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## Bridging distant technological domains: A longitudinal study of the determinants of breadth of innovation diffusion

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### ABSTRACT

The diffusion of innovations is identified as an important aspect of technological and social change. Innovations diffuse through segmented networks of knowledge that limit the flow of knowledge from any one technological domain to any other. Despite this segmentation, some organizations are capable of developing pieces of knowledge that overcome these limitations. Within this context, we develop four hypotheses regarding specific R & D strategies that affect a firm's ability to develop inventions that diffuse beyond the firm's technological boundaries. Specifically, we examine how a firm's scientific intensity, technological collaborations, technological diversity, and internal focus impact breadth of innovation diffusion. We use two of the main determinants of innovation diffusion, namely, the *relative advantage* and the *observability*, as theoretical mechanisms to build our arguments. We empirically test our hypotheses on longitudinal data from the industries of pharmaceuticals, biotechnology, and chemicals. Our findings show that the extent to which the knowledge embedded in a firm's inventions diffuses in distant technological areas is positively related to the firm's scientific intensity and to its extent of collaboration, but it is negatively related to its technological diversity.

### 1. Introduction

Innovation diffusion plays a fundamental role in the technological progress of our society. As Hall (2005: 459) eloquently remarks, “without diffusion, innovation would have little social or economic impact”. Given the importance of innovation diffusion, the voluminous amount of research and the diversity of scientific approaches that have been devoted to this topic come as no surprise (Geroski, 2000). Whether it is framed in terms of scholarly research in economics, sociology or management, the central question is largely the same: why do some pieces of technological knowledge diffuse more than others? In their attempt to answer this question, some researchers have focused on the properties of innovation itself (Lee et al., 2003), others on the characteristics of those who develop (i.e., innovators) or adopt (i.e., the adopters) the innovations (Attewell, 1992), and others on the attributes of the network through which knowledge flows (Sorenson et al., 2006).

Knowledge diffuses from organization to organization through social networks. These networks are segmented at various levels such as the technological level or the industry level, in the sense that there exist knowledge boundaries that limit the diffusion of knowledge from any one technological domain to any other (Abrahamson and Rosenkopf, 1997). Despite this natural segmentation of networks, it is a well-known fact that some organizations develop pieces of knowledge that

transcend these boundaries. This transcendence can be manifested by the technological innovations that diffuse beyond the technological boundaries within which those organizations operate or even the more extended technological boundaries of the industry to which those organizations belong. Those innovations become the technological “ancestors” for a lineage of innovations that are located in distant (relative to the original) technological domains. They serve as bridges that eventually link different technological domains.

Xerox PARC is a typical example of such organizations, for the reason that plenty of its innovations established links among different technological domains within the information-technology industry (Rosenkopf and Nerkar, 2001). In addition, there exist a number of well-known cases where the diffusion of a firm's innovations crossed the boundaries of entire industries. For example, the laser, which was mainly developed by Bell Laboratories, originated in the electro-optical technological domain and generated multifarious innovations in various different domains, such as consumer electronics, medicine and telecommunications (Podolny and Stuart, 1995). Another example emerges from the history of Thomas Edison's laboratory, in which Edison and his colleagues transferred their knowledge of electro-magnetic power from the telegraph industry, where they first applied it, to the lighting, telephone, phonograph, railway, and mining industries (Hargadon and Sutton, 1997). Similarly, James Watt's steam engine

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moved successfully across broad technological fields, as widely diverse as water pumping in the coal mining industry and propelling locomotives in the railroad industry (Banerjee and Cole, 2010).

The necessity of examining more deeply the breadth of innovation diffusion stems from a general characteristic of the way that technology evolves, namely, the diffusion and transfer of knowledge components among technological domains characterized by disparate knowledge bases. This diffusion originates mainly from the activities of the inventors who are engaged in explorative research because of their need to seek useful knowledge beyond their own technological domains. Searching in distant technological areas is one of the two fundamental directions that exploration projects can follow to discover novel and useful knowledge that could lead to groundbreaking technological innovations (the other direction is deepening in already familiar technological domains). Inventors that participate in explorative projects look for diverse and reliable technological knowledge that has the potential for “wider applicability”, and some firms have the ability to develop and to provide such knowledge, or in the words of Rosenkopf and Nerkar (2001: 291), “to create broadly useful technological developments”. Thus, the examination of the breadth of innovation diffusion could provide important insights into the foundations of exploration phenomenon and shed light on those characteristics that enable a firm to create knowledge capable of bridging distant technological domains.

The purpose of this study is to examine firm-level factors that can limit or enhance a firm’s capability to develop knowledge that is influential for potential adopters operating in distant technological domains, as reflected in the citations its patent(s) receives from subsequent patents located in distant technological areas. We focus on the innovator’s R&D strategies, and, in particular, we investigate how a firm’s scientific intensity (i.e., the extent to which it draws upon scientific knowledge), technological collaborations, technological diversity of its knowledge base, and internal focus (i.e., the extent to which it builds upon its own technological achievements) affect its inventions’ breadth of diffusion. We anticipate these four R&D strategy characteristics to have an impact on the inventions’ *relative advantage* or on their *observability*, which are two of the most important attributes of innovation diffusion (Rogers, 1983), and we conceptually develop our hypotheses on this particular basis.

