Sequential Investment in Emerging Technologies under Risk Aversion and Policy Uncertainty

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Investment in emerging technologies is often made in the light of uncertainty in both the arrival of new versions and the revenue that may be earned from their deployment. Further complicating such investment decisions is that the future development of emerging technologies depends crucially on government support, yet the absence of a clear policy framework increases uncertainty in revenue streams. We show how a firm can optimally take advantage of the flexibility over the investment timing and the technology adoption strategy facing price, technological, and policy uncertainty. More specifically, we analyse the impact of these features on the optimal investment decision, and, in particular, we illustrate the relative value of each type of discretion for a risk-averse decision maker, thereby capturing real-world attributes shaping decision making such as costs of financial distress and shareholder constraints over borrowing. Although the incentive to delay investment increases as both price uncertainty and the level of risk aversion increase, whether the sudden provision of a subsidy or the potential to replace equipment with more efficient ones mitigates the impact of price uncertainty and risk aversion remains an open question.

Indeed, a gap in the real options framework is that it assumes that financial markets are complete, and, therefore, that the investor is risk neutral. However, for projects that involve undiversifiable risks, such as R&D of new products, risk aversion on part of investors should be considered. Nevertheless, much of the real options framework has been developed under the assumption of complete markets, which is the underlying assumption of contingent claims analysis. However, with the increasing amount of investment in emerging markets and new R&D-based sectors of the economy, such as renewable energy (RE) technologies, the assumption of hedging via spanning assets breaks down as the underlying commodities are not likely to be freely traded. Hence, risk-neutral valuation may not be possible and dynamic programming can then be used to maximize the expected utility of the lifetime profits of a risk-averse decision maker. Examples that indicate risk-averse behaviour include Black Berry that was once the industry standard for professional users. They relied on their reputation for security and a full QWERTY keyboard, but were slow to recognize the value of the apps (Harvard Business Review, 2013). Another example is Kodak, that was reluctant to adapt to the digital age, and unlike its competitor Fujifilm eventually went bankrupt (The Economist, 2012). The impact of risk aversion on investment decisions has been analysed by Henderson and Hobson (2002), who extend Merton (1969) by taking the perspective of a risk-averse decision maker facing incomplete markets. Henderson (2007) explores the effects of risk aversion on investment timing and option value by utilizing an exponential utility function, and finds that increasing risk aversion may accelerate investment. Hugonier and Morellec (2013) use the analytical framework of Karatzas and Shreeve (1999) in order to determine the analytical expression of the expected

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utility of a perpetual stream of cash flows that follow geometric Brownian motion (GBM) and express the investment policy as the solution to an optimal stopping problem. Chronopoulos et al. (2011) extend Hugonier and Morellec (2013) and show that increased operational flexibility mitigates the impact of risk aversion. Alvarez and Stenbacka (2003) show that price uncertainty does not necessarily decelerate investment. Note that these papers address the impact of risk aversion on investment and operational decisions allowing only for price uncertainty, and, as a result, the implications of technological and policy uncertainty remain underdeveloped.

Although risk aversion reduces the expected utility of a project, and, in turn, the investment incentive, the likelihood of subsidy provision may facilitate investment. For example, Tesla chose to build its battery factory in Nevada due to a special tax provision of $1,25 billion dollar over 20 years (CNBC, 2014). While Spain retroactively capped its RE subsidies, causing Spain’s second biggest wind operator to state that this will destroy their RE investments (Bloomberg, 2014). The subsidy induced early investment in Spain under the understanding that the subsidy would be long lasting. Examples of policy oriented papers include Boomsma et al. (2012), who explore how the investment decision is affected by different support schemes, namely feed-in tariffs and RE certificate trading. They find that, policy uncertainty can positively affect both investment timing and capacity sizing decisions. Adkins and Paxson (2013) model the random provision and retraction of a subsidy via a Poisson process and develop an analytical model for investment under price and quantity uncertainty. They investigate five cases: no subsidy, permanent subsidy without policy uncertainty, sudden subsidy retraction, sudden provision of a permanent subsidy, and finally a sudden provision of a retractable subsidy. They find that the presence of a subsidy lowers the investment threshold and that the sudden retraction of a subsidy facilitates investment. This reflects the fact that it is beneficial for the firm to take advantage of the subsidy while it is still active. In the fourth case, sudden provision of a permanent subsidy increases the investment threshold considerably. In the last model, if the current price is out-of-the-money the value is similar to the third case. Additionally, the value of the option to invest increases as the correlation between the price of electricity and quantity of electricity produced increases, since this raises the aggregate volatility. Although these papers address the impact of policy uncertainty on investment in RE power plants, they ignore the implications of risk aversion or how technological innovations provide the opportunity for sequential investment, thereby creating considerations for technology adoption strategies.

