Journal of Business Research 89 (2018) 57–66

Contents lists available at ScienceDirect

Journal of Business Research

journal homepage: www.elsevier.com/locate/jbusres

Peer interaction and learning: Cross-country diffusion of solar photovoltaic technology

Hongbo Duan[a], Gupeng Zhang[b,*], Shouyang Wang[c], Ying Fan[d]

[a] School of Economics and Management, University of Chinese Academy of Sciences, Beijing 100190, China
[b] School of Public Policy and Management, University of Chinese Academy of Sciences, Beijing 100049, China
[c] Academy of Mathematics and Systems Science, Chinese Academy of Sciences, Beijing 100190, China
[d] School of Economics and Management, Beihang University, Beijing 100083, China

ARTICLE INFO

Keywords:
Cross-national innovation diffusion
Photovoltaic solar
Learning effect
Peer interactive effect
Technological marketing

ABSTRACT

We develop a two-dimensional dynamic framework in this work to theoretically and empirically capture cross-national diffusion interactions of technology innovation, including different types of learning relationships, such as so-called lead-lag, lag-lead, and simultaneous effect, and potential peer interactive relationships, such as the common relationships of mutualism, pure competition, and predator-prey. We find that external and internal effects should not be the only factors determining the penetration of photovoltaic technology—that penetration can also be governed largely by the trade-offs between the learning effect and the peer interactive effect. In effect, different combinations of learning effects and peer effects yield different results for technology penetration and market potential. Our conclusions provide effective evidence and insights for multinational technology managers to make decisions related to selecting market entry and timing and to formulating market promotion strategies.

1. Introduction

External and internal effects (such as advertising and word-of-mouth) are found to be the dominant factors affecting the product innovation process (Bass, Krishnan, & Jain, 1994). Globalization in the economy, trade, and cultural communication has gradually extended the close-form boundary of society assumed in the original Bass model, broadening and increasing the effect of internal and external factors of innovation diffusion (Ganesh & Kumar, 1996; Massiani & Gohs, 2015). The popularization of international networks and satellite television, frequent launches of cross-continent entertainment programs and worldwide sports events, and popular cross-border tourism, visits, and international academic exchanges all enhance the effect of advertising and word-of-mouth and blur the social boundary of innovation. In fact, in addition to strengthening the external and internal effect in the process of innovation penetration, extending the social boundary will make cross-national diffusion relationships more flexible and complex (Huarng, Yu, & Lai, 2015; Kumar, Ganesh, & Echambadi, 1998; Putsis, Balasubramaniam, Kaplan, & Sen, 1997).

The learning effect, involving lead-lag, lag-lead, and simultaneous effects, is the most typical cross-country relationship found and empirically verified in related work (Kumar & Krishnan, 2002). Generally, the lag country (the country in which the given innovation is later introduced) will derive great benefits from the innovation adoption process of the lead country (the country in which the given innovation was introduced a few years earlier), triggering a significant difference in diffusion rates of innovation between this pair of countries (Benvignati, 1982; Munshi, 2004). Putsis et al. (1997) and Kumar et al. (1998) call this phenomenon the lead-lag effect. From the adoption experience of the lead country, the lag country obtains the opportunity and sufficient time to learn more product and technology information that helps the lag country improve cognition and acceptance of the product or technology, which in turn reduces the risk associated with innovation adoption and accelerates market penetration (Kalish, Mahajan, & Muller, 1995). Ganesh and Kumar (1996) referred to this lead-lag effect as one typical learning effect. Further investigation revealed that for some ranges, the degree of the learning effect would improve as the lag time increases before gradually diminishing after the lag time crosses a certain threshold. The action mechanism of the lag-lead effect is very similar to that of the lead-lag effect, as discussed in Takada and Jain (1991) and Helsen, Jedidi, and Desarbo (1993).

It is almost impossible for an innovation to penetrate an area independently, because we find that the learning effect appears to affect cross-country diffusion; we therefore expect some interactive

---

[*] Corresponding author.
E-mail address: zhanggupeng@ucas.ac.cn (G. Zhang).

https://doi.org/10.1016/j.jbusres.2018.04.004
Received 30 August 2017; Received in revised form 3 April 2018; Accepted 5 April 2018

relationships (or peer effects) between a pair of countries, similar to types of relationships in the process of species evolution in ecosystems (Chung, 2011; Mahajan, Muller, & Bass, 1990; Sacerdote, 2001). Technological growth actually shares a similar diffusion pattern to that of ecological populations, as perceived by P. Allen in 1976 (Allen, 1976). Other studies aim to explain industrial evolutionary paths by employing the theory of population ecology, with further investigations finding that the competitive environment of industrial innovation plays a formidable role in the diffusion of innovation (Batten, 1982; Robertson & Gatignon, 1986). Thus, the typical ecological population model, i.e., the Lotka-Volterra model, has been broadly employed to examine technological substitution and evolutionary relationships; and the classical innovation substitution model, i.e., the Fisher-Prey model, could be viewed as a derivative of the Lotka-Volterra model (e.g., Bhargava, 1989; Chiang & Wong, 2011; Duan, Zhu, & Fan, 2014; Yan & Ma, 2011). Thus, the interactions between technologies, including pure competition, symbiosis, mutualism and predator-prey, have been further confirmed in the area of innovation diffusion (Farrell, 1993; Pistorius & Utterback, 1997). This confirmation suggests the importance and possibility of exploring the evolutionary laws of technology diffusion, particularly capturing cross-national relationships between a pair of countries.

