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SCIENTIFIC ABSORPTIVE CAPACITY: THE ROLE OF CORPORATE SCIENTISTS AS MICRO-FOUNDATIONS OF INNOVATION CAPABILITY

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Abstract

Purpose. The purpose of this study is to explain the connection between firms' investment in basic scientific research and their innovation performance. Basic research and its outcomes generally belong to the public domain and are accessible to all interested parties. Yet, private firms' engagement in it, as we argue, helps create absorptive capacity needed to access and benefit from cutting edge knowledge created outside their organizational boundaries.

Design/methodology/approach. This is a conceptual paper dedicated to the development of a contingent theoretical framework to link firm investments in basic scientific research to their ability for form and benefit from external knowledge access collaborations. The developed theoretical model draws from extant empirical literature on the role of basic research in firm innovation including anecdotal observations that hint at managerial intentions behind their encouragement of corporate scientists to engage in basic research, particularly in collaboration with external scientists.

Findings. The model suggests two sets of mechanisms as part of a contingent theory of the role of scientific absorptive capacity in driving external knowledge sourcing of firms. Whereas the first set of contingencies is based on the nature of the firm's scientific research activities, the second set focuses on other internal firm processes that may suppress or substitute the effect of the resultant absorptive capacity.

Research limitations/implications. As a conceptual paper, this study is limited in that it relies on insights from prior literature and the verification of its proposed relationships would require future empirical investigations. Yet, the theoretical insights developed here could pave the way for more fruitful future inquiries into the nature of basic scientific research in the private sector and enhance our understanding of how science fits into firms' overall innovation strategy.

Originality/value. As one of the first studies to elaborate on the concept of scientific absorptive capacity, this paper not only contributes to the burgeoning literature on the process of absorptive capacity development in firms, it also offers insights for practitioners regarding the effective management of the research and development process inside their firms.

Keywords: Scientific research; Knowledge accessing; Absorptive capacity; Firm innovation.

INTRODUCTION

Research has long speculated about the how basic scientific research contributes to firm innovation (Gambardella, 1992; Cockburn & Henderson, 1998; Zucker et al., 1998; Durand et al., 2008). Science has been generally identified in this research as a driver of a significant subset of innovations in various industries (Mansfield, 1991 and 1997). Mansfield (1991), for instance, found that about one-tenth of all product and process innovations introduced between 1975-1985 in a wide range of industries including pharmaceuticals, chemicals, metals, oil, instruments, and information processing could not have been developed in the absence of recent basic scientific research. A common theme among these various lines of research is that firms do not consider science as a mere external entity existing in the public domain (Stern, 2004; Huang & Murray, 2009). To the contrary, firms, especially in technology-driven industries, have been shown to actively pursue science by making significant investments in its creation and development (Gambardella, 1992; Gittelman & Kogut, 2003).

The observation that for-profit firms make significant investments in basic scientific research (Rosenberg, 1990), has presented a puzzle to scholars given the public good nature of its outcomes that generate no tangible rents for the firm in the traditional sense. Relatedly, this literature has also noted that significant heterogeneity exists among firms in their ability to benefit from knowledge created outside their boundaries (Cohen & Levinthal, 1990; Gambardella, 1992). In particular, while a great deal of external knowledge, including public science, appears to be equally and inexpensively accessible to all firms, only a subset of firms manage to harness its benefits in their own internal innovation processes. A joint consideration of these two observations has offered a solution to the puzzle of private firm's engagement in public science: private firms invest in basic science in order to develop the 'absorptive capacity' to understand and utilize external knowledge (Cohen & Levinthal, 1990; Rosenberg, 1990; Gambardella, 1992). Absorptive capacity allows firms to monitor the flow of knowledge outside their boundaries, internalize relevant knowledge, and exploit it in their internal innovation processes (Rosenberg, 1990).

