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Convex drops in technological substitutions

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A B S T R A C T

In many empirical cases of technological substitution, the diffusion dynamics bifurcate and the sales of the incumbent technology suddenly shift from the smooth end-of-life pattern anticipated by classical diffusion models directly into the convex end-of-life phase. These sudden convex drops lead to significant differences in cumulative sales compared to forecasts used for selecting a firm's technological capabilities. This paper develops an integrative model whose structure includes key interactions between performance trajectories, price dynamics, market heterogeneity, and information. Simulation results explain the underlying dynamics of convex drops, provide a boundary condition for the phenomenon, and extend the notion of demand heterogeneity.

1. Introduction

Technology-based firms, those which rely on technological innovation as a mean to achieve competitive advantage, are often dependent on a few core technologies in their portfolio. The decision-making process to define their technological capabilities (Cetindamar et al., 2016) and their innovation strategy are partly based on the expected size of the market in which their innovations will be deployed (Smith, 1992; Adner and Levinthal, 2001). Incumbent companies are interested in the duration of the dominance of their technology to maintain their competitive position (Cooper and Schendel, 1976; Smith, 1990). Since the market value of a technological opportunity is affected by its diffusion pattern (Wang et al., 2015), the modeling and forecasting of the diffusion of an innovation (either a product or a technology) has received immense academic interest (Geroski, 2000; Meade and Islam, 2006). While many diffusion or substitution studies focus on the front-end of a technological innovation's lifecycle, the ultimate potential market, from which expected cumulative volumes and strategic investments are derived, is often the single most important forecast obtained for evaluating technological options (Schmittlein and Mahajan, 1982; Jolly, 2012).

The process by which a new technology displaces an incumbent technology has three well-known components: the supply side characteristics of the old and the new technologies, the demand characteristics, and in the context of diffusion, information. The many interactions between these components are classically found in the qualitative theories of innovation diffusion but only partially included in the structural elements of existing diffusion models. Mainly, diffusion studies seldom take into account technological evolution and mostly consider the focal innovations as static (Kim and Kim, 2004; Adner and Kapoor, 2016).

This is problematic because in numerous empirical cases, the dynamics of diffusion suddenly bifurcate from the classical pattern universally expected and anticipated by epidemic diffusion models. Most diffusion or substitution models based on an epidemic structure do not take into account the interactions between technological evolution and market dynamics. An epidemic structure expects a smooth transition from a concave shape after the peak of sales to a convex end of the lifecycle, even for those models which can replicate asymmetrical lifecycles by incorporating additional explanatory variables. However, in many empirical cases when successive generations of technology overlap in a given market, a sudden convex drop in sales occurs whereby the sales suddenly

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plummet and the lifecycle shifts into the convex end-of-life phase instantaneously or much earlier than anticipated by diffusion models. This paper presents several such cases which have received significant attention in the diffusion literature and demonstrates this previously unnoticed phenomenon. In some of these cases, these sudden drops occur even before the anticipated peak of sales. These convex drops in sales pose a real challenge to epidemic models whose structure can neither explain nor replicate them, even if high statistical fit had been achieved with available data. This problem is particularly acute in cases where the peak of sales of the current product or technology had already been achieved, because the predictive power of diffusion models is usually expected to be high after that point in the lifecycle. Moreover, given the large volumes under the right-hand side of a diffusion curve, the significant difference between the actual sales and the anticipated pattern of diffusion forces the recalibration of parameters after the convex drop in order to statistically fit the overall lifecycle data again. Yet, by that time it may already be too late for an incumbent firm to react.

This paper proposes a model whose structure integrates the key interactions between performance trajectories, price dynamics, and market heterogeneity to account for the distribution of threshold requirements and for the behavioral assumptions of different adopter categories. The simulation results offer a causal explanation for why and when these sudden convex drops occur and suggest a boundary condition as a necessary condition for the phenomenon of convex drops to occur. The causal explanation and the model's ability to replicate such transient behavior are then tested further against empirical data.

