own shortcomings. The structural perspective neglects the fact that social interactions between individuals within an organization affect information aggregation above and beyond the effects of formal hierarchy (McEvily, Soda & Tortoriello, 2014). Research in the cognitive tradition shed light on how social interactions contribute to the emergence of predominant frames within an organization (Walsh, 1995); however, it provided a limited understanding of how structural factors affect the formation of predominant frames and technology selection within an organization (Cornelissen & Werner, 2014).

In this paper, we borrow from both these perspectives to provide a more comprehensive understanding of the determinants of selection errors in established organizations. Since socialization plays a key role in the emergence of predominant frames and interpretations in an organization (Walsh, 1995), we examine how inventors' social interactions with peers and with key decision-makers affects their capacity to influence the process of technology selection. We propose that socially or geographically embedded inventors are more effective at sharing their frames within the organization. Because frames help actors to make sense of and interpret technological opportunities, key decision-makers are more likely to make commission errors when evaluating technological opportunities by individuals endowed with cohesive social networks or who are proximate to the key decision-makers. In contrast, individuals spanning boundaries between disconnected groups or locations are less able to influence the predominant frames used to assess and evaluate technological opportunities within the organization. Hence, the opportunities they generate are more prone to omission errors (i.e., they are more likely to be disregarded even if they are of a higher quality).

We examine the antecedents of selection errors in the context of the mobile phone and personal digital assistant (henceforth, PDA) industry between 1990 and 2010, combining the data on patents, inventors, products, and financial performance of a sample of 53 established industry players. We operationalize technological opportunities available to a firm in terms of its patented innovations. To capture firms' opportunity selection decisions, we use patent renewal data (Lanjouw, Pakes & Putnam, 1998; Serrano, 2010). We measure errors in terms of deviations from the optimal decision based on patent quality indicators (Griliches, 1990; Trajtenberg, 1990; Bessen, 2008). The results provide support for both of our main hypotheses.

Our research makes two primary contributions. First, we contribute to studies of the sources of selection errors within organizations (Sah & Stiglitz, 1986; Ocasio, 1997; Knudsen & Levinthal 2007; Csaszar, 2012; Klingebiel, 2017). Departing from the traditional area of emphasis for this research on information aggregation as a determinant of errors, we propose that the structure influences selection by determining which frames key decision-makers use to interpret information about technological opportunities (Kaplan, 2008; Kaplan & Tripsas, 2008; Eggers, 2016.) Our findings suggest that while studying decision-making in organizations, scholars should pay more attention to the interplay of formal structural features and informal social interactions (McEvily, Soda & Tortoriello, 2014), which originate from collaborations and collocation.

Secondly, our work helps reconcile existing contradictory findings regarding the relative benefits of cohesion versus boundary-spanning within organizations (Nerkar & Paruchuri, 2005; Reagans & McEvily, 2003; Lahiri, 2010; Monteiro, 2015). Research on the management of R&D networks has previously highlighted the benefits of boundary-spanning for idea generation, but it left unclear under which conditions organizations could benefit from the breakthrough ideas generated by such inventors. Our results indicate that one of the potential reasons why organizations may not benefit from the cognitively distant or dissonant breakthroughs generated by the boundary-spanners relates to their limited ability to shape predominant frames in the organization. Conceptualizing innovation as a two-stage model entailing not only generation but also selection of the technological opportunities (Knudsen & Levinthal, 2007) can thus help reconcile previous contradictory findings. This is the case even though the factors instrumental in the generation of technologies may differ substantially from those driving their selection.

THEORY AND HYPOTHESES

Selection of technological opportunities as a framing contest

According to evolutionary accounts (Baum & McKelvey, 1999; Lovas & Ghoshal, 2000), technological opportunities are generated through a process of variation, selection, and retention. Organizations generate technological opportunities by engaging in both distant and local searches (Levitt & March 1988, Tripsas & Gavetti 2000). Subsequently, based on the ensuing learning experiences, organizations select their opportunities: some are developed further and commercialized and others are rejected or abandoned (Burgelman, 1983a, 1983b, 1994; Knudsen & Levinthal, 2007). Scholars recognized that the internal selection processes shape organizations' technological trajectories (Levinthal, 1997; Levinthal & Myatt, 1994) and that organizations are exposed to the pressures of external selection when they fail to select the right technological trajectories (Singh, Tucker & House, 1986).

Selection and retention of technological opportunities within a large organization can result from either top-down, deliberate choices of top managers (McGrath, 1997; Adner & Levinthal, 2004) or bottom-up, emergent strategic actions undertaken by middle managers in response to market challenges (Burgelman, 1983a). In both these cases, if decision-makers were rational, they would retain high-quality options and abandon low-quality ones (McGrath, 1997; Zardkoohi, 2004; Bessen, 2008). However, managers are boundedly rational (Barnett, 2008) and they operate under uncertainty (Adner & Levinthal, 2004). Thus, selection and retention of technological opportunities in large organizations is often plagued by decision-making biases (Reitzig & Sorenson, 2013; Criscuolo *et al.*, 2017). For instance, Reitzig and Sorenson (2013) showed that firm members systematically underestimate ideas associated with employees outside their subunit, thereby lowering the probability of adopting of those ideas. Consistent with prior studies (Sah & Stiglitz, 1986; Garud *et al.*, 1997; Csaszar, 2012), we label deviations from objective quality assessments as errors (**Figure 1**). A commission error occurs when key decision-makers select an inferior, low-quality technological opportunity. An omission error occurs when the firm dismisses a superior, high-quality technological opportunity.

--------------Insert Figure 1 here--------------

Why do omission and commission errors occur? Previous work addressed this question and focused on how structure affects information aggregation in organizations (Csaszar, 2012). Complementing this line of work, we study how interactions between organizational members affect the interpretation of information about technological opportunities in an organization's portfolio. Organizations have been conceptualized as "interpretation systems," in which organizational actors interpret equivocal information through the processes of sense-making (Daft & Weick, 1984; Weick, 1990). In a complex and information-munificent environment, such processes are facilitated by the pre-existing "cognitive frames" of the actors (Goffman, 1974). An actor's cognitive frame has two key elements: (1) simplified, low-dimensional cognitive representations of the complex, high-dimensional fitness landscape, and (2) mental models of causal relationships among choices and outcomes (Gavetti & Levinthal, 2000; Johnson-Laird, 1983; Walsh, 1995).

Cognitive frames related to a technology, labeled as "technological frames," exemplify key actors' understanding of a technology: what it is, how it works, which problems it solves, and how it performs *vis-à-vis* its alternatives (Orlikowski & Gash, 1994). Such frames help actors (producers, users, and institutions) make sense of the technology (Kaplan & Tripsas, 2008). If a technological opportunity is incongruent (distant from or dissonant) with the predominant frames, actors fail to foresee ways to exploit and extend it (Ocasio, 1997), even if the technology is promising. Thus, it is likely to be rejected or abandoned regardless of its technological potential. Conversely, if a technological opportunity is aligned with the collective frames, it is perceived relevant and retained regardless of its quality.

Frames at the organizational level are not homogenous. Multiple and often competing frames coexist within large organizations (Kaplan, 2008). Thus, technology choices can be modeled as a contest between multiple frames (Kaplan, 2008; Burgelman, 1983a, b; 1994). Here, we propose that in organizations, predominant frames and beliefs about a technological opportunity emerge through social interactions that technology producers (R&D scientists and inventors) maintain with their peers (Nerkar & Paruchuri, 2005) and with the key decision-makers involved in opportunity-selection decisions, (such as CEOs, CTOs, BU heads, and product managers) (Eggers & Kaplan, 2009). Depending on their social and geographical position, certain individuals will be more effective than others at sharing their frames and interpretations within the organization (Goffman, 1974; Kaplan, 2008; Eggers, 2016). Thus, they will have a greater influence on the way key decision-makers and peers comprehend technologies and encounter more favorable decisions even when their technological projects are characterized as low-quality.

Interactions with peers: Intra-organizational networks and selection errors

Technology development within organizations is carried out by R&D scientists and inventors collaborating on multiple projects (Allen & Cohen, 1969). An intra-organizational collaboration network consists of all the inventors in the firm, including two inventors who are connected if they have collaborated on at least one invention. Earlier research has shown that the intra-organizational networks reflect social interactions and knowledge flows between inventors (Nerkar & Paruchuri, 2005), thus playing an important role in shaping organizational processes and determining R&D outcomes (Reagans & McEvily, 2003; Carnabuci & Operti, 2013; Funk, 2014; Paruchuri & Awate, 2017).

Previous research has uncovered the relative benefits of network cohesion and boundary-spanning. Boundary-spanners (actors connecting alters who are not directly connected with one another) have access to diverse information (Coleman, 1990; Burt, 1992). They are more productive (Parachuri, 2010) and more likely to discover breakthroughs (Fleming, Mingo & Chen, 2007). Network cohesion, in contrast, has been associated with an increased depth of knowledge, superior mobilization, and norm enforcement. Common connections allow individuals to triangulate the information they receive (Tortoriello & Krackhardt, 2010), “invest time, energy, and efforts in sharing knowledge with others,” (Reagans & McEvily, 2003: 240), develop a common understanding akin to communities of practice (e.g., Brown & Duguid, 2001), and either sanction or reject diverse viewpoints (Burcharth & Fosfuri, 2014).

Elaborating on the same mechanisms, we expect that network cohesion will be associated with an increased rate of commission errors and a reduced rate of omission errors. Inventors embedded in cohesive networks typically come up with less radical and less valuable ideas (Burt 1992; Fleming et al. 2007). However, thanks to the information depth and mobilization advantages commonly associated with third parties, inventors embedded in cohesive networks can disseminate their frames and interpretations more effectively in the organization. Thus, they are more capable of shaping the dominant beliefs in the organization regarding the technological opportunities they have generated. By contrast, boundary-spanners lack common connections with their collaborators; hence, they are less effective in convincing the latter about the quality of distant or dissonant opportunities they have envisioned. Lacking in cohesive social support, they are also less capable of mobilizing their peers to influence the predominant cognitive frames in organization in the case of framing contests. Therefore, when they produce cognitively distant, radical combinations of high quality (Fleming *et al*. 2007; Tortoriello & Krackhardt, 2010), these inventions may be comprehended less in the organization, go unnoticed by the decision-makers, and get summarily rejected or abandoned by the firm.

These expectations resonate well with some anecdotes describing corporate R&D project selection. Royer (2003) showed that Essilor, the French maker of corrective lenses for eyeglasses, took eleven years to terminate a project developing a lightweight, shatter-resistant, scratch-resistant, and light-sensitive lens. Though there have been concerns about the viability and quality of such lenses since 1981, the project was never questioned by the firm's top management team because of the cohesive support built by the researcher within the team around the project. Only after a new R&D manager was appointed in 1989 did the top management order a thorough and objective assessment of the project and considered its termination.

Based upon the discussions above, we expect that boundary-spanning inventors will come up with high-quality ideas, but they will be less able to share their frames with peers. Hence, the opportunities they generate are less likely to be interpreted as useful even when their quality is greater, and these ideas end up being rejected. In contrast, inventors embedded in cohesive networks can effectively share their frames in the organization. Hence, the technological opportunities they generate are more likely to be retained, even if they have inferior value:

H1a: The more cohesive the network of the inventors that generated a technological opportunity, the greater the likelihood of commission errors in its evaluation.

H1b: The greater the extent of network boundary-spanning of the inventors that generated a technological opportunity, the greater the likelihood of omission errors in its evaluation.

Interactions with key decision-makers: Geographic proximity and selection errors

The internationalization of firms' R&D activities (Granstrand, Håkanson, & Sjölander, 1993; Lahiri, 2010) has led to an increasing distance between technology producers and key decision-makers (Bouquet & Birkinshaw, 2008; Monteiro, 2015).

Bottom-up processing of data (experiences) and socialization are two key factors influencing the formation of cognitive frames (Walsh, 1995). Collocated actors are more likely to have common experiences. Furthermore, geographical proximity between actors engenders social and cognitive proximity (Boschma, 2005). Thus, inventors located at headquarters are more likely to have congruent cognitive frames when compared with those of key decision-makers. Consequently, technological opportunities generated by such inventors, even when they are of low-quality, are more likely to resonate with the key issues that the decision-makers have enacted (Ocasio, 1997). In contrast, the experiences of geographically distant inventors may differ substantially from those of key decision-makers. Such inventors often engage in social exchanges with regional actors external to the firm than with their peers or decision-makers located at faraway headquarters (Andersson, Forsgren & Holm, 2002). As a result, they develop frames and interpretations about technological opportunities independent of what is predominantly held by the actors at headquarters. Thus, technologies generated by such inventors may be considered irrelevant by the key decision-makers even though research shows that embeddedness in remote clusters leads to higher-quality innovations (Funk, 2014).

Geographical proximity becomes a substantial advantage in mobilizing decision-makers, especially when competing frames emerge and the inventors need to engage in framing contests (Monteiro, 2015). Collocation increases the chances of serendipitous interactions and lowers the costs of scheduled ones (Catalini, 2017). When technology-producers and key decision-makers have different cognitive representations and mental models, they can sort it out through argumentation, contestation, mutual sense-making, and sense-giving processes (Daft & Weick, 1984). In contrast, geographically distant inventors cannot interact with decision-makers iteratively with the same frequency as the collocated or proximate ones. Thus, they cannot influence decision-makers' frames and interpretations in order to obtain a buy-in (Burgelman, 1983a; Louis & Sutton, 1991; Walsh, 1995). Elaborating on these mechanisms, we propose that technological opportunities generated by the inventors located at a distance from the key decision-makers have a lower likelihood of acceptance even when their quality is objectively superior. To illustrate this, consider the troubled relationships between the Xerox headquarters, located first in Rochester (New York) and then in Stamford (Connecticut), and the Xerox Palo Alto Research Center, known as Xerox PARC, which was established in 1970 as a semi-autonomous unit. The unit was in California and benefited tremendously from the networks and specialized human capital available in the region, generating many modern computing technologies, such as the graphical user interface (GUI), laser printing, text editors, and Ethernet. However, these inventions were frowned upon by the board of directors at that time, who ordered the Xerox engineers to share them with Apple technicians. As PARC's Vice President and Chief IP officer, Damon Matteo, recollects,[6] such technologies were too frequently developed on the sidelines. Because of geographic distance, PARC researchers were not able to champion their way of seeing the "office of the future" with executives. Evaluators did not realize the potential of ideas developed at PARC and they remained focused on copiers. Accordingly, we hypothesize that:

H2a: The greater the geographical proximity of the inventors that generated a technological opportunity to the key decision-makers, the greater the likelihood of commission errors in its evaluation.

