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Exploring technological opportunities by mining the gaps between science and technology: Microalgal biofuels

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ABSTRACT

The interaction between scientific and technological knowledge facilitates exploration of new technological opportunities; however, gaps between them typically impede exploration of these opportunities. Scientific papers and technological patents record modern and advanced knowledge in scientific discovery and technological development; therefore, comparing their statuses can identify the gaps and explore potential technological opportunities. Because microalgal biofuels are a promising alternative energy resource devoid of territorial land use problems, this study applies text mining and an algorithm that can cluster objects of high-dimensional data to microalgal biofuel papers and patents, and explores their potential technological opportunities. The results demonstrate that a text-based clustering approach is appropriate for identifying scientific and technological applications for microalgal biofuels. The results indicate that microalgal photosynthesis and light utilization have abundant scientific outcomes for technological engineers to potentially apply. Technological opportunities exist in synthesis, harvesting, extraction, and lipid conversion. Scientific knowledge underlying biofuels accompanying high-value co-products of production require sustained exploration and reporting through research. These needs represent potential technological opportunities.

1. Introduction

Technological opportunity is the potential for technological progress in general or within a particular field (Klevorick et al., 1995; Olsson, 2005; Frenz and Prevezer, 2012) that affects the overall industry and individual enterprises. At the industrial level, technological opportunities determine technological development (Olsson, 2005), affect industry R&D intensity, and lead to heterogeneous R&D productivity in different industries (Klevorick et al., 1995; Olsson, 2005). At the enterprise level, technological opportunities affect R&D costs and innovation activities, resulting in different R&D productivity and operating performance among enterprises (Frenz and Prevezer, 2012; Nieto and Quevedo, 2005; Cohen et al., 1987; Cohen and Levinthal, 1989). In addition to affecting current enterprises, technological opportunities can facilitate the startup of new businesses and successful commercialization of entrepreneurs' inventions (Shane, 2001). Because technological opportunities profoundly influence industries and enterprises, systematic methods of exploring potential technological opportunities undoubtedly benefit industries and enterprises.

Klevorick et al. (1995) identify three sources that contribute to an industry's technological opportunities: advances in scientific knowledge, technological advances originating outside the industry, and feedback from industrial technology. Among those, advances in scientific knowledge are most powerful. It provides an expanding pool of theory, technique,

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and problem solving capability that industrial R&D uses, and unlocks new technological capabilities (Klevorick et al., 1995; Narin et al., 1997; Meyer, 2000). The interaction between scientific and technological knowledge nourishes exploration of new technological opportunities. Scientific knowledge lays the foundation for technological knowledge and provides better solutions for product commercialization. Feedback stimulus from technological knowledge can promote continuous exploration and study of scientific knowledge (Glänzel and Meyer, 2003; Ziman, 1988; Meyer, 2002).

Scientific and technological knowledge are complementary, but the gap between science and technology hinders the development of technological opportunities. Previous studies on exploration of technological opportunities have, therefore, used a single knowledge source. For example, Yoon and Park (2005) and Yoon and Kim (2012) explore technological opportunities based on technological knowledge alone. In contrast, Shibata et al. (2010) successfully combine scientific and technological knowledge sources to analyze the gap between them. Their method employs a citation-based clustering approach that identifies citation networks and further compares scientific clusters with technological clusters to identify commercialization gaps. The extracted commercialization gap is equivalent to the potential of technological opportunities. However, Shibata et al. (2010) analyze only the largest component in the citation networks and remove isolated nodes and components not connected with the largest one. This study, however, observes that citations among literature materials in some emerging technological fields occur infrequently. Applying their methods may omit a large portion of literature data, losing important information. To solve this problem, a text-based clustering approach that analyzes nonstructured text through text mining, which replaces the citation network for identifying scientific and technological clusters, and extracts commercial gaps and potential technological opportunities, is adopted.

This approach extracts representative words and terms–features–from documents. Because the literature typically contains hundreds to thousands of features, the matrices representing the relationship between documents and features are high-dimensional spaces; thus, clustering these objects poses challenges presented by the "curse of dimensionality" (or "distance concentration effect"), whereby similarity measures cannot discriminate between the nearest and farthest neighbors for a given object (Beyer et al., 1999). The vector space extracted by text mining contains more or less irrelevant features, which may conceal relevant features and confuse the clustering process (Kriegel et al., 2009). Therefore, a suitable clustering algorithm is selected for our empirical technology.

Due to serious global climate change, the development of clean, environmentally-friendly, and renewable energies has become an important strategy in many countries (Rosenberg, 1982). Biofuel is the fourth largest energy source, after petroleum, coal, and natural gas. Although biofuel can reduce CO_2 emission, planting biofuel crops requires large land areas and may reduce space for grain crops. Microalgae are a type of amphibious plants, and thus, are unaffected by land area restrictions. The oil content of microalgal cells is higher than that of any land plant, producing higher biofuel yields; moreover, it has the advantage of rapid growth (Smith et al., 2010). However, microalgal biofuel production cost remains higher than that of fossil fuel (Davis et al., 2011). Exploring the gaps between scientific research and technological development provides useful clues to technological opportunities for overcoming the challenge in microalgal biofuel production systems. The citation network relationships among scientific and technological literature are not frequent because microalgal biofuels remain a newly emerging field. Therefore, text-based clustering is more appropriate than citation-based clustering for exploring technological opportunities in microalgal biofuels.

Therefore, on the basis of scientific and technological literature related to microalgal biofuels and by employing text-based clustering for analysis, this study examines current major scientific and technological research fields, and then explores future potential technological opportunities by exploring the gaps between them. Finally, this study suggests future R&D directions for microalgal biofuels.

2. Related research

2.1. Technological opportunity

Scientific technological knowledge and technological knowledge within and beyond industries are important sources of technological opportunities (Klevorick et al., 1995). The interaction between science and technology has been studied since Price's (1965) research. Price finds that science and technology are independent, and accumulate their own knowledge structure; in special cases, the two interact. Since then researchers have found that interactions between science and technology have become increasingly active. Rich scientific research fields can stimulate innovation and technological development (e.g., Rosenberg, 1982); conversely, technologies with less scientific exploration may also inspire important scientific breakthroughs. Additionally, basic science advancement requires support from more advanced technologies (e.g., Nelson, 1982). Thus, science and technology are interdependent (Meyer, 2002; Petrescu, 2009).

Despite this interdependence, a gap exists between them. Scientists may be unaware of the application of their discoveries, while manufacturers are often unaware which scientific discoveries can improve their technological development and commercialization (Hellmann, 2007). Scientific papers and technological patents present the results of scientific discovery and technological development (Martino, 2003; Robinson et al., 2013; Kostoff, 2006); thus, an analysis and comparison of scientific papers and technological patents can determine the gap and identify technological opportunities (Shibata et al., 2010).

Some previous studies exploring technological opportunities are based on technological patents alone, whereas others combine scientific papers and technological patents. Among the patent studies, Yoon and Park (2005) use text mining to extract patents' keywords, through which they establish a technological dictionary and morphology. The undeveloped morphological combination indicates potential technological opportunities. The method of exploring technological opportunities proposed by Shibata et al. (2010) combines science and technology. They use social network analysis to establish citation networks of science and technology based on citation relationships in paper and patent references. After extracting the papers and patents in the largest components from both network diagrams, they identify scientific and technological

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