However, while the general benefits of investing in basic science for facilitating firms' access to external knowledge are discussed at length in this literature, there is surprisingly little discussion on the challenges faced by firms in developing and deploying the type of absorptive capacity that results from basic science investments, also known as scientific absorptive capacity. Particularly, on the development side, the question of how to effectively allocate such internal investments toward maximizing the resultant absorptive capacity remains unanswered. That is, we do not know which types

of research projects tend to have higher contributions to the firm's absorptive capacity and hence, merit higher shares of the firm's basic research budget. On the deployment side, literature also seems to have assumed that once developed, absorptive capacity is automatically incorporated into the firm's innovation strategy to its fullest potential. As such, we know little about internal mechanisms that might potentially interfere with the deployment of absorptive capacity and suppress its role in enabling the firm's access to external knowledge.

We set out to close these gaps in our understanding of how firms develop and deploy absorptive capacity. On the one hand, we consider the nature of the research projects that represent the ingredients of the firm's scientific absorptive capacity to determine the characteristics that set the projects apart in terms of their eventual contribution. On the other hand, we consider a set of internal firm mechanisms that could potentially eclipse the role of scientific absorptive capacity and suppress its effect in facilitating external knowledge access. In particular, we formulate a contingent theory of the effect of basic science projects, and their resultant absorptive capacity, on the formation of new knowledge sourcing collaborations (e.g. R&D alliances), encompassing two sets of contingencies that correspond to our study's dual contributions outlined above. The first set of contingencies – *isolation of firm scientists*, *arm's length co-authorships*, and *organizational dispersion of scientific projects* – probes the nature of the research projects that contribute to the firm's absorptive capacity. The second set – *patenting productivity of the firm and R&D alliance experience* – reflects internal firm capabilities that arguably hold more tangible associations with the process of new collaboration formation relative to scientific absorptive capacity and hence, overshadow its fundamental role within the process. Finally, we consider the role of scientific absorptive capacity at the time of forming new collaborations on the long-term benefits of those collaborations for the firm's innovative output.

A THEORY OF SCIENTIFIC ABSORPTIVE CAPACITY

METHODOLOGY

Given the conceptual nature of this study, we employed an extensive literature review methodology to identify all key studies in various streams of literature that have dealt with the topic of basic scientific research in the private sector. After several rounds of refinement, we ended up with a collection of scholarly work that directly addressed the role of scientific research in firm innovation and the potential contingencies surrounding its impact. The insights from these studies were distilled into a novel theoretical framework that proposes a contingent relationship between firm investments in basic

scientific research and the ability to form external collaborations to benefit from knowledge residing outside firm boundaries. Figure 1 summarizes our proposed theoretical framework which is explained in detail in the following sections.

