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A bibliometric method for measuring the degree of technological innovation

Woondong Yeo [a,b], Seonho Kim [b], Hyunwoo Park [b], Jaewoo Kang [a,*]

[a] Department of Computer Science and Engineering, College of Informatics, Korea University, 5-Ga Anam-Dong, Seongbuk-Gu, Seoul 136-713, Republic of Korea
[b] Korea Institute of Science and Technology Information, 66, Hoegi-ro, Dongdaemun-gu, Seoul 130-741, Republic of Korea

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ABSTRACT

Knowing the degree and stage of a product's innovation is essential for technological forecasting and beneficial for governments and firms that want to come up with product promotion strategies and prioritize investments. Bibliometric analysis has been widely used as a practical tool to evaluate scientific activities. Although there were many bibliometric-based attempts to model product innovation stages, there have not been any trials that approach it from the standpoint of uncertainty reduction in technological product innovation. This paper suggests two hypotheses: 1) at a macro level, the year-to-year difference in relative research volumes of each component decreases over time as the uncertainty of a product decreases; and 2) at a micro level, the year-to-year difference in relative research volumes of each component is correlated with the technological life cycle of a product's core component. In addition, we provide empirical evidence that supports the hypotheses in the case study of mobile phones. From the evidence, we conclude that bibliometric analysis using research papers can measure the uncertainty in a product's technological innovation.

1. Introduction

Knowing the degree and stage of a product's innovation is essential to technological forecasting (Watts and Porter, 1997) and beneficial for governments and firms that want to come up with product promotion strategies and prioritize investments (Abernathy and Utterback, 1978; Cusumano et al., 2007). It is because that the stimuli and barriers to success are different in each stage of product innovation. For example, cost reduction is not a good policy at the early stage of product innovation. Also, the government's policy to force a young industry to be standardized before a dominant design (also known as an industry standard) emerges, has been proven to fail (Abernathy and Utterback, 1978). Despite its importance, the difficulty of measuring the degree of product innovation has hindered the progress and practical use of the product life cycle model.

Bibliometric analysis has been used as a practical tool to monitor technology (Coates et al., 2001) and evaluate scientific activities. When bibliometrics focuses on measuring the quality of science and technology, it is often called scientometrics (Hood and Wilson, 2001). To date, many trials based on bibliometric methodologies have been done to measure the degree of innovation in terms of technology, product, or industry (Watts and Porter, 1997); however, bibliometric analysis suffers from the following limitations: 1) the number of published scientific papers is not indicative of the quality of research activity; 2) much scientific development is not published (Watts and Porter, 1997); and 3) most scientific publications are not product-based.[1] Although bibliometric analysis may be less accurate than other traditional analysis methods due to these limitations, bibliometric analysis still has its own merits. It is fast, low-cost, and can complement existing methods. At the least,

* Corresponding author. Tel.: +82 2 3290 4840.
E-mail addresses: wdyeo@kisti.re.kr (W. Yeo), haebang@kisti.re.kr (S. Kim), hpark@kisti.re.kr (H. Park), kangj@korea.ac.kr (J. Kang).

[1] R&D that produces scientific papers is oriented to science and technology. Products or product components are all necessary items for technology-related activities (Guglielmi et al., 2010) and are associated with different types of technologies. Thus, in bibliometric analysis, if a scientific paper about a technology is related to a product with a clear statement, the paper is considered to be related to the product.

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bibliometric analysis can be used as a preliminary hypothesis-screening tool before launching a major analysis project.

The analysis based on the S-curve pattern of product life cycle (e.g., Meyer et al., 1999; Bengisu and Nekhili, 2006; Daim et al., 2006; Liu and Wang, 2010; Ryu and Byeon, 2011) is a good example that uses a growth pattern of the number of related papers. However, in bibliometrics analysis, there has not yet been a trial that approaches it from the standpoint of uncertainty reduction in technological innovation. The uncertainty may be technological, market-related, and regulatory/institutional (Jalonen, 2012; Jalonen and Lehtonen, 2011). In this paper, we show that bibliometrics can be used to measure the degree of technological innovation in the Abernathy and Utterback model (Abernathy and Utterback, 1978; Utterback and Abernathy, 1975; Utterback, 1994). To this end, we suggest two hypotheses: 1) at a macro level, the year-to-year difference in relative research volumes of each component decreases over time as the uncertainty of a product decreases; and 2) at a micro level, the year-to-year difference in relative research volumes of each component is correlated with the technological life cycle of a product's core component. We provide empirical evidence to support these hypotheses from the case study of mobile phones. Mobile phones were chosen as the subject of the case study because their empirical results can be validated easily, and their evolution of technology is well studied (e.g., Dalum et al., 2005; Koski and Kretschmer, 2007; Lin et al., 2009; Ansari and Garud, 2009; Giachetti and Marchi, 2010; Chen et al., 2012; Kim, 2012).

