Strategic Technology Adoption under Risk Aversion and Uncertainty

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As a product of research and development (R&D), technological innovations are subject to frequent upgrades. Consequently, a firm typically does not hold a single but rather a sequence of investment opportunities, and, as a result, it must determine both the optimal technology-adoption strategy, and, within each strategy, the optimal investment policy. Although investment is typically deferred as both price uncertainty and the level of risk aversion increase, the presence of a rival hastens investment. Here, we examine these opposing effects in a duopoly setting under price and technological uncertainty. Although various models have been developed in order to analyse sequential investment in technological innovations, most of these assume a single, risk-neutral decisionmaker (Grenadier and Weiss, 1997; Farzin *et al*., 1998; Doraszelski, 2001; Chronopoulos and Siddiqui, 2015), while models that allow for strategic interactions typically do not consider technological uncertainty or the sequential nature of investment decisions (Takashima *et al*., 2008; Paxson and Pinto, 2005). As a result, how strategic interactions impact sequential investment decisions with risk-aversion under price and technological uncertainty remains an open question.

Incorporating such features in an analytical framework for sequential investment in renewable energy (RE) technologies is crucial, since the rapid pace of innovation in combination with uncertainty in revenue streams in deregulated industries pose a formidable challenge for firms devising strategies for technology replacement. For example, Vestas had an eminent role in the early days of the wind turbine market. However, strong competition from General Electric and Siemens combined with subsidies being slashed, eroded Vesta's profitability and market share. Nevertheless, after a radical restructuring process and a subsequent strategic alliance with Mitsubishi Heavy Industries in order to develop offshore wind turbines, the company became once again the industry leader (Financial Times, 2012, 2014). Consequently competition and technological uncertainty play a crucial role in determining company's investment strategy. This is a typical situation in many industries, where firms producing patented products enjoy high revenues so long as their patents are protected. Once their patent protection expires, a rival firm may launch a homogenous product, thereby lowering prices (Wall Street Journal, 2013).

Although real options theory finds particular application in such sectors as it facilitates the analysis of capital budgeting under uncertainty, models that combine attitudes towards risk with various interacting uncertainties remain somewhat underdeveloped. We consider the case of proprietary and non-proprietary duopoly, where two firms invest sequentially in technological innovations facing price and technological uncertainty. The former occurs when a firm controls the innovation process, and, therefore, does not run the risk of pre-emption, while the latter occurs when both firms fight for the leader's position, e.g., when the innovation process is exogenous. Technological uncertainty reflects the random arrival of innovations and is modelled via a Poisson process while price uncertainty is modelled via a geometric Brownian motion. Additionally, we assume that each firm 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). Consequently, the contribution of our work is threefold. First, we develop a theoretical framework for investment under

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uncertainty and risk aversion for pre-emptive and non-pre-emptive duopolies in order to derive closed-form expressions (where possible) for the optimal investment thresholds. Second, we quantify the degree to which the rate of innovation and competition impact the strategic investment decisions of a risk-averse firm. Finally, we provide managerial insights for investment decisions and relative firm values under each setting based on analytical and numerical results.

Results indicate that the relative loss in the value of the leader due to the presence of a rival decreases as the first-mover advantage and the rate of innovation increase, yet increases with greater price uncertainty. Interestingly, while technological uncertainty has a non-monotonic impact on the optimal investment threshold of the follower, it does not impact the leader's decision to invest under risk neutrality. Figure 1 illustrates the value function of the proprietary leader (thin lines) and follower (thick lines). Note that the optimal investment threshold of the proprietary leader is the same investment threshold as that of a monopolist, i.e., 6.56. Once the leader enters the market, the follower may exercise the option to invest in the first technology when the price reaches 13. However, in a setting without proprietary technology, each firm would try to pre-empt the other when the price reaches 4.50 in order to become the leader. Furthermore, results indicate that increasing price risk leads to later investments by both companies (right panel), since this raises the opportunity cost of investment and in turn the value of waiting.

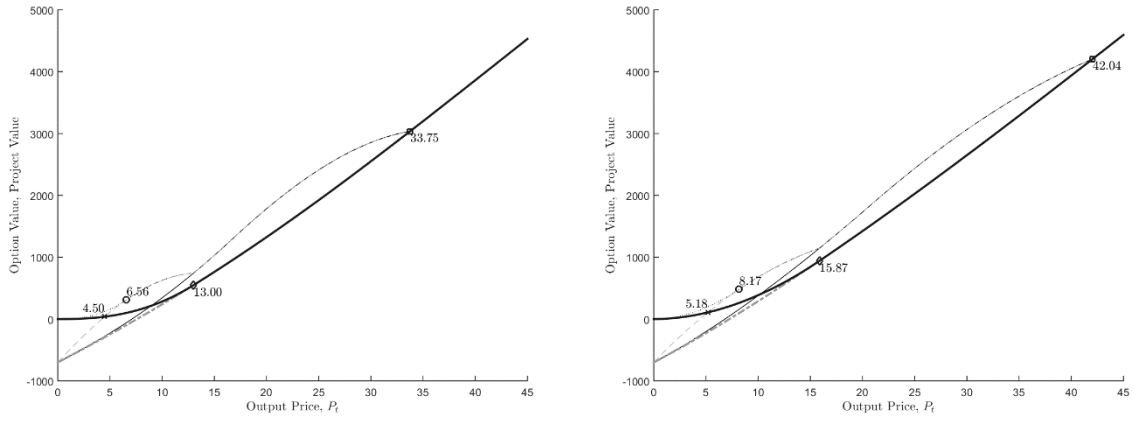

Figure 1: Value functions for the leader (thin lines) and follower (thick lines) and associated investment thresholds. Volatility is 20% in the left panel and 30% in the right panel.

References

1. Chronopoulos, M, and A Siddiqui (2015), "When is it better to Wait for a New Version? Optimal Replacement of an Emerging Technology under Uncertainty," *Annals of Operations Research*, 235(1): 177-201.
2. Doraszelski, U (2001), "The Net Present Value Method versus the Option Value of Waiting: A Note on Farzin, Huisman and Kort (1998)," *Journal of Economic Dynamics & Control*, 25: 1109-1115.
3. Farzin, Y, KJM Huisman, and PM Kort (1998), "Optimal Timing of Technology Adoption," *Journal of Economic Dynamics & Control*, 22: 779-799.
4. Financial Times (2012), "Vestas Talks with Mitsubishi Heavy," 28 August.
5. Financial Times (2014), "Vestas Regains Top Spot in Wind Turbine Manufacturing," 24 March.
6. Grenadier, SR and AM Weiss (1997), "Investment in Technological Innovations: An Option Pricing Approach," *Journal of Financial Economics*, 44: 397–416.
7. Paxson, D, & Pinto, H (2005), "Rivalry under price and quantity uncertainty," *Review of Financial Economics*, 14: 209-224.
8. Takashima, R, Goto, M, Kimura, H, and Madarame, H (2008), "Entry into the electricity market: Uncertainty, competition, and mothballing options," *Energy Economics*, 30: 1809–1830.
9. The Wall Street Journal (2013), "Generic-Drug Firms Go Beyond Knockoffs," 15 June.