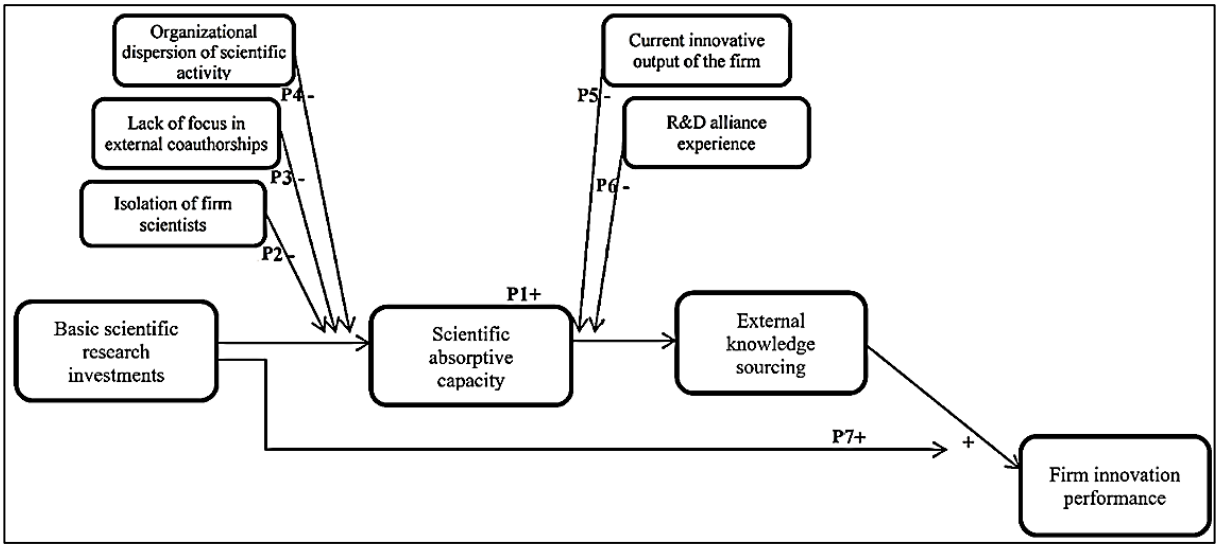

FIG 1. THE PROPOSED THEORETICAL FRAMEWORK OF THE STUDY

SCIENTIFIC ABSORPTIVE CAPACITY AND KNOWLEDGE SOURCING

A long tradition of research (e.g. Rosenberg, 1990; Gambardella, 1992; Zucker et al., 2002) has established that engaging in in-house basic scientific research allows firms to stay abreast of and tap into external flows of scientific and technological knowledge to boost innovation within the firm. Such capacity based on in-house scientific research to benefit from external knowledge is, in essence, an element of absorptive capacity. Cohen and Levinthal's (1990) ground-breaking article introduced the notion of absorptive capacity to strategy and organizational research as a firm's ability to evaluate, assimilate, and apply external information and knowledge in its innovation processes. According to Cohen and Levinthal (1990), absorptive capacity provides a ready explanation for firms' investment in basic research despite the fact that its findings inevitably spill out into the public domain in the form of scientific publications. Specifically, they suggested that firms' true goal in conducting basic research is not the mere results of the research itself but also the creation and maintenance of the ability to tap into knowledge developed outside the firm. In other words, in-house basic research can be thought of as "…broadening the firm's knowledge base to create critical overlap with new knowledge and providing it with a deeper understanding that is useful for exploiting new technical developments that build on rapidly advancing science and technology." (Cohen & Levinthal, 1990: 148).

Since the notion of absorptive capacity has grown to include several dimensions of a firm's internal capabilities, to maintain our focus on the role of basic science in firm's innovation strategies we adopt the term 'scientific absorptive capacity' (Schmidt, 2005; Roach, 2009) to refer to the capacity provided based on conducting in-house scientific research. Our baseline proposition captures the relationship between scientific absorptive capacity and external innovative knowledge sourcing by the firm. Specifically, we argue that a firm's scientific absorptive capacity reflected in its in-house science productivity impacts its willingness and ability to form future knowledge access collaborations. Particularly, scientific absorptive capacity enables the firm to assess a larger group of potential collaborating partners, leading to the formation and execution of a greater number of such collaborations (Arora & Gambardella, 1994). Scientific absorptive capacity also alleviates partners' appropriability concerns that inevitably overshadow any joint knowledge creation and access (Gulati & Singh, 1998; Oxley and Sampson, 2004). That is, the deeper knowledge of firm scientists about the knowledge areas involved in the collaboration will enable the firm to identify and prevent partner opportunism should it arise during the course of the collaborative effort (Gulati & Singh, 1998). Building on this line of reasoning, we propose that scientific absorptive capacity will impact the firm's extent of future external knowledge accessing collaborations. Therefore,

> P1: Scientific absorptive capacity will positively impact the extent of the firm's external knowledge access collaborations.

CONTINGENCIES BASED ON CHARACTERISTICS OF SCIENTIFIC PROJECTS

Isolation of firm scientists

Our first set of contingencies is based on the features of the scientific projects that underlie the firm's scientific absorptive capacity. We begin by considering the contingency of the isolation of firm scientists in their projects from the broader scientific community. The public good nature of basic science implies that scientific advances result from the collective efforts of the broader scientific community. In other words, the locus of major developments in basic science is most likely to fall in the public domain consisting of all public and private institutions that engage in basic scientific research. Collaboration of firm scientists with external coauthors represents the main mechanism through which the firm's internal research program stays connected to scientific advances in the field. Research has shown that connectedness to the external scientific community not only

enhances firms' ability to recognize, evaluate, and utilize scientific developments, it also increases research productivity inside the firm (Cockburn & Henderson, 1998).

The majority of external collaborations by firm scientists are with academic researchers who act as contact points helping corporate researchers to keep their knowledge updated with scientific advancements in academic research labs and other publicly-funded institutions that are dedicated to basic research. These collaborations are crucial to firm scientists as they can gain direct exposure to new knowledge at the boundaries of their respective fields. Particularly, knowledge of ground-breaking scientific discoveries is often tacit and its links to current codified knowledge base tends to be less clear. Hence, by collaborating with the star scientists, corporate researchers learn enough to be able to transfer that knowledge for internal use inside the firm.