This study was motivated by the work of Frenken and Leydesdorff (2000) who conducted a time series investigation about the amount of changes in scaling patterns among 143 designs in civil aircraft (1923–1997) to justify a heuristic. The heuristic is that many incremental improvements are associated with the rescaling of designs within the range of existing standard designs, whereas the major innovation that brings out a dominant design – a design that achieves a dominant position as a market or technological standard – is accomplished based on the redesign of existing standard forms and structures (Sahal, 1985). This redesign radically changes ratios between the characteristics of a product (e.g., increasing/decreasing the ratio of front and back wing lengths). Their work, whether they intended it or not, also showed the possibility that methodologies from information theory can be used to measure the extent of dominance, diffusion, and convergence of product designs.

The subsequent sections of the paper are organized as follows. Section 2 presents the theoretical background about a technological innovation process and the uncertainty existing in it. Section 3 reviews the work of Frenken and Leydesdorff (2000) in detail, and Section 4 suggests our model that measures a product's degree of development using the product life cycle viewpoint. Section 5 presents the case study about mobile phones, which validates our model, and Section 6 concludes the paper with discussion.

2. Background

2.1. Process of technological innovation

Technological innovation is the successful adoption of a technology-based invention for products and processes. The level of success of the adoption is determined by the economic value created in the marketplace (OECD, Oslo Manual, 2005). A mere adoption of an invention is not technological innovation until the effect of innovation is diffused in the marketplace and produces economic benefits for a firm that wants innovation. For technological innovation, a product or a process should be new or significantly improved for the marketplace, industry, or at least for the firm. In the perspective of product innovation, a technologically new product can be born by adopting new technology or devising new uses of existing technology, while a technologically improved product can be created through the use of higher-performing components or materials, or the innovation of a sub-system of the product (OECD, Oslo Manual, 2005).

There are different kinds of perspectives on what type of typology to use to classify technological innovations (Garcia and Calantone, 2002). Based on the general perspective, technological innovations are categorized into two classes: radical and incremental. Radical innovation, which creates a technologically new product, involves greatly "competence-destroying" technological advancements. Incremental innovation, which is related to a technologically improved product, involves modestly "competence-enhancing" technological changes.

The process and characteristics of technological innovation can be described as models such as those by Utterback and Abernathy (1975) and Roberts and Frohman (1978), or the S-curve model by Roussel (1984) and Foster (1986). Based on the Abernathy and Utterback model (Abernathy and Utterback, 1978; Utterback and Abernathy, 1975; Utterback, 1994), the innovation process in an industry is summarized in three phases: *fluid*, *transitional*, and *specific*.

In the fluid phase, market needs, design criteria, and performance requirements of a product are ill-defined. The technical uncertainty is high and the changes of the production and process are frequent. Also, the process is composed of non-standardized or nonspecific operations, which leads to firms developing a variety of products without using a stabilized product concept. However, the number of firms involved in an industry is relatively small; competition between them is focused on maximizing functional performance but not on standardizing and cost-minimizing product manufacturing. In this period, firms invest in radical product innovation rather than process innovation. Firms believe that considering customer needs can help them become dominant players in the market; consequently, product innovation occurs more frequently than process innovation.

The more a firm's product develops, the more the technical uncertainty reduces; after the target becomes clear, firms invest more in the formal research and engineering of a product. Cost competition and reduction in the number of incumbent occur during the transitional phase. The emphasis of investment shifts from radical product innovation to process innovation and product differentiation which uses a firm's internal technical capabilities. As a product concept becomes stable, a dominant design is established. Due to the advent of a dominant design, the increased production volume pressures the incumbents to discuss the standardization of a product for the sake of a production economy. The selection of a dominant design is not radical innovation even though it generally takes the form of a new product. Rather, it is a result of creatively synthesizing technological innovations that independently