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Decision Support

Technology choice under several uncertainty sources

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ABSTRACT

We analyze a model of irreversible investment with two sources of uncertainty. A risk-neutral decision maker has the choice between two mutually exclusive projects under input price and output price uncertainty. We propose a complete study of the shape of the rational investment region and we prove that it is never optimal to invest when the alternative investments generate the same payoff independently of its size. A key feature of this bidimensional degree of uncertainty is thus that the payoff generated by each project is not a sufficient statistic to make a rational investment. In this context, our analysis provides a new motive for waiting to invest: the benefits associated with the dominance of one project over the other. As an illustration, we apply our methodology to power generation under uncertainty.

1. Introduction

How does uncertainty affect technology choice by a firm or a public authority? Since the early works on the option value by Arrow and Fisher [2] and Henry [14], it has become common knowledge that under uncertainty, it is not optimal to invest as soon as the net present value generated by a project is positive. Indeed the option to wait in order to gather some information on the evolution of the uncertain state variable has to be taken into account. Therefore, the presence of uncertainty tends to delay investment. Recently, the question of the technology choice has been addressed and it has been proved that having the choice between several technologies to undertake an investment creates an other source of delay: indeed, the investor wants the two technologies to generate sufficiently different expected payoffs in order not to invest in the technology that turns out to be the less favorable. This is the theoretical result proved by Décamps et al. [6] who analyze the choice an investor faces in the presence of one uncertainty source on the output price. They find that as well when the expected profits of each project are too low as when they are equal (around the "indifference point"), waiting is optimal as Fig. 1 illustrates. If the initial price had been lower, the investor would have invested in the low return project, and had it been higher, he would have invested in the high return project. But in this intermediate region, more information is needed to know in which direction the price will evolve and to be sure of the decision that will be taken. Dias [7] and Dias et al. [8] find a similar result, but they focus on the case of the petroleum industry and use simulation methods to motivate their results. They analyze the case where three projects are available and show numerically that there exist two inaction regions around the two indifference points. However, in these different works, if at the beginning of the analysis the output price is low (lower than p_1^* in Fig. 1), investment will be triggered when the output price crosses the threshold defined by Arrow and Fisher [2] and Henry [14], p_1^* in Fig. 1, and the inaction region does not play any role.

In our article, we propose a deeper analysis of the problem as far as we consider two uncertainty sources. Two technologies, technology N and technology G, produce the same output whose price is random. Technology G is moreover subject to a second uncertainty source: input price uncertainty. This setting applies to a public utility who has the choice between two technologies to produce electricity sold at an uncertain price: either a nuclear power plant characterized by high sunk costs or a gas power plant that is more flexible but also subject to the uncertain cost of gas. This is also the kind of questions that any petroleum industry faces before it decides which field to exploit (as suggested by Dias [7] and Dias et al. [8]). Indeed, fields may present different features: gas may be necessary to extract petroleum or to carry it. In Alberta, for instance, petroleum extraction from bituminous sand is costly also from an environmental viewpoint. These additional costs should be taken into account.

In our setting, as in the one-dimensional case, we prove the existence of inaction regions when the two projects generate similar net expected present value. However, contrary to the existing literature, we prove that for some parameters' values there exists a path for

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the two state variables (input and output prices) such that no investment is optimal, whereas an investment could have been optimal in case the two technologies had been considered separately. One of the major features of bidimensional investment problems like ours is that the investment value is no longer a sufficient statistic to undertake optimally the project. Indeed, as we show, for some parameters' values, it may be optimal not to invest in any project even if their expected profit tends to infinity. Moreover, we also prove that it is never optimal to invest when the two projects generate the same expected payoff whatever size it has. This fact makes unexpected an explicit computation of the optimal time to invest and that is the main reason why the bidimensional investment models received little attention in the literature. Indeed, the introduction of input price uncertainty in addition to the usual output price uncertainty makes the problem quite more complex from a mathematical viewpoint. However, the presence of the two uncertainty sources reinforces the applicability of our model. We also show that contrary to the one-dimensional case, even if the state variables are low at the beginning, the optimal timing may be quite different than in the case without choice. This issue on technology choice under uncertainty had first been addressed by Dixit [10] but he did the implicit assumption that the date at which the technology is chosen does not coincide with the date at which investment is triggered. Décamps et al. [6] propose a different analysis by assuming that as long as no investment has been undertaken, the choice still exists: the two dates are thus the same. This is the approach we also chose.