Even though there is much literature covering the subject of innovation diffusion (Abrahamson, 1991; Hall, 2005; Tornatzky and Klein, 1982), Rogers’s (1983) attributes that facilitate innovation diffusion (e.g., *relative advantage* and *observability*) have, to our knowledge, not been used to explore questions related to innovation diffusion exclusively in distant technological domains. Nevertheless, the literature includes some studies that examine the determinants of the diffusion of inventions’ knowledge beyond their technological boundaries, although these studies’ theoretical backgrounds differ from that of innovation diffusion. For example, two of the most important works on this issue are the studies of Miller et al. (2007) and Rosenkopf and Nerkar (2001), who investigated a rich set of determinants of breadth of innovation diffusion through the lens of knowledge management within diversified firms and local search, respectively (they both used the term breadth of technological impact instead of breadth of innovation diffusion). However, both of these studies treated breadth of innovation diffusion more as a phenomenon complementary to the general notion of innovation diffusion rather than as a primary object of research. In contrast, the present paper focuses solely on breadth of innovation diffusion, theoretically and empirically.

Concerning the methodology, we briefly note that this study employs longitudinal (from 2003 to 2009), multi-industry (139 firms from biotechnology, pharmaceuticals, and chemicals), multi-national (19 countries of origin) secondary data from two sources; the EU Industrial R&D Investment Scoreboard for economic data and the Derwent Innovation Index for patent data. With regard to our main findings, the coefficients of our empirical models suggest that the degree of a firm’s

scientific intensity and R&D collaboration exerts a positive influence on the breadth of the firm’s innovation diffusion, in contrast to the technological diversity, which exerts a negative influence, while internal focus does not seem to exert any influence.

The remainder of the paper is structured as follows. The next section describes the theoretical framework within which the hypotheses are developed, while Section 3 presents our four hypotheses. Section 4 introduces our data, the variables employed, the statistical analysis and some brief descriptive statistics. In Section 5, we present the results of the regression models followed by a discussion of the main findings, while Section 6 highlights the main conclusions of our work.

## 2. Theoretical background

The diffusion of innovation, that is, the process by which an innovation is communicated through certain channels over time among the members of a social system, is acknowledged as an issue of great importance for a wide variety of fields within social science (Rogers, 1983). Sociologists and economists have studied the diffusion of innovation focusing on the societal benefits of innovation or on the stimulation of the economic development that stems from the use of the diffused innovations by other individuals and firms (Sorenson et al., 2006). In contrast, organization and management scientists have examined the flow of knowledge within or between firms, usually through the lens of innovation as a competitive advantage and innovation diffusion as spillovers to rivals (Sorenson et al., 2006). Regardless of the specific field of application, a common objective of all scholars is to better understand why some knowledge diffuses more than other knowledge.

Within the vast innovation-diffusion literature, the most common research questions that scholars have focused upon regard the factors that affect innovations’ extent of diffusion (including attributes of innovation itself, innovator’s and adopter’s characteristics and industry and national factors), the characteristics of earlier compared to later adopters, and the structure of the diffusion network or the bandwagon pressures that emerge in an innovation diffusion network (Abrahamson, 1991; Abrahamson and Rosenkopf, 1993, 1997). Our work is situated within the broader framework of innovation diffusion and particularly in the research area that examines the factors affecting innovation diffusion. Within this field of research, the focus of this study is on how specific innovator characteristics pertaining to R&D strategy affect the extent of innovation diffusion in distant technological areas.

Hoetker and Agarwal (2007) note that, just as any artifact embodies knowledge that new producers of similar artifacts can use, a focal firm’s technological inventions embody pieces of knowledge that subsequent developers can rely upon while building on their own technological achievements. Knowledge diffuses through social networks that “are segmented by internal boundaries which can form at geographic, status, cultural, or industry lines” (Abrahamson and Rosenkopf, 1997: 290). We are concerned with those firms whose technological innovations manage to diffuse beyond their own narrow technological boundaries or the (presumably) broader boundaries of their industry and, in particular, with the factors that can affect the extent to which a firm develops such innovations.

Within the context of this study, we consider a patented invention as a technological innovation, while the novel knowledge components that are embedded in a patented invention and diffused to inventors of subsequent patents are viewed as manifestations of the innovation diffusion phenomenon. To gauge innovation diffusion, we rely on patent citations as one of the most common methods to measure innovation diffusion (Nelson, 2009; Nelson et al., 2014). In particular, we employ forward patent citations, that is, the citations that a patent receives from subsequent patents. However, we are concerned only with those cases where the knowledge diffuses in distant technological domains, meaning that the adopters of the innovations (i.e., the inventors of subsequent patents) are operating in technological areas that are not

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