Examples of analytical frameworks for sequential investment under risk neutrality include Majd and Pindyck (1987), who demonstrate how traditional valuation techniques understate the value of a project by ignoring the flexibility in the time to build. Dixit and Pindyck (1994) utilize a GBM and develop a model for sequential investment assuming that the project value depreciates exponentially and the investor has an infinite set of options. In the same line of work, Gollier et al. (2005) demonstrate how the value of modularity may induce investment even below the now-or-never NPV threshold, while Kort et al. (2010) show that higher price uncertainty can make a lumpy investment more attractive compared to a more flexible yet more costly stepwise investment strategy. Allowing for technological uncertainty, Balcer and Lippman (1984) find that expectations regarding the arrival of innovations affect the investment decisions and that technological uncertainty may delay investment. Grenadier and Weiss (1997) develop a model for sequential investment, whereby a firm may either adopt every technology that becomes available (compulsive), skip an old technology in order to adopt the next one (leapfrog), purchase only an early innovation (buy and hold), or wait for a new technology to arrive before adopting the previous one (laggard). Farzin et al. (1998) model technological uncertainty via a Poisson process yet ignore price 
uncertainty, while Doraszelski (2001) identifies a mistake in Farzin et al. (1998) and shows that a firm will defer investment when it takes the value of waiting into account. Chronopoulos and Siddiqui (2014) develop an analytical framework for sequential investment in emerging technologies and analyse how the endogenous relation between price and technological uncertainty impacts the optimal technology adoption strategy and the associated investment rule. While these papers present a comprehensive modelling of investment in technological innovations, they assume a risk-neutral decision maker, and, as a result, the impact of risk aversion is not taken into account.

In this paper, we take the perspective of a risk-averse decision maker and develop real options framework for sequential investment under price, policy, and technological uncertainty. Thus, we extend the existing literature on investment under uncertainty, that either allows for risk aversion without considering policy or technological uncertainty or takes into account the impact of these features under risk neutrality. Following the approach of Hugonier and Morellec (2013), we can derive the expected utility of cash flows that follow GBM via Theorem 9.18 of Karatzas and Shreeve (1999) and then formulate sequential investment opportunities as a nested optimal stopping time problem. In addition, we assume that policy and technological uncertainty are modelled via independent Poisson processes. The former reflects the sudden provision or retraction of a subsidy, whereas the latter reflects the random arrival of innovations. By incorporating such features in an analytical framework for sequential investment, we can prove insights not only on how price, policy, and technological uncertainty interact to affect the optimal technology adoption strategy of a risk-averse decision maker, but also on how this may provide a feedback that will enable policy makers to devise more efficient policy mechanisms.

In an era of great financial volatility, firms in sectors such as energy, manufacturing, and telecommunications require managerial strategies that are responsive to market conditions. Indeed, the implications of the structural transformation of the power sector for both market participants and policy makers are expected to be crucial as they will change substantially the wholesale market dynamics (Sensfuß et al., 2008). Within this environment, private firms are required to make accurate investment decisions, while policymakers must take into account how private firms respond to price, technological, and policy uncertainty in order to incentivise investment. Hence, the contribution of this work is in delineating the value of flexibility when a firm faces both external, e.g., market, technological, and policy uncertainty, as well as internal, e.g., risk constraints, pressures.

References:


