Production Capacity and Patterns of Exit in Declining Industries

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This paper investigates how production capacities of firms affect the firm behavior in declining industries. An exit model in which firms do not have to operate at full capacity is presented. The result shows that it is the size of firms' operating costs relative to their opportunity costs of capital that determines the patterns of exit in declining industries. It is an interesting result since a larger firm, contrary to the existing literature, can survive longer than a smaller firm when the operating costs dominate the opportunity costs of capital. (*JEL* L10, D21)

I. Introduction

There are situations in which the order and timing of a firm's exit from a declining industry matter a lot. One example is a heavyweight motorcycle industry. The sole surviving US motorcycle manufacturer, Harley, was suffering substantial losses on sales well below its productive capacity as a result of shrinking overall demand and imports of cheaper competing products from Kawasaki and Honda. The USITC then granted relief for a five-year period in the form of increased tariff duties and tariff-rate quotas declining incrementally from an initial level of 45% (Brainard 1989). In this case, it was required that the government know the order and timing of firm exit without government intervention in order that government chooses a proper policy.

Ghemawat and Nalebuff (1985, 1987) investigate the exit behavior of firms in declining industries. They argue that the smallest firm or the firm with the smallest plant survives the longest since it survives even in such a pessimistic situation. They take the evidence from synthetic

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soda ash, steel casting and basic steel industries in order to support their conclusion. In all of these cases, early capacity reduction was concentrated among the largest firms.

However, other empirical studies commonly found that smaller firms have higher exit probabilities. One example is the U.S. lead gasoline anti-knock additive industry where the smallest producer was the first to leave, despite having production costs that were similar to those of the larger remaining firms (Whinston 1988). Lieberman (1989) also finds that smaller firms had much higher exit rates than large firms. Evans (1987) and Dunne, Roberts and Samuelson (1989) confirm this relation between exit and firm size, using cross-sectional data.

Empirical evidence also suggests that those who survive in the market often earn significant profits (Hall 1980, cited from Whinston). Thus, one can imagine the case that the larger firm earns more profits when it wins the race because of the larger capacity, and, therefore, it is conceivable that the larger firm has more incentive to stay in the industry. It is, thus, the first objective of this paper to test the robustness of Ghemawat and Nalebuff's conclusion and to generalize their model. An interesting question is whether their conclusion still holds when one relaxes their assumption that production with less than full capacity is impossible.

It is important to distinguish two different hypotheses: 1) Do larger firms reduce the capacity earlier than smaller firms? 2) Do larger firms exit earlier than smaller firms? The former question is more on the capacity reduction of multi-plant firms and the latter is more on the exit of single-plant firms in declining industries. Concerning the former question, Whinston (1988) argues that no natural generalization of Ghemawat and Nalebuff's (1987) strong prediction, that the larger of two duopolists reduces the capacity first, holds in a multiplant setting. He shows that the factors determining the pattern of capacity reduction, in general, can be quite complex, and that prediction in such settings often requires on intimate knowledge of the industry structure.

In this paper, I investigate the latter question, that is, the exit pattern of single-plant firms in a declining industry, assuming that firms are allowed to operate below the full capacity level. In contrast to Ghemawat and Nalebuff, it is shown that, even with small economies of scale, it is possible to have the smaller firm leave the industry earlier than the larger firm in duopoly if the operating costs dominate the opportunity costs of capital.

This paper is organized as follows. Section II describes the model in which firms are allowed to operate below the full capacity level. Based on the model, the new findings on the relationship between the capacity and the pattern of exit in declining industries is provided in section III. Section IV concludes the paper.

II. The Model

Consider a homogeneous market which is declining. Let p denote the price, q the industry output and t the index time. Following Ghemawat and Nalebuff, I assume

$$\frac{\partial p(q,t)}{\partial t} < 0, \ \forall \ t \in [0,\infty) \tag{1}$$

$$\frac{\partial p(q,t)}{\partial q} < 0, \ \forall \ t \in [0,\infty) \tag{2}$$

$$\lim_{t \to \infty} p(q,t) = 0. \tag{3}$$

At time 0, two firms, indexed by i = 1, 2, serve the market. K_i denotes firm i's capacity, where K_i is exogenously given. Production below full capacity is allowed. The game is set in continuous time, but firms make the output decisions only at discrete time intervals, $t = \Delta, 2\Delta, 3\Delta, \ldots$. Here, Δ is the length of the period between exit decisions in discrete time, Δ is assumed to be close to zero throughout this paper. Firms can exit the industry by choosing an output level of zero. For simplicity, let the period s denote time $t = s\Delta$ ($s \in \mathbb{N}$). The equilibrium concept used in this section is the limit equilibrium of a limit game by Fudenberg and Levine (1986). Let $\pi^m_i(K_i, t)$ denote the monopoly profit level and $\pi^d_i(K_i, K_j, t)$ the Cournot duopoly profit level of firm i at time t. Exit costs are zero and re-entry is not allowed. It is also assumed that it is too costly to adjust the capacity because of the lumpy nature and the indivisibility of capital. Flow costs are assumed to be

$$C_i(q_i, K_i) = \begin{cases} C(q_i) + S(K_i) & \text{if} \ \ q_i \le K_i \\ \infty & \text{if} \ \ q_i > K_i \end{cases} \tag{4}$$

where $C(q_i)$ denotes the operating costs and $S(K_i)$ denotes the opportunity costs of the capital embodied in the capacity.