To effectively benefit from external scientific knowledge, it is not enough for firms to hire top researchers and inspire them to actively engage in basic research. It is also important for the corporate researchers to actively engage in external collaborations with those in the academia and the public sector (Cockburn & Henderson, 1998). Zucker et al., (2002), for instance, argued that academic collaborations can be utilized by corporate researchers to capture and internalize the complex knowledge components that form the foundations for novel discoveries in university labs. The effectiveness of such collaborations are higher when they connect firm scientists to 'star' scientists most of whom work at top universities. In earlier research, Zucker et al., (1998) found that both start-up firms and existing firms entering a new technology area tend to collocate with the top star scientists of the field.

Overall, connectedness to the broader scientific community through external co-authorships implies that firm scientists are involved in the generation of cutting-edge knowledge within the scientific discipline and have first-hand exposure to its underlying components. In contrast, when firm scientists are isolated from the broader scientific community, the knowledge represented in their research output is likely to be distant from recent advances in the field, and hence, result in the diluting of the effect of the firm's scientific absorptive capacity in driving external knowledge access efforts of the firm. Therefore,

> P2: The positive effect of scientific absorptive capacity on the extent of the firm's external knowledge access collaborations is weaker when the degree of scientist isolation is high.

Lack of focus in external collaborations

By further examining the nature of the external collaborations of firm scientists, the next contingency complements the preceding arguments regarding the importance of external

connectedness for firm scientists. Specifically, Proposition 3 distinguishes between external collaborations that truly represent hands-on involvement of firm scientists in joint research projects with colleagues outside the firm, and those resembling arm's length relationships where firm scientists only receive credit for their general attachment to the project without performing any serious collaborative work. The basic argument here is that publications where a large number of scientists representing a myriad of public and private organizations are listed as coauthors most often represent instances of the latter type of external collaborations (Cronin, 2001).

Numerous studies in various disciplines have reported a growing trend in the number of authors on a typical research publication – e.g. Cronin (2001) in biomedicine, Slafer (2005) in crop science, Gibelman & Gelman (2000) in social work, and Englebrecht et al., (2008) in accounting research. The shift from solo-authored to multiple-authored publications has been generally regarded as a justified reaction to historical changes in the nature of research and publishing such as the shifting patterns of research funding, increased specialization, demands for higher quality and precision of scientific inquiry, the growing professionalism in academia, the need to train apprentices, and the demand for cross-fertilizing across disciplines (Katz & Martin, 1997). However, systematic analyses of scientific publications and their patterns of co-authorship have also revealed a creeping trend toward overcrowded lists of coauthors and the organizations and institutions represented by them on a growing subset of coauthored publications. Gelman and Gibelman (1999), for instance, reported that among the papers published in 4,000 journals indexed by the Institute for Scientific Information, the number of papers with 50 or more coauthors grew from 49 in 1981 to 407 in 1994. Such overcrowded lists of coauthors and institutions have been generally associated with denigrating the scientific research process without offering any real added value per every additional listing beyond what constitutes a convincing size of the actual team of researchers and their supporting institutions (Woods et al., 2010).

Thus, we argue that the presence of arm's length-type coauthored publications in the firm scientists' output will likely be a sign of the lack of engagement of firm scientists in rigorous joint efforts with the leading minds behind major discoveries in the discipline. Therefore,

> P3: The positive effect of scientific absorptive capacity on the extent of the firm's external knowledge access collaborations is weaker when firm scientists engage in many external co-authorships of the arm's length type.

Organizational dispersion of scientific activity

As a third contingency, we examine the implications of research activities that are dispersed across the corporate structure and are carried out by scientists employed at the subsidiaries. Particularly, we argue that basic research projects that are not concentrated in specific organizational units and are scattered across various organizational divisions tend to generate a type of knowledge base that requires significant mobilization costs in order to become beneficial for the firm's internal innovation process (Teece, 1977). In other words, the dispersion of basic research projects is likely to introduce added integration costs to the process of mobilizing and employing the firm's scientific absorptive capacity.

