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Exploring the relationship between technology diffusion and new material diffusion: the example of advanced ceramic powders

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ABSTRACT

New technologies have been recognized as key drivers for corporate profitability and growth in today's fast changing environments, especially in new materials field. However, little has been done in discussing the technology diffusion on the topic of new materials. In this study, we investigate the diffusion of advanced ceramic powders technology using patent citation data. We also adopt the sales data of the advanced ceramic powders for measuring the new material diffusion. At last we analyze the relationship between "technology diffusion" and "material diffusion" through the Bass diffusion model. The results show that the diffusion of technology through patent citation could be successfully explained by empirical analysis for which the Bass diffusion model was adopted. Furthermore, we can find out if technology diffusion can be the leading indicator of a new material's diffusion before its launching which is before the commercialization of the patent.

1. Introduction

New technologies have been recognized as key drivers for corporate profitability and growth in today's fast changing environments, especially in new materials field. The diffusions of a whole host of synthetic fibers are examples (Martino, 1993). Usually, these come about through the replacement of nature materials by synthetic ones that are cheaper or better. Hence, it is very critical that an enterprise should monitor and forecast the technology diffusion of new materials, to acquire or apply the most appropriate new technologies for possessing a competitive advantage over its rivals.

Among the many technology monitoring and forecasting indicators, patents are an objective and mature indicator. Patent data are accepted widely as a quantitative measure of the performance of technology diffusion (Griliches, 1990; Cincera, 1997; Caselli and Coleman, 2001). In each patent document, the inventor should describe the prior art of invention, that is usually presented by citing previous patents or former literatures. The more frequently a certain patent is cited by subsequent patents, the more the related technology can be said to be diffused, implying that the technology is more widely applied and more valuable. Therefore patent citations not only imply the importance of a patent, but they also regarded as tracing the spread of technology (Chang et al., 2009). Through patent citation, we can explore the technology diffusion of new materials field.

During the past several decades, there has been growth in the number of diffusion models for examining the diffusion of products and technologies. Diffusion is a process in which an innovation is spread through some specific paths in a social system (Rogers, 1983; Watanabe and Asgari, 2004; Tsoutsos and Stamboulis, 2005). One of the most popular models is the Bass diffusion model (Chang et al., 2009; Rogers, 1983; Lee et al., 2010). This model has been successfully used in various fields, such as industry, agriculture, education, marketing, etc., in order to measure growth rate, penetration level, and potential adoption rate (Lee et al., 2010; Soffer et al., 2010). However, little has been done in discussing the technology diffusion on the topic of new materials. Consequently, the main purposes of this study are to analyze the diffusion of technology using patent citation data and to measure the diffusion of new materials, which is based on the patented technology. Furthermore, we explore the relationship between "technology diffusion" and "material diffusion" by the Bass diffusion model.

2. Literature review

The domain literature related to this paper can be divided into two parts: diffusion theory and models, technology diffusion and patents citation. They are discussed in the following subsections.

2.1. Diffusion theory and models

Diffusion is defined as a dispersal process of information, a disease or a product by which an innovation is adopted (Rogers, 1983;

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Watanabe and Asgari, 2004; Tsoutsos and Stamboulis, 2005; Carayannis and Turner, 2006). Diffusion theory is centered on the processes whereby an innovation "is communicated through certain channels over time among members of a social system". There are four main components: innovation, communication channels, time, and social system, to determine the features of the diffusion process of an innovation (Rogers, 2003; Tsoutsos and Stamboulis, 2005; Carayannis and Turner, 2006; Lin and Lin, 2008). The innovation process spread through society in a way that is reflected by an S-shaped curve, with early adopters selecting the technology first, followed by the majority, until a technology or innovation is considered common. Usually individuals will initially perceive innovations as uncertain and even risky. To reduce uncertainty, most people look for others like themselves who have already adopted the new idea and gained some experience (Rogers, 2003).

Rogers (1995) proposed a classification of potential adopters based on their receptivity: innovators (2.5%) are risk takers willing to take the initiative and time to try something new, early adopters (13.5%) tend to be respected group leaders, the individuals essential to further adoption by whole group, early majority (34%) the careful, safe, deliberate individuals unwilling to risk time or other resources. Late majority (34%), those suspicious of or resistant to change. The latter category includes those who are hard to move without significant influence, Laggards (16%) which are consistent or even adamant in resisting change. Thus the spread of a new technology depends mainly on two types of adopters: the innovators and the imitators. Innovators are driven by their desire to try new technologies while imitators are primarily influenced by the behavior of their peers. The innovation and imitation factors determine the speed at which the technology is accepted into everyday use (Soffer et al., 2010; Rogers, 1995).

