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Diffusion of science-based inventions

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ABSTRACT

Scientific knowledge is central to the development of inventions in high-technology industries. Therefore, understanding the influence of scientific knowledge on the diffusion of innovation processes is essential to understanding and predicting future invention patterns. For this reason, this paper investigates how science intensity and the scope of technological knowledge of inventions influences the propensity and speed of diffusion of inventions in a sample of >40,000 patents from the US semiconductor and biotechnology field. The results show that patents with intermediate levels of science intensity displayed the highest citation propensity; however, the fastest diffusion speed is found in patents with high levels of science intensity. In the case of the semiconductor industry inventions with low levels of science intensity have the highest citation propensity but the science intensity does not influence diffusion speed. In regard to technological knowledge scope of invention, inventions with intermediate levels of technological knowledge scope have the highest citation propensity in both industries. However, a significant difference in the diffusion speed based on the technological knowledge scope exists only in the biotechnology industry. Overall, the results present a more detailed picture of diffusion process and support the idea that the norms and incentives of the scientific community positively affect the diffusion speeds of science-based inventions.

1. Introduction

It is widely accepted that the development of scientific knowledge, and its application in applied technologies, is a key driver of social and economic development (Acs et al., 1992; Griliches, 1979; Mansfield, 1991; Nelson and Romer, 1996; Shibata et al., 2010). From a macroeconomic perspective, scientific knowledge has important implications for technological change, economic growth, and competitiveness (Mansfield, 1991; Nelson and Romer, 1996; Van Looy et al., 2007). Similarly, at an organizational level, scholars have shown that scientific input increases both invention output and quality, which are crucial for firm survival, and profitability (Almeida et al., 2011; Cassiman et al., 2008; Cockburn and Henderson, 1998). However, while the links between the developments of science and technology are becoming more important (Branstetter and Ogura, 2005; Narin et al., 1997), the relationship between both is still very complex and leaves us with many open questions. For example, various studies have investigated the direct influence of scientific knowledge on individual innovation outcomes, i.e., in the form of patents. However, thus far, the results have been mixed, showing “positive” to “non-significant,” and even “negative,” relationships between the scientific knowledge embedded in an invention and its value (Cassiman et al., 2008; Gittelman and Kogut, 2003; Petruzzelli et al., 2015; Sapsalis and van Pottelsberghe de la Potterie, 2007). Furthermore, there is currently only limited research that investigates the influence of scientific knowledge on the diffusion speeds of inventions (Adams et al., 2006; Bacchiocchi and Montobbio, 2009; Jaffe and Trajtenberg, 1996).

The current study addresses some of these open questions and investigates the influence of scientific knowledge on the diffusion speeds of patented inventions. Based on the importance of technological knowledge scope within the innovation process (Lerner, 1994; Novelli, 2015), it also explores the diffusions of inventions in relation to the technological knowledge scope as well as the joint effects of technological knowledge scope, and science intensity.

Similar to prior research, the current study used patent citations to depict diffusion patterns of innovation. Thereby, diffusion patterns are understood as the level, and the distribution, of citations a patent receives in the years subsequent to its publication (Bacchiocchi and Montobbio, 2009; Jaffe and Trajtenberg, 1996). Notably, this approach differs to others that estimate the existence—or the cumulative number of citations—of a patent at one point in time (MacGarvie, 2005). The main advantage of the current approach is that, because it allows for fluctuations within the time-span of patent citations to be analyzed, it can provide a more detailed investigation into the diffusion of inventions. It is implemented by a quasi-structural estimation, which models the citation patterns of a patent, over time, and with two exponential processes. Doing so allows for the overall citation propensity of an invention, and its diffusion speed, to be individually accounted (Caballero and Jaffe, 1993; Jaffe and Trajtenberg, 1996). The scientific knowledge (i.e., science intensity) within inventions is captured by measuring the number of scientific publications associated with a patent (Callaert et al., 2006; Cassiman et al., 2008; Gittelman and Kogut, 2003; Petruzzelli et al., 2015). Technological knowledge scope refers to the breadth of an

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invention's various technological domains and is measured by the number of International Patent Classification (IPC) codes it holds (Gao et al., 2013; Hohberger, 2014; Lerner, 1994; Novelli, 2015; Petruzzelli et al., 2015).

By separately modeling knowledge diffusion, and knowledge obsolescence, while approximating the knowledge components of an invention (i.e., scientific knowledge and technological scope), this study provides an alternative, yet complementary, view on the diffusion process. First, while other studies that have investigated the influence of scientific knowledge, and the technological scope, of an invention in the innovation process have primarily focused on overall citation levels (or other value indicators), very few investigated diffusion patterns or analyzed diffusion speeds (Almeida et al., 2011; Cassiman et al., 2008; Gittelman and Kogut, 2003; Harhoff et al., 2003; Novelli, 2015; Petruzzelli et al., 2015). However, diffusion speed is a key variable of the innovation process, and without a better understanding of it, our knowledge of the innovation process remains incomplete.