We know from past research that integrating the knowledge created by distributed research efforts across different corporate divisions presents significant challenges. In one such study, Singh (2008) explored how the geographic dispersion of a firm's R&D activities impacts the quality of its innovative output, and found that such distribution lowers the value of the resulting innovations. The higher transfer costs of knowledge created by distributed research efforts is partly driven by a phenomenon known as knowledge 'stickiness' (Kogut & Zander, 1993; Szulanski, 1996). The concept of knowledge stickiness builds on the notion that, besides transfer agents and transfer media, transfer costs are also driven by the characteristics of the knowledge itself. Szulanskie (1996) found that contrary to the previously-accepted wisdom, the major impediments to the transfer of knowledge are not rooted in motivational factors, but are due to the characteristics such as the causal ambiguity of the knowledge itself. Organizations can deal with knowledge stickiness by investing in proper organizational structures and cultures that inspire employees to engage in tacit knowledge transfer across the entire organizations rather than simply focusing inside their work teams (Osterloh & Frey, 2000). Organizations would also need to speed knowledge transfer by attempting to codify their tacit knowledge as much as possible and in doing so, risk imitation of their innovative ideas by competitors (Zander & Kogut, 1995). Thus, we expect that the impact of the resulting scientific absorptive capacity will be diluted by the integration and deployment costs arising from the dispersion of scientific projects across the organizational structure. Therefore,

> P4: The positive effect of scientific absorptive capacity on the extent of the firm's external knowledge access collaborations is weaker when the organizational dispersion of scientific projects is high.

CONTINGENCIES BASED ON INTERNAL FIRM PROCESSES

Current innovative output of the firm

Our second set of contingencies is based on internal firm processes that suppress the effect of scientific absorptive capacity by reducing the firm's sensitivity to its availability in its decisions regarding the formation of new knowledge access collaborations. The underlying logic here is that various internal capabilities may be considered as drivers of the same organizational outcome even though the nature of their impact as well as their long-term consequences may be inherently different. By overlooking such differences, managers are prone to presumptions regarding their equifinality and substitutability. Prior literature has shown that firms do indeed substitute certain capabilities for each other. Makadok (2001), for instance, developed a model that predicted that the two rent creation mechanisms of resource picking and capability building, while complementary in some circumstances, often tend to substitute each other. Relatedly, Rothaermel and Hess (2007) examined the individual-, firm-, and network-level antecedents to firm innovation and found that these antecedents sometimes compensate for each other's effects on a firm's innovative output.

In Proposition 5 we examine the contingency of the firm's patenting productivity as an important internal capability and argue that firms with a high patenting productivity will be less sensitive to the availability of scientific absorptive capacity in their external knowledge access efforts. This is primarily due to the upstream position of scientific absorptive capacity in the innovation value chain as opposed to the downstream position of the firm's patenting productivity. That is, whereas scientific publications contain knowledge pertaining to potential future innovations that are still in their nascent stage, patents represent applied inventions with more tangible connections to the firm's current innovations and new product development processes. In fact, science is so far upstream relative to patented inventions that its role is often portrayed as a map in technological search and patenting activity. Fleming and Sorenson (2004), in particular, argued that scientific knowledge functions as a map by providing a means of predicting untried combinations of technological components, identifying fruitless directions before the inventors attempt them, and motivating inventors in the face of repeated failure to continue the search.

Hence, the downstream position of patents in the innovation value chain implies that firms are more likely to assess the vigor of their internal innovation activities as well as their capacity to undertake more collaborations based on their patenting productivity than their scientific absorptive capacity. As such, we expect that under situations of high

patenting productivity firms will become increasingly less sensitive to the availability of scientific absorptive capacity. Therefore,

> P5: The positive effect of scientific absorptive capacity on the extent of the firm's external knowledge access collaborations is weaker when the firm has a high patenting productivity.

