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Strategic real options under asymmetric information

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ABSTRACT

This paper studies the effect of private information on the capital allocation decisions of firms who operate under imperfect competition. I analyze two interactive firms, one with private information and the other without, who must decide when to undertake an irreversible and uncertain investment decision. Traditional non-strategic models of irreversible investment under uncertainty involve a single decision maker and result in an optimal period of delay before the investment is undertaken. In a strategic setting, firms must balance their desire to delay against competitive advantages from early investment. I find that an equilibrium may not exist within the standard continuous framework when the private information is over revenues. Moreover, when an equilibrium does exist the competitive pressures from the uninformed firm are weak. This is in contrast to existing models with asymmetric information over costs, where an equilibrium always exists and the competitive pressures remain strong (Hsu and Lambrecht, 2007). This work shows that the investment timing decision, and thus the value of the private information, is highly sensitive to the nature of incomplete information.

1. Introduction

By adopting the tools used to value financial options, the real options literature has significantly improved our understanding of irreversible investment decisions under uncertainty. The primary message from this literature is that the option to invest has an intrinsic value that must be accounted for. As with financial options, the firm gives up this option upon investment. This represents an implicit cost in addition to any explicit costs. Investment rules which neglect this cost, such as the traditional net present value (NPV) rule, lead to significantly sub-optimal behavior. The gains from delaying the investment decision are often referred to as the *option value of waiting*. For even conservative parameters, these gains can be quite large. For example, if an investment opportunity has a risk-return profile that roughly matches the stock market, the value of the investment at the optimal exercise level may be over 3.6 times that of the positive net present value exercise level.[1]

What differentiates real options from financial options is that the investment decision is typically made by a firm operating within a goods market. Since financial options usually grant the holder exclusive rights, the framework has typically been applied to situations in which a single firm would have such rights, such as real estate development or natural resource extraction. This simplification made the applications cleaner, but clearly it is a special case. Many firms operate within competitive environment and their investment opportunities are not exclusive. A more applicable question is how the market structure might affect the firm's optimal investment decision. In particular, it is interesting to investigate how strategic interactions within a competitive environment affect the value of the option.

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[1] The parameters used in this example are a growth rate of 8%, a standard deviation of 20% and a discount rate of 12%. Table II in McDonald and Siegel (1986) provide some other numerical examples where the value of the project at the optimal exercise value is significantly above that of the NPV rule.

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The goal of this paper is to add to the literature on strategic real options under incomplete information by showing how the information structure significantly affects the model's predicted outcome. This paper considers a leader/follower game inspired by Dixit and Pindyck (1994) and introduces asymmetric information over the potential revenue stream. There are two firms competing to enter the same market. Exercising the option before its competitor allows that firm to earn higher monopolistic rents while it is the only firm in the market. However, exercising early comes with the cost of foregoing any further option value of waiting. Once the second firm decides to exercise its option, they both earn duopolistic rents. The incomplete information is meant to capture the firm's uncertainty over the market's demand function, and thus the revenue it can expect to earn. I show that an equilibrium to this game may not exist.[2] Moreover, when an equilibrium does exist, I show that the outcome can be quite different from the complete information game (Dixit and Pindyck, 1994). These two facts are the main contributions of this paper.

The information structure is asymmetric, in that one firm knows more about the monopolistic revenue stream than the other firm. This means that the net value of the project is identical across players and its true value may be unknown. In the language of auction theory, the game is akin to a common valuation auction (Krishna, 2009). The duopolistic revenue stream is known to both players. Asymmetries can easily arise if one firm has a little more experience or knowledge about the market. Perhaps, it may have prior experience in similar markets or it may have conducted more extensive market research. A model of this sort would be appropriate if, for example, the firms are uncertain about the size of the market and market transactions are observable to all firms. This means that if either firm was ever in the position of entering as a duopolist, it would be able to infer the size of the market from observing the monopolist's revenue stream. Thus, we can simply model the duopolistic revenue stream as known to both players.[3]

Even in the simplest case, when the unknown parameter can only take one of two values an equilibrium in trigger strategies may not exist. An equilibrium in trigger strategies will exist if and only if the two possible parameters are sufficiently "far apart." Extending the model to an arbitrary number of possible values for the unknown parameter leads to similar conclusions. The values must be sufficiently spaced for an equilibrium to exist. A corollary of this result is that if the set of possible parameter values is an interval then no equilibrium will exist. When the unknown parameters are sufficiently spaced, the firm with the informational advantage is able to delay its investment without the threat of preemption for all but the most pessimistic parameter value. In these cases, the informed firm will exercise the option at the same level that a single firm acting in isolation would. This is quite different to the result in Hsu and Lambrecht (2007) where the informationally advantaged firm retains little if any of its option value of waiting.

Tian (2009) recently provided a complete characterization of pure strategy Nash equilibria for a large class of games. He showed that a game contains a pure strategy Nash equilibrium if and only if it satisfies the condition of *recursive diagonal transfer continuity*. As an interesting aside, I show how the 2-*type* game violates this condition.

When working with stochastic processes it is usually easier to work in continuous time, as it increases the tractability of the problem. However, in this situation, the fact that the choice set is a continuum contributes to the equilibrium existence problem. Discretizing the choice set while allowing the state variable to move continuously is a simple way to circumvent this problem, but still retain some of the desirable features of continuous time stochastic processes. For the 2-*type* case, a discretized version of the continuous game is specified and an equilibrium is identified. The qualitative features of the equilibrium are dependent on the parameter characteristics. For games in which the types are very similar or one type is very unlikely, the incomplete information plays a minor role and the equilibrium outcome is close to the strategic complete information model. For games in which the types are very different, the incomplete information plays a larger role and the equilibrium outcome is closer to the continuous model. In this sense the discretized model shows that the results from the continuous model are not knife-edge results.

The rest of the paper is organized as follows. Section 2 discusses some of the relevant literature and relates it to this paper. Section 3 discusses the basic model with complete information, as well as some results that will be used for comparison to the incomplete information model. Section 4 introduces the framework for the incomplete information model. Section 5 begins with the simplest incomplete information model where the unknown parameter can take only two values. The 2-*type* model will be used to provide some intuition and highlights the key issues that lead to nonexistence of equilibria. The parameter spaces which admit an equilibrium are characterized. Here the game is shown to violate Tian's condition. In Section 6, I introduce the discretized model and identify an equilibrium. Section 7 generalizes the 2-*type* model with a continuous action space to an *N-type* model. The parameter spaces which admit and equilibrium are again be characterized. Section 8 offers some concluding remarks. All proofs are in Appendix.

2. Related literature

The foundations for investment under uncertainty were laid down by McDonald and Siegel (1986). Dixit and Pindyck (1994) took this framework and astutely investigated how the conclusions from the single firm model translate to

[2] Similar results can be obtained by defining a game in which the firms have a common, unknown, cost of entry. It seems more natural to share a common, unknown revenue stream, so I focus on this game.

[3] If there was also uncertainty over duopolistic revenues, it would add signaling aspect to the game. In this case, the firm with more information can use its entry decision to signal something (or nothing) about the size of the market to the less informed firm. Incorporating the signaling aspect may be interesting in certain settings, but I leave this for future research.