There are many different kinds of diffusion models for evaluating the diffusion of products and technologies nowadays. But one of the most popular models is the Bass diffusion model (Chang et al., 2009; Lee et al., 2010). Bass analyzed the diffusion process through consumers' behavior, under the basic assumption that the probability of initial purchase is related linearly to the number of previous buyers. Buyers or adopters may be innovators or imitators. While the number of previous buyers does not influence innovators in the timing of their initial purchase, imitators are strongly affected by the number of adopters. Bass's model has been successfully used in various fields in order to forecast growth rate and usage of numerous new and innovative technologies with an emphasis on predicting the ultimate level of penetration and the rate of potential adoption (Chang et al., 2009; Rogers, 1983; Lee et al., 2010; Soffer et al., 2010). Bass model implies exponential growth of initial purchases to a peak and then exponential decay. The shape of the diffusion curve is therefore a function of the rate at which awareness of the new product develops, as well as of the product's appeal. The model can predict how many customers will eventually adopt the new product and when they will adopt (Soffer et al., 2010). Hence we will use the Bass diffusion model for evaluating the technology diffusion and new material diffusion in this study.

2.2. Technology diffusion and patents citation

Technology diffusion model, the main difference from the above models is that the diffusion object changed from product to technology. There are many approaches for technology diffusion in the industries. In practice, technology conferences, product exhibitions, and technology licensing and transfers are possible ways to diffuse technologies (Archibugi and Planta, 1996; Chang et al., 2009). However, the diffusion effect of the above methods cannot be observed or measured clearly. A patent is a medium for the disclosure of technology. There are more and more studies focusing on the technology diffusion or knowledge spillover among industries through patent data (Cincera, 1997; Caselli and Coleman, 2001; Shibata et al., 2008, Lee et al., 2010). In the content of a patent, the "prior art" which is to clearly explain the developmental trace of the technology of the invention, is a critical element. The prior art is presented in words and through citing linkages, such as patents, journals, or other literature. From another aspect, the more a patent is cited, the wider the technology is diffused, and it implies that the applications and values of the patent are higher (Chang et al., 2009; Jaffe et al., 1993; Narin et al., 1997; Stople, 2002; Park and Park, 2006).

Accordingly, patent citation is related to the diffusion of technology or knowledge, as investigated in related literature. Various researches analyze the diffusion process of a specific field's patent to other firms or industries through patent citation (Cincera, 1997; Caselli and Coleman, 2001; Chang et al., 2009; Lee et al., 2010, Petruzzelli, 2011). In this study, we define patent citation as the demand for technology. In other words, as the number of patent citations increase, we can infer that the demand for cited patents or technology also increases from the perspective of demand for technology.

3. Methodology

Diffusion is a process in which an innovation is spread through some specific paths in a social system. There have been many researches on the diffusion of innovations, including products and services in various fields (Rogers, 2003). Fourt and Woodlock (1960) assume that a consumer's adoption rate for a new product or technology is constant over time. The model is called as the common source model (Geroski, 2000) and represented as follows:

$$n(t)=a(m-N(t-1)), \tag{1}$$

where $n(t)$ is the sales of a new product at time t; $N(t)$ is the cumulative sales of a new product at time t; m is the market potential; a is the constant adoption rate (this model is limited in that the number of potential adopters is gradually decreased.)

On the other hand, Mansfield (1961) suggests a logistic model to think of the word-of-mouth effect among consumers. This model can be represented as follows:

$$n(t)=m/(1+b\ \exp(-ct)) \tag{2}$$

where $n(t)$, $N(t)$, and m are the same as in (1), b is the adoption level when the product was introduced, c is the adoption rate when the product was introduced;

Bass (1969) suggests a diffusion model by mixing models (1) and (2), this model is called the mixed information source model (Geroski, 2000). Consumers are divided into two groups: innovators, who adopt the new product as a result of external influence, and imitators, who adopt it due to word-of-mouth effect. The Bass model is shown as follows:

$$n(t)=\left(p+q\frac{N(t-1)}{m}\right)(m-N(t-1)) \tag{3}$$

where $n(t)$, $N(t)$, and m are the same as in (1), p is the innovation coefficient, q is the imitation coefficient.

Recently, there are more and more researches empirically integrated the Bass diffusion model and patent data, and found that technology diffusion fit the Bass model very well (Chang et al., 2009; Lee et al., 2010; Jaffe et al., 1993). Hence, we will use the Bass model to analyze the technology diffusion and new material diffusion through patent citation in this study.