This work comes within the scope of the literature on investment under uncertainty that has developed very quickly since the early works by Arrow and Fisher [2] or by Henry [14] who show that investment under uncertainty creates what is commonly called a time value. The existence of such an option value requires three features: (i) the investment problem has to be dynamic insofar as waiting allows to learn more on the state variables; (ii) there must be some uncertainty concerning the cash flow that will be generated in the future; (iii) the investment decision has to be irreversible. McDonald and Siegel [19] were the first to give an expression to the option value. Moreover, they showed that when the underlying value of the investment project evolves as a geometric Brownian motion, the optimal strategy is usually a trigger strategy, that is, invest as soon as the investment value is greater than a threshold that can sometimes be explicitly computed using standard smooth-fit techniques (see Dixit and Pindyck [11]). Many authors extended the original model in different directions. Dixit [9], Kandel and Pearson [16] and Aguerrevere [1] studied how such an approach could be used by a firm to choose both an optimal capacity and an optimal timing. Other authors rather concentrated on a strategic viewpoint by considering not a monopolist but many firms and they tried to characterize the competitive equilibrium. Leahy [17] showed that "the interaction of competition does not affect the timing of irreversible investment decisions at all".

Our results are also related to the literature concerning American options on multiple assets. Broadie and Detemple [5] and Villeneuve [24] studied the exercise regions of such American options (they mostly focused on convex payoff options) and both showed that exercise regions may exhibit interesting shapes. In particular, in the case of an option on the maximum between two assets, when the underlying assets are equal, it is not optimal to invest in one of them even if the payoff process tends to infinity, but it is optimal to wait in order to collect information about the evolution of the state variables. However, we do not consider an option on the maximum of two different assets, but on the maximum of two different linear combinations of assets and this approach is new. This allows to introduce correlation in the two alternative projects. Last Geltner et al. [12] considered an investor who has the choice to invest in a land but for two different uses: if the first use is chosen, the value of the land follows a geometric Brownian motion, but if the second use is chosen, the value is a different state variable that also follows a geometric Brownian motion. The construction cost is assumed to be fixed and to be the same in the two cases. The investor chooses the use that yields the highest payoff. Geltner et al. [12] studied the exercise region in this bidimensional setting and found that it can be decomposed into two symmetric disjoint regions (one for each use). When the value of each use generates the same profit, the investor prefers to wait rather than to invest in one of the two.

As already explained above, this paper focuses on a bidimensional setting. But in contrast to Geltner et al. [12], the output process is the same for both projects and the second source of uncertainty comes from the input price. In our setting, we prove the existence of an "inaction region". When both projects have the same value or very similar values, it is optimal to wait rather than to invest in one of the two. In

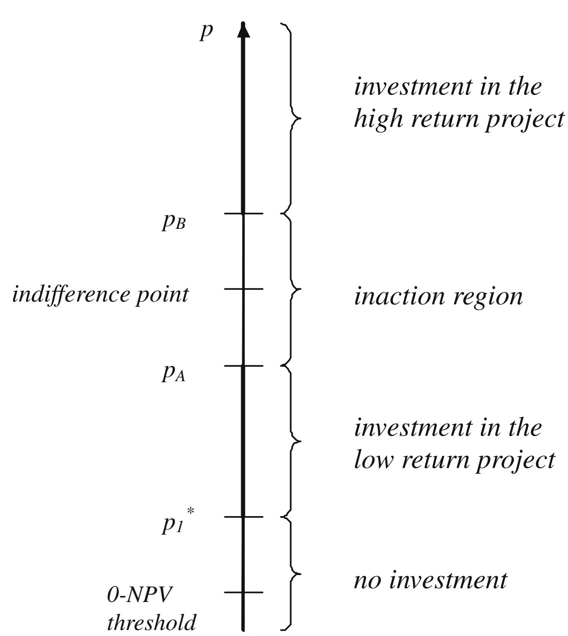

Fig. 1. Investment strategies in Décamps et al. [6].