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Increasing science and technology linkage in fuel cells: A cross citation analysis of papers and patents

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ABSTRACT

This study aims to explore the relationship between science and technology via analyzing cross citations between papers and patents in fuel cells. To calculate cross citation indicators, papers were retrieved from the WOS database and patent data from the USPTO during the period between 1991 and 2010, resulting in a total of 20,758 papers and 8112 patents. This study shows that there is a gradually increasing convergence between science and technology, particularly of science linkage in recent years. Papers citing patents are more time-sensitive than patents citing papers. Academic institutions are more likely to cite papers and patents published by other academic institutions.

1. Introduction

Collaboration between science and technology has been much discussed among scholars in recent years. An interactive relationship between science and technology is the key to innovation (Bhattacharya & Meyer, 2003; Cole & Eales, 1917). To encourage technological invention and seek innovative breakthroughs, experts in emerging disciplines such as nanotechnology and biotechnology integrate science and technology.

Cross citation analysis is a bibliometric method extensively used in investigating science and technology interaction. The primary assumption of cross citation analysis is that papers represent science output, patents represent technology creativity (Bassecoulard & Zitt, 2004; Meyer, 2002; Verbeek et al., 2002), and the cross citations between papers and patents illustrate knowledge exchange between science and technology (Verspagen, 2000). Although papers and patents cannot represent the whole intellectual achievement of science and technology, the general trends of basic research efforts can be gauged from the quantity of papers (Tijssen, 2004), and detailed and sufficient information about technology activities can be explored through patents (Jaffe, Fogarty, & Banks, 1998; Schmookler, 1950, 1953). Hence papers and patents can be used as proxy indicators of technological and scientific activity (Bhattacharya, Kretschmer, & Meyer, 2003). The cross citations between papers and patents which are quantitative, standardized and easily obtained, can therefore be used to reveal reliable linkage relationships between scientific and technological outcomes (Bhattacharya et al., 2003; Meyer, 2000).

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In related analysis of science and technology interaction, a great deal of researches have conducted patent citation analyses to explore contributions of science to the development of technology (Gittelman & Kogut, 2003; McMillan, Narin, & Deeds, 2000; Narin, Hamilton, & Olivastro, 1997; Schmoch, 1993; Tijssen, 2001; van Vianen, Moed, & van Raan, 1990; Verbeek et al., 2002). A few studies have paid attention to patent citations by papers (Bassecoulard & Zitt, 2004; Glänzel & Meyer, 2003; Hicks, 2000), but few have analyzed both paper citations by patents and patent citations by papers at the same time. Science linkage and technology linkage can be seen as two symmetrical dimensions of science and technology interactions. A more detailed and systematic comparative study is needed to better understand the relationship between science and technology.

With high energy conversion efficiency and pollution-free operation, fuel cells has become an emerging field in renewable energy technology. The development of fuel cells has drawn widespread attention of many researchers and developers, and it has become a useful tool for examining the interaction between science and technology. Many studies have focused on patent citations analysis in fuel cell area, including Barrett (2005), Daim, Rueda, Martin, and Gerdsri (2006), Godoe and Nygaard (2006) and Verspagen (2007). Beyond these, few studies have examined papers citing patents in this area. In light of the lack of studies in the fuel cell area, this study attempts to analyze cross citations between papers and patents by applying cross citation indicators including science linkage, technology linkage, technology cycle time and science cycle time to understand the characteristics, speed and dynamic changes of the interactions between academic research and technological innovation in the field of fuel cells.

2. Literature review

2.1. Investigating science & technology interaction by cross citation analysis

Analysing citations of patents and papers can provide a direct approach in studying interactions between science and technology. Patent citations containing prior patents and related scientific literature can also be used to explore technological development trends and evaluate the connection between scientific research and technological development; here, time lag is used to calculate predicted technological lifecycle (Albert, Avery, Narin, & McAllister, 1991; Glänzel & Meyer, 2003; Narin & Olivastro, 1988). These findings serve as indicators of academic influence on patents, evaluating the connection between technology and science while reflecting the level of dependency of technological development on academic research; in other words, the contribution of academic research to technological industry (Narin & Olivastro, 1988). Narin et al. (1997) demonstrated that science linkage on US patents doubled during the periods of 1987–1988 and 1993–1994. They also found that most of the papers cited in these patents were published by authors located in American universities or academic institutions. Tijssen (2001) revealed that in the USTPO, the more frequently patents cite papers in one country, the more interactive the relationship is between science and technology in that country. This also shows that scientific research and technological development in these particular countries are similar in terms of fields of interest. Therefore, countries which lead technological development and have strong scientific foundations tend to have higher proportions of patents citing papers (Gittelman & Kogut, 2003; McMillan et al., 2000).

Besides research into science linkage, Verbeek et al. (2002) also employed indicators such as science cycle time to evaluate the interaction between science and technology when conducting research on American patents citing papers during the period of 1992–1996. Branstetter and Ogura (2005) and van Vianen et al. (1990) revealed that the citation time lag for U.S. patents citing papers is getting shorter, at times even moving faster than academic research, showing that patents are increasingly influenced by scientific research. Study also shows that papers in the fields of chemistry and biotechnology are more likely to be cited, showing the importance of foundational scientific knowledge in patent citation in these fields (Schmoch, 1993; van Vianen et al., 1990; Verbeek et al., 2002).

The advantages of measuring science and technology interaction by patent citation have been highlighted by many researchers. According to Bhattacharya et al. (2003), Meyer (2000), patent citation analysis can objectively present the linkage between science and technology, due to the fact that patent citation extracts data that are collected for legal reasons, strengthening the credibility of those data. Theoretically patent citations are determined or added by the patent examiner, so the references reveal the patent's novelty and provide important and quantifiable background knowledge information, like the spillovers or related dimensions of the innovation, for bibliometrics analysis (Hall, Jaffe, & Trajtenberg, 2005; Narin et al., 1997).

Nonetheless, some researchers have expressed disagreement with this point and questioned the reliability of patent citation analysis. The central problem lies in the meaning of citation behaviour (Bornmann & Daniel, 2008). Due to the complexity of citation behaviour, we are unable to confirm the motivation of citation nor the content to which an author refers (Martyn, 1964). Some scholars doubted whether citations ultimately decided by patent examiner can truly represent actual references of inventors (Criscuolo & Verspagen, 2008). Jaffe and Trajtenberg (2002) argued that patent citations only reference novel arts or limited output and cannot reveal the complete knowledge transfer flows of patent innovation.

To our knowledge, though patent citation is not a perfect method for investigating science–technology interaction, it is still an adequate one which is available, quantitative, and standardized. Hence, we use patent citation data to uncover the relationship between science and technology.

Corresponding to science linkage which focus on patents citing papers, examining papers citing patents using technology linkage as indicator provides another channel to explore the interaction between science and technology (Glänzel & Meyer, 2003; Hicks, 2000; Lo, 2010; Yeh, Sung, Yang, Tsai, & Chen, 2013). Technology linkage uses statistical analysis to discuss