4. Research design

4.1. Survey design

According to the "Advanced ceramic powders and nano ceramic powders" (Business Communications Co., 2006) represented the advanced ceramic powders were used very popular for their features, such as height melting point, insulation, wear-resisting, etc. (Business Communications Co., 2006). Those powders occupied important parts in new material field. Hence, we adopt the advanced ceramic powders for object of this study.

Owing to the research is to investigate the diffusion of technology using patent citation data and to measure the diffusion of new materials, which is based on the patented technology. We first collect patent citation data from United States Patent and Trademark Office (USPTO) database, which owns the main patents in the advanced ceramic powders field (Business Communications Co., 2006; Cheng and Chen, 2008). Then the data will be input into the Bass model to evaluate the diffusion of new materials that is based on the patented technology. We also adopt the sales data of the advanced ceramic powders for measuring the new material diffusion. Finally we can analyze the relationship between "technology diffusion" and "material diffusion" by modifying the Bass diffusion model.

4.2. Data collection and analysis

The data collections of this survey are divided into two parts. One is "patent data", the other is "sales data of the material". The patent data collections were on the advanced ceramic powders technology to be applied for and registered. The data of patent citation can be obtained from the USPTO database, which built up around from 1970 to the present. We will use the citation number of these patents to analyze the diffusion of advanced ceramic powders technology, as shown in Fig. 1.

Furthermore, the sales data collections of the material in this research have resulted from the application of advanced ceramic powders technology. The increase in the number of advanced ceramic powders consumption quantity represents the diffusion of the materials. The volume of sales data of advanced ceramic powders were obtained from the statistics of U.S. Census Bureau and Fed stats.

In this research, we contemplate "technology diffusion" as knowledge spillover, which is caused by patent citation and "material diffusion" as the sale of a product, which is developed through the application of the said technology. Therefore, we can survey the relationship between "technology diffusion" and "material diffusion" through the Bass diffusion method.

5. Results and discussion

The number of advanced ceramic powders patent citations is estimated by nonlinear least squares (NLS) in the Bass diffusion models. Table 1 shows the estimation results of the diffusion model of advanced ceramic powders patent citations. As seen in Table 1, all parameters are statistically significant and have the expected signs. This result is reasonable in that, according to Sultan et al. (1990), the average of the innovation coefficient is 0.03 and the imitation coefficient is 0.42. In addition, the adjusted R-square value is 0.813, indicating that the Bass diffusion model appropriately explains the diffusion pattern of advanced ceramic powders patents.

The imitation coefficient q and the innovation coefficient p have significant values, denoting that the word-of-mouth effect is an important factor in the diffusion of advanced ceramic powders patents. Originally, the word-of-mouth effect means the information acquired from contact with prior purchasers, which influences a consumer to adopt a new product (Rogers, 2003; Dodson and Muller, 1978). When applying this definition to technology spillover, it means that the patent is cited indirectly from the basic (root) patent (Chang et al., 2009; Lee et al., 2010; Lai et al., 2004).

Fig. 2 shows both the actual and estimated number of annual patent citations. We can confirm that the Bass diffusion model put quite a good performance in the diffusion of advanced

Table 1
Estimation results: diffusion of advanced ceramic powders technology.

Parameter	Coefficient	St. error	t statistic
m	2525.83**	65.3715	75.66
p	0.03**	0.0472	5.68
q	0.42**	0.0567	8.17
Adjusted R-squared=0.8131			

** Statistically significant at 1%.

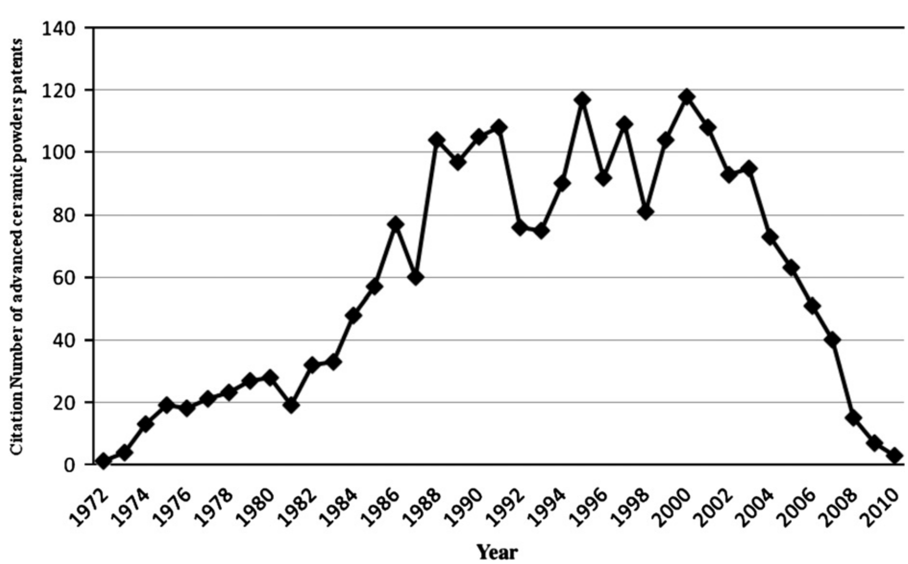

Fig. 1. Patent citation of advanced ceramic powders technology.

