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Competitive investing equilibrium under a procurement mechanism

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ABSTRACT

This paper proposes a procurement mechanism for a research and development (R&D) project, in which the stochastic nature of R&D is incorporated, and the potential agents needed to invest prior to the agent are selected. The incentive contract aims to attract the investment of potential agents through a sharing rate. By establishing the stopping time game, an optimal investing strategy for potential agents is derived. Furthermore, the investment equilibria are discussed, and the conditions under which the equilibrium represents preemption or simultaneous investment are presented.

1. Introduction

An agent is typically contracted by a principal to invest in a new product's research and development (R&D) process during procurement. For example, contractual R&D is performed for the US government by various research laboratories. Defense procurement is also the mechanism by which the French government acquires highly technology-based defense equipment (Anton and Yao, 1987; Tan, 1996; Rogerson, 1995; Oudot, 2010). However, numerous studies show that two or more prospective suppliers often compete in the R&D stage but the subsequent production contract is awarded to a single firm (Bag, 1997; Arozamena and Cantillon, 2004; Figueroa and Cisternas, 2007).

A common procurement mechanism used for agent selection is the auctioning of R&D contracts through competitive bidding schemes. The contract is awarded to the bidder with the lowest bid. In the case of an auction-type mechanism, a significant advantage is an increase in the net revenue of the principal.

However, given the uncertainty of the R&D process, the principal is primarily concerned about success in R&D. The agent who wins the contract through the lowest bid may fail to achieve a successful R&D stage. For a not-for-profit principal or for the nonprofit procurement of targeted R&D, the selection of an agent with the lowest bid is less important than selecting a capable agent to complete the objectives stated in the contract.

In addition, some investments in the R&D stage occur prior to the selection of the winner. The potential agents undertake investment as a device of innovation and also as a strategic action devised to win R&D procurement auctions. If the contract is awarded to a single investor, then agents carry the risk of investment when they enter the R&D contract competition. Therefore, risk sharing and investment incentives are important issues in designing R&D procurement mechanisms.

Risk sharing and incentives in contract have been widely discussed in the procurement literature. For example, a principal–agent analysis by McAfee and McMillan (1986) suggested that an optimal contract that minimizes procurement costs is usually an incentive contract. Moreover, a principal's choice of sharing ratio could determine the contractor's choice of cost-reducing activity. Goel (1999) modified McAfee and McMillan's linear contract and suggested an incentive contract to study an auction of an R&D contract, in which uncertain outcomes were considered. In his model, the principal invites an agent from a pool of potential agents by announcing a sharing rate α. That is, the principal will pay α percentage of the research cost and $(1-\alpha)$ percentage of the bid. Based on the case studies, a number of works discussed the selection of appropriate sharing rates as well as the factors that influence the selection of a sharing ratio (Broome and Perry, 2002; Badenfelt, 2008).

An R&D contract that creates incentives for investment has to consider ex ante the investment strategy of potential agents under an uncertain environment. From the perspective of real options, the R&D investment for entering a contract competition is an investing opportunity rather than an obligation for potential agents, such that they may or may not invest in the R&D stage as a response to the procurement contract. That is, potential agents hold an investing option, and their investment is analogous to the exercise of American option differing in that the underlying process is the payment specified by the R&D contract (Dixit and Pindyck, 1994; Trigeorgis, 1996). Moreover, the interaction of the investment strategy among potential agents can be modeled as an options game, a combination of option pricing theory with game theoretic models (Ziegler, 1999; Leung and Kwok, 2011).

This paper considers an incentive procurement contract for R&D in which a number of uncertainties associated with a contractual R&D are considered. The procurement mechanism is similar to Goel's work,

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the difference being that the principal's objective is to design a sharing rate α in such a way that his procurement contract can attract potential agents to invest in the R&D stage, and the winner is the first to complete the research successfully. Furthermore, the paper emphasizes the analysis of sharing rate effects on potential agents' investment strategy. We thus establish a stopping game among potential agents using the real options framework to study agents' investment behavior under the risk from the procurement contract. The condition under which the equilibrium represents preemption or simultaneous investment is likewise derived in this paper.

The remainder of this paper is organized as follows: A procurement model involving three uncertainties is developed in Section 2. In Section 3, we use the real options approach to evaluate potential agent's investment decisions. Section 4 explores the equilibrium of potential investment strategies. Finally, the conclusion and discussions are presented in Section 5.

2. Model and assumptions

We consider a model with one principal and two potential agents. The principal is a not-for-profit organization and has an indivisible new product development project. Two potential agents, firms 1 and 2, need to invest in the R&D project before a winner is selected. Further assumptions are given as follows:

Assumption 1. The feature of R&D is described by a number of uncertainties associated with the new product development process.