By noticing this empirical phenomenon and explaining its underlying dynamics, this paper extends the theory of innovation diffusion and technological substitution. Convex drops during technological substitutions have significant implications for the innovation strategies of firms on both sides of a technological disruption. While most academic work is focused on the early phase of an innovation lifecycle (e.g. time of performance crossover, time of sales take off, time of market dominance, speed of adoption, etc.), this paper demonstrates that other points in the lifecycle should be more clearly distinguished. A finer time-bracketing of the process of technological substitution can yield important indicators of what is going on, and even improve the ability to forecast critical bifurcation points and, thus, the timeframe in which an incumbent firm must respond to the challenge of disruption. Moreover, the simulation results also indicate that we should pay more attention to demand heterogeneity not only in terms of the categories of adopters within a given technology's lifecycle but also in terms of heterogeneity between new users and upgrading users from previous generations.

2. Key interactions in diffusion and substitution models

We dispose of two kinds of theory of technology diffusion. On one hand, there are the qualitative explanations for the supply-side technological trajectories and for the demand-side process and timing of adoption by different categories of adopters in various segments (Rosenberg, 1976; Sahal, 1981; Dosi, 1982; Malerba et al., 1999; Adner and Levinthal, 2001; Adner, 2002; Moore, 2002; Christensen, 2003; Rogers, 2003; Utterback and Acee, 2005; Adner and Kapoor, 2016). On the other hand, there are the analytical models which replicate the S-shaped pattern of cumulative adoption through either aggregate-epidemic or individual-behavioral structures (Norton and Bass, 1987; Chatterjee and Eliashberg, 1990; Geroski, 2000) with an emphasis on market heterogeneity (Adner and Levinthal, 2001; Adner, 2002). Given the complexity of the diffusion process, many scholars have focused on the effects of an explanatory variable or of particular dynamics on the statistical fit to the overall lifecycle data, but not on these sudden convex drops.

Existing models make different assumptions about the number of stages in the adoption process, of categories of adopters, of market segments, or about opinion leadership, growth of the potential market, performance trajectories, evolution of price, timing of introduction of the successive generations, and the types of sales (adoption, renewal, and upgrading).

2.1. Market heterogeneity

Individual level models consider behavioral thresholds in terms of expected utility for certain attributes, of price sensitivity, or of critical amount of information required to overcome the perceived risk of adoption (Roberts and Urban, 1988; Chatterjee et al., 1990; Malerba et al., 1999; Adner and Levinthal, 2001; Adner, 2002). These thresholds are considered to be heterogeneously distributed across the agents in the social system. Yet, models often assume a uniform distribution for analytical closure. A few models account for two other types of heterogeneity. Following the qualitative theory of innovation diffusion, some models distinguish adopters either as innovators or as followers, and focus mainly on how the distribution of innovativeness and opinion leadership (Shi and Fernandes, 2014) or a non-uniform social structure affects word-of-mouth communication and may lead to diffusion patterns with saddles and troughs (Milling, 1996; Adner, 2002; Iyengar et al., 2011). Other models consider divergent preferences to explain how disruptive technologies can start diffusing in niche segments before encroaching on the main market (Goldenberg et al., 2002; Muller and Yogev, 2006; Van den Bulte and Joshi, 2007).

2.2. Technological evolution and market potential

Studies of technology diffusion and substitution have tended to consider the technological innovation as static (Kim and Kim, 2004; Adner and Kapoor, 2016). Nonetheless, some models consider a dynamic potential market – a hallmark of technological discontinuity (Utterback and Acee, 2005) – in order to account for the interaction between the evolution of a technology's performance and the induced growth in its addressable market (Dodson and Muller, 1978; Mahajan and Peterson, 1978; Adner and Levinthal, 2001). This is usually done by a monotonic function to increase the potential market (Kim et al., 2005). For example,