H2a: The greater the geographical distance between the inventors that generated a technological opportunity and the key decision-makers, the greater the likelihood of omission errors in its evaluation.

DATA AND METHODS

Setting and sample

We tested our hypotheses in the mobile phone and PDA industry between 1990 and 2010. This context was characterized by high product-market uncertainty, intense competition, and severe technological disruptions (Kenney & Pon, 2011; Reidenberg *et al*., 2015; Vuori & Huy, 2015). This setting is ideal for our study for two reasons. First, it is an R&D-intensive context where both generation and selection of technological opportunities are essential. Many industry leaders made novel inventions, but failed to exploit them (Kenny & Pon, 2011). Microsoft, for example, developed an electronic reader back in 1998 and acquired Danger in 2008, which had a working smartphone prototype. Similarly, Nokia prototyped a smartphone with a touchscreen in 1996, but was unable to compete with Apple and Google a decade later (Vuori & Huy, 2015). Understanding why firms dismiss promising opportunities and commit

[6] This example elaborates on the following article: https://www.forbes.com/sites/marshallphelps/2015/11/14/the-dumbest-innovation-mistakes-ever/#56c40a031f2d

to low-quality ones is critical in this context. Second, this industry is ideal in terms of data availability. Mobile phone firms proactively patent their inventions and must manage their patent portfolios under resource constraints (Reitzig, 2004). The context allows us to use patent renewal choices as a proxy for technology selection.

To create our sample, we used both product data and USPTO patent data. We retrieved a list of firms that launched at least five products (mobile phones or PDAs) from PDAdb.net, the world's largest online repository of mobile devices. Next, we retrieved all patents in each mobile phone USPTO technology class granted between 1990 and 2010 using Google patents and the disambiguated Harvard patent database (Li *et al*., 2014).[7] Our sample includes all firms that launched at least five mobile devices or appeared in the top ten patent assignees in the mobile industry during at least one year between 1990 and 2010. This step returned a list of 59 firms. For each firm, we collected financial data from Compustat. Six firms had missing financial data. Thus, our final sample includes 53 firms for which product, patent, and Compustat information were available. We also conducted four interviews[8] with professionals working on patent portfolio management. The interviews explored how patent renewal decisions come about, the actors involved, the extent to which renewals reflect the firms' technology strategy. Two interviewees allowed us to record the interviews. We took notes during the other two interviews and transcribed the notes. We also attended a one-day seminar and webinar on the topic, organized by the MIP European Patent Reform Forum and Questel (an IP consulting firm), respectively. The qualitative data helped us construct our measures and interpret the results.

Dependent Variables

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[7] According to Reidenberg *et al*. (2015), the USPTO technology classes that are relevant to the mobile phone and PDA industries are: 320, 341, 349, 361, 370, 375, 379, 398, 455, 704, 706, 707, 715 and 719.

[8] We contacted two IP lawyers working at the headquarters of a semiconductor handset producer and a mobile phone company, in addition to two IP consultants, one of whom was working for a large public consortium and one for an IP consulting firm. The consultants had prior corporate experience and are now advising a broad range of companies regarding IP portfolio management and licensing issues.

Research on omission and commission errors presents serious hurdles because, as emphasized by Csazsar (2012: 618), the operationalization of dependent variables requires the following information: (1) the choice-set of technological opportunities that a firm has at any given time, (2) information regarding which opportunities the firm selected and which ones it dismissed, and (3) a measure of the underlying quality of each technological opportunity. To address the first challenge, we operationalized technological opportunities available to a firm in terms of patented inventions.

Information regarding (2) and (3) was harder to collect. Firms rarely document the projects they reject, rendering it difficult to observe internal selection decisions for a large sample of firms (Csaszar, 2012).[9] In this paper, we use publicly available data on renewal (maintenance) of patents to trace which technological opportunities a firm decided to retain and which it dismissed (Bessen, 2008; Serrano, 2010). The USPTO requires an assignee to renew its patent rights over the invention after 3.5 (4th), 7.5 (8th), and 11.5 (12th) years after the patent granting. At each stage, the assignee must pay a gradually increasing maintenance fee. At each renewal request, the firm that owns the patent rights (assignee) needs to decide whether to pay the maintenance fee and keep the patent rights over the protected innovation. Both prior research (Granstrand, 1999a, b; Davis, 2004; Hanel, 2006) and field interviews indicate that established firms take a systematic approach to patent renewal decisions. These decisions reflect the shared views of the executives at company headquarters and in the R&D units based on company strategy. In the words of one individual we interviewed, who worked at the corporate headquarters of a handset manufacturer:

"*We advise the BU [Business Units] on what to do on a regular basis when we have our usual strategy planning meeting with them. We also have worldwide strategy meetings annually [with BU Strategy heads]. We review our portfolios and all granted patents in all*

[9] Most studies on the selection of technological opportunities within organizations build on primary data from a single firm for a short time window (Criscuolo *et al*., 2017; Reitzig & Sorenson, 2013; Monteiro, 2015)

jurisdictions that year, and we prepare the plan for the following year. Here, we decide, for example, that these are the areas where we need to file more, these are the areas where we need to file less, these are the areas in which we are facing problems and need to exit, or here is where we need to develop a portfolio."

Archival evidence corroborates the view that renewal decisions reflect corporate technology selection decisions. For instance, Davis (2004) shows that firms like Dow Chemical conduct a business audit of its intellectual property. As such, each BU categorizes its patents by their value, and a screening methodology is implemented at the corporate level. At IBM, a company well-known for its patent portfolio "best practices" (Davis, 2004), patent portfolio pruning is based on specific evaluation criteria (use, value, enforceability) and this takes place at the corporate level. Consistent with this evidence, we assume that if the firm renews a patent, then its key decision-makers must have decided to retain the technological opportunity protected by the patent scope. If the patent is not renewed, we assume that the firm has dismissed the technological opportunity protected by the patent.

Collecting data regarding the underlying quality of a technological opportunity (3) is even more challenging. Inventions can have firm-specific value, and it is even more difficult to ascertain the potential value of inventions that were not pursued by the firm. To address this issue, we use forward citation counts that a patent receives in its lifetime to estimate the quality of the underlying invention. The use of patent citations as a measure of quality is well-established in the literature: studies showed that citations are indicators of the underlying innovation's scientific value (Griliches, 1990; Harhoff, Narin, Scherer & Vopel, 1999), social value (Trajtenberg, 1990), and economic value (Albert, Avery, Narin & McAllister, 1991; Bessen, 2008). We normalized forward citations by the average number of forward citations received by all patents granted in that year to account for the fact that older patents are more likely to be cited than more recent ones. We operationalize errors as patent renewal decisions that do not reflect the quality of the underlying technology (Lanjouw, Pakes & Putnam, 1998; Bessen, 2008). When a patent belonging to the bottom 10%[10] of patent quality is not renewed, we code it as a commission error. An omission error occurs when the firm does not renew a patent that belongs to the top 10% of the quality distribution. Patents falling in the top decile by citation often represent the start of a technological trajectory upon which other inventors can build. Our fieldwork suggested that patents that may open new technological paths are expected to receive many citations. Even if an assignee firm does not enter related product markets, it can still benefit from operating in markets for technologies by licensing such patents. Dismissing patent rights over inventions that are being rapidly developed is *prima facie* an issue of opportunity recognition.

Independent variables

We use inventors' career tracks to reconstruct the intra-organizational collaboration networks of the firms in our sample. A connection exists between two inventors if they recently collaborated on a shared patent project within the past three years (Nerkar & Paruchuri, 2005; Carnabuci & Operti, 2013). As an illustration, **Figure 2** provides a visualization of the co-patenting networks of Apple and Samsung in 2010. We also leveraged inventors' addresses to assign them to locations. The geographic distribution of Apple and Samsung inventors is presented in **Figure 3**.

----------------Insert Figures 2–3 here---------------

We measured social cohesion and the extent of boundary-spanning exhibited by an inventor by looking at his position in the intra-organizational co-patenting network (Nerkar & Paruchuri, 2005). In line with the literature, ***Social Cohesion*** was operationalized through

[10] The choice of a cutoff of 10% at each tail was due to the insights gained from the interviews. One informant told us: *"Only 8–10% of patents are the real big ones, but we don't know which those are. When we are not sure (of their objective quality), we maintain (renew) them (patents). But companies need to be prudent. We can't renew everything all the time." In separate analyses, we used 5% and 15% thresholds. These results are identical to those discussed in the paper.*

network constraints (Burt, 1992; Reagans & McEvily, 2003). For each patent, we computed the average constraint for all of its inventors. We used R igraph to compute all network measures.

. Although organizations have increasingly internationalized their R&D, our fieldwork and prior research (Bouquet & Birkinshaw, 2008; Monteiro, 2015) suggest that the key decisions about firms' technologies and products follow strategic directives from their global headquarters. Thus, we construct ***Geographic Distance*** measures by looking at the distance between a firm headquarters and the inventors' locations. We computed the average geodesic distance of each inventor's location from the firm headquarters[11] in thousands of kilometers using STATA command geodist (Picard, 2010). The inventors' locations were retrieved from Harvard Patent database, whereas the headquarters locations were ascertained from Compustat and Factiva.

Control variables

We controlled for several patent and firm-level factors which might affect a firm's patent value assessments and renewal decisions. To disentangle the influence of Social Cohesion from simple connectivity (Burt, 1992), we controlled for the average normalized network centrality of the inventors listed on a patent. Star scientists within the firm are more likely to receive corporate attention (Tzabbar, 2009). Hence, they can more easily share their frames and interpretations within the organization. Accordingly, we control for the proportion of stars present in the inventor team. An inventor was classified as a star if he or she belongs to the top 5% of the productivity distribution in our sample.[12] Since prior research showed that

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[11] It is assumed that technology selection decisions are made at corporate headquarters and are consistent with prior work on technology scouting and attention (e.g. Monteiro, 2015).

[12] We also tried to examine individual inventor effects by trying to identify inventors who moved between locations within the same firm, but who kept working on similar technologies over the observation period. However, moves between locations represent a rare event in our sample (less than 6% of the inventors change location at least once) and a large majority of mobility events are associated with a change in the employer (83%) or a change in the technology domain (46%). Matching the same employer with the same specialization, including a change in location as a treatment, returns a sample size that is too small to perform analyses.

novelty is a key factor underlying R&D project evaluations (Criscuolo *et al.*, 2017), we account for patent novelty by using the ratio of new patents to the amount of world subclass combinations assigned to a patent and we normalize this by the total number of possible subclass combinations based on the patent classification (Fleming *et al*., 2007). Firms' renewal decisions and quality assessments also depend on the level of crowding or competition in a technological area. Thus, our models include the count of backward citations listed in a patent application, which typically indicate that the inventor is operating in a crowded technological area with several "nearby" competing technologies (Lanjouw & Schankerman, 2001). Analogously, according to Harhoff and colleagues (2003), at least one-third of first-time patents and patent renewals are initiated to block competitors. Given that self-citations are often used to create patent clusters or "thickets," we include the share of each patent's self-citations in our models to control for the strategic motives that may underlie patent renewal (Moore, 2004). The strength and breadth of protection of a patent is likely to affect both quality assessments and renewal decisions. At the level of the patent, we use the count of independent claims (Lanjouw & Schankerman, 2001) to account for the strength of protection of the patent under examination. We also use the number of subclass assignments to control for the scope of a patent application (Lerner, 1994).

We also include many firm-level controls that may affect errors in technology selection. To account for the impact of organizational structure on decision-making (Csaszar, 2012), we use three variables. The first, which we refer to as R&D Network Centralization, accounts for the extent to which a firm's intra-organizational network is centralized. We also use a dummy variable set to 1 if the firm has a centralized hierarchical structure (0 otherwise). We apply the criteria developed by Argyres and Silverman (2004) to establish a firm's structure using publicly available sources. We conflate the hybrid and decentralized categories into one because the boundary between the two turned out to be ambiguous for the firms in our sample. Third, we use the number of countries from which a firm has active inventors to account for the degree of geographic decentralization of its R&D activities. R&D-intensive firms are more likely to renew their patents (Harhoff *et al.*, 2003; Bessen, 2008). Technology-intensive firms compete by innovating: knowledge is a key organizational resource and intellectual property rights give them monopoly power. Accordingly, we include firms' R&D expenditures normalized by assets in our models. Because the quality of renewal decisions is affected by the cognitive burden that decision-makers face, we control for a firm's patent portfolio size. Older firms tend to display greater inertia and are more prone to commission errors than omission errors. Similarly, prior studies showed that successful incumbents are more likely to omit emerging technologies. Thus, we include the firm's return on assets (Firm ROA) and age.

We include maintenance year dummies to allow the baseline error rate to vary over time (Jaffe & Trajtenberg, 2002) and to control for macroeconomic conditions (such as uncertainty and resource munificence), which could affect renewals and citations in the industry. Furthermore, we included primary class fixed effects and continent dummy variables in order to allow the quality of selection decisions to vary across technologies and countries.

Data structure and estimation method

Our unit of analysis is patent renewal decisions, which are typically nested within firms. For each patent, one may observe up to three decisions at 3.5, 7.5, and 11.5 years after the patent is granted. We use two independent, random-effect panel logit models to estimate the probability of omission or commission errors as a function of our independent and control variables. While both random- and fixed-effect models to allow for explicit consideration of the unobserved effects. The random-effects model makes an additional assumption that the unobserved effect is not correlated with the independent variables. Although a fixed-effect approach would require fewer assumptions than the random-effect approach, this would omit all firms that do not commit errors over the observation period, which represents highly relevant information given our research question. In the robustness section, we present results based on alternative model specifications.

