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Decision Support

Optimal technology adoption when the arrival rate of new technologies changes ☆

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ABSTRACT

Our paper contributes to the literature of technology adoption. In most of these models it is assumed that the intensity rate of new arrivals is constant. We extend this approach by assuming that after the last technology jump the intensity of a new arrival can change. Right after the arrival of a new technology the intensity equals a specific value that switches if no new technology arrival has taken place within a certain period after the last technology arrival. We look at different scenarios, dependent on whether the firm is threatened by a drop in the arrival rate after a certain time period or expects the rate to rise.

We analyze the effect of a mean preserving spread of the time between two consecutive arrivals on the optimal investment timing and show that larger variance can accelerate investment in case the arrival rate rises while it can decelerate investment in case the arrival rate drops. We find that firms often adopt a new technology a time lag after its introduction, which is a phenomenon frequently observed in practice. Regarding a firm's technology releasing strategy we explain why additional uncertainty can stimulate customers' buying behavior. The optimal adoption timing changes significantly, depending on whether the arrival rate is assumed to change or be constant over time.

Adding uncertainty about the length of the time period after which the arrival intensity changes, we find that increasing uncertainty accelerates investment, a result that is opposite to the standard real options theory.

1. Introduction

The trend in innovation arrivals regarding capabilities of digital electronic devices is strongly linked to the famous statement of Gordon E. Moore about computing hardware. He described that 'the number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every two years'. Observed over several periods of decades we see that several measures of digital technology are improving at exponential rates related to Moore's law, including the size, cost, density and speed of components. Processing speed, memory capacity and sensors, all of these are improving at (roughly) exponential rates as well. His law is now used in the semiconductor industry to guide long-term planning and to set targets for research and development. However on the other hand, managers have to consider that this technological innovation progress has natural boundaries. At some point the physical possibilities of improvement are exhausted. This means that the rate of improvements approaches zero at some point. Ignoring this fact, and instead assuming that technological improvements evolve at exponential rates forever, would lead to crucial mistakes in a firm's technology adoption decisions. However, the literature of technology adoption widely assumes that arrival rates for technological innovations are constant. This assumption has been made among others in Farzin, Huisman, and Kort (1998) and Huisman (2001). In this paper we want to relax this assumption and assume that the arrival rate of technological innovation changes.

Another example of technology adoption decisions where arrival rates should not be considered as constant, is typical for the consumer electronics industry. Big companies like Apple, release new improved

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versions of their most popular electronic devices on a regular basis. Apple released, for example, a first version of the iPod Mini in February 2004 and announced a second generation of the iPod Mini in February of the following year. In September 2005 Apple officially discontinued the iPod Mini line and replaced it by the iPod Nano. The first generation of iPod Nano was replaced by the second generation in September 2006. From then on Apple has updated the iPod Nano on a regular basis every year,[1] while rarely giving information about new products before their official announcement and release. Therewith the company creates additional uncertainty about the release schedules of their new products. From the point of view of a single consumer this means that right after the release of a new iPod Nano generation, one does not expect a new release soon. However, after one year without any release, one would expect Apple to announce a new series of the product line. In this paper we raise the question of how such a product release policy would influence the consumer's consumption behavior.

In this paper, we investigate a firm that decides about technology adoption with an investment to change from old to new technology facing uncertain timing of future technology improvements. The technological process advances exogenously to the firm. A large fixed cost occurs upon the adoption, which becomes a sunk cost because technology choice is irreversible. We assume that the arrival rate is changing over time, unlike the assumption of constant arrival prevalent in the technology adoption literature. Specifically, we assume a specific arrival rate to be present right after the last technology arrival. This arrival rate changes (increase/decrease) to another value if no arrival should take place for a certain time period (of Δ time units) since the last technology arrival. We do not impose a specific ordering of these two values of the arrival rate, which allows to look at two different scenarios that constitute for different technology adoption environments faced by firms or customers.

We add to a strand of papers that started with early work of Baldwin (1982), Balcer and Lippman (1984) as well as McCardle (1985). For an extensive survey about decision theoretic models of technology adoption see Huisman (2001) and Hoppe (2002).