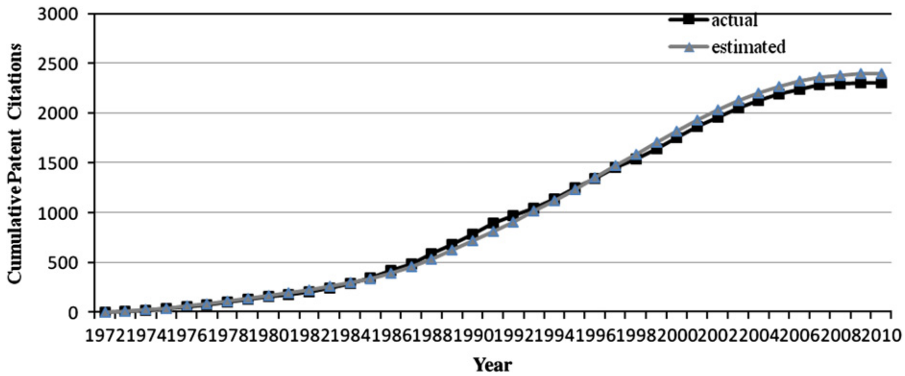

Fig. 2. Cumulative actual and estimated patent citations of advanced ceramic powders technology.

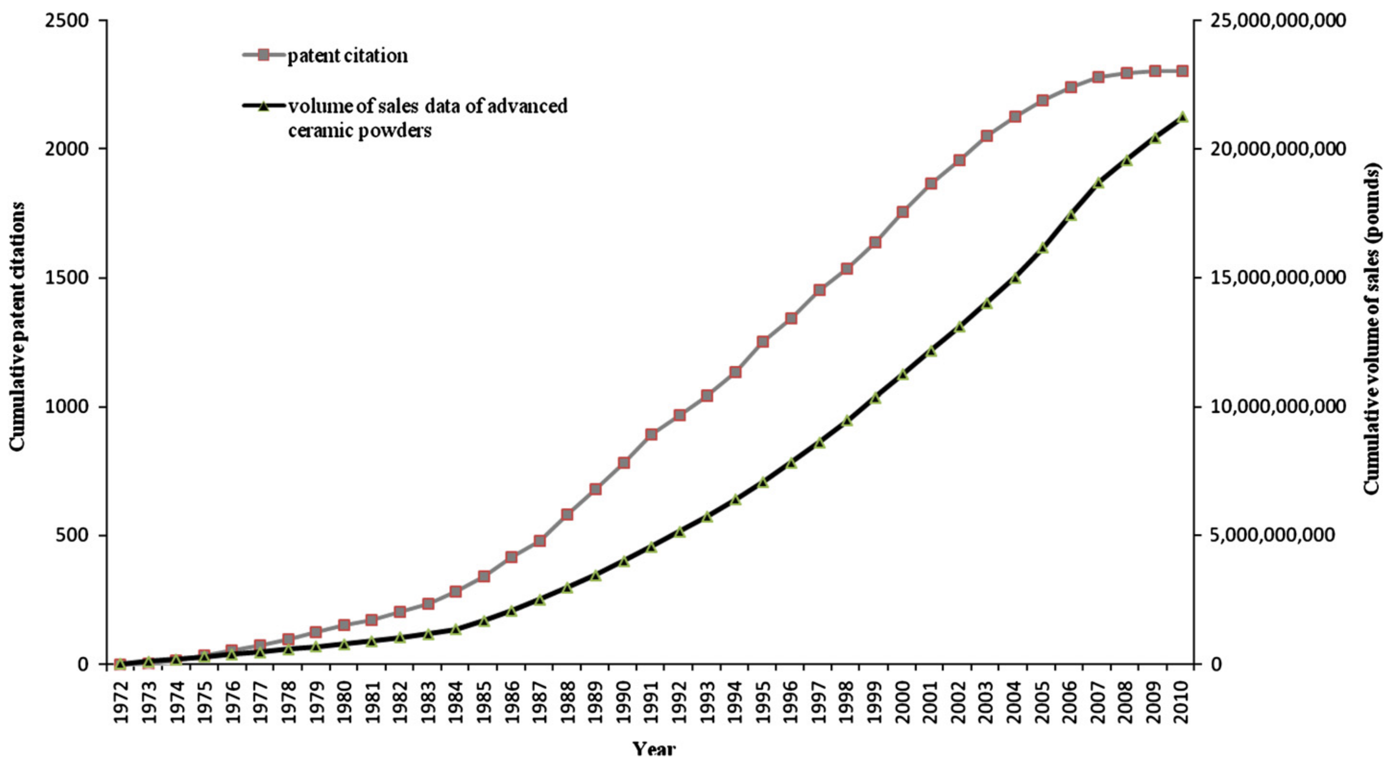

Fig. 3. Cumulative patent citations and volume of sales data for advanced ceramic powders.

ceramic powders patents again. Meanwhile, Fig. 3 shows a time lag of four to six years between the diffusion of advanced ceramic powders technology and the diffusion of materials.

We also used the Bass model to analyze the diffusion of materials. To take into account the spillover effect of the advanced ceramic powders patents on the diffusion of materials, we modified the Bass model so that it incorporated the term of patent citation.

$$f(t)=\left\{p+q\frac{F(t-1)}{\overline{F}}+r\,acp(t-5)\right\}\{\overline{F}-F(t-1)\} \tag{4}$$

where $f(t)$ represents the net sales volume of advanced ceramic powders and $F(t)$, the cumulative sales volume, at time t. The parameter $\overline{F}$ represents the market potential, the variable $acp(t)$, the frequency of advanced ceramic powders patent citations, and r, the effect of advanced ceramic powders patent citations on the diffusion of materials. The estimation results of Eq. (4) are presented in Table 2.

As observed from the estimation results, the coefficient r has a statistically significant and positive value, indicating that advanced ceramic powders patent citations have a positive effect on the diffusion of materials, with a five-year time lag. We also deliberated several time lags besides 5 years, but they were not statistically significant. Therefore, we can conclude that the materials are diffused after the diffusion of advanced ceramic powders technology with a five-year time lag, and that the diffusion rate of materials is accelerated by the spillover of advanced ceramic powders technologies.

Table 2
Estimation results: diffusion of advanced ceramic powders.

Parameter	Coefficient	St. error	t statistic
$\overline{F}$	1,687,110,750**	235,007,122	8.3395
p	−0.0653*	0.0398	−2.8311
q	−0.0812	0.2812	-0.2677
r	0.0081**	0.0018	5.3772
Adjusted R-squared = 0.8017			

** Statistically significant at 1%.
* Statistically significant at 10%.

6. Conclusion

