Technological Forecasting & Social Change 122 (2017) 12–23

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Investigating the dynamics of interdisciplinary evolution in technology developments

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ARTICLE INFO

Keywords:
Interdisciplinary
Patent
Technology
Innovation

ABSTRACT

In a global economy where technology plays a vital role, technology fusion is important for developing designs of outstanding innovations. These designs often involve the transfer of knowledge between different technological industries, a term known as "interdisciplinarity." This paper aims to contribute to the literature on interdisciplinary innovation by using a novel methodological approach to explore how conventional technologies have evolved into interdisciplinary technologies in different industries. The new methodological approach was based on patent citation analysis and negative binomial regressions conducted to: 1) observe the dynamics and evolution of interdisciplinary technologies, and 2) explore how interdisciplinary knowledge influences technology developments. The study found that interdisciplinary knowledge plays a significant role in the development of valuable technologies in all investigated industries. An important managerial implication from this is that firms should consider developing interdisciplinary technologies whenever possible.

1. Introduction

Interdisciplinarity is a popular concept in the literature on innovation and management. However, it is often used interchangeably with "cross-disciplinarity" by academic researchers. In fact, the two words have been interchanged so often that it becomes difficult to understand their differences. Interdisciplinarity involves integrating knowledge and methods from different disciplines using a real synthesis of approaches, whereas cross-disciplinarity refers to viewing one discipline from the perspective of another (Jenseius, 2012; Stember, 1991). In the context of technological innovation, interdisciplinarity is defined as the merging or combination of knowledge from various technical industries in order to create new technologies, products, or processes. In most cases, R & D collaborations are the primary movers behind this concept. These occur as firms working together share their knowledge, with the objective of enabling them to bring new products to the market (Hagedoorn, 1993).

One popular research stream that has emerged from the concept of interdisciplinarity has concentrated on the dynamics of technology development through organizational collaborations and other networking strategies. Findings from studies in this area have highlighted the important role of alliances in acquiring interdisciplinary knowledge (Frankort, 2013; Frankort et al., 2012; Gomes-Casseres et al., 2006; Mowery et al., 1996; Oxley and Wada, 2009; Rosenkopf and Almeida, 2003). By comparison, another popular research stream has focused on the role of interdisciplinarity in new technology or product development (Chen and Li, 1999; Decarolis and Deeds, 1999; Deeds and Hill, 1996; Kotabe and Swan, 1995; Rothaermel and Deeds, 2004). However, the linkage between the two research areas has not been adequately investigated by researchers.

Understanding the relationship between interdisciplinary dynamics and new product development is essential. Over the past few decades, a lot of studies have investigated different characteristics and dynamics of knowledge flows, mostly through the use of patent data (Gerybadze and Reger, 1999; Hsu et al., 2015; Su et al., 2012). Since then, a number of important findings and managerial implications have emerged. For instance, a firm's competitive advantage was found not to be entirely dependent on acquiring important knowledge, but also through translating such knowledge into new products as well (e.g., Blundell et al., 1999; Sorescu and Spanjol, 2008).

One of the longstanding and still-debated research gaps is the need to understand how interdisciplinary knowledge contributes to the development of new inventions. While the bulk of empirical studies have provided evidence that important inventions involve the transfer of knowledge across technological domains (e.g. Arthur, 2007; Hunter et al., 2011; Nemet, 2012), other studies found that such knowledge transfers have no significant impacts on important inventions (e.g. Nemet and Johnson, 2012). Because of these inconsistencies, a consensus on the role of interdisciplinary knowledge in the development of important inventions is far from being reached. This indicates the need

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http://dx.doi.org/10.1016/j.techfore.2017.04.024
Received 6 January 2017; Received in revised form 26 April 2017; Accepted 27 April 2017
Available online 09 May 2017

for further investigation.

To fill the above described research gap, this paper aims to explore the role of interdisciplinary knowledge in technological innovation using a new approach. This is important for firms as it can help them find ways to maximize their technological capabilities by facilitating their knowledge search and acquisition. That outcome, in turn, may provide them with efficient product designs and improved productivities (Arora and Gambardella, 1990; Cassiman and Veugelers, 2002; Wu and Shanley, 2009).

The originality and contribution of this study to the innovation literature lies mainly in its methodological approach. The approach employed is novel in the sense that it constructs and measures the interdisciplinarity of a patent in a way that has never been done before. This unique method is based on the IPC classification and the idea that a patent citing patents from multiple technology sectors is interdisciplinary in nature. The more technology sectors cited, the more interdisciplinary a patent is. The first step in this approach utilized patent citation data to show the evolution of interdisciplinary patents, and the second analyzed the impacts of the constructed indicators of interdisciplinary knowledge on patent value. By utilizing patents' citation data and IPC classification, different levels of interdisciplinary measures were constructed and analyzed. Using patent forward citation count as a proxy for how valuable (or important) a technology is, the study found strong positive relationships between interdisciplinary variables and the development of important technologies. In doing so, it has provided new empirical evidence that interdisciplinarity is a relevant contributor to the development of important technologies.