R&D alliance experience

Next, we consider the contingency of the firm's R&D alliance experience as a particularly relevant internal firm capability and argue that more experienced firms are likely to be less sensitive to scientific absorptive capacity in their decisions to form new collaborations. Research has shown that, over repeated collaborations, organizations learn the nuances involved in managing alliances and deploy such learning in future alliances to ensure their success despite potential shortcomings that may strain less experienced partners (Anand & Khanna, 2000; Kale & Singh, 2007; Gulati et al., 2009). Experience firms, on the other hand, have a good grip on the challenges of collaborative knowledge creation and transfer which allows them to better navigate the challenges that often cripple less experienced partners (Simonin, 1999; Larsson et al., 1998). One such major challenge is the possibility of spiraling into a 'learning race' that typically characterizes knowledge-focused alliances where each partner feels the pressure to learn as much as possible while minimizing the leakage of its proprietary knowledge in the partnership (Khanna et al., 1998; Hamel, 1991). Therefore, the ability to maintain the balance between learning new knowledge and protecting the firm's proprietary knowledge represents a valuable capability to every alliance partner (Kale et al., 2000). Alliance experience, especially if captured and internalized through a dedicated alliance function (Kale et al., 2002), contributes to the firm's capability to overcome the challenges of learning and knowledge transfer in R&D alliances.

R&D alliance experience accrues to the firm as it engages in repeated R&D collaborations with various partners and continues to store and retrieve the inferences drawn from every instance of partnership. The progress along the alliance learning curve increasingly enables the firm to identify the effective interfirm routines for managing the process of knowledge creation and transfer within the alliance (Lane & Lubatkin, 1998). The growing alliance management capability, we argue, will likely boost the firm's confidence regarding its ability to face the challenges in potential future knowledge access collaborations even in the absence of sufficient scientific absorptive capacity. Therefore,

> P6: The positive effect of scientific absorptive capacity on the extent of the firm's external knowledge access collaborations is weaker when the firm's R&D alliance experience is high.

CONSEQUENCES FOR FIRM INNOVATIVE OUTPUT

Finally, we turn to the consequences for the innovative output of the firm of building external knowledge access collaborations on a strong foundation of absorptive capacity. Our basic argument here is that such a foundation not only increases the benefits of such collaborations for the focal firms, it also minimizes their potential hazards including the internalization of technology components that are incompatible with the firm's existing knowledge and technology base. Avoiding such incompatible components minimizes the challenges to the firm's internal innovation processes and prevents the subsequent weakening of the firm's innovative capabilities. The arguments in this section build on a modular representation of firms' internal innovation systems that particularly suits the firms in industries with a fast pace of technological change (Sanchez & Mahoney, 1996; Pil and Cohen, 2006). Modular innovation systems encompass various loosely-coupled components of knowledge and technology whereby the loose coupling between components reduces the costs and difficulty of adaptation and increases the firm's speed and flexibility in responding to rapid technological changes (Ethiraj & Levinthal, 2004). The flexibility of the modular architecture is due to the fact that innovative products can be developed by substituting different modular components into the product architecture without the need to redesign other components. In other words, the 'mixing and matching' capacity of the modular system allows firms to develop a potentially large number of innovations by recombining new or existing components of knowledge and technology (Henderson & Clarck, 1990; Sanchez & Mahoney, 1996).

The ability to recombine technological knowledge in novel ways to explore potential innovations that alter and advance the firm's current technological trajectories largely determines the innovative performance of a firm (Kogut & Zander, 1992; Tzabbar, 2009). Dividing organizational competence into component and architectural, Henderson and Cockburn (1994) argued that architectural competence, composed of the organizational control systems and the dominant values, allows a firm to exploit its component competence by integrating them in new and flexible ways. Henderson and Cockburn (1994) also suggested that in the context of the pharmaceutical industry the ability to access external knowledge and the ability to flexibly recombine and integrate knowledge across the various disciplinary and therapeutic class boundaries represent two forms of architectural competence that determine the innovative performance of the firm.

Successful exploitation of externally-sourced components of knowledge and technology requires a certain level of complementarity and compatibility to exist between those components and the firm's existing social and technological structures (Teece, 1986). That

is, in order for the process of mixing and matching of components in a modular innovation system to work efficiently, every new knowledge and technology component must have a certain level of compatibility with the existing structure of the system. Compatibility implies that the new and existing components can be connected using a common interface without needing any extraordinary translation and interpretation efforts. Since firms typically search for technological solutions that fall within the boundaries of their existing knowledge base (March and Simon, 1958), knowledge components that substantially deviate from this existing base significantly challenge the firm and its members as they attempt to comprehend and recombine them in crafting future innovations.