New technologies have been recognized as key drivers for corporate profitability and growth in today's fast changing environments, especially in new materials field. It is very critical that an enterprise should monitor and forecast the technology diffusion of new materials to acquire or apply the most appropriate new technologies for possessing a competitive advantage over its rivals. However, little has been done in discussing the technology diffusion on the topic of new materials. In this study, we investigate the diffusion of advanced ceramic powders technology using patent citation data. We also adopt the sales data of the advanced ceramic powders for measuring the new material diffusion. At last we analyze the relationship between "technology diffusion" and "material diffusion" through the Bass diffusion model.

Owing to this research defines patent citation as the demand for technology, and estimates the diffusion model using data of patent citations. The results reveal that all parameters are statistically significant, which means that our approach is appropriate and support the empirical analysis of previous literature that patent citation is related to knowledge spillover. Although this study is limited to advanced ceramic powders technology, our approach is meaningful in that patent citations can be regarded as technology demand and explained by the diffusion model.

Moreover, the diffusion of advanced ceramic powders technology has a positive effect on the diffusion of materials, and there is a time lag of about 5 years between them. We have also shown that technology demand can be a leading indicator of material demand, and it takes a long time to progress from patent applications to material commercialization. The implications that the number of patent citations for a specific technology increases can be indirectly interpreted as its potential strength for technological ability or market success. Further, this technology can be continuously expanded and advanced by many researchers or firms that have cited patents on it. Consequently, the technologies, which have high patent citations are expected to be more successful for commercialization than those, which have low patent citations. Hence, before materials commercialization, the diffusion of technology can provide helpful information for the diffusion of the new materials. Finally, the application of patent citation incorporated with the Bass diffusion method that can provide the avenue for corporation policy makers and researchers to evaluate the technology diffusion of new materials.

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