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THE ORGANIZATION OF CORPORATE SCIENCE AND TECHNOLOGY: OUT OF SIGHT, OUT OF MIND?

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INTRODUCTION

While empirical evidence shows an overall declining trend in for-profit firms' investments in science, biopharmaceutical firms continue to commit a large share of their R&D expenditures to scientific research (Arora et al., 2019). The primary motive of biopharmaceutical firm's investments in science is the need to create a substantial pool of internal know-how that forms the basis for many future technological developments (Arora et al., 2018). Especially for science-based firms, the know-how developed through corporate science informs the re-combinations of different knowledge components necessary to breed innovation (Fleming and Sorenson, 2001, Della Malva et al., 2015; Cassiman et al., 2008).
In spite of the great importance of science in generating valuable innovations (Rosenberg, 1990) the exploitation of scientific discoveries, even within a firm, is a complex process. While there are multiple examples of scientific discoveries leading to breakthrough innovations (e.g., Cockburn and Henderson, 1998), it is at the same time acknowledged that only a small fraction of a firm's scientific discoveries is further taken up in technology development (Gittelman and Kogut, 2003).

In this paper, I examine one particular yet potentially important way in which a firm's ability to exploit science in follow-up technology can be enhanced: the co-location of scientific research and technology development activities. More specifically, I investigate the role of the geographical distribution of a firm's science and technology activities. I do this in the context of large, multiunit biopharmaceutical firms that conduct scientific and technological activities in a network of geographically dispersed units. Building on the R&D organization literature (Argyres and Silverman, 2004; Arora et al., 2014; Argyres et al.,2020), I contend that the spatial co-location of science and technology enables the creation of linkages and (managerial) synergies between the two activities.

My results show that firms are better able to exploit internal scientific research in technology domains where science and technology activities are geographically co-located. The analysis contributes to the literature on R&D organization (Geerts et al., 2018; Argyres & Silverman, 2004; Arora et al.,2014; Argyres et al.,2020) by pointing at an understudied aspect of the innovation process. While prior studies have shown that a firm's scientific research is important for internal technology development, little is known about how this relationship depends on the organization of scientific and technological units within a firm. This study provides the first empirical evidence of the relationship between co-location of scientific and technological units and a firm's ability to appropriate its scientific research findings in follow up technology development.

BACKGROUND LITERATURE AND HYPOTHESIS

Corporate science and technological development

The prior art has provided ample evidence of the effects and importance of science for innovation (Fleming and Sorenson 2004; Brooks 1994; Tijssen 2002; Verbeek et al. 2002; Gittelman

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and Kogut 2003; Cassiman et al. 2008; Subramanian & Soh 2010). With regard to the biopharmaceutical industry, prior studies have found a positive effect of scientific research performed in-house on the number and average quality of firms' inventions (Gambardella, 1992; Furukawa & Goto, 2006; Della Malva et al., 2015).

Research has not only provided evidence that science stimulates innovation but also that exploitation of science in technology development leads to more valuable innovations. For example, Petruzzelli et al. (2015) show that the use of scientific knowledge positively influences a firm's ability to appropriate its technological developments since patents that cite scientific research are used more in the development of subsequent internal technologies.

The geographic organization of science and technology in MNCS

Along with the increasing internationalization of R&D activities by MNCs, foreign subsidiaries, and their role in the scientific knowledge creation process has evolved (Bartlett and Ghoshal,1989; Hedlund, 1994). It has been shown that foreign R&D subsidiaries increasingly operate with a knowledge-seeking and a knowledge-creation mandate (Florida, 1997; Frost, 2001; Gupta & Govindarajan, 2000). Subsidiaries that attain such mandate in an MNC's R&D network become active producers and repositories of scientific research that can be leveraged for a firm's technology development. However, as MNCs expand their geographic scope, the increased global dispersion of scientific activities complicates the organization-wide dissemination of knowledge required for successful innovation (Holm and Pedersen, 2000; Gupta and Govindarajan,2000). Hence, a key challenge for such an R&D-intensive, multiunit firm is to effectively transfer and recombine the different pieces of scientific knowledge within the internal network of dispersed laboratories (Miller et al.,2007).

