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Innovative Applications of O.R.

Strategic entry in a triopoly market of firms with asymmetric cost structures

Takashi Shibata*

Graduate School of Social Sciences, Tokyo Metropolitan University, 1-1 Minami-osawa, Hachioji, Tokyo 192-0397, Japan

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ABSTRACT

This paper examines the strategic investment timing decision in a triopoly market comprising firms with asymmetric cost structures. We present three novel results. First, in the case where there are relatively small cost asymmetries between firms and a relatively small first-mover advantage, the firm with the lowest cost structure is not always the first investor. In other cases, the firm with the lowest cost structure is the first investor. Second, an increase in volatility increases the possibility that a firm without the lowest cost structure is the first investor. Finally, even in the three-asymmetric-firm model, we show that the first investor threshold is larger in a triopoly than in a duopoly, although it is smaller in a duopoly than in a monopoly.

1. Introduction

"Investment under uncertainty" considers the problem of the investment timing decision in a *monopoly* market using a contingent claim approach following the seminal work of McDonald and Siegel (1986). Dixit and Pindyck (1994) provide a thorough review.

"Strategic investment under uncertainty" examines the problem of strategic (preemptive) investment timing decisions in a *duopoly* market using a contingent claim approach. Grenadier (1996), Weeds (2002), Huisman and Kort (2004), and Nishihara and Shibata (2010) examine the strategic investment timing problem in a duopoly market of firms with *symmetric (homogeneous)* cost structures. See Chevalier-Roignant, Flath, Huchzermeier, and Trigeorgis (2011) and Azevedo and Paxson (2014) for a thorough review of "strategic investment under uncertainty".

More recently, there have been various extensions to the literature on "strategic investment under uncertainty". One important extension is to incorporate *cost asymmetry (heterogeneity)* between firms. Pawlina and Kort (2006), Kong and Kwok (2007), Nishihara and Fukushima (2008), and Shibata and Yamazaki (2010) investigate the problem of strategic investment timing decisions in a duopoly market of firms with asymmetric cost structures. We call this model the "two-asymmetric-firm" model. Importantly, all of these studies examine the strategic investment timing decision in a *duopoly* market.

Another important extension of the literature on "strategic investment under uncertainty" is to examine the problem of strategic investment timing decisions in a *triopoly* market. Bouis, Huisman, and Kort (2009) consider the strategic investment timing decision of firms with *symmetric* cost structures.[1] We call this model the "three-symmetric-firm" model. Alternatively, Ko and Shibata (2012) consider the strategic investment timing decision of firms with *asymmetric* cost structures. The main result is that the firm without the lowest cost has the possibility to be the first firm (i.e., the first investor) to enter the market. We call this model the "three-asymmetric-firm" model. However, we can extend Ko and Shibata (2012), which we undertake in this analysis.

Our extension is to derive a region where the firm without the lowest cost is the first investor in a triopoly market. Ko and Shibata (2012) find that, under only one specific parameter, the firm without the lowest cost is the first investor. However, we do not know whether such a result is robust to other parameters. In this three-asymmetric-firm model, there are three important parameters. One is a "cost asymmetry" parameter between firms. The second is a "first-mover advantage" parameter where it measures the gain to the first-moving significant occupant of a market. The third is a "volatility" parameter of cash inflows. Thus, for any combination of cost asymmetry, first-mover advantage, and volatility parameters, we derive a region where the firm without the lowest cost is the first investor. Our contribution is to describe the market environment of a firm without the lowest cost that is a first investor in a triopoly market.

Our model contains elements of the two-asymmetric-firm model in Pawlina and Kort (2006) and the three-symmetric-firm model in Bouis et al. (2009). In the extreme case where the profit for a third

* Tel.: +81 42 677 2310; fax: +81 42 677 2298.
E-mail address: tshibata@tmu.ac.jp

[1] In addition, Bouis et al. (2009) provide numerical examples of an n-firm symmetric cost structure model.

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investor is zero, our model is equivalent to the two-asymmetric-firm model. The main result of this extreme case is that the low-cost firm is always the first investor at the equilibrium. In the extreme case where the degree of cost asymmetry is zero, our model is equivalent to the three-symmetric-firm model. The important result of this extreme case is that the preemptive (strategic) investment threshold of being the first investor is larger in the three-symmetric-firm model than in the two-symmetric-firm model. In other words, the first investor's investment threshold in a triopoly market lies between those in the monopoly and duopoly markets, such that in their numerical example, the investment thresholds are 2.2078 for the monopoly, 1.3997 for the duopoly, and 1.5115 for the triopoly.[2]

There are two ways in which the three-asymmetric-firm model is complicated, compared with the two-asymmetric-firm and three-symmetric-firm models. First, the three-asymmetric-firm model is more complex than the two-asymmetric-firm model. In the three-asymmetric-firm model, after one of the three firms invests as the first investor, the other two firms compete to be the second investor. This environment differs from that of the two-asymmetric-firm model.[3] Thus, each firm considers its preemptive investment strategy as the first investor on the condition that the preemptive investment strategies of the second investor are through competition. Second, the three-asymmetric-firm model is more complex than the three-symmetric-firm model. In the three-asymmetric-firm model, each firm's preemptive investment threshold to be the first investor is not necessarily the same. This differs from the three-symmetric-firm model. Suppose there are three Firms, A, B, and C, with asymmetric (heterogeneous) cost structures. Consider, for example, Firms A's (B's) preemptive investment thresholds to be the first investor. Firm A's (B's) preemptive investment threshold of being the first investor is then obtained backwardly through dynamic programming on the condition that Firms B (A) and C are the second and third investors, respectively. Consequently, the strategic interaction between Firms B and C differs from that between Firms A and C. This leads to a difference between Firms A's and B's preemptive investment thresholds of being the first investor. Thus, it is difficult to conjecture intuitively the results of the three-asymmetric-firm model by combining the two-asymmetric-firm model with the three-symmetric-firm model. These complexities produce interesting results.

