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Predicting the pattern of technology convergence using big-data technology on large-scale triadic patents

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ABSTRACT

Understanding technology convergence became crucial for pursuing innovation and economic growth. This paper attempts to predict the pattern of technology convergence by jointly applying the Association Rule and Link Prediction to entire IPCs related to triadic patents filed during the period from 1955 to 2011. We further use a topic model to discover emerging areas of the predicted technology convergence. The results show that the medical area is in the center of convergence, and we predict that technologies for treating respiratory system/blood/sense disorders are associated with the technologies of genetic engineering/peptide/heterocyclic compounds. After eliminating the majority of convergence, we found the convergence pattern among activating catalysts, printing, advanced networking, controlling devices, secured communication with in-memory system, television system with pattern recognition, and image processing and analyzing technologies. The results of our study are expected to contribute to firms that seek new innovative technological domain.

1. Introduction

Technological convergence occurs where inventions emerge at the intersection of established technology boundaries. Technological convergence has been regarded as the major source of new innovations among industries and technologies (Curran and Leker, 2011; Karvonen and Kässi, 2013). A new technological domain can be created by identifying technology convergence (Sohn et al., 2013; Park et al., 2013; Karvonen and Kässi, 2013). In this regard, a systematic and broad understanding of technology convergence is important in pursuing continued innovation and economic growth.

There have been a number of studies covering technology convergence on RFID, MEMS (Micro-Electro Mechanical Systems), bioinformatics, mechatronics, NFF (Nutraceuticals and Functional Foods), nanotechnology, bio-technology, and ICT (Information and Communication Technology). However, most of them have focused on special areas or analyzed a limited amount of data, pointing to the need for additional research. These studies can be limited and fragmentary. Given that technological convergence is a result of interaction among different technological fields, it is necessary to analyze and predict the technological convergences of all technological fields.

In this paper, we identify and predict convergence patterns of all technological fields by analyzing large scale patent data across all technological domains. We utilize triadic patent families, a series of patents filed at the United States Patent and Trademark Office, the European Patent Office, and the Japan Patent Office that are deemed more valuable than other patents (Baudery and Dumont, 2006). In addition, we apply open source big data technologies to all the patent datasets which are big in size and include a variety of information because processing and analyzing these big data under a normal PC environment can be challenging. Moreover, we predict future convergence patterns by analyzing possible links between technologies on the IPC co-occurrence network showing the technology convergence, and suggest the most probable keywords to identify emerging areas related to the predicted technological fields by using a topic model. Predicting future technological convergence patterns can contribute to technology management.

This paper consists of the following sections. Section 2 introduces the preceding research on technology convergence and patent analysis, along with research issues. Section 3 illustrates a research framework which will be followed by Sections 4 and 5 which discuss the analysis results, their implications, the research limitations, and future research topics.

2. Literature review and research issues

2.1. Understanding technology convergence

Technology is continuously evolving to meet market demands, rather than safeguarding the status quo (Iwai, 2000). Technological advances are considered a major force behind economic growth (Bernard and Charles, 1996). From a Schumpeterian perspective, technological change is deemed as a major force for continued economic

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growth (Mulder et al., 2001). In recent years, with emphasis on evolutionary economics, such change is actively understood from an evolutionary point of view (Dosi and Nelson, 2010; Safarzynska and van den Bergh, 2011; Safarzynska et al., 2012).

Dosi and Nelson (2010) stated that there are numerous analyses on technological change through a technological evolution analysis, a perspective that is linked to recent studies on economic growth and industry dynamics. Safarzynska and van den Bergh (2011) also attempted to understand technological evolution by modelling technological change. In a follow-up study, Safarzynska et al. (2012) presented a framework on the analysis of a dynamics system which consists of various objects using an evolutionary approach. In particular, it explained that technology is evolving hand in hand with living organisms through Devezas' Evolutionary Theory of Technological Change (ETTC) (2005), underlining that technological diversity is the most critical aspect of technological evolution. In this regard, Mulder et al. (2001) explained technological diversity is one of the most important drivers behind technological change while Geels (2002) stressed that openness and diversity require variations in technological evolution considered as the process of choosing, focusing and maintaining.

What is important is that technological diversity requires technology standardization which ironically can lead to technological lock-ins (Blind and Gauch, 2008). Consequently, standardized technology can undermine technological evolution because it triggers path dependency and technological lock-ins (Meyer-Krahmer and Schmoch, 1998; Safarzynska et al., 2012). With respect to technological and economic progress, the ETTC underscores a need to break away from these lock-ins by creative destruction through technological diversity (Devezas, 2005). How then can technological diversity, a byproduct and driver of technological evolution, contribute to technological innovation while minimizing the paradoxical lock-ins caused by technological standardization? This study considers technological convergence can be the answer.