A number of prior studies examined the role of proximity, and particularly co-location of firms' R&D activities or R&D teams and its effect on technological performance (Geerts et al., 2018) and knowledge flows (Alllen, 1971; Van den Bulte and Moenaert,1998; Moenaert and Caeldries,1996). Overall, the findings of these studies confirm the importance of proximity for a firm's R&D activities by empirically demonstrating that co-location enables synergies between a firm's activities and also that it diminishes the communication barriers among R&D employees.

Empirically, I analyze a panel dataset (2000-2015) containing detailed information on patents and scientific publications of the 227 large R&D spending biopharmaceutical firms located in Europe, Japan, and the US. In line with prior literature (e.g., Arora et al. 2017), I measure the degree of a firm's exploitation of its own science in subsequent technology development by backward citations made in a firm's patents to its scientific articles. To capture the degree of co-location of a firm's scientific and technological activities, I use geo-located addresses of corporate publications and inventor addresses listed on firm's patent applications, and I measure the degree to which science and technology activities take place in the same geographical regions. To investigate the proposed relationship, I estimate fixed-effects models at the detailed firm-technology level. This fine-grained level of analysis allows me to analyze simultaneously firm and technology characteristics, and hence I can account not only for the between-firm but also within-firm heterogeneity in the geographic organization and exploitation of scientific research.

HYPOTHESIS ON THE CO-LOCATION OF SCIENCE AND TECHNOLOGY ACTIVITIES

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A firm's scientific knowledge base represents its most important resource for (radical) technology development (Miller et al., 2007). To benefit from the investments made in scientific research, a firm needs to process and translate the scientific knowledge before it can be applied in technology development (Furman & Stern, 2011). However, this process of translation and exploitation of scientific findings is complex as often the most valuable parts of scientific knowledge are difficult to articulate due to their tacit nature (Nelson and Winter, 1982; Polanyi,1966; von Hippel, 1994). The exploitation of such tacit and embedded scientific knowledge is enabled by intensive interaction between scientific and technical personnel in organizations (Brown and Duguid, 2001; Hansen, 1999; Tyre and Von Hippel, 1997). The co-location of scientific and technological staff supports frequent communication as well as it allows employees to gain experience through observation and practice (Grant, 1996), consequently enhancing exploitation of the tacit scientific knowledge in technology development.

Also, frequent face-to-face interactions are conducive to build trust between scientists and technical personnel in organizations (Hoegl and Proserpio, 2004; Handy, 1995). This has strong implications for the exploitation of scientific knowledge that is tacit and embedded because trust has been found to play a key role in the willingness of individuals to share their knowledge and experience (Szulanski, 1996; Dakhli and De Clercq, 2004; Mooradian et al., 2006). Indeed it has been shown that trust among firm employees is negatively impacted by geographical distance between units to which they belong (Handy, 1995; Rocco, Finholt, Hofer, & Herbsleb, 2001). All in all, the co-location of scientific and technical personnel and specifically face-to-face encounters are imperative for trust-building (Nohria and Eccles 1992, O'Hara- Devereaux and Johansen 1994).

Another argument in favor of the co-location of science and technology activities within a firm is related to the joint management of science and technology. An important dimension of R&D management is the incentive scheme offered to R&D personnel. Managers of business units that conduct both scientific and technological research can create reward structures that stimulate scientists to direct their scientific search towards more applicable ends (Lerner and Wulf, 2007) and to actively transfer scientific knowledge to technical personnel. Thus, when science and technology activities are co-located and managed jointly, it enables the use of a unit-specific management system. This, in turn, promotes the alignment and exchange of information between scientists and engineers (Gassman and von Zedtwitz, 1999) and the exploitation of scientific knowledge.