External knowledge access collaborations typically expose firms to unfamiliar technology landscapes without a map to guide the firm's search for compatible components (March, 1991; Fleming & Sorenson, 2003). If, due to a low level of absorptive capacity, the firm also lacks a clear understanding of the nature of knowledge and technology components involved in the joint R&D projects, the search for new knowledge within the framework of such collaborations will be a blind search on a rugged technological landscape. Such a blind search is likely to lead the firm to try to internalize any components that might appear to be relevant to the firm's internal knowledge base and fail to verify their actual compatibility. Incompatible components that are introduced into the firm's internal innovation system through external knowledge access collaborations present significant challenges to the firm in its attempts to incorporate them into ongoing recombination efforts and match them with existing knowledge and technology components. Particularly, attempting and discarding a multitude of potential configurations and combinations is likely to introduce a creeping element of inefficiency into the firm's innovation processes leaving a negative impact on the firm's innovative output. Such a drop in the innovative output is likely to result from the gradual alterations of the firm's search routines to accommodate the inclusion of incompatible external components in new configurations.

Moreover, every new component of knowledge tends to deform and expand the search space of the firm's innovation system by suggesting new competing hypotheses and presenting previously unknown discovery paths (Orsenigo et al., 2001; Fleming & Sorenson, 2004). However, when new components are incompatible, such deformation of the search space is likely to throw the firm's innovation processes off their current functioning paths requiring extra effort over time to restructure the search space and restore the efficiency of the innovation processes. As time and other resources are invested toward reformation and restoration of the firm's innovation system, the

inefficiency induced by incompatible knowledge components is likely to build up leading to a drop in the system's output over time.

Conversely, building external knowledge access collaborations on a strong foundation of absorptive capacity enables the firm to more effectively screen for compatible components of knowledge and technology while navigating the novel technology landscape. Absorptive capacity guides the firm's search on the less familiar technology landscapes that dominate the inter-firm search space and allows the firm to pick the most compatible from among the various components that might initially appear as attractive additions to the firm's existing technology base (Fleming & Sorenson, 2004). Therefore, only those components will be internalized that imply a minimal impact on the efficiency of the firm's recombination efforts to introduce new innovations. Also, such compatible components will likely only deform the firm's innovation search space in ways that minimally impact its ongoing innovation processes. Given the gradual nature of the subsequent inefficiencies introduced into the firm's innovation system in external knowledge access collaborations not supported with sufficient absorptive capacity, we expect that the benefits of absorptive capacity in offsetting those inefficiencies to also emerge in the long run. Therefore,

> P7: Science productivity at the time of forming new external knowledge access collaborations will enhance the benefits of those collaborations for the firm's long-term innovative output.

DISCUSSION AND CONCLUSION

This study joins a lively stream of research that aims to explain how science relates to firms' innovation strategies (Gambardella, 1992; Zucker et al., 1998; Gittelman & Kogut, 2003; Tzabbar, 2009). Firms invest in basic research to develop absorptive capacity that allows them to recognize, access, and exploit knowledge and technology developed outside their boundaries (Cohen & Levinthal, 1990; Gambardella, 1992; Roach, 2009). Particularly, absorptive capacity functions as a driver of the firm's engagement in external knowledge access collaborations (Arora & Gambardella, 1994). We theorized about a number of key contingencies surrounding the link between firms' science productivity and their extent of engagement in external knowledge access collaborations (Arora & Gambardella, 1994). The first set of moderators– i.e. isolation of firm scientists, arm's length co-authorships, and organizational dispersion of scientific projects – corresponded to factors that dilute the effect of scientific absorptive capacity. The second set – i.e. the firm's patenting productivity and R&D alliance experience – corresponded to internal firm capabilities that lowered the firm's sensitivity to the availability of

absorptive capacity. We also proposed that science productivity at the time of forming new external knowledge access collaborations will enhance the long-term benefits of those collaborations for the firm's innovative output.