RESULTS

Table 1 presents descriptive statistics and the correlation between variables. The mean VIF for the full model is 1.61, which is well below the recommended multicollinearity thresholds. **Table 2** presents the results of our analysis. Models 1–3 estimate the likelihood of commission errors. The first model is the baseline model. In Model 2, we introduce the variable Social Cohesion. The effect of Social Cohesion on the probability of commission errors is positive (β=0.522, p=0.000), corroborating our hypothesis H1a that social cohesion of inventors increases the probability of commission errors in the selection of a technological opportunity. In Model 3, we introduce the variable Geographical Distance, which has a negative effect on the probability of commission errors (β= – 0.033, p=0.000). Consistent with H2a, the likelihood of commission errors increases with the geographic proximity of inventors to the corporate headquarters. These data suggest that the values are not likely to be generated by a true effect of zero because in Models 1–3, the effect is estimated with p-values of 0.000. Based on Model 3, for an increase of one unit in Social Cohesion, the odds of commission errors increase by a factor of 1.69. A one-unit increase in Geographic Distance decreases the likelihood of commission errors by a factor of 0.96.

Model 4–6 estimate the likelihood of omission errors. Model 4 is the baseline model. Model 5 introduces the Social Cohesion variable. The coefficient associated with our measure of Social Cohesion is negative (β= –0.202, p=0.002), supporting H1b, which predicted a lower likelihood of omission errors for the technological opportunities generated by inventors embedded in cohesive networks. Model 6 introduces the variable Geographical Distance, which has a positive and significant effect on the probability of omission errors (β=0.020, p=0.001). Thus, if inventors generating a technological opportunity are distant from the firm's headquarters, the chances of omission errors increase substantially, which is in line with what we posited in H2b. Based on Model 6, for an increase of one unit in Social Cohesion, the odds of an omission error decrease by a factor of 0.81. In terms of geographical distance, the odds of omission errors increase by a factor of 1.02 for every unit of geographical distance.

-------------Insert Tables 1–2 here----------------

All controls add to our understanding of the drivers of omission and commission errors in the selection of technological opportunities. First, two well-studied factors in search literature—the presence of stars (Tzabbar, 2009) and the degree of novelty of the project (Criscuolo *et al*., 2017)—influence the likelihood of errors in a way that cannot be distinguished from zero. However, prior studies only validated the effect of Stars and Novelty with respect to the likelihood of idea selection. Given that our error measure combines an indicator of patent quality and renewal decisions, inconsistencies *vis-à-vis* prior studies may stem from the fact that stars and novelty may also affect quality in ways that compensate for selection biases.

The effects of patent-level covariates are highly informative and consistent with prior studies. Project that are broad in scope, build on diverse fields, and are in crowded technological areas are less likely to engender commission errors and more likely to trigger omission errors. This may be because of the greater uncertainty-quality trade-off associated with these projects, as well as the cognitive weight associated with assessing large-scale, complex projects. In line with previous findings on strategic patenting (Harhoff *et al*., 2003), the negative coefficient associated to self-citation share indicates that decision-makers are less likely to make both omission and commission errors when evaluating patents that have been filed for strategic reasons (such as for the purposes of blocking or building patent-thickets). This result suggests that when patent renewal is done to block competitors or establish patent-thickets, firms are more rational in assessing options and commit fewer errors of either type. The fact that our covariates of interest have an effect on controlling for strategic patenting suggests that structure plays a role above and beyond the strategic use of patent renewal.

All our indicators regarding the role of formal structure have effects aligned with prior research (Csazar, 2012; Sah & Stiglitz, 1986): centralized structures increase omission errors, while decentralized structures decrease them. P-values range from 0.000 to 0.109 in Models 1–3, providing evidence of a non-zero effect for both formal and informal centralization. In Models 4–6, p-values range from 0.482 to 0.846. In line with the inertia hypothesis, older firms are more likely to commit omission errors.

Robustness analyses

We performed a number of additional analyses to assess the validity of our findings. In our sample, only 1.3% of the renewal decisions are coded as omission errors and 7.3% of the renewal decisions are coded as commission errors. For robustness, we used alternative model specifications with a rare-event logit (King & Zeng, 2001). Rare-event logistic regression has been applied to predict binary variables in which the events are thousands of times less frequent than non-events (such as wars). In **Table 3,** Models 7 and 8 present the results of a rare-event logit. Results for omission and commission errors align with those previously discussed.

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

Second, as mentioned above, we decided not to use a fixed-effect panel logit because it would drop all firms that do not commit errors during the observation period, which are theoretically meaningful in our context. An alternative approach is to use linear probability panel regression with a firm's fixed effects. Firm-fixed effects would also account for organizational differences in R&D organization policies, including practices regarding project assignments to subsidiaries,[13] and stable differences in patent portfolio management practices. The inclusion of firm-fixed effects (Models 9 and 10) does not significantly affect our results.

Third, we modeled patent quality using forward citation counts. However, firms may decide to retain patents for reasons other than technological impacts. For instance, patents that are expected to become part of a standard are more likely to be renewed regardless of their quality. Also, firms may retain patents with broad applicability scope, keeping the rights on a promising technology even if they have not yet found a downstream market. To rule out these confounding variables, we constructed two additional controls. For each patent in our sample, we constructed a dummy variable that is 1 if the owner of a patent disclosed to a standard setting organizations (SSOs) that a piece of IP might be infringed by implementing a proposed standard and committed to license their "essential" patents on terms that are fair, reasonable, and non-discriminatory. We used the OEIDD Open Essential IPR Disclosure Database (Bekkers *et al*., 2012) to identify standard patents. We use a text-based approach to construct an alternative measure of patent scope, which counts the number of OR statements in the patent claims (Kuhn & Thompson, 2017). Both the standard dummy and the Claims Text Breadth are positively and significantly correlated to forward citations, corroborating the validity of our quality measure. Models 11–12 include these additional controls. Firms are significantly less likely to make errors of both types (omission and commission) when evaluating patents belonging to a standard. This may be due to the increased attention that key decision-makers dedicate to the valuation of these patents. Regarding patent scope, we find that technologies with a broader and a more uncertain domain of applicability tend to be systematically associated with the incidence of omission errors. They are also less likely to

[13] One friendly reviewer pointed out that allocation rules (e.g., assigning more exploratory projects to remote subsidiaries) may be confounding our results. Whether firms vary in the type of projects they carry out at different locations is an interesting question. Research indicates that other rules may also be at work. For instance, firms may allocate projects based on the specialization of the cluster where the subsidiary operates (Funk, 2014) or based on IP protection in a host country (Bouquet & Birkinshaw, 2008). In any case, such practices are stable within firms over a short panel and, hence, are captured using fixed effects.

engender commission errors. These results indicate that key decision-makers are less likely to recognize the value inherent in technologies for which the scope is not well-defined. Our results remain robust to the inclusion of these controls.

Economic implications of omission and commission errors

Thus far, our analyses highlighted the existence of systematic biases affecting the selection of technological opportunities within organizations. In particular, we showed that key decision makers within organizations are more prone to omission errors when evaluating technological opportunities generated by disconnected, distant inventors. In contrast, they are more likely to make commission errors when evaluating opportunities generated by inventors endowed with cohesive support networks or by inventors located close to the company's headquarters. However, do evaluation errors bear consequences for organizations? Showing that omission and commission errors in general are likely to have detrimental economic effects, in addition to identifying which type of error has more significant consequences for the organization, would help us understand why studying errors in opportunity selection is important for managerial practice. To address this question, we conducted analyses at the firm level, exploring the effect of the cumulative number of omission errors on the future sales of a firm while controlling for several factors that prior research has shown to be related to firms' sales. We present the results of these analyses in Table 4. In Models 13–15, the independent variables lag by 1 year.

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

Results indicate that both omission and commission errors tend to reduce sales. Based on standardized coefficients, a one standard deviation increase in omission errors reduces future sales by 4.6%, while a one standard deviation increase in commission errors reduces future sales by 14%. Such considerations are in line with anecdotal evidence from our research study. In the last two decades, prominent incumbent mobile phone and PDA firms lost their sales leadership despite their high R&D expenditures and the number of inventions they owned. Omissions and commission errors in selecting technological opportunities played a significant role in this respect. Returning to the opening examples, the sensors for mobile phone cameras were developed in Motorola's Arizona R&D laboratory, which is far from the company's headquarters in Schaumburg, Illinois. This represented a key omission error for the firm. Once the team moved to STMicroelectronics, thanks to a partnership with Nokia, the innovation significantly contributed to Nokia's booming market share in the 1990s. The two inventors responsible for the projects were at the geographic and social boundaries of the organization and, despite their efforts, could not convince the top management to envision a future where cellular phones could have a camera. Our paper can help generalize anecdotal evidence and provide insights on similar cases in other firms.

DISCUSSION AND CONCLUSION

This paper examines why large firms make errors in selecting technological opportunities. What holds them from pursuing certain high-quality opportunities despite generating them and having intellectual property rights over them? At the same time, why do they sometimes commit organizational resources to low-quality opportunities or redundant technologies? We argue that firms miss high-quality technological opportunities or retain low-quality ones when competing frames and interpretations about these technologies emerge in the organization. Since prior work on organizational cognition indicates that predominant frames emerge (evolve) through socialization processes (Walsh, 1995), we focus on two structural factors that affect inventors' interactions with their peers and key decision-makers, thus influencing their ability to win framing contests. We examine (1) their embeddedness in a cohesive intra-organizational collaboration network and (2) their geographical proximity to key decision-makers. Accordingly, we hypothesize that an opportunity is more likely to be subject to commission error if it is generated by the inventors with a cohesive social (peer) support.

Meanwhile, this opportunity is subject to omission errors if generated by boundary-spanning inventors. Similarly, if the inventors are located close to the locus where the most crucial technology and product-related decisions are made, the opportunity is more likely to be subject to a commission error. Conversely, if inventors are geographically distant from the decision-makers, the opportunity is more likely to be subject to an omission error. Our hypotheses gained empirical support in the context of the mobile phone and PDA industry between 1990 and 2010.

Theoretical contribution

Our study makes contributions to two areas of research. First, we contribute to work on the evaluation of innovation initiatives within established organizations. Two streams of research emerged and developed in this respect almost independently from each another. On the one hand, a successful line of research looked at how technology producers (R&D scientists, inventors, product managers) champion their projects to gain support and increase funding allocations (Dutton & Ashford, 1993; Wooldridge, Schmid & Floyd, 2008). On the other hand, researchers looked at the biases that affect key decision-makers' decisions to promote or terminate an innovation initiative (Reitzig & Sorenson, 2013; Monteiro, 2015; Criscuolo *et al*., 2017). By providing evidence that the interactions between technology-producers and key decision-makers shape information-processing and decision-making in an organization, the paper suggests that error and biases can be better understood by jointly considering innovation generation and selection, innovators, and evaluators.

Secondly, we contribute to the study of the organizational sources of selection errors (Sah & Stiglitz, 1986; Ocasio, 1997; Knudsen & Levinthal 2007; Csaszar, 2012). Extant studies have established the effects of hierarchy, pointing to the role of information aggregation in selection decisions and, thus, the probabilities of omission or commission errors (Knudsen & Levinthal 2007; Csaszar, 2012; Eggers, 2016). We argue that an additional mechanism is at work. Specifically, how an organization as a social collective makes sense of and interprets the quality of a technological opportunity, and how this influences the probability of errors. In this context, we suggest that structural factors (such as embeddedness of the concerned inventors in an organizational co-invention network and their geographical proximity) affect the probability of an opportunity being subject to commission or omission errors. We suggest that these factors affect the inventors' abilities to succeed in framing contests by linking research structure and cognition (Tripsas & Gavetti, 2000; Kaplan, 2008; Kaplan & Tripsas, 2008; Eggers & Kaplan, 2009). Cumulatively, our work calls for a deeper attention to the effect of social interactions on technology selection.

This approach differs substantially from traditional models of technology decisions under uncertain conditions, which are based on real-option theory (McGrath, 1997; Zardkoohi, 2004). These models ignore such interactions. They assume that uncertainty resides primarily in the environment, and that objective decisions are possible once uncertainty is resolved. Our findings indicate that uncertainty can stem from interactions within the organization. Socio-cognitive processes can impede the objective assessment of alternatives, even when external sources of uncertainty are resolved. The observation that low-quality inventions championed by well-connected inventors tend to be retained regardless of their value empirically validates the existence of "option traps" (Adner & Levinthal, 2004: 80). This research calls for more caution with regard to the extension of real-option theory to organizations.

The second contribution of this paper is to our understanding of the management of intra-organizational collaboration with respect to R&D activities (Nerkar & Paruchuri, 2005; Reagans & McEvily, 2003; Lahiri, 2010; Funk, 2014; Monteiro, 2015). By reconciling existing mixed findings with the relative benefits of building cohesive networks versus boundary-spanning, we illustrate how spanning may prove beneficial for idea generation.

However, shaping selection decisions within organizations requires cohesion. Accordingly, we suggest that conceptualizing innovation as a two-stage model of idea generation and selection (Knudsen & Levinthal, 2007) can help reconcile contrasting findings regarding the benefits and shortcomings of spanning because that the factors entailed in the generation of technologies differ substantially from those determining technology selection.

Limitations

This paper also has several limitations. First, we measured errors using bibliometric proxies to determine patent values. Although this practice is well-established in the literature (Griliches, 1990; Harhoff *et al*., 1999; Albert *et al*., 1991; Bessen, 2008) and our approach is robust to alternative thresholds that define breakthroughs, we are aware that the bibliometric approach may not always be suited to capturing valuable innovation. Researchers who have access to records of R&D project selection (Reitzig & Sorenson, 2013; Criscuolo *et al*., 2017) can extend our line of research by jointly studying decisions and idea quality. Such comparisons are likely to deliver a better picture of the nature of omission and commission errors in organizations. Second, our data do not allow us to directly observe cognitive frames, which are the mechanisms underpinning our hypotheses. Further work that adopts qualitative or experimental methods, is needed to explore how structure affects the emergence and diffusion of frames in an organization. Third, based on interviews with IP attorneys, we learned that patent portfolio management practices in firms differ substantially. In line with our paper's assumptions, most companies' final decisions regarding which technological areas they should file in or which patents to renew emerge from the interactions between strategy-makers and R&D labs. However, modes of interactions and renewal practices differ substantially across firms. While reviewing research in this area, we realized that the study of IP portfolio management within large corporations is scant. Further research is needed to augment our understanding of how firms manage their patents after they are granted, and this is in line with recent work on the strategic management of intellectual property.