Our approach to extend the technology adoption literature is closest related to Huisman (2001, Chapter 2). Huisman (2001) introduces an approach to technology adoption timing decisions in a real options context and extends the traditional decision theoretic models on technology adoption with a model in which the technologies arrive according to a Poisson process. We briefly explain Huisman's basic model, which forms the starting point for our work, in Section 2.1. Huisman (2001) studies the optimal time to irreversibly switch to a new technology when the value and the arrival date of future improvements are uncertain. Technology advances according to a compound Poisson process with constant arrival rate. As in Huisman (2001) we model the technological process with a Poisson process but assume that the arrival rate changes.

Three recent papers dealing with technology adoption are Smith and Ulu (2012), Kwon (2010) and Cho and McCardle (2009). Smith and Ulu (2012) study a general model of technology adoption in which time is finite and discrete and a firm faces uncertainty on both costs and quality. They solve their model for three investment decision models: NPV, single adoption, multiple adoption. Due to their general model setup their focus is on deriving structural properties of the value function and the optimal policies. The focus of this paper is to study the effect on the adoption strategy when the arrival rate of new technologies changes over time. Kwon (2010) focuses upon investment and exit decisions of a firm facing a declining profit stream. The firm can continue operation, exit or use the one time option to undertake an investment that boosts the project's profit rate. This leads to the result that in case of a sufficiently large profit boost upon investment, this investment threshold decreases with volatility. Cho and McCardle (2009) investigate the role of economic and stochastic technological dependence on the adoption of multiple type of new technologies. They show that the dependence among different types of technologies has a material impact on a firm's adoption decisions. This impact is not unidirectional, it can either delay or expedite the adoption of an improved technology.

In this paper we study the technology adoption decision of a single[2] firm in the absence of strategic considerations. We describe the firm's adoption decision as the solution of an infinite horizon dynamic programming problem in a continuous time setting.[3] The firm decides about the optimal moment to adopt a new technology, while it currently uses a less efficient technology. The improvement in the value of the available technology follows a compound Poisson process and evolves exogenously to the firm. Technologies become more valuable over time. At each moment in time the firm learns whether an innovation occurs or not.

We focus our analysis on the optimal adoption strategies of a firm facing changing arrival rate, also in comparison to the results of a constant arrival rate model. We introduce possible applications and analyze numerical examples suited to those in order to gain more insight about the optimal timing strategy for technology adoption in specific scenarios. Our numerical results suggest that a firm expecting a decrease in the arrival rate after a certain period without any arrival, should apply a different adoption timing strategy than a firm assuming constant arrival rate forever. In case a firm is confronted with a lower arrival rate right after the last technology arrival, it should invest later than a firm that considers constant arrival intensity forever.

We find that in some cases the firm optimally adopts a new technology a time lag after the innovation took place. In fact our analysis shows that the probability of a time lag between innovation and adoption can be substantially high. Introducing a model with changing arrival rate allows to account for the fact that firms often adopt new technology a time lag after its arrival. This has been criticized by Cho and McCardle (2009) in the following way: "due to the assumption of the memoryless and stationary probability distribution, their model (Huisman's (2001) model) does not explain a time lag between the occurrence of an innovation and its adoption". Doraszelski (2004) gives the same kind of criticism and concludes that the firm may have an incentive to delay adoption of a new technology until it is sufficiently advanced. While McCardle (1985) argues that such a time lag can be explained by a firm's uncertainty regarding the profit potential of a new technology, we show (as in Balcer & Lippman, 1984) in this paper that such a phenomenon can be also explained by prevalent uncertainty about the arrival of new technology.

Furthermore, we analyze the effect of the variance of time between two consecutive technology innovations on the firm's adoption decision while keeping the expected time between two technology arrivals fixed. The introduction of a changing arrival rate to the basic problem introduced by Huisman (2001) adds to the significance of our results by one additional degree of freedom. Which effect increasing variance has on the technology adoption decision depends on the scenario considered as well as the specific changes in parameters. In case the arrival rate would increase if no new arrival takes place within a certain time period Δ after the last technology arrival, we find that increasing variance by increasing the arrival rate

[1] See http://en.wikipedia.org/wiki/Ipod for a graphical illustration of the time line of iPod models and the releases of improved versions from 2001 on.

[2] The main focus is the effect of changing arrival rate on the investment behavior. A natural extension would be to extend to a competitive setting. There is a large strand of literature in which the strategic effects of technology adoption are studied (see Hoppe, 2002; Huisman, 2001).

[3] Alvarez and Stenbacka (2001) develop a different mathematical approach based on the Green representation of Markovian functionals for finding the optimal exercise thresholds both of the ordinary real option associated with the updating decision and of the compound real option associated with the incumbent technology.