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Early identification of emerging technologies: A machine learning approach using multiple patent indicators

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ABSTRACT

Patent citation analysis is considered a useful tool for identifying emerging technologies. However, the outcomes of previous methods are likely to reveal no more than current key technologies, since they can only be performed at later stages of technology development due to the time required for patents to be cited (or fail to be cited). This study proposes a machine learning approach to identifying emerging technologies at early stages using multiple patent indicators that can be defined immediately after the relevant patents are issued. For this, first, a total of 18 input and 3 output indicators are extracted from the United States Patent and Trademark Office database. Second, a feed-forward multilayer neural network is employed to capture the complex nonlinear relationships between input and output indicators in a time period of interest. Finally, two quantitative indicators are developed to identify trends of a technology's *emergingness* over time. Based on this, we also provide the practical guidelines for implementation of the proposed approach. The case of pharmaceutical technology shows that our approach can facilitate responsive technology forecasting and planning.

1. Introduction

Emerging technologies are of great interest to a wide range of stakeholders in both industry and government who aim to set up investment-related strategies (Rotolo et al., 2015). The existing literature has shown that patent citation information is useful for measuring the economic value of a technology (Lerner, 1994; Narin et al., 1987). In this respect, many methods – such as cluster analysis, association rule mining, and conjoint analysis – have been employed to identify emerging technologies using patent citation information. However, the outcomes of previous studies are not forward-looking because most have been limited to *ex post* evaluation which measures past performance, impacts, or consequences (Lee et al., 2016). The value of predictive analysis for identifying emerging technologies has seldom been addressed.

Arguably, the most scientific approaches to identifying emerging technologies use curve fitting techniques (Daim et al., 2006; Shin et al., 2013) and stochastic models (Jang et al., 2017; Lee et al., 2011; Lee et al., 2012; Lee et al., 2016; Lee et al., 2017) to show future-projected trends of a technology by estimating the future citation counts of the relevant patents as a quantitative proxy. Curve fitting techniques using least squares estimation or least absolute deviation fit growth curves to time-series patent citation data and extrapolate those curves beyond the range of the data, whereas stochastic models estimate probability distributions of patent citations in the future by analysing fluctuations observed in historical data. However, the outcomes of these methods are likely to reveal no more than current key technologies, since they can only be performed at later stages of technology development due to the time required for patents to be cited (or fail to be cited) (Haupt et al., 2007). It should be noted that the time lag between citing and cited patents is found to be between 4 and 5 years on average (Verspagen and De Loo, 1999), and the latest patents have naturally less chance to be cited by other patents (Karki, 1997). Moreover, these methods have been criticised due to their reliance on making assumptions about pre-determined growth curves and probability distributions (Jang et al., 2017; Lee et al., 2011; Lee et al., 2012; Lee et al., 2016; Lee et al., 2017; Shin et al., 2013), which are difficult to identify at early stages of technology development and are heterogeneous across technologies. Hence, curve fitting techniques and stochastic models are of little practical assistance in identifying emerging technologies, especially when a technology is at its early stages and there is no historical data (Jang et al., 2017).

As a remedy, we propose a machine learning approach to identifying emerging technologies at early stages using multiple patent

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indicators that can be defined immediately after the relevant patents are issued. Economic and innovation literature has presented a wide range of patent indicators – such as patent family and originality – that may be indicative of the future citation count of patents and that further the relevant technology's economic value (Lerner, 1994; Narin et al., 1987). The tenet of this research is that analysis of those patent indicators can provide evidence for a patent's value and further the relevant technology's value in the future. For this, first, a total of 18 input and 3 output indicators are extracted from the United States Patent and Trademark Office (USPTO) database. Second, a feed-forward multilayer neural network – that is a supervised machine learning technique inspired by attempts to model the neuro-physical structure of the human brain – is employed to capture the complex nonlinear relationships between input and output indicators in a time period of interest. The primary advantage of this method for identifying emerging technologies is its ability to infer a function from observations (Buscema et al., 2017). It should be noted that there is no theoretical understanding of the relationships between those patent indicators, and moreover, the complexity and nonlinearity associated with innovation processes makes the design of a certain function impractical (Chen et al., 2012). Finally, two quantitative indicators are developed to identify trends of a technology's *emergingness* over time. Based on this, we also provide the practical guidelines for the implementation of our approach in terms of the choice of machine learning models and model update.

We applied the proposed approach to support Korean small and medium-sized high tech companies in technology forecasting at the request of the Korea Institute of Science and Technology Information (KISTI). We adopted the USPTO database for this research, since it contains the most representative data for analysing international technology (Lee et al., 2013). Our experience showed that the proposed approach can find emerging technologies at early stages, using the limited patent indicators that can be defined and extracted immediately after the relevant patents are issued. Our method also enabled us to perform systematic and continuous monitoring of emerging technologies, yielding high potential benefits at relatively low cost. Moreover, the results of our case study enabled us to identify a way to improve the proposed approach, which we expect to be a useful complementary tool to support experts' decision making in emerging technologies, especially for small and medium-sized high-tech companies. We believe that the systematic process and quantitative outcomes our approach offers can facilitate responsive technology forecasting and planning.

This paper is organised as follows. Section 2 presents the background to our research and Section 3 explains the research framework and methodology, which are then illustrate by a case study on pharmaceutical technology in Section 4. Section 5 provides the guidelines for implementation of our approach. Finally, Section 6 offers our conclusions.

2. Background

2.1. Definitions and characteristics of emerging technologies

Although emerging technologies have been the subject of many previous studies, there is no consensus as to what qualifies a technology to be emergent (Rotolo et al., 2015). As Table 1 reports, the definitions and concepts of emerging technologies presented by a number of studies overlap, but at the same time, point to different characteristics. For instance, Day and Schoemaker (2000) defined an emerging technology as a science-based innovation that has the potential to create a new industry or to transform existing ones. Porter et al. (2002) referred to an emerging technology as a technology that could exert much enhanced economic influence in the coming 15-year horizon. Considering that the economic influence of emerging technologies should exert not just on a specific domain, but also on the entire socio-economic system, Martin (1995) introduced the concept of general emerging technologies, and emphasised the wide scope and convergence of technological fields as

Table 1
Definition and characteristics of emerging technologies.

Authors	Definition	Characteristics						
		Prominent impact	Scope and coverage	Uncertainty and ambiguity	Development effort and developers' capabilities	Novelty	Science-intensity	Coherence	Growth speed
Day and Schoemaker (2000)	Science-based innovation that has the potential to create a new industry.	✓	✓	✓	✓	✓	✓	✓	
Porter et al. (2002)	Technology that could much enhanced economic influence in the coming 15-year horizon	✓		✓	✓				
Martin (1995)	Technology that exploits a wide scope and coverage of technology fields	✓	✓		✓		✓		
Cozzens et al. (2010)	Technology that shows high potential but has not yet demonstrated its value	✓		✓			✓		✓
Small et al. (2014)	Technology that has universal agreement on its novelty and growth					✓			✓

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