Managerial implications

Our results also have important managerial implications, especially in light of the economic implications of omission and commission errors presented in Table 4. Managers should pay attention to the role of networks and geography in organizations and be aware of the biases engendered by these factors. Errors cannot be completely avoided, especially in fast-changing, uncertain environments (Garud *et al.*, 1997). Our findings, however, provide insights into some structural correlates of omission and commission errors, which have direct practical implications. If managers want to minimize omission errors, they should allocate more resources and discretion to projects carried out in remote locations or by boundary-spanning individuals. If they want to minimize commission errors, they should set strict deadlines and abandonment triggers, which should be enforced against well-connected, geographically central actors. Also, managers should decide to proactively shape the interactions between individuals in order to compensate for biases illustrated by this paper. For instance, team and location rotations or hybrid structures can be established to keep enough variation in frames. Although designing informal organizational networks from the top-down is harder than designing its formal hierarchy, both aspects need to be at the top of the agenda in turbulent, fast-changing environments.

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Firm's selection-decision	Underlying quality of technological opportunities: Low	Underlying quality of technological opportunities: High
Retain	**Commission error** Retaining a low-quality technological	Retaining a high-quality technological opportunity
Dismiss	Dismissing a low-quality technological opportunity	**Omission error** Dismissing a high-quality technological opportunity

Figure 1. Commission and omission errors in internal selection

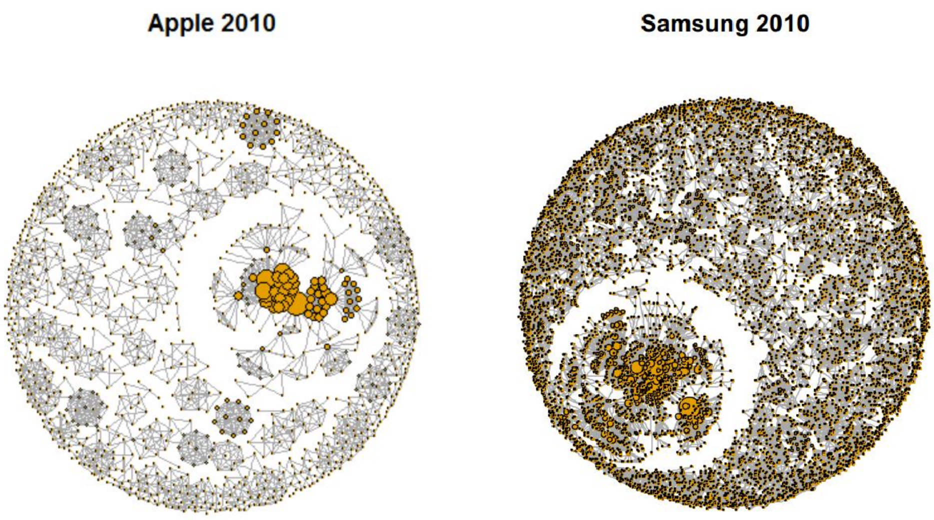

Figure 2. Apple and Samsung intra-firm co-invention networks in 2010

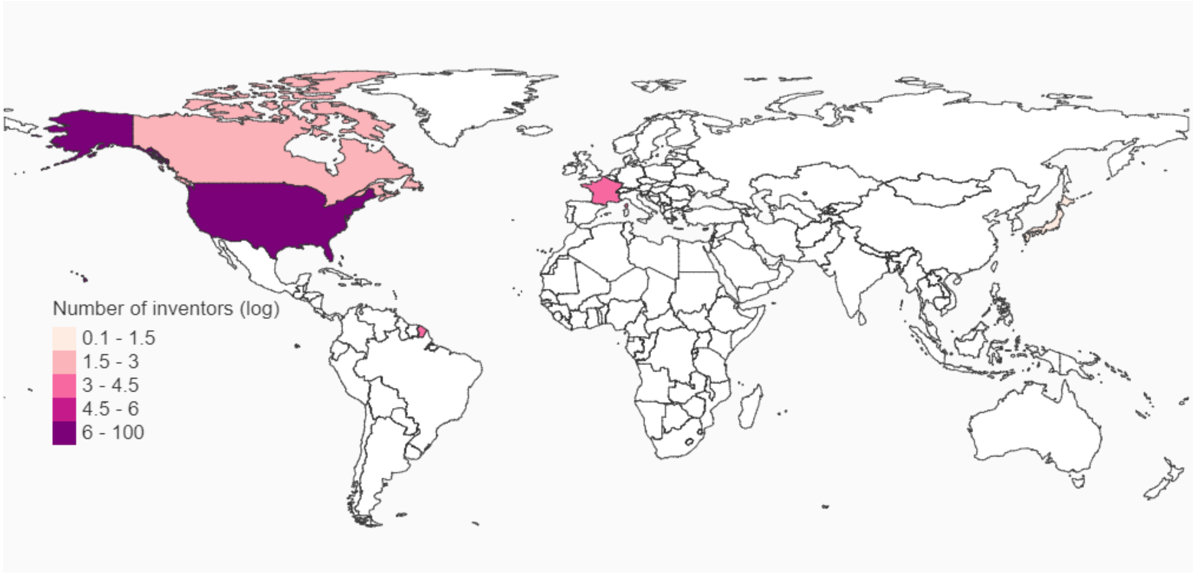

Figure 3a. Apple: Inventors' locations in 2010

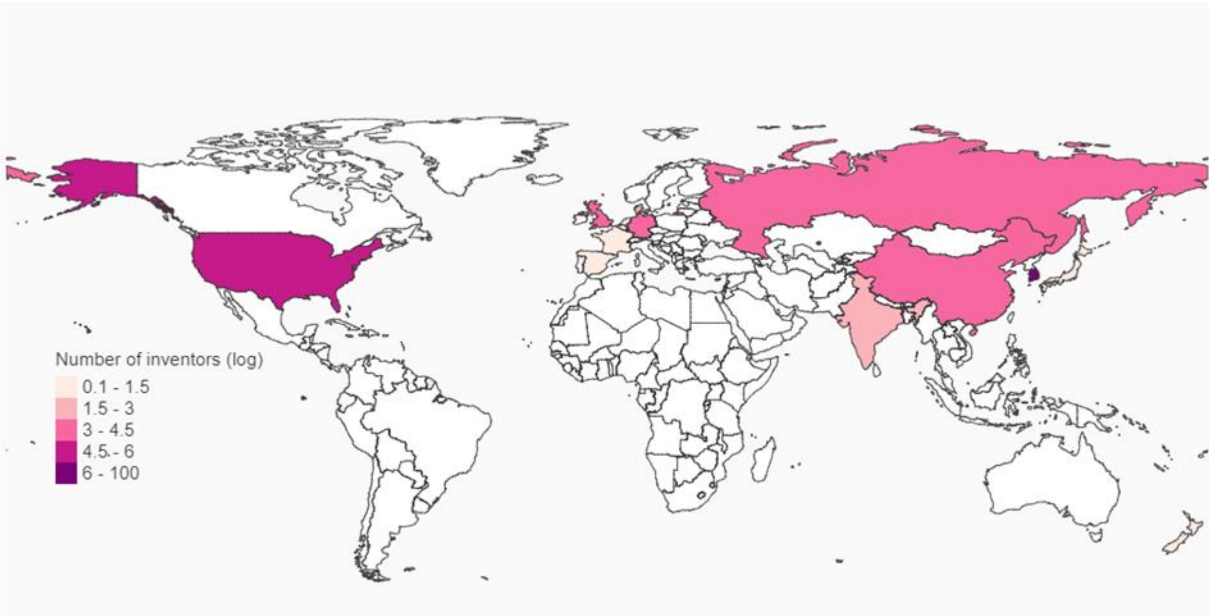

Figure 3b. Samsung: Inventors' locations in 2010

Table 1. Descriptive statistics and correlations

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Commission Error	1.00																	
2	Omission Error	-0.03	1.00																
3	Geographical Distance	-0.02	0.02	1.00															
4	Social Cohesion	0.04	-0.01	-0.01	1.00														
5	Average degree (norm)	-0.02	-0.01	-0.03	-0.16	1.00													
6	Proportion of stars	-0.03	0.00	0.00	-0.46	0.12	1.00												
7	Recombinant novelty	-0.04	0.00	-0.05	0.20	0.03	-0.12	1.00											
8	Backward citations (ln)	-0.06	0.03	0.05	-0.12	0.05	0.10	-0.05	1.00										
9	Self-citation share	-0.04	0.01	0.01	-0.16	0.00	0.13	-0.18	0.02	1.00									
10	Number of subclasses (ln)	-0.05	0.02	-0.00	-0.01	-0.00	0.01	0.28	0.11	-0.03	1.00								
11	Number of claims (ln)	-0.07	0.01	0.08	-0.12	0.03	0.06	-0.04	0.12	0.04	0.03	1.00							
12	Formal R&D centralization	-0.07	0.08	0.09	-0.06	-0.05	0.03	-0.08	0.10	0.10	-0.01	0.05	1.00						
13	R&D Network centralization	0.01	0.02	0.06	-0.02	-0.67	-0.02	-0.08	-0.02	0.04	0.00	-0.02	0.08	1.00					
14	R&D intensity	-0.03	-0.03	0.03	-0.07	0.02	0.04	-0.02	0.05	0.04	-0.06	0.18	-0.26	-0.01	1.00				
15	Firm patent portfolio size	0.04	0.04	0.11	-0.21	-0.16	0.05	-0.27	0.09	0.07	-0.00	0.08	0.38	0.27	-0.00	1.00			
16	Firm age	0.04	0.02	0.16	0.08	-0.15	-0.07	-0.01	-0.07	0.00	-0.03	-0.10	-0.12	0.21	-0.09	0.03	1.00		
17	Firm R&D internationalization	0.02	0.04	0.25	-0.18	-0.15	0.04	-0.23	0.12	0.10	-0.01	0.15	0.36	0.26	0.31	0.70	0.17	1.00	
18	Firm ROA	-0.02	0.01	0.00	-0.05	0.02	0.04	-0.05	0.06	0.06	0.00	0.03	0.15	-0.04	-0.13	0.17	-0.07	0.13	1.00
	Mean	0.07	0.01	1.53	0.75	0.01	0.12	0.65	2.04	8.50	1.34	2.60	0.18	0.98	8.47	0.42	85.53	9.56	-0.00
	S.D.	0.26	0.11	2.76	0.33	0.02	0.28	0.38	0.75	16.36	0.61	0.76	0.39	0.03	4.74	0.35	39.26	6.41	9.77
	Min	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	4.00	1.00	-100.99
	Max	1.00	1.00	18.67	1.13	1.00	1.00	1.00	6.72	100.00	4.01	5.81	1.00	1.00	33.16	1.89	167.00	27.00	27.39

Table 2. Random-effects panel logit predicting the probability of commission and omission errors

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
	DV: Commission Error	**DV: Commission Error**	**DV: Commission Error**	**DV: Omission Error**	**DV: Omission Error**	**DV: Omission Error**
Geographical Distance			-0.033			0.020
			(0.000)			(0.001)
Social Cohesion		0.522	0.526		-0.202	-0.211
		(0.000)	(0.000)		(0.002)	(0.002)
Average degree (norm)	-8.281	-2.555	-2.464	1.215	-0.332	-0.382
	(0.000)	(0.003)	(0.004)	(0.519)	(0.873)	(0.855)
Proportion of stars	-0.226	-0.002	0.003	0.044	-0.038	-0.038
	(0.000)	(0.953)	(0.923)	(0.495)	(0.582)	(0.590)
Recombinant novelty	0.043	0.022	0.018	0.001	0.009	0.011
	(0.056)	(0.336)	(0.429)	(0.992)	(0.867)	(0.839)
Backward citations (ln)	-0.183	-0.180	-0.176	0.220	0.217	0.216
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Self-citation share	-0.002	-0.001	-0.001	-0.006	-0.006	-0.006
	(0.001)	(0.019)	(0.009)	(0.000)	(0.000)	(0.000)
Number of subclasses (ln)	-0.310	-0.304	-0.305	0.289	0.286	0.286
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of claims (ln)	-0.343	-0.336	-0.323	0.166	0.162	0.160
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Formal R&D centralization	-0.321	-0.344	-0.337	0.119	0.127	0.124
	(0.000)	(0.000)	(0.000)	(0.508)	(0.482)	(0.492)
R&D Network centralization	-1.110	-0.638	-0.617	1.137	0.317	0.317
	(0.003)	(0.097)	(0.109)	(0.515)	(0.846)	(0.846)
Firm R&D internationalization	-0.006	-0.004	-0.003	0.038	0.038	0.037
	(0.109)	(0.263)	(0.476)	(0.000)	(0.000)	(0.000)
R&D intensity	-0.003	-0.003	-0.002	-0.001	-0.001	-0.002
	(0.521)	(0.593)	(0.743)	(0.926)	(0.931)	(0.867)
Firm patent portfolio size	0.493	0.553	0.559	-0.022	-0.033	-0.023
	(0.000)	(0.000)	(0.000)	(0.861)	(0.792)	(0.856)
Firm age	-0.002	-0.001	-0.000	0.005	0.005	0.005
	(0.288)	(0.688)	(0.728)	(0.127)	(0.130)	(0.142)
Firm ROA	-0.002	-0.001	-0.001	-0.006	-0.006	-0.006
	(0.186)	(0.221)	(0.263)	(0.013)	(0.014)	(0.013)
Region FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Technology class FE	Y	Y	Y	Y	Y	Y
Renewal stage dummies	Y	Y	Y	Y	Y	Y
Constant	1.168	0.114	0.065	-9.291	-8.298	-8.292
	(0.001)	(0.764)	(0.864)	(0.000)	(0.000)	(0.000)
Log likelihood	-59982.24	-59843.27	-59780.50	-16662.96	-16658.35	-16653.11
Wald Chi2	9202.00	9483.20	9577.08	1793.11	1801.85	1814.70