In a nutshell, this paper is designed to contribute to the innovation literature by exploring the dynamics and trends of interdisciplinary knowledge, and how they influence the development of new technologies, using a novel methodology. Moreover, this involves a first-time systematic analysis of citation data on a complete range of patents granted by USPTO over a long period of time, the years 1983 to 2013.

The rest of the paper is organized as follows. Section 2 reviews the existing literature on the technology development, why it is important, and recent related research findings; the evolution of interdisciplinary technologies; and the use of patent data to explore knowledge flows and innovative performances. Section 3 presents the data and methodological approach employed in this study. Section 4 presents and discusses the empirical results, while Section 5 concludes the paper.

2. Literature review

2.1. The role of R & D in science and technology developments

Science and technology play important roles in the business world (Castells, 2014; Kazmeyer, 2016; Utterback, 1994). In fact, important scientific discoveries over the past decades have led to major technological breakthroughs. These technological advancements have in turn caused dramatic changes in the ways businesses operate (Satell, 2013; Vitez, 2016). For instance, since the scientific discovery of the binary number system by Gottfried Wilhelm Leibniz from as long ago as the 17th century, a series of breakthrough technologies based on the binary number system have emerged. These include the first-generation computers by IBM in the 1950s as well as the advent of the Web in the 1990s. Due to the widespread use of such technologies, most business transactions and processes have become digitized. This clearly demonstrates how such breakthrough technologies have brought significant changes to the ways businesses operate. These digital technologies bring immense benefits not only to businesses but also to users, in both commercial and social settings (Vitez, 2016). As a result, most outstanding technologies no longer appear within a single technological area but rather between multiple areas (Duysters and Hagedoorn, 1998; Hacklin et al., 2009). Moreover, small businesses are becoming more efficient and thus able to withstand competition from big companies. Many of the developments in science and technology have been attributed to improvements in knowledge and skills through R & D.

The findings of past studies examining the use of various forms of R & D have been mixed. However, an increasing number of recent publications and empirical studies have provided support for the positive contribution of technical cooperation in science and technology developments (Herstad et al., 2014; Maietta, 2015). In addition, studies such as Roper and Hewitt-Dundas (2015) have provided empirical evidence on strong and positive relationships among R & D, knowledge, and firm performance. Furthermore, in a global knowledge environment, many countries are collaborating with each other, with the hope of reducing their R & D costs (Narula and Santangelo, 2009). This kind of strategic alliance can lead to an effective integration of R & D capabilities between different industries and, in turn, to the creation of a more innovative and valuable new product. In the early years of the “one technology-one industry” era, firms often focused their R & D and production in a single technology area (Christensen et al., 2005; Kodama, 1992). Knowledge transfer and product diversification were rarely practiced. Over the years, knowledge transfer across different technological domains became popular and quickly led to product diversification. Soon, the one technology-one industry business strategy no longer applies. Now, relying on a technological breakthrough alone is not sufficient any more. Firms must also consider diversifying and expanding their product domains through knowledge and technology fusion strategies.

Technology fusion often requires some form of knowledge and skills sharing. This can include research collaborations either between organizations or across national boundaries. Some empirical studies have found that industry-university collaborations may not only lead to cost efficiencies but also to improved innovations (Bodas Freitas et al., 2013; Etzkowitz and Leydesdorff, 2000; Maietta, 2015). This type of collaboration has been around for quite a long time and the rate at which it is adopted is still growing. Consequently, industry-university collaboration became one of the indicators of technology developments (Sung et al., 2015).

2.2. Measuring interdisciplinarity of research publications

Interdisciplinary research is a popular phenomenon in scientific studies. For decades, scholars have tried to measure the scientific outputs of interdisciplinary researches through the use of bibliometric approaches. The term “bibliometrics” was first coined and defined by (Pritchard, 1969) as the application of mathematics and statistical methods to books and other media of communication. There are two main bibliometrics research approaches that have emerged from the core literature – the structuralist approach and the spatial approach (Wagner et al., 2011). While the former mainly uses citation analysis based on the structure of science (characterized by authors, articles, and disciplines), the latter uses the disciplinary distance between authors or journals. Some of the recent studies employing spatial distance approaches to investigate interdisciplinary research include (Boyack, 2004; Leydesdorff, 2007a,b; Leydesdorff and Schank, 2008; Porter and Rafols, 2009; Rafols and Meyer, 2010; Stirling, 2007; Van den Besselaar and Heimeriks, 2001; van Raan, 2005). Three of the most common methods used in spatial analysis are based on the concepts of diversity, entropy, and betweenness centrality.

A number of papers have proposed indicators of interdisciplinarity based on diversity measures. Some of these include (Stirling, 1998, 2007); (Porter and Rafols, 2009); and, (Rafols and Meyer, 2010). (Stirling, 2007) provided a general framework for understanding diversity in a range of different contexts by recognizing it as a function of three necessary but individually insufficient properties: variety; balance, and disparity. (Porter and Rafols, 2009) used bibliometric indicators, the RaoStirling diversity index, and a visualization method based on overlay science maps (Leydesdorff and Rafols, 2009) to show how the degree of interdisciplinarity has changed between 1975 and 2005. Their study covered six research domains including long-estab-