Second, the few studies that applied estimation approaches, which allowed them to distinguish citation propensity and diffusion speed, often did not account for the underlying knowledge characteristics of inventions. Studies that have modeled diffusion patterns, based on scientific knowledge, have typically focused on the applicant types (i.e., assignee) of patents, e.g., university patents vs. non-university patents (Adams et al., 2006; Bacchiocchi and Montobbio, 2009; Jaffe and Trajtenberg, 1996). However, it is important to distinguish applicant type from knowledge. As per the above example, universities not only engage in basic scientific research but also applied research, and likewise, firms might also engage in both research activities (Geuna and Nesta, 2006). Using the references of a patent provides an approximation of the knowledge that is embedded in that a patent and, therefore, is a better approach for capturing the scientific knowledge base of a patented invention.[1] Similarly, despite the fact that technological scope has been identified as a key variable in innovation studies, its impact on diffusion patterns—particularly on diffusion speed—has not been explored (Dechenaux et al., 2008; Gao et al., 2013; Hohberger, 2014; Lerner, 1994; Nerkar and Shane, 2003; Novelli, 2015; Petruzzelli et al., 2015). Consequently, a better understanding of the diffusion patterns of scientific knowledge, and inventions, with differing technological scope, enables firms to optimize their knowledge acquisition activities across relevant knowledge types.

Third, and most importantly from a theoretical point of view, the current study contributes to existing theories about knowledge search (Fleming, 2001; Laursen, 2012). Studies in this area frequently investigate the diffusion, and adaption, of knowledge with regard to specific knowledge characteristics, and the contexts of knowledge searches (Ahuja and Lampert, 2001; Hohberger, 2014; Laursen, 2012; Nerkar, 2003). By discussing different theoretical perspectives regarding the diffusion of scientific knowledge, and exploring their empirical implications on inventions' diffusion patterns, this paper presents methods by which to increase predictive precision of diffusion pattern. Thus, by comparing and testing possible outcomes that would be considered consistent with the theory of search this paper increases the overall quality of theories of search and diffusion (Edwards and Berry, 2010; Leavitt et al., 2010).

The remainder of this paper is organized as follows: Section 2 (Theoretical Background) briefly discusses the underlying theory of scientific knowledge—with a focus on its commercial applications, and its potential influence on the diffusion patterns of patent inventions; Section 3 (Methods and Data) introduces the methodology and data; Section 4 (Results) presents the results of the estimation procedures, and Section 5 (Discussion and Conclusion) provides a summary discussion and conclusion.

[1] However, as the diffusion institutional environment of the applicant can influence the diffusion, it is still important to account for the applicant types and therefore this studies accounts for both applicant type and knowledge inputs.

2. Theoretical background

An understanding that innovation is a result of the combination and/or recombination of discrete bodies of knowledge can be found in the early work of Schumpeter (Schumpeter, 1939) and is still prominent in more modern views of innovation (Fleming, 2001; Henderson and Clark, 1990; Kogut and Zander, 1992; Nelson and Winter, 1982). For example, evolutionary economics (Nelson and Winter, 1982) and organizational learning (Levitt and March, 1988; March, 1991) stress the concept of knowledge "search" as well as its limitations. Such work also emphasizes its importance in enabling organizations to source a variety of knowledge. Therefore, successful search is necessary for organizations to create new combinations of technologies. Building on the above theory, a large body of research has investigated different knowledge characteristics and contextual factors, which influence the diffusion of knowledge, and subsequently, innovation outcomes, such as knowledge age, depth, and national origin (Ahuja and Lampert, 2001; Almeida et al., 2011; Fleming, 2001; Hohberger, 2014; Kaplan and Vakili, 2014; Laursen, 2012; Nerkar, 2003; Phene et al., 2006; Rosenkopf and Almeida, 2003). The current study follows similar lines of research but focuses on two knowledge characteristics, i.e., levels of scientific knowledge, and technological knowledge scope.

2.1. Scientific knowledge

Innovation research has a long tradition of investigating the influence of scientific knowledge on innovation outcomes (Griliches, 1979); however, thus far, its results have been mixed. For example, Gittelman and Kogut (Gittelman and Kogut, 2003) demonstrated that patents with high science intensity are more frequently cited. Similarly, Petruzzelli et al. (2015) showed that the use of scientific knowledge positively influences an applying organization's appropriation of a patent. However, their results also suggest that it negatively affects influence outside the relevant organization and/or industry. Alternatively, Novelli (2015) demonstrated that science intensity negatively influences the self-appropriation of an invention. Furthermore, Cassiman et al. (2008) argued that science linkages and inputs do not impact firms' patent-level invention outcomes and that patents with a greater degree of scientific input do not receive greater numbers of forward citations. Finally, Sapsalis and van Pottelsberghe de la Potterie (2007) found no significant link between scientific input and the resultant value of a patent or forward citations.

While the overall impact of scientific knowledge has received significant attention, relatively little is known about the influence of scientific knowledge and diffusion speeds. However, notable exceptions do exist and have focused on differences between the assignee of patents. For example, Jaffe and Trajtenberg (1996) showed that university patents are more frequently cited but are less likely to be cited after long periods of time. Additionally, they found that governmental patents are less cited than corporate patents, but with governmental knowledge being slower to decay. Bacchiocchi and Montobbio (2009) also illustrated that knowledge, which is embedded in university and public research patents, tends to diffuse more rapidly than corporate knowledge, and that these effects vary between countries. However, such studies are primarily focused on the difference between organizations, i.e., of inventing organizations, and less on the knowledge embedded in inventions.

There are two central and opposing arguments regarding why scientific knowledge can influence the diffusion patterns and speeds of an invention (Sorenson and Fleming, 2004). The first perspective is based on the *specific purpose and method* that underpins a particular instance of scientific knowledge production. At the center of this view is the proposition that scientific knowledge is based on the generation, and testing, of theories, i.e., through a process that follows the "scientific method." The scientific method refers to a set of techniques that are used to investigate phenomena, to generate new knowledge, and to correct or refute