Observations	260,318	260,318	260,318	260,318	260,318	260,318
Number of firms	53	53	53	53	53	53

p values in parentheses

Table 3: Robustness checks

	Model 7	Model 8	Model 9	Model 10	Model 11	Model 12
	DV: Commission Error	DV: Omission Error	DV: Commission Error	DV: Omission Error	DV: Commission Error	DV: Omission Error
	Rare event logit	Rare event logit	Fixed effect panel OLS	Fixed effect panel OLS	Random effects panel logit	Random effects panel logit
Geographical Distance	-0.031	0.019	-0.002	0.000	-0.034	0.021
	(0.000)	(0.019)	(0.000)	(0.037)	(0.000)	(0.001)
Social Cohesion	0.563	-0.250	0.033	-0.003	0.521	-0.210
	(0.000)	(0.005)	(0.000)	(0.000)	(0.000)	(0.002)
Average degree (norm)	-2.543	1.042	-0.035	-0.019	-2.256	-0.127
	(0.007)	(0.738)	(0.319)	(0.248)	(0.007)	(0.951)
Belongs to a standard					-0.792	-0.939
					(0.000)	(0.000)
Claims text breadth					-0.007	0.005
					(0.000)	(0.000)
Proportion of stars	0.018	-0.050	0.001	-0.001	0.015	-0.029
	(0.690)	(0.605)	(0.737)	(0.559)	(0.680)	(0.682)
Recombinant novelty	0.039	-0.003	0.000	-0.001	0.017	0.008
	(0.172)	(0.972)	(0.842)	(0.390)	(0.453)	(0.884)
Backward citations (ln)	-0.188	0.216	-0.013	0.003	-0.176	0.215
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Self-citation share	-0.002	-0.006	-0.000	-0.000	-0.001	-0.006
	(0.015)	(0.000)	(0.000)	(0.000)	(0.010)	(0.000)
Number of subclasses (ln)	-0.312	0.300	-0.021	0.003	-0.306	0.285
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Number of claims (ln)	-0.340	0.152	-0.021	0.002	-0.308	0.148
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Formal R&D centralization	-0.561	0.505	-0.014	-0.000	-0.332	0.130
	(0.000)	(0.000)	(0.003)	(0.998)	(0.000)	(0.470)
R&D Network centralization	-0.681	3.578	-0.078	-0.002	-0.634	0.254
	(0.127)	(0.069)	(0.007)	(0.864)	(0.099)	(0.876)
Firm internationalization	-0.005	0.069	-0.000	0.001	-0.002	-0.001
	(0.173)	(0.000)	(0.572)	(0.000)	(0.684)	(0.918)
R&D intensity	-0.016	-0.069	0.000	-0.000	0.562	-0.026
	(0.000)	(0.000)	(0.667)	(0.174)	(0.000)	(0.837)
Firm patent portfolio size	0.302	-0.011	-0.004	-0.013	-0.000	0.005
	(0.000)	(0.933)	(0.254)	(0.000)	(0.767)	(0.136)
Firm age	-0.000	0.002	0.028	-0.001	-0.003	0.036
	(0.416)	(0.082)	(0.000)	(0.262)	(0.448)	(0.000)
Firm ROA	-0.005	-0.012	-0.000	-0.000	-0.001	-0.006
	(0.000)	(0.000)	(0.001)	(0.027)	(0.267)	(0.014)
Region FE	Y	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y	Y
Technology class FE	Y	Y	Y	Y	Y	Y

Renewal round FE	Y	Y	Y	Y	Y	Y
Firm FE	N	N	Y	Y	N	N
Constant	0.477	-10.854	-2.306	0.099	0.076	-8.207
	(0.276)	(0.000)	(0.000)	(0.294)	(0.840)	(0.000)
R squared			0.057	0.019		
Observations	260,318	260,318	260,318	260,318	260,318	260,318

p values in parentheses

Table 4: Fixed-effects panel regression showing the effect of omission and commission errors on firms' sales

	Model 13 Sales (t+1)	Model 14 Sales (t+1)	Model 15 Sales (t+1)
Cumulative omission errors			-0.195
			(0.012)
Cumulative commission errors		-0.303	-0.199
		(0.003)	(0.011)
Number of products	0.110	0.135	0.134
	(0.046)	(0.039)	(0.029)
Number of patents	0.314	0.264	0.226
	(0.000)	(0.000)	(0.001)
Number of design patents	0.061	0.088	0.089
	(0.248)	(0.052)	(0.063)
Network density	-1.034	-0.165	-0.091
	(0.077)	(0.813)	(0.894)
Network centralization	0.359	0.140	0.122
	(0.093)	(0.499)	(0.579)
R&D Intensity	-0.063	-0.057	-0.059
	(0.000)	(0.001)	(0.000)
Firm age	-0.008	0.099	0.113
	(0.695)	(0.010)	(0.004)
Firm FE	Y	Y	Y
Year FE	Y	Y	Y
Constant	9.417	3.152	2.415
	(0.000)	(0.177)	(0.308)
Observations	676	676	676
R-squared	0.494	0.555	0.573

p-value in parentheses

THIS CLOUD HAS A SILVER LINING

ECONOMIC CRISIS AND TECHNOLOGICAL EXPLORATION

Amit Kumar and Elisa Operti

ABSTRACT

This paper argues that economic crises lead to a higher incidence of exploration in regions. Crises induce behavioral and strategic response from firms. To improve their sagging performance, they engage in distant search and creating growth options along emerging technologies, thereby producing exploration at the regional level. We further hypothesize an indirect effect of crises on regional exploration, mediated through structural changes in the network. Crises generate a churn in regional knowledge networks: many existing ties are dissolved due to crisis, whereas many new ones are created in new technology areas. This lowers network-hierarchy, thereby supporting exploration processes. We find empirical support to our hypotheses in context of US regions in context of Financial Crisis (2007-08). We contribute to literature studying the effects of crises and recessions on innovation. Additionally, we add to the literature studying the effects of network structure on region's innovation performance. We also respond to the calls of research on network dynamics.

Keywords: Economic crisis, exploration, regional knowledge network, R&D strategy.

INTRODUCTION

Large-scale economic crises are identified with the contraction of real GDP, crash of the real assets and equity markets, collapse of international trade, and spikes in unemployment (Levchenko, Lewis and Tesar, 2010; Reinhart and Rogoff, 2009). One of the most influential theorist of entrepreneurship – Joseph Schumpeter – who experienced Great Depression (1929-35[14]), however, remained unruffled by the incidence of such crises. He considered them as laboratories of new ideas, when much of the deadwood was cleared and entrepreneurs adopted the best innovations and practices (Schumpeter, 1939). It seems counter-intuitive and paradoxical – an event, which has catastrophic effects on society and economy, can have positive long-terms effects on welfare! And yet few scholars in the field of management and innovation examined whether crises truly accentuated emergence or evolution of new technologies. We play with a piece of this puzzle in this paper, and ask whether crises bring in qualitative shifts in the search behavior of regional actors so that it produces exploration at the aggregate, regional level.

Building upon behavioral theory (March, 1991; Greve, 2003) and the economic theories of opportunity cost and growth options effects (Bloom, 2014), we argue that crises change the opportunity-structure for organizations, which respond by engaging in distant search, possibly along emerging technologies. We further argue that the crises trigger a churn in regional knowledge network. Inducing exits, layoffs, and termination of innovation projects, crises lead to the dissolution of existing ties. Simultaneously, responding to top-down incentives to pursue opportunities in new technology areas, inventors engage in a social search for collaborators. Thus, new ties are created between those working on new, non-core technologies. As a result of

[14] Just to give a perspective, between 1929 and 1932, the global GDP fell by an estimated 15%.

such churning, the knowledge network becomes less hierarchical, and thereby more supportive to exploratory search processes (Lazer and Friedman, 2007). Thus, we hypothesize that the economic crises have an additional indirect effect on regional exploration, mediated through the flattening of its knowledge network.

We test our hypotheses in the empirical context of US. Operationalizing regions in terms of Metropolitan Statistical Area (henceforth MSA), we establish a relationship between the intensity of Financial Crisis (2007-08) and the incidence of regional exploration. Building on a rich research tradition (Fleming, King and Juda, 2007; Ter Wal and Boschma 2009), we use patent data to construct knowledge networks and measure technological exploration within regions, controlling for a number of factors that may theoretically affect our dependent variable. We employ two empirical strategies. First, we employ fixed effect panel regression model (2004-14) to establish the relationship between the crisis, network structure (mediation analysis), and exploration. Further, we used difference-in-difference for a stronger claim of causality. For this, we exploited differences in the severity of Financial Crises on different MSAs. Our preliminary analyses support our hypotheses. We tested additional mechanisms, viz. changes in the organizational and inventor populations, lest they mediate the effects of shock on regional exploration. We failed to prove that any additional or alternate mechanism was at work.

Our paper contributes primarily to two streams of literature. First, it broadens our understanding of crises and downturns (Bloom 2014; Garcia-Sanchez, Mesquita and Vassolo 2014). In spite their severity and frequency, we know surprisingly little about decision-makers' response to such events and their organizational outcomes. One stream of works examines the effects of economic crises on firms' innovation strategy. It asks whether firms increase their R&D-spending during crises and recessions (Aghion, Askenazy, Berman, Cette and Eymard, 2012; Aghion and Saint-Paul, 1998; Paunov, 2012), and whether such counter-cyclical investments in R&D have performance-effects (Archibugi, Filippetti and Frenz, 2013; Flammer and Iaonnou, 2018). We broaden the scope of inquiry by asking whether economic crises also alter firms' learning strategies so that it produces effects at the aggregate level (regional network or ecosystem). That crises may trigger new path-creation through increased technological exploration may help us uncover new sources of adaptability, in line with the recent calls for research on regional, organizational and network resilience (Boschma, 2015; Martin and Sunley, 2015; Kahn, Barton, and Fellows, 2013; Van der Vegt, Essens, Wahlstrom and George, 2015).

Secondly, this paper joins the works that establish the effects of structural characteristics of regional knowledge networks on innovation and entrepreneurship (Cowan and Jonard 2004, Fleming, Juda and King, 2007; Saxenian, 1994; Stuart and Sorenson 2007). However, most of these works fail to take a dynamic perspective (Ahuja, Soda and Zaheer, 2012; Brenner, Cantner and Graf, 2013). Some scholars have anecdotally documented the occurrence of structural changes in certain regional innovation networks. For instance, Fleming et al. (2007: 952) show that the enhanced connectedness of the knowledge network in Silicon Valley can be traced back to the investments in R&D by IBM and to the repeated career moves between Stanford and IBM in the eighties; in contrast, similar exchanges did not take place between MIT and DEC in Boston. Other studies on network dynamics have focused primarily on organic, incremental changes (Madhavan, Koka and Prescott, 1998, Sytch and Tatarynowicz 2014) or quantitative case studies of cluster evolution (Ter Wal, 2013). Recently, Hernandez and Menon (2017) in their simulation-based study, have explored the effects of radical events such as node deletion due to exogenous conditions, on network structure. This paper adds a step forward in this direction, illustrating how a sudden change in the external conditions in which inventors operate can trigger changes in the structure of knowledge networks, and in the behavior of inventors therein.

LITERATURE: EFFECTS OF ECONOMIC CRISES ON INNOVATION

Most economic crises originate in the realms of finance[15] (Reinhart and Rogoff, 2008). For instance, financial crisis in the United States (2007-08) can be traced back to the sub-prime lending crisis (Mian and Sufi, 2009). Similarly, the 2009 sovereign debt crisis in Europe was triggered by weaknesses in public finance (Lane, 2012). Despite its origination in finance, crises often have profound, disruptive consequences for the whole economy. Past research indicates that such events trigger periods of higher uncertainty (Bloom, 2014; Singh, Mahmood and Natarajan, 2017), in which consumer demand decreases or is difficult to predict (Mian, Rao and Sufi, 2013), cost of capital increases (Chodorow-Reich, 2014; Lee, Sameen and Cowling, 2015), and the incidence of contractions, massive layoffs, and firm-failures increases (Bernanke, 1981; Bhattacharjee, Higson, Holly, and Kattuman, 2009; Chodorow-Reich, 2014). Periods of crisis are often associated with changes in the regulatory and policy framework, aimed at containing the consequences of such events, or easing recovery (Baker, Bloom and Davis, 2016; Rodrik, 1996).

Management and organization scholars have recently started studying economic crises, primarily in context of organizational survival and its strategic response. For instance, Greve and Yue (2017) have investigated what determines firms' capacity to execute collective action to tide over a looming crisis. Similarly, Dowell, Shackell and Stuart (2011) studied how corporate governance and CEO power factor in survival of the firms during financial crises. An emerging stream of works focuses on the effects of crises and downturns on firms' strategy and innovation

[15] Hence, large-scale crises come as exogenous shock to regional innovation.

expenditures. Crises and recessions have constraining effects on innovation, especially for less resourceful firms (Lee, Sameen and Cowling, 2015; Brautzsch, Gunther, Loose, Ludwig and Nulsch, 2015; Paunov, 2012). However, resourceful firms in technology-intensive industries may indeed invest more (rather than less) in R&D in order to get themselves out of the crisis (Aghion, Berman, Eymard, Askenazy and Cette, 2012; Aghion and Saint-Paul, 1998; Flammer and Ioannou, 2018). Flammer and Ioannou (2018) discovered that those firms which strategically invested more in R&D during the crisis perform better in the following years. Archibugi, Filippetti and Frenz (2013), based on the UK Community Innovation Surveys, found that the crisis led to a concentration of innovative activities within a small group of firms. Large firms with internal financial resources which were already highly innovative before the crisis increased their investments. Additionally, fast-growing new entrants also exhibited high R&D investments during the crisis. They found that firms pursuing strategies towards new products and markets development during the crisis coped better. Amore (2015) highlights learning effects in R&D strategies during recessions: firms that invested heavily in R&D in previous downturns invest more, and more effectively in R&D in the following business downturn.