Two extreme cases of the above cost function are analyzed to investigate what determines the pattern of exit from the industry. One extreme case is

$$C_i(q_i, K_i) = rK_i \tag{5}$$

which means that only capital costs matter. In this case, the operation must be at full capacity as long as the marginal revenue is positive. One can notice that this is a weaker version of Ghemawat and Nalebuff's hypothesis since they assumed directly that $q_i = K_i$. The other extreme case is

$$C_i(q_i, K_i) = \begin{cases} F + mq_i & \text{if } q_i \le K_i \\ \infty & \text{if } q_i > K_i \end{cases} \tag{6}$$

which means that the opportunity cost of capital is zero, that is, the capital embodied in capacity is sunk. F is the fixed cost other than the costs of capital, such as rents and manager's salary.

III. Patterns of Exit in Declining Industries

Before describing the subgame perfect equilibrium of the exit game, consider first the results of Ghemawat and Nalebuff. Suppose $C_i(q_i) = aq_i(q_i \le K_i)$ and the firm must set $q_i = K_i$. Define $\hat{t}(K_1 + K_2) \equiv \{t \in \mathbb{R} \mid p(K_1 + K_2, t) = a\}$ and $t_i^*(K_i) \equiv \{t \in \mathbb{R} \mid p(K_i, t) = a\}$. $\hat{t}(K_1 + K_2)$ denotes the time duopoly profits become zero and $t_i^*(K_i)$ the time monopoly profits of firm i become zero $(\hat{t}(K_1 + K_2) < t_i^*(K_i))$. Then, we have the following proposition.

Proposition (Ghemawat-Nalebuff 1985)
Suppose that $\forall t \in [0, \infty)$, $\partial p(q, t)/\partial t < 0$, $\partial p(q, t)/\partial q < 0$, $\lim_{t\to\infty} p(q, t) = 0$, $\partial p(q, t)q/\partial q > 0$, $C_i(q_i) = aq_i(q_i \le K_i)$ and the firm must set $q_i = K_i$. Then, the unique subgame perfect equilibrium of the exit game is that firm 1 exits at $\hat{t}(K_1 + K_2)$ and firm 2 exits at $t_2^*(K_2)$ if $K_1 > K_2$.

The above proposition implies that the larger firm exits earlier than the smaller firm. Note that firm i has to exit at t_i^* regardless of firm j's strategy, since t_i^* is the time after which firm i receives negative profits even in monopoly. Since $t_1^* < t_2^*$ if $K_1 > K_2$, firm 1 exits at time t_1^*, and it is a dominant strategy for the firm 2 to stay at time $t_1^* - \varepsilon$ if ε is small enough, and thus firm 1 has to exit at time $t_1^* - \varepsilon$. Using backward induction, it is not difficult to show that firm 1 must exit as soon as the duopoly profits become zero in equilibrium.

An important question is whether this result is robust. Is it possible to have the larger firm stay longer? Should the larger firm exit first even when it earns more monopoly profits than the smaller firm when it becomes a monopolist? Can a firm commit itself to the industry by having a sunk investment?

To answer these questions, I relax a typically unrealistic assumption in Ghenawat and Nalebuff that firms must operate at full capacity. The following definitions are useful in generalizing their results.

Definition

Define $\hat{t}_i(K_i, K_j) \equiv \{t \in \mathbb{R} \mid \pi^d_i[t, K_i, K_j] = 0\}$ and $t^*_i(K_i) \equiv \{t \in \mathbb{R} \mid \pi^m_i[t, K_i] = 0\}$.

Not that $\hat{t}_i$ is the time duopoly profits of firm i become zero and t^*_i the time monopoly profits of firm i become zero. Then the following proposition generalizes the result of Ghemawat and Nalebuff under the assumption (4) when the production below full capacity is allowed.