We provide three new insights into the three-asymmetric-firm model. First, for the case of a relatively small first-mover advantage and a relatively small cost asymmetry, a firm without the lowest cost structure is the first investor. For all other cases, the firm with the lowest cost structure is the first investor. These results are new because the solutions are derived for only one parameter in Ko and Shibata (2012). The result that the firm with the lowest cost structure does not always enter the market as the first investor is obtained by increasing the number of asymmetric firms from two to three. This is because the low-cost firm is always the first investor in the two-asymmetric-firm model developed by Pawlina and Kort (2006). Second, we show that an increase in volatility enlarges the region where the firm without the lowest cost structure is the first investor. This result implies that the firm without the lowest cost structure has the possibility to be the first investor by increasing the volatility. Finally, we show that the first investor's preemptive investment threshold is larger in a triopoly than in a duopoly, although it is smaller in a duopoly than in a monopoly. Thus, the "nonmonotonic investment threshold with respect to the number of firms" property is obtained, even in the three-asymmetric-firm model. Moreover, our theoretical results are consistent with the empirical results.

The remainder of the paper is organized as follows. Section 2 describes the setup of the model and derives the value functions given the investment strategies. As benchmarks, we provide the strategic investment decisions in the monopoly and duopoly markets. Section 3 considers the strategic investment decisions in the triopoly market. Section 4 discusses the implications of the model. Section 5 concludes.

2. Model

In this section, we begin with a description of the model. We then provide the value functions for the triopoly market. Finally, as benchmarks, we provide the optimal investment strategies in the monopoly and duopoly markets.

2.1. Setup

Consider three firms, Firm A, Firm B and Firm C. These firms have an investment opportunity. The firms are risk neutral and compete with each other to maximize profit. The risk-free interest rate $r > 0$ is a positive constant.

The cash flow from exercising the investment opportunity depends on the number of firms operating in the market (i.e., monopoly, duopoly, or triopoly). The investment yields a cash flow $D_n Y(t)$, where $D_n > 0$ represents the competition parameter and the subscript "n" represents the number of operating firms ($n \in \{1, 2, 3\}$). If the number of operating firms increases, more firms share the market. Thus, we assume that

$$D_1 > D_2 > D_3 > 0. \tag{1}$$

These conditions imply that the profit rate of each firm is lower when more firms invest (enter the market). Let $Y(t)$ follow a geometric Brownian motion:

$$\mathrm{d}Y(t) = \mu Y(t)\mathrm{d}t + \sigma Y(t)\mathrm{d}W(t), \quad Y(0) = y > 0, \tag{2}$$

where $\mu > 0$, $\sigma > 0$, and $W(t)$ denotes a standard Brownian motion. We denote the risk-free interest rate as $r > 0$. In order to obtain a finite valuation, we assume that $r > \mu$. [4] Throughout our analysis, we assume that the current demand level $Y(0) = y$ is sufficiently low such that all three firms do not enter the market immediately.[5]

When the investment option is exercised, each firm pays a fixed cost I_i ($i \in \{\mathrm{A}, \mathrm{B}, \mathrm{C}\}$). We assume that the cost structures of the three firms are asymmetric (heterogeneous), which leads to the three-asymmetric-firm model. The assumptions of asymmetric cost structures are given by $I_\mathrm{A} < I_\mathrm{B} < I_\mathrm{C}$. Thus, Firm A is the lowest-cost firm, Firm B is the second lowest-cost firm, and Firm C is the highest-cost firm.

2.2. Value functions for the triopoly market

In this section, we consider the value functions for the first, second, and third investors. Because the three firms have asymmetric (heterogeneous) cost structures, we can ignore cases of simultaneous entry by two or more firms into the market.

Suppose that Firms i, j, and k enter the market as the first, second, and third investors, respectively ($i, j, k \in \{\mathrm{A}, \mathrm{B}, \mathrm{C}\}$; $i \neq j \neq k$). Let $\tau_{ijk}^{(1)}$, $\tau_{jk}^{(2)}$, and $\tau_{k}^{(3)}$ denote the adoption (stopping) times for entering the market for the firms as the first, second, and third investors,

[2] In this literature, once the state variable reaches the investment threshold from a sufficiently low level, the firm undertakes the necessary market-entry investment. Following existing studies, we assume that a smaller (larger) threshold implies earlier (later) investment.

[3] In a duopoly market with two asymmetric firms, after one of the two firms invests as a first investor, the other decides upon its (nonstrategic) investment strategy as the second investor without competition.

[4] This assumption is the same as in Kort, Murto, and Pawlina (2010), Shibata and Nishihara (2011), and Shibata and Nishihara (2015).

[5] This assumption is the same as in Kong and Kwok (2007) and is justified because we focus on the preemptive investment, not the joint investment. See Thijssen, Huisman, and Kort (2012) for the joint investment.