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Decision Support

Optimal regime switching under risk aversion and uncertainty

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ABSTRACT

Technology adoption is key for corporate strategy, often determining the success or failure of a company as a whole. However, risk aversion often raises the reluctance to make a timely technology switch, particularly when this entails the abandonment of an existing market regime and entry in a new one. Consequently, which strategy is most suitable and the optimal timing of regime switch depends not only on market factors, such as the definition of the market regimes, as well as economic and technological uncertainty, but also on attitudes towards risk. Therefore, we develop a utility-based, regime-switching framework for evaluating different technology-adoption strategies under price and technological uncertainty. We assume that a decisionmaker may invest in each technology that becomes available (compulsive) or delay investment until a new technology arrives and then invest in either the older (laggard) or the newer technology (leapfrog). Our results indicate that, if market regimes are asymmetric, then greater risk aversion and price uncertainty in a new regime may accelerate regime switching. In addition, the feasibility of a laggard strategy decreases (increases) as price uncertainty in an existing (new) regime increases. Finally, although risk aversion typically favours a compulsive and a laggard strategy, a leapfrog strategy may be feasible under risk aversion provided that the output price and the rate of innovation are sufficiently high.

1. Introduction

Within an environment of rapid technological innovation and increasing economic uncertainty, reluctance towards technological change may have devastating consequences for the viability of private firms (Bos, Kolari, & Lamoen, 2013; Hoppe, 2002). For example, in 1976 Kodak held an impressive market share of 90 per cent in film photography in the US and owned an extensive portfolio of valuable patents, including digital photography. Yet in 2012 it filed for bankruptcy, displaced by the same technology it had initiated, as it failed to make a timely switch from film to digital photography (The Economist, 2012a). Similar examples include Xerox, which could not adapt to a world dominated by digital imaging, or NCR (National Cash Register), which was once a dominant player in computer hardware and software but failed to adjust itself to personal computers and ended up relegated to ATM machines (The Economist, 2012b). Common features of these examples are the underestimation of the magnitude of technological change, as well as the reluctance to abandon a well-established technology in order to enter a potentially more profitable market regime. Indeed, decisionmakers often exhibit risk aversion, which hobbles any effort for technological change, while market-regime asymmetries combined with economic and technological uncertainty complicate technology-switching decisions. Although the impact of technological uncertainty on the propensity to invest in technological innovations has been analysed extensively under risk neutrality (Chronopoulos & Siddiqui, 2015; Huisman & Kort, 2004), how attitudes towards risk influence investment and operational decisions under price and technological uncertainty has not been thoroughly studied yet.

Indeed, although empirical research has studied the implications of market incompleteness for the development and adoption of innovations in nascent markets (Ang, 2014), how market incompleteness influences attitudes towards risk, and, in turn, incentives for technology adoption remains an open question. Therefore, we develop a real options framework in order to explore how economic and technological uncertainty impact incentives for technological change, taking into account a decisionmaker's risk preferences as well as her discretion over the technology-adoption strategy. The latter is implemented by assuming that the decisionmaker may invest in either each technology that becomes

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available (compulsive) or delay investment until a new technology arrives and then either invest in the older (laggard) or the newer technology (leapfrog). Thus, the novelty of this work is that, by combining attitudes towards risk with various market uncertainties, it is possible to analyse how their interaction impacts not only the dominant technology-adoption strategy, but also, within each strategy, the optimal investment and operational decisions. In fact, this work takes into account a wide range of attitudes towards risk by considering both risk-averse and risk-seeking behaviour. Although the former is more plausible, evidence of the latter can be found in at least two situations that are particularly relevant to technology adoption. For example, it may be common to invest in projects with high upside potential, e.g., startups, rather than in conservative ones, with the expectation of making a high return in just a small subset of the selected projects (Nawrocki, 2002). Also, firms that are underperforming their peers might distantiate themselves from the competition by adopting a new technology, thus acknowledging that only a bold move may salvage an otherwise doomed company (Bowman, 1982; Bromlay, 1991).

Additionally, despite the extensive literature on sequential investment in improved versions of a single technology (Parente, 1994), the implications of technological uncertainty for investment in technological breakthroughs have not been analysed thoroughly yet (Doraszelski, 2004). Therefore, we assume that once an innovation takes place at a random point in time, it not only creates a new market regime but also reduces the profitability of the existing one. Within this context, a decisionmaker has the flexibility to abandon the existing regime and invest in the new one. Consequently, the contribution of our work is threefold. First, we develop a regime-switching, utility-based framework for sequential investment under uncertainty and operational flexibility in order to derive optimal investment and operational thresholds. Second, we show how attitudes towards risk interact with price and technological uncertainty to affect not only the optimal regime-switching strategy, but also, within each strategy, the optimal investment and operational decisions. Third, we provide managerial insights for investment and operational decisions based on analytical and numerical results.