All the above arguments suggest that firms that organize their technological development in proximity to where they perform scientific research may be better positioned to exploit its science in technology development.

Hypothesis 1: Co-location of scientific and technological activities is positively associated with a firm's exploitation of its internal scientific research in follow-up technology development.

EMPIRICAL DESIGN AND METHOD

To address my research question, I constructed a dataset on the publication and patent activities of 227 pharmaceutical and biotechnology firms based in the United States (117), Europe (85), and Japan (25), covering the period 2000 – 2015. The sample firms have been selected as top R&D spending biopharmaceutical firms from the 2004 and 2016 EU Industrial R&D Investment Scoreboard. The dataset consists of a firm-level panel with publication and patent data that are collected at a consolidated level, taking into account annual changes in the group structures of firms due to M&As, green-field investments, and divestments.

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To explore how the co-location of scientific and technological activities impacts a firm's ability to build on its scientific discoveries in subsequent inventions, I matched the ownership structure with publication information from the Web of Science and patent level information from the PATSTAT (2018 version) database.

In line with prior literature (e.g., Arora et al. 2017), I measure the degree of a firm's exploitation of its own science in subsequent technology development by backward citations made in a firm's patents to its scientific articles. To capture the degree of co-location of a firm's scientific and technological activities, I use geo-located addresses of corporate authors listed on publications and corporate inventors addresses listed on patent applications, and I estimate a cosine index to measure the degree to which science and technology activities take place in the same geographical regions.

To investigate the proposed relationship, between the firm's exploitation of its science in technology development and the degree of co-location of its scientific and technological laboratories, I employ a firm and technology fixed-effects, linear model. Given the nature of my data, which is organized in three dimensions – firm, technology, and year – I use robust standard errors clustered at the technology-firm level to take into account dependence over time in the exploitation of own science by firms in the focal technology domain.

RESULTS

The results confirm my hypothesis: spatial co-location, i.e., the higher degree of spatial proximity between a firm's technological activities and scientific activities, is positively associated with a firm's exploitation of its own science in technology development. In terms of the implied magnitude of the relationship between the science and technology co-location and exploitation of a firm's science in technology development, the results show that a one standard deviation increase in the co-location index increases the exploitation of own science by 8%.

To test for a curvilinear relationship, I add a quadratic term of the index capturing the scientific and technological activity co-location. This model shows that the variable has an inverted U-shaped relationship with the exploitation of science, as evidenced by the positive and significant linear term and the negative and significant quadratic terms. The top of the inverted U-curve is reached at the value of 0.65, which is lower than the maximum sample value of 1.

To assess the consistency of my findings, I conduct a number of robustness checks. Findings remain consistent in these alternative models.

DISCUSSION AND CONCLUSIONS

In the context of the biopharmaceutical industry, it has been shown that a firm's ability to encourage and sustain an extensive flow of knowledge among scientific and technological disciplines and organizational units is crucial for new drug discovery and commercialization (Henderson and Cockburn, 1994, 1996). My results show that firms are better able to exploit internal scientific research in technology domains where science and technology activities are geographically co-located. The analysis contributes to the literature on R&D organization (Geerts et al., 2018; Argyres & Silverman, 2004; Arora et al.,2014; Argyres et al.,2020) by pointing at an understudied aspect of the innovation process. While prior studies have shown that a firm's scientific research is important for internal technology development, little is known about how this relationship depends on the organization of scientific and technological units within a firm.

This study provides the first empirical evidence of the relationship between co-location of scientific and technological units and a firm's ability to appropriate its scientific research findings in follow

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up technology development. I show that the organizational structures in which technology development and scientific research are co-located provide better opportunities for firms to create synergies and linkages between the two activities.