The literature reviewed so far suggests a persistence of innovation activities, at least by some firms, during the crises despite financial constraints. However, a few questions remain unanswered. Firstly, what is the nature of innovative activities during crises: do firms continue developing technologies along their core technologies, or they invest in promising new ones? Secondly, scholars have studied the effects of crises primarily on individual firms. As ecosystems become increasingly important for technological innovation (Adner and Kapoor, 2010; Asheim and Gertler, 2006; Clarysse, Wright, Bruneel and Mahajan, 2014; Fleming, King and Juda, 2007), it is pertinent to inquire whether such crises have system-level effects, either in a regional or an industrial context. Thirdly, scholars have established the effects of inventor-level knowledge network[16] on both innovation productivity (Fleming, King and Juda, 2007; Funk, 2014) and the types of innovations produced (Carnabuci and Operti, 2013; Fang, Lee & Schilling, 2010; Keum and See 2016; Lazer and Friedman, 2007). Currently, we don't know how the structural properties of such knowledge networks underpin the deployment of R&D investments during crises. To fill these gaps, we inquire whether economic crises produce distant search at aggregate levels so that it potentially shifts the whole regional ecosystem towards new technological trajectories. We also examine how shocks affect regional knowledge networks, and to what consequences.

HYPOTHESES

Effects of the crisis on technology search

Crises adversely affect the demand conditions, thereby lowering firms' performance and simultaneously altering their opportunity-structure. Firms respond to the crises both behaviorally and strategically. According to behavioral theory (Cyert and March, 1963), when a firm performs below aspiration levels, it triggers search processes, and at the same time, starts adjusting its aspirations. Crises are also characterized by high-levels of uncertainty (Bloom, 2014). Thus, at least some actors in the firm believe that the macroeconomic conditions are only temporarily adverse; instead, the solution lies in upgrading firm's technology and strengthening its product-portfolio. Such beliefs slow down firm's adjustment of performance-aspirations despite poor

[16] We use this term following Phelps, Heidl and Wadhwa (2010), who define "a knowledge network as a set of nodes— individuals or higher level collectives that serve as heterogeneously distributed repositories of knowledge and agents that search for, transmit, and create knowledge—interconnected by social relationships that enable and constrain nodes' efforts to acquire, transfer, and create knowledge." (p. 1117). It is akin to "co-invention" (and co-inventor) network, used by Breschi and Lissoni (2004), and "collaboration networks on innovation", used by Fleming, King and Juda (2007).

performance, and instead intensify problemistic search. If local search in firms' core domains cannot restore the performance, firms engage in distant search into promising domains (Cyert and March 1963; Greve, 2003).

Crises also change firms' opportunity-structure. Firms' strategic response to these changes can be explained through (a) opportunity cost theory (Aghion and Saint-Paul 1998; Aghion et al, 2012), and (b) growth options effects (Bloom, 2014). Under weak demand conditions, exploration has low opportunity costs. As development efforts, i.e. incremental refinement of existing products, don't have high payoffs, firms can emphasize on distant search. Bloom (2014) argues that recessions engender high uncertainty, incentivizing firms to seek opportunities that are risky but have enormous payoffs. Firms respond by creating bets on emerging and futuristic technologies. In a qualitative study, Laperche, Lefebvre and Langlet (2011) reported that during financial crisis (2009-10), French firms aggressively pursued green technologies, which could help them develop and dominate new niches. Thales focused on lowering CO_2 emission from aircrafts; ArcelorMittal and Saint-Gobain shifted their R&D towards developing environmentally sustainable products and processes. French car-makers entered the segments of electric (Renault) and hybrid (PSA) cars.

Slack search is another source of exploratory R&D during crises and downturns (Greve, 2007; Nohria and Gulati, 1996). Resourceful firms generate organizational slack (resources) beyond what they require to function efficiently. When their performance falls below aspiration, organizations engage in slack search, i.e. they select and commercialize innovations developed by their excessive human capital. Researchers may generate repository of knowledge informally, working on their own projects in their free time, without the guidance from or knowledge of firm's management. During slack search, firms identify and develop innovations generated by such processes. Firms may also formalize and facilitate slack search by allocating time and resources to their knowledge-workers to pursue projects of latter's interest, and by keeping loose performance evaluation criteria in the early stages of such projects (Cyert and March, 1963; Greve, 2003). Such moonshot projects essentially involve experimentation and distant searches. Further, managers generate higher risk-tolerance when their firm is performing below aspiration, which is essential for distant-search based learning strategy (Greve, 2003; Kahneman and Tversky, 1979).

To conclude, economic crises push and incentivize firms to engage in distant search, arguably into emerging technologies, even if the firms or their current collaborators lack competence in these new technologies. Thus, it produces exploration at the systemic levels.

H1. An economic crisis will lead to increased levels of exploration in regional innovation networks (compared to pre-shock networks).

Effects of the crisis on knowledge network structure

Crises affect the structure of regional knowledge networks in two ways. First, as discussed above, crises alter learning strategies of the regional firms, pushing them towards exploration into new technology areas. This triggers "social search" processes at the inventor-level: inventors incentivized or interested to pursue new technologies would search for and collaborate with those who have expertise or interest in these technologies. Thus, new ties are created with (between) inventors who hitherto didn't work primarily in core technologies and did not have high centrality in the regional knowledge network.

Secondly, crises fall heavily on many firms, especially those which depend upon external finance or foreign markets. Numerous innovation projects get terminated, employees get laid off, and organizations get liquidated (Archibugi et al, 2013; Bhattacharjee et al, 2009; Brautzsch et al, 2015; Chodorow-Reich, 2014; Lee et al, 2015; Paunov, 2012), leading to dissolution of many existing ties. Exits are also known to propel entries in the region (Pe'er and Vertinsky, 2008). Dahl and Sorenson (2012) show that the mobility of knowledge workers is spatially constrained. Many of them react to unexpected unemployment by setting up new firms, typically with limited collaboration network. While pursuing novel and distant opportunities, they wouldn't necessarily forge ties with dominant inventors in the region specialized normally in its core technologies.

Altogether, deletion of the existing collaboration ties in core technology areas and creation of new ones with (between) working on non-core technologies lowers hierarchy (variance in distribution of collaboration-ties: Jackson, 2008) in the knowledge networks.

H2. An economic crisis will to decreased levels of hierarchy in regional innovation networks (compared to pre-shock networks).

Crisis, network structure and exploration

Search processes are facilitated and constrained by the network-structure (Sparrowe et al. 2001). Network studies provide ample evidence that exploration and distant search are favored by flatter structures. They support diverse worldviews and parallel search processes, leading to greater exploration (Carnabuci and Operti, 2013; Lazer and Friedman, 2007). Studies indicate that hierarchy and centralization negatively impact improvisation and performance in highly exploratory contexts (Keum and See 2016; Sparrowe, Liden, Wayne and Kraimer, 2001). Extending this body of works, we posit that the crisis-induced changes in the network structure mediate the effects of economic crisis on the incidence of exploration in a region.

H3. Decreased network hierarchy partly account for (mediate) the increased levels of exploration in regional innovation networks after an economic shock (compared to pre-shock networks).

Figure 1 below presents the theoretical model employed in this paper.

----------------Insert Figure 1 here---------------

METHODOLOGY

Data and sample

Following previous works (Fleming et al. 2007; Singh, 2005), we operationalize region in terms of Metropolitan Statistical Area (MSA), and take it as our unit of analysis. An MSA is a geographical entity, with an urban core with a minimum population of fifty thousand, which consists of the adjacent counties deeply integrated with the urban core socially and economically (National Longitudinal Survey, Bureau of Labor Statistics)[17]. For our analysis, we focus on the period 2003 – 2014[18], during which the Financial Crisis (2007-08) occurred. We combine data on housing prices from Federal Housing Finance Agency, macroeconomic and political economic data at the state and MSA levels from US Census Bureau and US Bureau of Economic Analysis, and patent data from the USPTO. Following Fleming et al. 2007, we use co-patenting networks using all inventors in the region as nodes and the co-invention of a patent representing a tie between them to proxy regional innovation networks. To create the co-patenting network,

[17] For example, Tucson (46040) in Arizona is an MSA with only one urban region and one county (Pima). San Francisco-Oakland-Fremont (41860), on the other hand, has three integrated urban centers and it consists of five counties - Alameda, Contra Costa, Marin, San Francisco, and San Mateo. http://www.nlsinfo.org/usersvc/NLSY97/NLSY97Rnd9geocodeCodebookSupplement/gatt101.htm#cbsa8

[18] A change in MSA-delineation and code-assignment (CBSA-scheme) occurred in 2003. Census Bureau created a new standard - Core-Based Statistical Areas (CBSA) that includes both metropolitan and micropolitan statistical areas. We use regions as delineated in 2003, together with their CBSA.

we adopted three-year moving windows (Carnabuci and Operti, 2013), i.e. to create the patenting network of 2005, we took into account all granted patents filed (applied) from the region in 2003, 2004 and 2005. We use the application date of the granted patents in order to capture the time when knowledge was created in the region. We used Table 1 summarizes our constructs, our proposed operationalization (variables), and details on the data source.

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

Research design and empirical approach

We propose two research designs to test our framework. First, we estimate a panel regression, with MSA-fixed effects (Fleming et al. 2007). Although this approach does not allow us to fully address the problem of unobserved heterogeneity in the regional knowledge networks, it can help us unveil the associations between constructs of interest in our hypotheses. In the second stage, we adopt difference-in-difference design to establish causation between crisis and incidence of regional exploration.

We operationalize exploration in terms of distant searches – "a pursuit of new knowledge" (Levinthal and March, 1993). In our data, a patented invention represents an instance of exploration if it is assigned a main-class which was never assigned to any other patented invention from that region in last ten years. Each patent is classified into at least one main class and within it, at least one subclass. By examining the class-subclasses assignment of patents filed from a region, we can identify the technology areas in which it has developed knowledge (Fleming and Sorenson, 2001; Rosenkopf and Nerkar, 2001). If the regional inventors have not filed patents in a technology main class in last ten years[19], it indicates that the

[19] Technologies evolve over time – and a region's (organization's) knowledge and competencies in a technology area gradually become redundant if it is not continually generating new knowledge in that area. A gap of ten years are good

region doesn't possess knowledge-base in that broad technology area. Therefore, if an inventor from the region generates knowledge in such an area, he is engaging in a distant search. Our dependent variable is the share of exploratory inventions in ratio of all patents filed from the region in that specific year.

We capture the intensity of 2007-08 Financial Crisis in regions through changes in their housing price index (hereafter HPI). Immediate cause of the Crisis was the bursting of housing bubble, which had grown since late 1990s and peaked in 2006-07 (Sanders, 2008). The Crisis began in the sub-prime mortgage market, with a high default rate of home mortgage sector, which later led to rapid devaluation of mortgage-backed securities, and thereby a liquidity crisis for banks and financial institutions that had invested heavily in such financial instruments. Lehman Brothers filed for bankruptcy on September 15, 2008, and firms like AIG and Merrill Lynch were on the brink of failure. As a result the housing prices further plummeted, resulting in evictions and foreclosures at a large scale. We also considered housing prices as an indicator of the intensity of crisis in the regions because it correlated strongly with the changes in consumer demand, employment growth, and wages at the US county-level (Adelino, Schoar, and Severino, 2015; Mian and Sufi, 2014). Scholars in the fields of economics and finance also use housing price elasticity to measure the variation in the severity of recession (Flammer and Iaonnou, 2015; Giroud and Mueller, 2015). We obtained the MSA-level quarterly data on the movement of housing price index from Federal Housing Finance Agency, and took its mean for the year. The origin of Financial Crisis also indicates that it was an exogenous shock to regional innovation.

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to suggest that the region's knowledge-base in the technology area is non-existent or redundant for all practical reasons. Further, if we don't take a ten-year window, more exploration will be reported in early years, e.g., in 1992 than in 2017.

We operationalize our mediating variable – *hierarchy of the regional knowledge-network* –in terms of the centralization of regions' knowledge network (Cook, Denny, Goist, Huynh, 2016). Centralization is a whole-network property. It measures to what extent network's most central node is central in relation to other nodes. Centralization of a network is measured by calculating the sum of the difference in the centrality of its most central node and all other nodes, and then dividing it by the theoretically largest sum of the differences (Borgatti, Everett, and Johnson, 2018). Thus, network-centralization C_x is measured as follows, when $p_m$is the node with highest centrality.

$$C_x = \frac{\sum_{i=1}^{N} C_x(p_m) - C_x(p_i)}{max \sum_{i=1}^{N} C_x(p_m) - C_x(p_i)}$$

A highly centralized network has a core-periphery structure.

Table 1 presents the list of controls comprised in vector Z. One category of controls comes from the patent-data and informs us about the size (intellectual resourcefulness), connectedness and density of the regional knowledge network, and the outward orientation of its inventors in forging collaboration ties with inventors located outside the region. Further, we use patent-data to compute the concentration of patenting by the USPC technology main classes and by the assignee organizations. Further, we controlled for macroeconomic variables: public investment on higher education (at state level), and regional resourcefulness, the size of high-technology sector, and the quality of its human capital (at MSA level).

We used a one year lag between the dependent variable (exploration) and the control variables, and further two years lag with the crisis. We assume that the housing price crash took some time to show effects on the whole economy. Figure 2 exhibits the temporal trends of declines in HPI and GDP in MSAs – it is evident that the latter followed the former with a lag of about one year. Firms and inventors would take further time to respond to the crisis by reorienting their innovation strategies and collaboration networks, and file patents. USPC main-class and year fixed effects (dummies) are included to account for unobserved time trends and technology domain heterogeneity. All variables are standardized (normalized) so that the coefficient-size is easier to interpret.

The present analyses report the results of a panel fixed effect regression

$$Exploration_{i\,t+1} = \beta_0 + \beta_3 Shock_{i\,t-2} + \alpha Z + \varepsilon_{it}$$

$$Centralization_{i\,t} = \beta_0 + \beta_2 Shock_{i\,t-2} + \alpha Z + \varepsilon_{it}$$

$$Exploration_{i\,t+1} = \beta_0 + \beta_4 Shock_{i\,t-2} + \beta_5 Centralization_{i\,t} + \alpha Z + \varepsilon_{it}$$

We test our mediation hypothesis by performing the Sobel test (Baron and Kenny, 1986).