It is thus easy to infer that the cross-country technology diffusion mechanism becomes more flexible and complex in light of potential interactive relationships. A better investigation and understanding of technology diffusion relationships benefits multinational technology managers who make decisions about market entry and develop marketing strategies. To the best of our knowledge, no attempt to explore cross-national diffusion relationships in industrial technology innovation has been successful, despite several studies on product diffusion relationships. Whether potential mutualism, predator-prey, or pure competition exist in the process of cross-country technology diffusion remains an open question (Albuquerque, Bronnenberg, & Corbett, 2007; Helsen et al., 1993; Kalish et al., 1995; Massiani & Gohs, 2015; Peres, Muller, & Mahajan, 2010). Ganesh and Kumar (1996), Putsis et al. (1997), and Kumar and Krishnan (2002) examined the cross-country diffusion relationships of durable consumer goods. By developing a learning model, Ganesh and Kumar (1996) empirically discussed the potential diffusion relationship between the lead and lag countries (i.e., the lead-lag effect), and Putsis et al. (1997) verified this relationship when also exploring the simultaneous effect and providing an empirical demonstration by using a mixed learning model. Kumar and Krishnan (2002) developed an extended generalized Bass model (GBM) to accommodate all types of possible learning relationships, namely, lead-lag, lag-lead, and simultaneous, and concluded that omitting any type of learning relationship would do a disservice to multinational managers eager to explicitly master cross-country diffusion relationships and create effective market strategies.

Compared with product innovation, technology diffusion differs in several respects. First, the diffusion mechanism of industrial technology innovations is generally more complicated due to its high adoption risk and switching costs. Second, technology adopters are likely to be enterprises or households, but rarely individuals; therefore, adoption decisions should not only depend upon individual willingness but also greatly support the preparation effort of related supportive facilities and policies (Huarng et al., 2015). Finally, adoption size and diffusion speed for a new technology innovation closely relates to the homogeneity and degree of competition of the analogous enterprises in the market (Benvignati, 1982; Ganesh & Kumar, 1996; Gatignon, Eliashaberg, & Robertson, 1989; Guidolin & Mortarino, 2010; Kumar & Krishnan, 2002). It is thus more difficult to explicitly study the multinational diffusion relationships of technology innovation compared with durable consumer goods, both in theoretical models and in terms of the larger amount of data required for an effective verification and empirical analysis. As indicated in Kumar and Krishnan (2002), the current method of modeling product innovation might not be a suitable means to investigate technology diffusion problems, and the corresponding conclusions cannot be generalized to industrial innovation as well.

In this context, we propose a new model framework of technology diffusion dedicated to a systematic examination of cross-country technology diffusion relationships for targeted country pairs, including well-verified learning relationships (e.g., lead-lag, lag-lead, and simultaneous) and potential interactive dissemination relationships (e.g., predator-prey, pure competition, and mutualism). We employ differential dynamic system theory to prove the existence of complex peer interactive relationships between cross-national diffusion of different country pairs and provide the required sufficient conditions. We then further analyze the effect of integrated interactive diffusion effects on a technology's market potential. In fact, the lack of theoretical support is a common limitation of prior research into cross-country innovation diffusion, which makes it difficult to generalize results and findings (Albuquerque et al., 2007; Putsis et al., 1997; Talukdar, Sudhir, & Ainslie, 2002). The theoretical analysis in our paper helps fill this gap. We extend that analysis by using an example energy technology (solar thermal collectors) to empirically verify the results of the theoretical analysis and make penetration forecasts of equilibrium market status. Generally, the innovation diffusion model is developed either for descriptive or for normative use. The former involves theoretical analysis and proposition verification, and the latter refers to effective parameter estimation and empirical analysis (Mahajan et al., 1990). The literature lacks research into modeling innovation diffusion that accommodates both descriptive and normative use. It is not feasible for some typical GBMs, such as the Robinson-Lakhani model and the Dockner and Jorgensen model, to obtain effective parameter estimations (Dockner & Jorgensen, 1988; Peres et al., 2010; Robinson & Lakhani, 1975). Fortunately, our proposed model allows for a theoretical analysis in conjunction with corresponding empirical verification, successfully accommodating both descriptive and normative use of the innovation diffusion framework.

The remainder of this work is structured as follows. In Section 2, we briefly introduce the proposed model based on the classical Generalized Bass Model (GBM). Theoretical analysis is shown in Section 3, in which we discuss the relationships between innovation diffusion trade-offs and market penetration potential given various conditions. In Section 4, we give empirical analysis results by using cross-country Photovoltaic (PV) solar collector data. Conclusions are drawn in Section 5, and some related policy implications are shown.

2. Proposed model

Like popular innovation diffusion models such as the mixing and learning models, our proposed model is also inspired by the original GBM (Guo, 2014; Kumar & Krishnan, 2002; Putsis et al., 1997). Actually, the GBM is a general and typical model for us to consider the effects of marketing effects and policy intervention in the process of innovation diffusion (see Supplementary information for details on GBM, Bass et al., 1994). So-called learning and other interactive effects are also included in the market variable $x(t)$ of Eq. (S1) (Kumar & Krishnan, 2002); we therefore develop our model based on the typical GBM. For convenience of theoretical exploration, we focus on the diffusion relationships between a pair of countries in this version of the model. Assume $f_i(t)$ and $F_i(t)$ as the adoption rate and cumulative adoption rate of the given innovation in country i, respectively, and $x(t)$ the market effort item. Then, the proposed model is as follows:

$$\begin{cases} \frac{dF_1}{dt} = (1 - F_1)(p_1 + q_1F_1)x_1 \\ \frac{dF_2}{dt} = (1 - F_2)(p_2 + q_2F_2)x_2 \end{cases} \tag{1}$$

$$\begin{cases} x_1(t) = a_{21}F_2 + b_{21}F_2F_1 \\ x_2(t) = a_{12}F_1 + b_{12}F_1F_2 \end{cases} \tag{2}$$