Technological convergence is generally considered as the combination of multiple technological elements for creating new technological domains (Kodama, 1995; Kim et al., 2014). The technology convergence can be further regarded as the result of dynamic evolution of different technologies (Kim et al., 2014). Such blurring of boundaries between two or more technologies can be classified into convergence and fusion. Convergence means two different objects change or interact with each other to create one new domain. Fusion, on the other hand, means one of the objects is merged into the same domain as the other (Curran and Leker, 2011). The current paper seeks to refer to the two phenomena as convergence and analyze them as a single phenomenon. Because technological convergence allows a variety of technologies to create a new domain and evolve themselves, today's many promising scientific and technological areas are a result of such process (Martin et al., 2012). In particular, a Neo-Schumpeterian approach insists that convergence across various fields creates new opportunities and understanding such opportunities can offer a new competitive edge to companies and governments (Allarakhia and Walsh, 2012). Furthermore, technological convergence facilitates knowledge exchange among industries and technologies, and generates new combinations of technologies which leads to innovation (Karvonen and Kässi, 2013).

Along with technological innovation, technological convergence has been actively taking place in many industries such as the telecommunications industry (Bigliardi et al., 2012; Grove and Baumann, 2008). According to Lee and Sohn (2013), based on IPC co-occurrence from an IPC sub-class level (IPC 4-digit) perspective, 63% of the entire triadic patents underwent technological convergence. Therefore, understanding these patterns and applying them to reality are significant. In this regard, Shin (2005) presented cases of convergence between broadcasting and telecommunications facilitated by digital technologies in Korea and relevant policy implications. Hacklin et al. (2004) undertook a study on technological convergence on ICT, developed strategic management tools for innovative management and called for a need to conduct broader research for corporate planning and technological management.

2.2. Analyzing patents to understand technological convergence

Technological convergence can be understood and observed from several perspectives. Among them, when analyzing technological convergence through patents, objective data are common. Patents can facilitate a systematic analysis on a given technology and present technological trends as well as be used as an indicator for technological evolution and growth (Sen and Sharma, 2006). Curran and Leker (2011) monitored technological convergence through patents and understood the phenomenon through the co-classification of patents. Karvonen and Kässi (2013) considered that analyzing large-scale patent data is effective in understanding technological convergence.

A patent plays a crucial role in providing a wide range of quantitative and objective information from a variety of perspective on a technology. For instance, its claims offer legal rights to technology while the International Patent Classification (IPC) provides information on technological domains. Furthermore, citation information helps foster an understanding on complex interdependent relationships and interactions among different technologies (Han and Park, 2006; Allarakhia and Walsh, 2012; Karvonen and Kässi, 2013). Consequently, a number of studies use patents, especially those filed at the United Stated Patents and Trademark Office (USPTO) for a technological analysis. Patent management is considered to be important for companies and governments to maintain a competitive advantage (Jim and Liu, 2006). Jim and Liu (2006) conducted a patent map analysis of patents from 1990 to 2002 to investigate technology innovation in the e-marketplace. Li et al. (2014) measured the citation frequency of scientific papers with regard to citing the motivation of the inventor, the applicant, and the examiner, finding that self-citation by an inventor or applicant is appropriate for examining science linkages. In contrast to existing studies, this paper seeks to analyze triadic patents which are known to be valuable (Baudery and Dumont, 2006).

Many studies have used patents to analyze their citations by industry, analyze the centrality of patent citation networks or conduct further analyses through data-mining. Recently, a Social Network Analysis (SNA) on the link information of a patent has been widely used to understand the complicated interactions in technological evolution (Constant, 2002; Devezas, 2005). The SNA of patent data not only explains the complex interdependency among different technologies but also offers some insights on trends in technological interaction and changes by industry (Biju and Soumyo, 2001; Murray, 2002; Phene and Almeida, 2003; Han and Park, 2006; Daim et al., 2012; He and Fallah, 2009; Choi and Park, 2009; Lee et al., 2009a; No and Park, 2010; Lee et al, 2009b, 2010; Gress, 2010).

Recently, patents have been used to analyze the diffusion mechanism of emerging technologies. Patent citation networks can also be used to value patents. Hu et al. (2012) provided a new methodology for analyzing the value of patents using what they termed an ego patent citation network. They discovered that the structural indicators for an ego patent citation network could explain the characteristics of patents.

A key issue related to the SNA of patent data is link prediction which makes a prediction about a relationship within a network. Link prediction is considered valuable in foreseeing social relationships (Liben-Nowell and Kleinberg, 2007; Al Hasan and Zaki, 2011; Dong et al., accepted for publication). It is a way of predicting links between certain nodes based on the provided link information. Fundamentally, a prediction can be made based on similarity between nodes at a network level. Because SNA has successfully provided meaningful results after being applied to a patent's link information, link prediction is expected to provide meaningful results in terms of link information such as IPC co-occurrence or citation.