Our study holds important implications for the knowledge management literature, particularly the stream of research focused on transfer and absorption of external knowledge from professional networks as well as the broader knowledge community (Oliva, 2014; Matricano et al., 2014; Del Giudice & Maggioni, 2014). The process of knowledge management encompasses several elements from knowledge definition and identification to knowledge usage and retentions (Oliva, 2014). The knowledge management processes most relevant to our work are those pertaining to accessing, acquiring, and using of externally-sourced knowledge in the firm's internal innovation process. We know from prior research that knowledge management indeed influences firm competitiveness and performance through different organizational mechanisms (Andreeva & Kianto, 2012), including via its role in firm innovation as innovation is highly dependent on the availability and accessibility of advanced and cutting-edge knowledge (du Plessis, 2007). The ultimate connection from investments in basic scientific research to the firm's innovative performance maps onto what is known as the realized absorptive capacity. Specifically, the contingent role of basic research investments in the development of scientific absorptive capacity that in turn enables the firm to form future knowledge access collaborations can be thought of as an underlying mechanism for the development of a dynamic capability to acquire and assimilate cutting-edge knowledge from external sources (Teece et al., 1997). However, such cutting-edge knowledge can only benefit the firm's internal innovations if it is transformed and exploited effectively by deploying the firm's advanced dynamic capabilities developed earlier through proper investments in underlying basic research to align the firm's knowledge repertoire with the external knowledge landscape of the industry. Moreover, the contingencies proposed in our model can be thought of as particular instances of knowledge management barriers in the special context of managing the transfer of basic scientific knowledge (Oliva, 2014). For instance, isolation of firm scientists and lack of focus in external co-authorships would most resemble human barriers, while organizational dispersion of research efforts, R&D alliance experience, and current innovative output of the firm would correspond to organizational barriers.

The argument that isolation from the external scientific community and the organizational dispersion of scientific projects both lower the firm's availability of absorptive capacity holds implications for the process of managing and organizing basic research in firms. These implications particularly concern firms with well-developed

hierarchical structures where the firm's in-house basic research program is likely to be managed as an independent function. Specifically, by encouraging external collaborations and consolidating basic research in the organization, the executives in charge of the firm's basic research program may be able to boost the impact of science as a foundational link in the firm's innovation value chain and ensure that basic research maintains its status as a map guiding the firm's search for new innovations (Fleming & Sorenson, 2004). We also argued that the firm's patenting productivity, experience with R&D alliances, and size are all likely to suppress the effect of scientific absorptive capacity as a driver of new R&D alliance formations. This suggests that executives in charge of basic research programs in large, innovative, and experienced firms may have to face higher barriers to recognition regarding the contribution of their program and its outcomes to the firm's innovation strategy.

The theoretical framework developed in this paper also contributes by painting a multi-layered picture of firms' innovative capabilities (Teece et al., 1997; Eisenhardt & Martin, 2000). Prior research has mainly focused either on the internal or the external dimension of what constitutes a firm's innovative capability. Subramaniam and Youndt (2005), for instance, examined the influence of intellectual capital in a firm on its innovative capabilities. Hagedoorn and Duysters (2002), on the other hand, explored the differences in firms' preferences toward external sources of innovative capabilities such as strategic alliances or mergers and acquisitions. This study highlights the need to re-conceptualize innovative capabilities as multilayered constructs with internal components (e.g. science productivity) and external elements (e.g. R&D alliances) that are closely-knit and nearly impossible to dissect and analyze independently. In fact, innovative capabilities may be better understood as residing not only in individual internal and external components, but also in the architecture connecting these components (Henderson & Cockburn, 1994).

Future research could extend our theory by adopting a two-sided perspective on the process of forming knowledge collaborations to account for differences in partner capabilities and motivations in the formation of the collaborations. Future research could also examine the nature of external knowledge access collaborations in more details to determine if the alliances that are not based on sufficient absorptive capacity involve a systematically different set of partners that might have been attracted to the focal firm for such reasons as favorable terms of partnership. Research could also probe how differences in partner type and quality impact the formation and outcomes of knowledge accessing collaborations. Lastly, it is worth examining if scientific collaborations with researchers employed at former organizational collaboration partners impacts the

effectiveness of the resulting absorptive capacity in any specific manner including its effect on the trajectory of the future collaborations formed by the focal firm.

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