The analysis also reveals that the co-location of science and technology has a curvilinear relationship with the firm's exploitation of internal scientific research. Hence the positive relationship between the focal variable and the firm's exploitation of own science diminishes at higher co-location levels. I propose two tentative interpretations for this finding. First, in multiunit organizations, R&D teams have to both compete and collaborate with each other. Organizational units like to learn from each others' internal developments, and at the same time, these units have to compete with one another for internal resources. Competition might become more pronounced when two units obtain resources from the same source. Hence, when the same R&D manager supervises scientific and technological developments, both units are likely to compete with each other to gain preferential access to internal resources. In such situations, the exchange of knowledge and the extent of collaborations between the two R&D activities might be negatively affected. Secondly, this finding is in line with the so-called proximity-paradox (Broekel & Boschma, 2012). Thus, while spatial proximity is an important driver for R&D employees to connect and exchange knowledge, firms that co-locate the majority of the relevant science for the focal technology development in proximity to where the technology is being developed might reduce the potential of newness and innovation in the scientific realm. In particular, when scientific research is performed with an intent to enhance the development of technology in the proximate unit but not to create cutting-edge science, it might ultimately lead to a decrease in the value of the science for technology development. Subsequently, the internal scientific research might become redundant in the development of new technology.

The results for the control variables also reveal some interesting findings. First, the negative association between the firm's scientific portfolio and the exploitation of its science in technology development shows that inventors might face challenges in appropriating the internal scientific findings when a scientific portfolio of a firm is vast. Scientific literature is complex and fast-changing, and hence identifying useful scientific discoveries is a difficult task (Bikard, 2018). Especially when a firm is involved in cutting-edge, basic science without specific technological applications, corporate inventors might be faced with fundamental challenges in identifying which scientific discoveries might be of value in the development of new technologies and thus be reluctant to exploit the internally produced science. Moreover, I find that spreading scientific activities within the firm might be beneficial for the exploitation of corporate scientific research. With the growing complexity of science, spatially dispersing the scientific laboratories may enable a firm to adapt quicker scientific research to the firm's current technological needs.

On the other hand, the decentralization of focal technology is negatively associated with the exploitation of a firm's internally produced science. A plausible explanation is that firms might decide to spatially decentralize units in technological domains where the benefits of tapping into external knowledge are higher (Chacar and Liberman, 2003). This explanation can be

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further reinforced by the negative association between the exploitation of a firm's science and the average strength of regions that host technological units in scientific domains relevant for focal technology development. This finding points out the possibility that technological units located in regional scientific hubs are likely to search for scientific solutions locally. Hence it is important to note that there is an apparent trade-off between access to own and external science. Some firms might choose to structure their R&D to tap into external knowledge sources rather than to exploit internal scientific research.

By underscoring the role of co-location in a firm's ability to exploit their science in follow-up technology development, the results of this study contribute to the R&D management literature, particularly to the literature focusing on the importance of geographical proximity for a firm's R&D activities (Geerts et al., 2018). Secondly, I complement prior research on the R&D organization (Argyres & Silverman, 2004; Arora et al.,2014; Argyres et al.,2020). The literature on R&D strategy and organization posits that, given the tacit nature of much scientific and technological knowledge, and the related importance of personal face-to-face contacts, firms can promote the realization of knowledge spillovers and lower coordination costs by centralizing R&D. Where previous contributions stressed the importance and benefits of performing R&D in a single, centralized location for effective knowledge transfer, this study by examining the spatial location of science and technology within a firm points to a specific mechanism that has not been so far considered in the literature on R&D organization. Furthermore, Argyres and Silverman 2004 argue that R&D centralization improves innovation output because it economizes on costs of communication and coordination when there is potential to benefit from economies of scope. This study contributes to the above-mentioned stream of literature by examining the relationship between the exploitation of the firm's scientific research findings that are relevant for the follow-up technology development and the spatial co-location of both activities.

REFERENCES AVAILABLE FROM THE AUTHOR