----------------Insert Figure 2 here---------------

RESULTS

Descriptive analysis

As a starting point, we did the descriptive analysis in order to see the distribution of each variable. It is presented in table 2. On an average, 14.1% innovations represent exploration in terms of distant search from the regional perspective. Housing Price Index was 100 for each MSA in the first quarter of 1995. Its mean value for our period was 169.087. Mean per capita real GDP (chained 2009 US Dollars) across MSAs is 41650.38, whereas the mean salary in high-tech industries was 49732.14. New assignees in the region accounted for 29.375% of the total innovations in the region.

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

After running the full panel regression, we generated correlation matrix (estat vce, corr), which is presented in Table 3 below. As we can notice, correlation between the independent and the control variables is low.

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

Main-results

Table 4 presents our main results. Model 1 and 2 predict the incidence of exploration in the MSA. Model 3 predicts the effects of economic crisis on hierarchy (degree centralization) of the regional knowledge network. Model 1 includes the control variables, which can theoretically explain innovation and exploration in the regions. As expected, large, hierarchical networks with are less supportive of exploration. Coefficient of the natural log of network size is -.478 at the p-value of 0.000. Coefficient of network-hierarchy is -.096 at the p-value of 0.000. Network connectedness and density have positive but non-significant effects on regional exploration. Dominance of few large firms (coefficient: -.077; p-value: 0.000) and deep technological specialization (coefficient: -.039; p-value: 0.091) negatively affect region's tendency to undertake distant searches. Quality of human capital is positively related to regional exploration (coefficient: 0.066; p-value: 0.002). In model 2, we introduce the independent variable – housing price index (HPI). We find empirical support to our hypothesis 1 as HPI negatively affect the incidence of exploration in regions (coefficient: -0.050; p-value 0.000). It means that exploration in regions is counter-cyclical – lower the HPI, higher is the exploration. Direction and effect-size of the control variables remain quite similar.

In Model 3, we regressed our independent and control variables over hierarchy in the regional knowledge network with similar lag structure, and observed a positive and significant effect of the Housing Price Index (coefficient: 0.036; p-value: 0.003). Thus, supporting our hypothesis 2, the crisis (lowering of HPI) decreases network hierarchy in the regions. To test whether flattening of regional knowledge network mediates the effects of economic crisis on regional exploration, we ran the Sobel-Goodman mediation analysis. The results are presented in Table 5. We observed that crisis has a relatively small indirect effect on exploration by affecting the structural characteristics of regional knowledge-network (coefficient: -.0035; p-value: 0.008). The direct effects are much stronger with coefficient-size -.050 at a p-value of 0.000. Thus, the total effect of crisis on exploration is -.0533 at p-value of 0.000. Altogether 6.489% of the effects are mediated. Thus, our hypothesis 3 is also supported.

----------------Insert Table 4 and 5 here---------------

ADDITIONAL ANALYSIS

Assessing causality

For a stronger claim that economic crisis causes a higher incidence of regional exploration, we use difference-in-difference design. It has been used in natural experiments and captures the differential effects of a treatment on the experimental versus the control group. It requires measuring the dependent variable for both groups before and after the treatment. We first computed the drop in housing prices in each MSA between 2007, when the prices were at the peak in pre-crisis period, and 2011, when the prices were at the bottom in the post-crisis period. Depending on the percentage drop in prices by 2011 from 2007, the MSAs were divided into two halves. A dummy 'hit' was created with value 1 for MSAs that experienced higher than median drop in housing prices.

As housing price normally crashed since 2008 and bottomed in 2011, we assume that the effects on regional exploration in these period start reflecting in filed patents immediately in the following period. Hence, we took a post-crisis time-dummy t, with value 1 for years 2011-14 (a lag of three years as in panel regression model). This period was characterized by recessions. According to our hypothesis, MSAs that were severely affected by the crisis (hit = 1) should exhibit a higher incidence of exploration in the post-crisis period (t = 1). The results are presented in Table 7. It seems that there is a declining secular trend in regional exploration. The period 2011-14 has negative effects on the incidence of distant search (coefficient: -1.300; p-value: 0.000). However, MSAs that experienced the shock in a substantial manner (hit = 1) engaged significantly more in distant search (coefficient: .194; p-value: 0.000). Thus, it strengthens the causality between crisis and regional exploration.

----------------Insert Table 6 here---------------

Additional mechanisms

While there seems to be robust evidence for the *crisis leading to exploration*, we can only theoretically propose the mechanism. We did additional sensitivity analyses to check two other mechanisms: changes in the inventor-population, and changes in the organizational population in the region.

Distant search in a region can be brought by the inventors coming from outside the MSAs. Knowledge is predominantly tacit in the early stages of technology life-cycle and hence embedded in the inventors. Their mobility is an important conduit of knowledge-flow into the region (Breschi and Lissoni, 2009; Song, Almeida and Wu, 2003; Singh and Agrawal, 2011). Entry of new-generation inventors specializing in emerging technologies may also influence regional exploration. Hence, we tested whether newness of inventors in regions mediated the effects of crisis on regional exploration. Accordingly, we created a variable – "newness of the inventors in the region" to capture patenting experience of the most junior co-inventor from the region. For instance, if a patent is filed by a single inventor, who is highly experienced – the patent is his 120th innovation, but he has newly relocated to the MSA, from where it is only his 2nd filed patent, the variable "newness of inventors in the region" will compute the experience 2 and not 120. Similarly, suppose two more inventors – one from the region (8th patent from the region) and the other from outside the region (22nd patent) – have patented the innovation mentioned above. The newness variable still reads 2. Thus, the variable captures how from much new insight, from region's perspectives, was infused for the innovation.

Similarly, a change in organizational population can affect regional exploration. New ventures have higher incentives and abilities to undertake exploration (Henkel et al, 2015; Tushman and Anderson, 1986). Even when an inventor leaves a firm and starts a new venture (new assignee) or applies for patent-rights as individual assignees (potentially pre-incubation stage), he is more likely to engage in distant searches because of de-socialization and cognitive unbounding (Cirillo, Brusoni and Valentini, 2014; March, 1991). On the other hand, large incumbents tend to favor exploitation (Denrell and March, 2001; Tushman and Anderson, 1986). We capture entries through the share of patenting by the first-time assignees. It proxy three conditions: (1) de alio entries into the region, (2) de novo ventures in the region, and (c) first-time individual assignees (potentially pre-incubation stage ventures). All these can favor distant search from the regional perspective. We proxy the dominance of large firms by computing the share of patenting done by the four largest assignees from an MSA in all patents filed by all assignees from the MSA. A high share of patenting by four largest assignees should push the region more towards exploitation. It also implies that innovation efforts in the region should be aligned to the technological strategies and choices of these dominant assignees.

----------------Insert Table 7 here---------------

In Table 7, Models 6, 7 and 8 show whether shock affected the populations of inventors and organizations in the region. Model 7 suggests that the economic crisis (opposite of HPI) had a non-significant effect (coefficient: -.082; p-value: 0.571) on inventors' mean newness. Hence, we can discount our provisional hypothesis that the regional exploration during crises is spearheaded by new inventors. Model 8 and 9 present the effects of crisis on the organizational population in the region. Crisis (opposite of HPI) has a non-significant effect on technology entries (coefficient: -.002; p-value: 0.548). The direction of coefficient shows that entries in the technology-intensive industries take place when the economic conditions are favorable. The entries may also be fewer because of higher costs of capital during crises and a higher dependence of the entrants upon external funding. Further, necessity-driven ventures founded by displaced knowledge workers, as opposed to the opportunity-driven ventures, may not be as technology-intensive. Interestingly, the crisis significantly increases the concentration of patenting by the large firms. HPI negatively affects patenting by the four large firms in the region (coefficient: -.031; p-value: 0.036). It is possibly because, as the literature suggests, the large firms are more resourceful and fare better with the crisis. Hence, we could argue that regional exploration is not spearheaded by the changes in region's organizational population.

DISCUSSION AND CONCLUSION

This study explored how an exogenous economic shock triggers distant search processes and exploratory learning in regions. We partly explain the effects through the behavioral and strategic response of the firms to their sagging performance and the opportunities and threats posed by the economic crisis. In this sense, we contribute to the literature studying firms' R&D behavior during crises and recessions (Archibugi, Filippetti and Frenz, 2013; Aghion, Berman, Eymard, Askenazy and Cette, 2012; Aghion and Saint-Paul, 1998; Amore, 2015; Flammer and Ioannou, 2018). They have shown that firms in technology-intensive industries tend to "invest their way out of crisis". We further add to it by studying what kind of search activities they engage in. We found that these firms engage in distant search, generating knowledge along new, possibly emerging technologies. In doing so, they create effects at the regional level; they innovate in technology areas in the region didn't possess competence and didn't file any patent in those USPC main classes for a long time. Thus, the crises possibly help the entire region shift towards emerging and futuristic technologies.

We also show that a part of the aforementioned effect is mediated through changes in the structure of regional knowledge network. Crises lead to a structural reorientation in the network in such a way that its hierarchy is lowered. Changed opportunity-structures and top-down incentives by firms to explore into new technologies beyond firms' (and regions') core areas encourage the inventors to seek new collaborators (what we call a "social search"). Thus, crises lead to formation of new ties with (between) the peripheral inventors who specialize in or are interested in technologies that are non-core to the firm/region. Additionally, crises also lead to churning of many existing ties through liquidation, layoffs, and project-termination events. Many affected inventors explore into new technology areas. Their new projects may not be with prior collaborators working on firm's/region's core technologies and having high centrality in the regional network.

Flatter networks are more supportive of exploration (Carnabuci and Operti, 2013; Fang, Lee & Schilling, 2010; Keum and See 2016; Lazer and Friedman, 2007). Our study shows that the crisis has a relatively small but significant indirect effect on regional exploration, mediated by the lowering of network hierarchy. In this sense, we extend and complement works establishing a relationship between the structure of a region's network and its innovativeness (Saxenian, 1994; Fleming et al, 2007). Studying how network structure change in the face of an exogenous shock and how these changes influence region's innovation outputs and potentially its technological trajectories, we take a dynamic perspective (Ahuja, Soda and Zaheer, 2012; Brenner, Cantner and Graf, 2013).

Limitations

Currently, this study has certain limitations that we are working on. We want to check the robustness of our analysis by taking alternate operationalization of Financial Crisis, such as foreclosures (Aalbers, 2009). We can also take alternate operationalization of network-hierarchy (Cook et al. 2016). Further, we checked only a few policy measures as control, such as public capital outlays, spending on public services, and public funding to higher education. We didn't find these effects significant, and for the sake of parsimony, only included the funding to higher education in our final analysis. However, we are working on the data on public legislation on plant-closures and layoffs, and disbursement of public funds in regions through American Recovery and Reinvestment Act (ARRA), 2009. While the first is a bit difficult to comprehend and code, the data on regional disbursement of funds is fragmented (almost two-thirds are missing).

Overall, this study reveals at least one potential upside of economic crises! Increased levels of exploration is efficient in long run – it facilitates new path-creation and thus add to the dynamic adaptability of an organization, both at firm and regional levels (March, 1991). Thus, our work resonates with the literature on regional resilience which conceptualizes the resilience in terms of "bouncing forward" and creation of new efficient specialization lock-ins along adapted trajectories rather than "bouncing back" to the old ones (Boschma, 2015; Martin and Sunley, 2015). Further, explaining how firms' strategic responses and structural aspects of knowledge-networks influence exploration and an ecosystemic shift to new, emerging technologies, we contribute to both strategy and policy.

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FIGURES

Figure 1. Effects of exogenous, economic shocks on regional knowledge networks

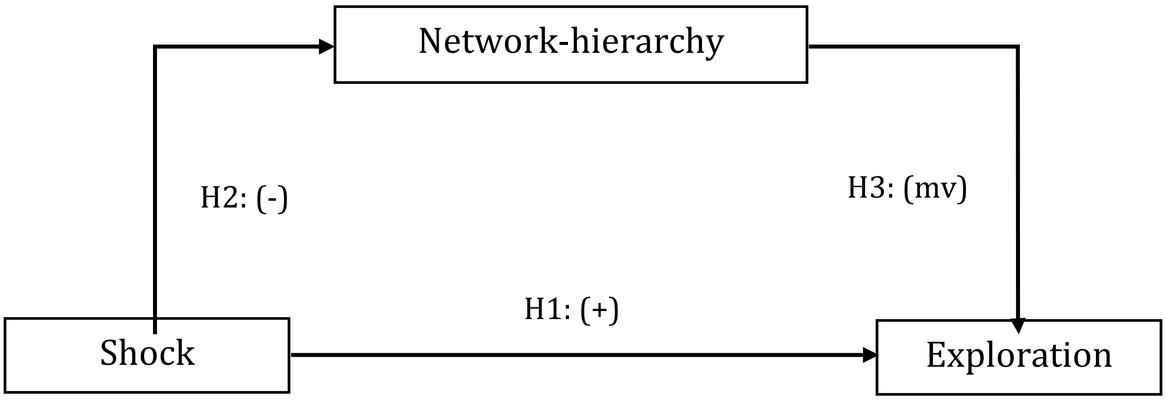
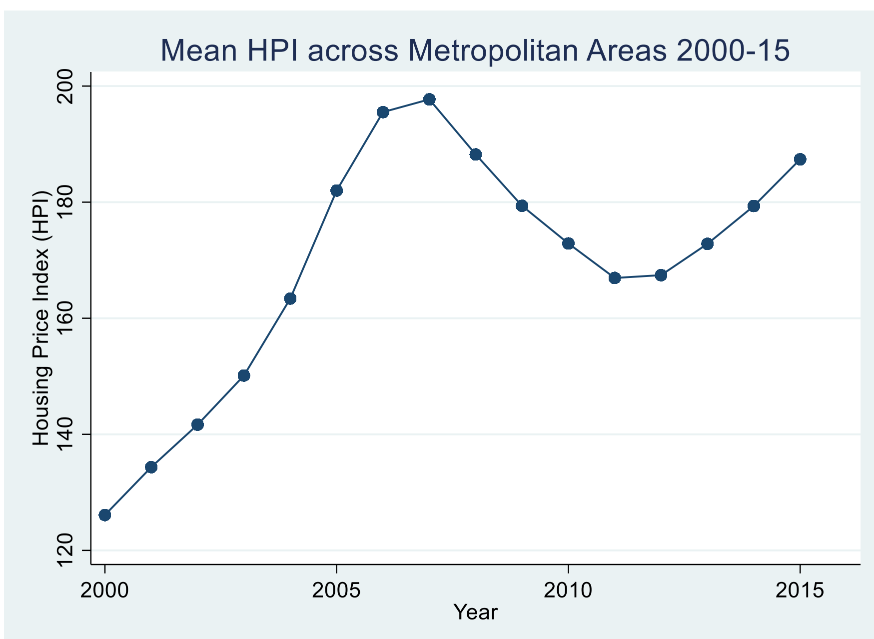
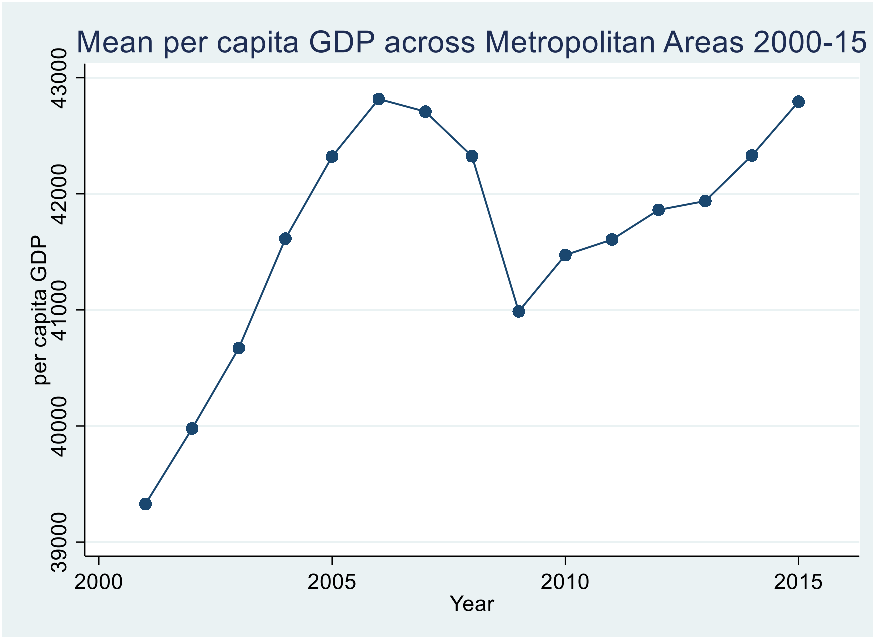