We proceed by discussing some related work in Section 2 and introduce assumptions and notation in Section 3. The problem of investment in a new regime is addressed in Section 4.1, while, in Section 4.2, we tackle the problem of abandoning an old regime in order to invest in a new one, and, in Section 4.3, we analyse the problem of investment under regime switching. In Section 5, we analyse the choice between two alternative market regimes, and, in Section 6, we present a comparison of the different technology-adoption strategies. Section 7 provides numerical examples for each case and examines the effects of uncertainty and risk aversion on the optimal investment and operational thresholds. Section 8 concludes and offers directions for future research.

2. Literature review

The seminal work of McDonald and Siegel (1985); 1986) and Dixit and Pindyck (1994) has spawned a substantial literature in the area of investment under uncertainty. However, most of this literature is developed on the premise that decisionmakers are risk neutral and hold a perpetual option to invest, facing a single form of uncertainty. Consequently, analytical models that explore the implications of risk aversion as well as the combined impact of different types of uncertainties on investment and operational decisions remain somewhat underdeveloped. The two main methods for addressing the canonical real options problem are contingent claims and dynamic programming. The former assumes that either markets are complete or that the project's unique risk can be perfectly hedged. Consequently, it cannot be applied to projects with idiosyncratic risk that cannot be diversified, as is the case with most technology adoption problems, or, more generally, when markets do not have substantially developed financial instruments. In these cases, the dynamic programming approach can still be applied as it uses a subjective discount rate, and, therefore, it can be used to maximise the expected discounted utility of the lifetime profits of a risk-averse decisionmaker.

Examples of early work in the area of investment under technological uncertainty include (Balcer & Lippman, 1984), who model technological uncertainty via a discrete semi-Markov process and find that a higher rate of innovation tends to delay technology adoption. Grenadier and Weiss (1997) consider a firm that, in the light of technological uncertainty, may either adopt each technology that becomes available (compulsive) or postpone investment until an innovation takes place and then either adopt an older (laggard) or a newer technology (leapfrog). They find that, depending on technological uncertainty, a firm may adopt an available technology even if more valuable innovations may occur in the future, while future decisions on technology adoption are path dependent. Farzin, Huisman, and Kort (1998) develop an analytical framework for sequential investment in technological innovations that follow a Poisson process, using dynamic programming. They find that the investment rule derived via the real options theory coincides with the net present value (NPV) criterion for all but the last investment. By contrast, Doraszelski (2001) identifies an error in Farzin et al. (1998) and shows that, compared to the NPV criterion, a firm will defer the adoption of a technology when it takes the value of waiting into account.

In the same line of work, Bethuyne (2002) considers a firm that holds a number of technology investment options and identifies an ambiguous effect, whereby technological improvement induces replacement but the prospect of further improvements slows down the replacement process. In addition, a decrease in the number of remaining technology switches raises the value of each investment option. Huisman and Kort (2003) replace technological uncertainty in the framework of Grenadier and Weiss (1997) with game-theoretic considerations, while Huisman and Kort (2004) develop an analytical framework for duopolistic competition allowing for technological uncertainty. Their results indicate that, when technology upgrading is not optimal, a second-mover advantage arises when producing with the new technology in the future leads to a higher payoff than the current temporary monopoly profits. Doraszelski (2004) introduces a distinction between technological breakthroughs and engineering refinements. He shows how firms do not necessarily wait for a future technological breakthrough, but instead may delay the adoption of a new technology until it has been sufficiently refined. More recently, Koussis, Martzoukos, and Trigeorgis (2013) model market uncertainty via a jump-diffusion process that allows for multiple classes of jumps, and, in turn, for the flexibility to model different independent risks affecting a firm, e.g., entry of differentiated products and technological uncertainty. Although technological uncertainty is a crucial feature of emerging technologies, the scope of the aforementioned papers is limited as they assume risk neutrality, thereby ignoring the implications of risk aversion due to technical risk for investment and operational decisions.

Examples of analytical frameworks that incorporate risk aversion into the dynamics of investment decisions include (Henderson & Hobson, 2002), who extend the real options approach to pricing and hedging assets by taking the perspective of a risk-averse decisionmaker facing incomplete markets. They introduce a second risky asset on which no trading is allowed in the framework of Merton (1969) and address the problem of pricing and hedging this random payoff. Henderson (2007) addresses the problem of irreversible investment under uncertainty taking the perspective of a risk-averse decisionmaker. Although part of the uncertainty