OPTIMAL STOPPING GAME WITH INVESTMENT SPILLOVER EFFECT FOR ENERGY INFRASTRUCTURE

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Overview

Energy and environmental policy solution sometimes requires substantial investment for infrastructure that includes not only physical but also intellectual bases, i.e., development of intellectual properties, R&D, etc. In developed countries with market economy, such investment is presumed to be primarily carried out by privately-owned firms, but not governmental bodies or centrally-controlled firms. The role of the government is limited to provide a guide and/or impose regulation to the firm's activity. The question is how to shape governmental policy for the guidance and/or regulation.

Investment for infrastructure—both physical and intellectual—is typically associated with positive externalities because the infrastructure can be utilized as public goods. For example, once transmission network is established by some firm and is made available later to all new entrant firms in accordance with some liberalization policy, it definitely benefits these new entrants. It is noted, however, that existence of positive externality does not always mean benefits to the public. If the transmission network is set freely open to all firms, it results in a free lunch that dampens motivation for further investment of any firm. On the contrary, if the network is only possessed by the builder, the investment competition by firms may be described by the typical story of the theory of natural monopoly: In the well-known theory, firms are supposed to compete to each other to establish a monopolistic position in the market by investing more than others. In the process of establishing the monopolistic position by one firm, there will be double, triple, or multiple capital investment by those competing firms, resulting in the accumulation of excessive capital. That situation with excessive capital is not socially efficient. In any way, whether or not existence of positive externality benefits the economy is thus dependent upon a prediction of which and how many firms are willing to launch investment activity.

The purpose of this study is to analyze the consequence of existence of positive externality to the optimal choice of firm's investment time in a gaming environment. The paper is organized as follows. In Section 2, I develop a game model in which two firms compete for investment for infrastructure. Section 3 analyzes the model. Section 4 establishes propositions. Section 5 concludes the discussion.

Methods

I consider a situation where firms can increase their subsequent revenue stream by making an invest decision at one time. The investment opportunity is assumed to be one-time and once the decision is made, it cannot be redone, that is, the decision is irreversible. This means that the choice of optimal time of investment is formulated as a so-called "optimal stopping problem" in mathematics. Moreover, I assume that the investment has a spillover effect to other firms. That is, once a firm makes the expensive investment, all other firms can enjoy the same effect of the investment with no cost from the next time period. This positive externality allows firms to enter a game of identifying their own optimal investment time vis-à-vis their opponent's choice of time.

This setting is realistic in that it reflects firm's investment strategy on public goods. Typical examples are competitions for social infrastructure such as electric power network, telecommunication network, road between/among cities, regional environmental pollution abatement activity, etc.

The model is as follows. Consider two identical firms whose net present value of income stream when one of these firms invests at time τ, while the opponent invests at time σ is denoted by $g(\tau,\sigma)$. Both τ and σ are integer and non-negative. Note that if $\tau \leq \sigma$ holds true, the firm needs to make the investment with a positive cost, *I*. However, if $\sigma < \tau$ holds true otherwise, the cost of the investment for the firm is null (i.e. *I*=0) because the same effect has already become available to the firm. I introduce a definition of subgame perfect Nash equilibrium (SPNE) as follows:

Definition. SPNE is (τ^N,σ^N) *such that* $g(\tau^N,\sigma^N) \geq g(\tau,\sigma^N)\ \forall\tau$ *and* $g(\sigma^N,\tau^N) \geq g(\sigma,\tau^N)\ \forall\sigma$.

Results

Let $\tau^M \left(\geq 1\right)$ denote the optimal time of investment for the firm when the opponent is assumed to never invest, that is, $g\left(\tau^M, \infty\right) \geq g\left(\tau, \infty\right) \ \forall \tau$. The following proposition is obtained:

Proposition. SPNEs exist and $\left(\tau^N, \sigma^N\right) = \left(\tau^M, \tau^M + 1\right)$ *and* $\left(\tau^M + 1, \tau^M\right)$ *if* $\left\{1 - \left(\frac{1+g}{1+r}\right)^2\right\} \frac{(1+g)(a-1)}{r-g} X_{\tau^M} \geq I$ *. SPNE does not exist otherwise.*

This proposition indicates that under a certain condition for *I*, $\tau^N \neq \sigma^N$ holds true, meaning that there never happens double investment among these two firms.

Conclusions

This result is remarkable when we contrast it to the theory of natural monopoly. As was mentioned in the Overview, the theory of natural monopoly leads to a conclusion that completion among firms investing for monopolistic position may result in the accumulation of excessive capital, which is not socially efficient. In contrast, the above proposition declines such possibility, implying that the competition leads to social efficiency. Only one firm will make investment that is necessary and sufficient for the society to enjoy the outcome. This result thus supports policy formulations that promote competition rather than intervene between firms in a market with externality.