Figure 2. Movement of per capital GDP and Housing Price Index (mean across MSAs)





Mean per capita GDP across Metropolitan Areas 2000-15
per capita GDP
39000
40000
41000
42000
43000
2000
2005
2010
2015
Year

TABLES

Table 1. List of variables, operationalization and data-sources.

Constructs	Operationalization (variables) and data-sources
Region (unit of analysis)	Metropolitan Statistical Area (MSA), in the USA
For main analysis	
Exploration (dependent variable)	In terms of distant searches. A patented invention denotes a case of exploration if it is assigned a main-class, in which no other patent from the MSA was assigned in the last ten years. USPTO (US Patent Classification data)
Economic crisis (IV) [MSA]	Changes in the housing prices in the MSA. Housing Price Index (HPI) – non-seasonally adjusted (average of all quarters). Lower the prices, higher the intensity of crisis. Federal Housing Finance Agency
Hierarchy [MSA]	Degree-centralization in knowledge network of the MSA. USPTO (Patent-inventor-location data).
Intellectual resourcefulness [MSA]	Natural log of the size (number of nodes/inventors) of MSA's co-patenting network. USPTO (Patent-inventor-location data)
Connectedness [MSA]	Percentage of nodes (inventors) forming largest connected component in knowledge network of the MSA USPTO (Patent-inventor-location data)
Density [MSA]	Average degree of each node (inventor) in knowledge network of the MSA USPTO (Patent-inventor-location data)
Outward orientation of collaboration [MSA]	Ratio of total number of external collaboration ties over total number of internal ties, forged by inventors in MSA. USPTO (Patent-other references data).
Technological concentration in patenting [MSA]	Herfindahl index (HHI) of patenting in the MSA by USPC technology main classes. USPTO (Patent-inventor-location-classification data)
Organizational concentration in patenting [MSA]	Herfindahl index (HHI) of patenting in the MSA by assignee organizations. USPTO (Patent-assignee-location data)
Technology main-class assignment [MSA]	Dummy = 1 if inventors from the MSA have filed patent(-s) in a USPC main-classes (up to 2 digits). USPTO (US Patent classification at the time of issue; inventor-region data).

Regional resourcefulness [MSA]	Per capita GDP (chained 2009 US Dollars) in the MSA. US Bureau of Economic Analysis (regional data).
Relative size of high-technology sector [MSA]	Natural log of the number of employees in high-tech industries out of the total number of employees in the MSA. US Bureau of Economic Analysis (regional data).
Quality of human capital in high-tech [MSA]	Per capita annual payment in the high-tech sectors in the MSA. US Bureau of Economic Analysis (regional data).
Policy support to higher education [State]	Per capita expenditure on higher education. US Census Bureau: State and Local Government Finance (state data)
For additional analysis	
Newness of inventors (for robustness)	Mean experience of the junior-most co-inventors in the MSA. USPTO (Patent-inventor-location data)
Entrant assignees (for robustness)	Share of patenting done by the first-time assignees in the MSA. USPTO (Patent-assignee-location data)
Dominance of large firms	Share of patenting done by the four largest assignees in the MSA. USPTO (Patent-assignee-location data)

Table 2. Descriptive analysis (distribution of the variables)

Variable	Observations	Mean	Std. Dev.	Min	Max
Share of exploration	7,426	0.141	0.184	0	1
Housing Price Index	7,023	169.087	36.492	86.714	364.25
Network-hierarchy	6,144	0.0423	0.0350	0	0.389
Network size (log)	6,146	5.264	1.798	0	10.356
Share - largest component	6,146	0.118	0.103	0.008	1
Average degree	6,146	1.363	1.010	0	5.844
Outward orientation	6,802	6.031	10.600	0	229
HHI – USPC main class	7,418	0.198	0.238	0.026	1
HHI – assignees	7,378	0.165	0.180	0.004	1
Per capita GDP	6,576	4.165	1.223	1.586	17.831
Employment in high-tech (log)	6,355	9.219	1.571	3.689	13.949
PC salaries in high-tech	6,355	49.732	15.091	13.975	165.953
PC state-funding to higher ed.	5,707	0.680	0.375	0	8.119
Entrant assignees*	5,443	0.294	0.208	0.011	1
Newness of inventors*	7,426	6.217	8.307	1	270.333
Dominance of large firms*	7,378	0.724	0.180	0.229	1

*In robustness analysis.

Table 3: Correlation matrix [after the panel regression (fixed effects) model]

	e(V)	1	2	3	4	5	6	7	8	9	10	11	12
1	Housing Price Index (HPI)	1.000											
2	Network hierarchy	-0.033	1.000										
3	Network size (log)	-0.044	0.239	1.000									
4	Share - largest component	0.019	0.032	-0.061	1.000								
5	Average degree	0.039	-0.499	-0.487	-0.081	1.000							
6	Outward orientation	-0.049	0.034	0.018	-0.011	0.079	1.000						
7	HHI – USPC main class	-0.044	0.010	0.056	-0.027	-0.025	-0.038	1.000					
8	HHI – assignees	0.020	-0.006	0.077	-0.025	-0.109	-0.012	-0.126	1.000				
9	Per capita GDP	-0.357	-0.010	0.004	-0.095	0.000	0.010	0.023	-0.011	1.000			
10	Employment high-tech	-0.102	0.024	0.030	0.035	-0.012	0.016	0.009	-0.046	0.004	1.000		
11	PC salaries in high-tech	-0.050	0.014	-0.024	-0.124	0.002	0.013	0.002	0.019	-0.043	-0.104	1.000	
12	PC state-funding to high ed.	0.039	-0.008	-0.028	-0.015	0.028	-0.001	0.001	-0.025	-0.055	-0.012	-0.021	1.000

Table 4: Effects of economic crisis on regional exploration and knowledge network centralization

	Model 1	Model 2	Model 3
VARIABLES	FE Panel regression Exploration (distant search)	FE Panel regression Exploration (distant search)	FE Panel regression Degree centralization
Housing Price Index (HPI)		-0.050***	0.036**
		(0.014)	(0.012)
Network hierarchy	-0.097***	-0.093***	
	(0.018)	(0.018)	
Network size (log)	-0.478***	-0.447***	-1.339***
	(0.107)	(0.107)	(0.091)
Share - largest component	0.063**	0.059**	0.404***
	(0.022)	(0.022)	(0.018)
Average degree	0.058	0.053	0.577***
	(0.036)	(0.035)	(0.030)
Outward orientation	0.011	0.011	-0.016*
	(0.009)	(0.009)	(0.008)
HHI – USPC main class	-0.039^	-0.033	-0.027
	(0.023)	(0.023)	(0.020)
HHI – assignees	-0.077***	-0.077***	-0.056***
	(0.019)	(0.019)	(0.016)
Per capita GDP	-0.005	0.018	0.009
	(0.030)	(0.030)	(0.027)
Employment in high-tech	0.047	0.045	-0.031
	(0.030)	(0.030)	(0.026)
PC salaries in high-tech	0.066**	0.071***	-0.008
	(0.021)	(0.021)	(0.019)
PC state funding to higher education	0.012	0.012	0.003
	(0.009)	(0.009)	(0.008)
Main class FE	YES	YES	YES
Year FE	YES	YES	YES
Constant	0.931***	0.872***	0.113^
	(0.067)	(0.069)	(0.060)
Observations	4,483	4,483	4,494
Number of MSAstate	435	435	435
R-squared (within)	0.334	0.341	0.365
R-squared (overall)	0.5130	0.5086	0.5745

Standard errors in parentheses
*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1

Table 5: Sobel-Goodman mediation analysis: degree-centralization (hierarchy) in regional knowledge network

	Coefficient	Std. Error	Z	P<|Z|
Sobel	-.00346268	.0013092	-2.645	.00817208
Goodman-1 (Aroian)	-.00346268	.00132735	-2.609	.00908822
Goodman-2	-.00346268	.0012908	-2.683	.00730564
a coefficient	.037135	.012029	3.08724	.00202
b coefficient	-.093245	.018184	-5.12776	2.9e-07
Indirect effect	-.003463	.001309	-2.64488	.008172
Direct effect	-.049898	.01372	-3.63686	.000276
Total effect	-.053361	.013748	-3.88147	.000104
Proportion of the total effect that is mediated:		.06489151		
Ratio of indirect to direct effect:		.06939463		
Ratio of total to direct effect:		1.0693946		

Table 6: Difference-in-difference: effect of economic crisis on regional exploration

	Model 4	Model 5
VARIABLES	FE Panel regression Exploration (distant search)	FE Panel regression Exploration (distant search)
1.time (2011-14)	-1.300***	-1.405***
	(0.066)	(0.068)
1.hit		Omitted
0.time#0.hit		0.000
		(0.000)
0.time#1.hit		0.000
		(0.000)
1.time#0.hit		0.000
		(0.000)
1.time#1.hit		0.194***
		(0.033)
Network hierarchy	-0.097***	-0.094***
	(0.018)	(0.018)
Network size (log)	-0.478***	-0.466***
	(0.107)	(0.107)
Share - largest component	0.063**	0.059**
	(0.022)	(0.022)
Average degree	0.058	0.057
	(0.036)	(0.035)
Outward orientation	0.011	0.010
	(0.009)	(0.009)
HHI – USPC main class	-0.039^	-0.036
	(0.023)	(0.023)
HHI – assignees	-0.077***	-0.076***
	(0.019)	(0.019)
Per capita GDP	-0.005	0.023
	(0.030)	(0.030)
Employment in high-tech	0.047	0.054
	(0.030)	(0.030)
PC salaries in high-tech	0.066**	0.066***
	(0.021)	(0.021)
PC state funding to higher education	0.012	0.012
	(0.009)	(0.009)
Main class FE	YES	YES

Year FE	YES	YES
Constant	0.937***	0.943***
	(0.067)	(0.067)
Observations	4,483	4,483
Number of MSAstate	435	435
R-squared (within)	0.339	0.345
R-squared (overall)	0.5093	0.5192

Table 7: Effects of economic crisis on regional exploration and knowledge network centralization

	Model 6	Model 7	Model 8
VARIABLES	FE Panel regression Newness of inventors	FE Panel regression Entrepreneurial entries	FE Panel regression Dominance of large firms
Housing Price Index (HPI)	0.082	0.002	-0.031*
	(0.144)	(0.004)	(0.015)
Network hierarchy	2.838	-0.587***	0.601
	(5.148)	(0.129)	(0.527)
Network size (log)	0.664	-0.079***	-0.076
	(0.626)	(0.016)	(0.064)
Share - largest component	0.000	0.000	0.000*
	(0.000)	(0.000)	(0.000)
Average degree	0.311	-0.002	0.093**
	(0.338)	(0.009)	(0.035)
Outward orientation	0.030***	-0.000*	0.000
	(0.009)	(0.000)	(0.001)
HHI – USPC main class	0.138	0.048^	-0.164
	(1.013)	(0.025)	(0.104)
HHI – assignees	10.267***	-0.271***	3.266***
	(1.071)	(0.029)	(0.110)
Per capita GDP	-0.106	-0.002	-0.001
	(0.262)	(0.006)	(0.027)
Employment in high-tech	-0.111	0.004	-0.001
	(0.201)	(0.005)	(0.021)
PC salaries in high-tech	-0.016	-0.000	-0.001
	(0.015)	(0.000)	(0.002)

PC state funding to higher education	0.168	-0.003	-0.025
	(0.261)	(0.006)	(0.027)
Main class FE	YES	YES	YES
Year FE	YES	YES	YES
Constant	2.588	0.775***	-0.321
	(4.002)	(0.100)	(0.409)
Observations	4,494	4,113	4,494
Number of MSAstate	435	434	435
R-squared (within)	0.084	0.137	0.235
R-squared (overall)	0.031	0.409	0.577

Standard errors in parentheses

*** p<0.001, ** p<0.01, * p<0.05, ^ p<0.1