(1) The time of R&D success for firm $i(i=1,2)$ is uncertain and is denoted by a random variable τ_i, the expectation of which is related to the level of the firm's research effort. Let the parameter $h_i(\geq 0)$ measure the intensity of research effort of firm i, then $\tau_i=\tau(h_i)$. Following the framework of Loury (1979) as well as Lee and Wilde (1980), we adopt the exponential distribution. That is, the probability that firm i completes the research by date t is

$$\Pr\{\tau_i \leq t\} = 1-e^{-h_i(t-T_i)}, i=1,2$$

where T_i denotes the investment time of firm i.

(2) The market of a product is uncertain. The price of the product $\{p_t\}_{t>0}$ follows an exogenous geometric Brownian motion:

$$dp_t = \mu p_t dt + \sigma p_t dz \tag{1}$$

where μ and σ are drift and diffusion parameters, respectively. dz is the increment of a standard Wiener process. $0<\mu<r$, r denotes the risk free rate.

For simplicity, one unit product is considered. Thus, $\{p_t\}_{t>0}$ denotes perpetual cash flow.

Assumption 2. The potential agents invest the initial cost $I+C(h_i)$ to enter the contract competition, where I is the cost of R&D equipment, and $C(h_i)$ is the cost of firm's effort level h_i with the condition that $C(0)=0$, $C'(h_i)>0$. The costs $C(h_i)(i=1,2)$ are unknown at the time that the contract is designed. If $h_i \neq h_j$, the potential agents are asymmetrical.

Assumption 3. The principal invites potential agents by announcing the sharing rate α in a linear payment schedule. The bid of potential agent i is $B_i=B(h_i)$, which depends on its research effort level h_i. The first firm that completes the R&D project successfully wins the contract and is paid upon project completion according to the payment schedule stated in the contract:

$$W = \alpha I + (1-\alpha)B_i E[\Pi_i] \tag{2}$$

where $E[\Pi_i]$ is the expected revenue of production.

In the model, the investment opportunity given by the procurement contract causes potential agents to face three uncertainties: uncertainty of future reward, uncertainty of the time of R&D research completion, and uncertainty of winning the contract. If a potential agent does not win the contract, his total cost of investment is irreversible. Thus, potential agents use the option against investment risk. The strategy set will be {waiting, investing}.

The principal first announces a sharing rate α, after which two firms take α as given (α cannot be renegotiated) and choose "waiting" or "investing" as the reaction. In this work, "investing" is equivalent to "stopping," which means to stop "waiting." The game between two potential agents is also called the "stopping time game," which is a special type of stochastic game (Dynkin, 1969; Kifer, 2000; Ferenstein, 2007). In the following section, we will solve the game by using the real options approach. The optimal investment rule will be derived as part of the solution. The equilibrium will be studied with the stopping time game theory. The analysis aims to identify sharing rates that result in preemption or simultaneous investment.

3. Expected payoffs of the potential agents

By using the real options approach, the optimal investment rule is described by a threshold p^*, such that the "waiting" is the optimal strategy when $p \leq p^*$, whereas "investing" is the optimal strategy when $p > p^*$. We first consider the leader–follower game. The firm that invested in R&D earlier is the leader, and the other investor is the follower.

Let the payoffs of the leader and of the follower be respectively denoted by $L(p_i)$ and $F(p_i)$ and the corresponding thresholds are respectively p_L and $p_F(p_L<p_F)$. T_L denotes the random time at which the leader has entered, and that of the follower is T_F. The leader's optimal investment rule is to wait until the critical value p_L $(p(T_L)=p_L)$ is reached and then invest $(I+C(h_L))$ to enter the project. The follower has the same investment rule for p_F. We assume that $E_t[\cdot]$ denotes the expectation conditional upon the information available at time t. The information is from the history of the game, which has three components: the sample path of the state, the actions of the two players, and whether or not the innovation is successful. The critical values p_L and p_F divide the range of p_t into three segments: $[0,p_L]$, $(p_L,p_F]$, and (p_F,∞). In every interval, the investment situations differ. Using the real options approach developed in the competitive environment (Smets, 1991; Grenadier, 2002; Weeds, 2002), we could derive the values of $L(p_t)$ and $F(p_t)$ through backward induction.

3.1. Expected payoff of the follower

The follower's payoff, $F(p_t)$, is first considered by taking the leader's investment strategy as a pre-given. If $p_t \geq p_F$, the follower will invest at once on the condition that the leader is unsuccessful by time T_F. If such is the case, both firms have invested in the project. The probability that the follower wins at time t is

$$\Pr\{\tau_2 \in [t,t+dt] \& \tau_1 > t\} = h_F e^{-h_F(t-T_F)} e^{-h_L(t-T_L)} dt.$$

The follower's expected revenue, with information by time t, is thus given by

$$E_t[\Pi_F] = E_t\left[\int_t^\infty p_\tau h_F e^{-h_L(t-T_L)} e^{-h_F(t-T_F)} e^{-r(\tau-t)} dt\right] = \frac{p_t h_F}{r-\mu+h_L+h_F} e^{-h_L(t-T_L)} e^{-h_F(t-T_F)}.$$