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Timing of investment under technological and revenue-related uncertainties

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Abstract

The effects of two forms of uncertainty on the timing of irreversible investment are considered. Technological uncertainty is modeled as a Poisson arrival process that reduces the cost of investment, while revenue uncertainty is modeled as a diffusion process. Technological uncertainty has no effect on the optimal investment policy when revenue uncertainty is absent. However, when combined with revenue uncertainty, increased technological uncertainty makes investment less attractive relative to waiting. The paper also makes a more general point in clarifying the difference in how diffusion type of uncertainty and unidirectional stochastic progress affect investment timing.
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1. Introduction

Technological progress has an important role in shaping firms' investment behavior. The main objective of this paper is to clarify the distinct roles of

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technological *progress* itself and, on the other hand, *uncertainty* in such progress on optimal technology adoption decisions. Interestingly, it turns out that to fully understand the effects of the latter, one has to take into account the interaction of technological progress with other uncertainties that are relevant for the investment decisions. Therefore, to explain the influence of technological uncertainty on investment, this paper is concerned with the combined effect of technological uncertainty and uncertainties in other revenue-related factors such as output prices. Our results indicate that neglecting revenue-related uncertainty would lead to an underestimation of the role of technological uncertainty.

To motivate the relevance of both forms of uncertainty, consider capital intensive energy production or saving investment based on emerging technologies. Naturally, the foremost uncertainty concerns the uncertain development of energy prices after the up-front investment cost has been sunk. However, technological progress itself contains another source of uncertainty that has attained less attention in this context. Even if subsequent technological improvements would not affect the values of production facilities that already exist, an investor deciding whether to carry out an investment project now or possibly later must take into consideration the fact that postponing the investment may allow the accomplishment of the project later with an improved technology.

There is a conceptual difference between uncertainty in technological progress and revenue. A typical property of technological progress is that it moves in one direction only: innovations improve the best-available technology, but do not worsen it. Therefore, when pointing to uncertainty in such a case, one refers to the speed at which the technology progresses, not to the direction in which it moves. This is in contrast with revenue uncertainty, where the income stream is typically subject to both up- and downward shocks.

Our analysis follows the real option approach developed in, e.g., McDonald and Siegel (1986), Pindyck (1988), and Dixit (1989), and summarized in Dixit and Pindyck (1994). When classifying the existing real options literature according to the above mentioned two forms of uncertainty, most papers fall on the category of revenue uncertainty. Examples of papers that focus on technological uncertainty are Grenadier and Weiss (1997), Farzin et al. (1998), and Doraszelski (2004). An earlier related study is Balcer and Lippman (1984). However, these papers consider only technological uncertainty. The contribution of the present paper is in specifying a crude distinction between these two uncertainties and in showing how they act together. Another paper that considers technological uncertainty in conjunction with revenue uncertainty is Alvarez and Stenbacka (2001), but in their model technological uncertainty is revealed only after the investment has been undertaken, so there is no learning by waiting. In contrast, the present paper considers exogenous technological progress, which the firm observes already before investing.

Technically, the problem of choosing the timing of irreversible investment is an optimal stopping problem. To emphasize this, the paper starts with a general optimal stopping model of investment. This allows us to characterize the difference between uncertainties in revenue stream and in technological progress. We show that in the latter case, which we characterize by state variables that are non-decreasing

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