***Proposition* 1**

If $t^*_i(K_i) \neq t^*_j(K_j)$, then, as $\Delta \to 0$, there is a unique subgame perfect equilibrium of the exit game:

(1) If $t^*_i(K_i) > t^*_j(K_j)$ and $\hat{t}_i(K_i, K_j) \geq \hat{t}_j(K_i, K_j)$, then firm j exits at $\hat{t}_j(K_i, K_j)$ and firm i exits at $t^*_j(K_i)$,

(2) If $t^*_i(K_i) > t^*_j(K_j)$ and $\hat{t}_i(K_i, K_j) < \hat{t}_j(K_i, K_j)$, then firm j exits at $\hat{t}_j(K_i, K_j)$ and firm i exits at $t^*_i(K_i)$ if $\int_{\hat{t}_i}^{\hat{t}_j} e^{-(t-\hat{t}_i)}\pi_i^d(t,K_i,K_j)dt + \int_{\hat{t}_j}^{t_i^*} e^{-(t-\hat{t}_i)}\pi_i^m(t,K_i)dt > 0$, and firm i exits at $\hat{t}_i(K_i, K_j)$ and firm j exits at $\hat{t}_j(K_j)$ if $\int_{\hat{t}_i}^{\hat{t}_j} e^{-(t-\hat{t}_i)}\pi_i^d(t,K_i, K_j)dt + \int_{\hat{t}_j}^{t_i^*} e^{-(t-\hat{t}_i)}\pi_i^m(t,K_i)dt < 0$.

***Proof*:** The proof is similar to that in Ghemawat and Nalebuff. Note that t^*_i is the time when firm i has to exit even in monopoly. Suppose that $t^*_i > t^*_j$ and $\hat{t}_i \geq \hat{t}_j$, then firm i does not exit at time t^*_j since firm j has to exit at that time. At time $t^*_j - \Delta$, then, firm i will stay in order to become a monopolist at time t^*_j if $\Delta \to 0$. Then, by the backward induction, firm j exits, in the subgame perfect equilibrium, at time $\hat{t}_j$ when it starts to get negative duopoly profits.

Now suppose that $t^*_i > t^*_j$ but $\hat{t}_i < \hat{t}_j$, that is, firm i starts to get negative duopoly profits earlier than firm j. Using the same backward induction, one can show that firm j has to exit immediately if the game reaches time $\hat{t}_j$. Therefore, firm i is able to become a monopolist at $\hat{t}_j$ if it stays in the industry, bearing negative profits, until $\hat{t}_j$. If $\int_{\hat{t}_i}^{\hat{t}_j} e^{-(t-\hat{t}_i)}\pi_i^d(t, K_i,K_j)dt + \int_{\hat{t}_j}^{t_i^*} e^{-(t-\hat{t}_i)}\pi_i^m(t,K_i)dt > 0$, it is profitable for firm i to become a monopolist at $\hat{t}_j$ (until t^*_i) than to exit at $\hat{t}_i$. Therefore, firm i exits at t^*_i, in the subgame perfect equilibrium, if $\int_{\hat{t}_i}^{\hat{t}_j} e^{-(t-\hat{t}_i)}\pi_i^d(t,K_i,K_j)dt + \int_{\hat{t}_j}^{t_i^*} e^{-(t-\hat{t}_i)}$

$\pi_i^m(t, K_i)dt > 0$ and at $\hat{t}_i$ if $\int_{\hat{t}_i}^{\hat{t}_j} e^{-(t-\hat{t}_i)}\pi_i^d(t, K_i, K_j)dt + \int_{\hat{t}_j}^{t_i^*} e^{-(t-\hat{t}_i)}\pi_i^m(t, K_i)dt < 0.$

Q.E.D.

One interesting aspect of the exit behavior of firms in declining industries is that the exit decisions are not effected by the output choices of two firms while they operate. This is shown in the following proposition.

***Proposition* 2**

In the subgame perfect equilibrium, each firm produces at the Cournot equilibrium output level until one firm exits the industry if $t_1^* \neq t_2^*$.

***Proof*:** Since the exit game ends either at $\hat{t}_1$ or at $\hat{t}_2$ by Proposition 1, the game is a finite game, and therefore, by backward induction, one can easily show that each firm has to operate at the Cournot equilibrium output levels until one firm exits the industry.

Q.E.D.

It is worth noting what happens if two firms are identical, that is, if $t_1^* = t_2^*$ and $\hat{t}_1 = \hat{t}_2$. The following lemma is useful to find a subgame perfect equilibrium in this case.

***Lemma* 1**

If firm i decides to exit with probability one in a certain period, it should do so at $\hat{t}_i$.

***Proof*:** If firm i exits the industry with probability one at time $t > 0$, firm j will stay at time $t - \Delta$ in order to become a monopolist at t for Δ small enough. Then, firm i has to exit at $t - \Delta$ with probability one but this is a contradiction. Therefore, if a firm exits the industry with probability one, it should to so immediately.

Q.E.D.

***Proposition* 3**

Suppose $t_1^* = t_2^* = t^*$ and $\hat{t}_1 = \hat{t}_2 = \hat{t}$, then, there are three types of subgame perfect equilibria: (1) firm 1 exits at $\hat{t}$, (2) firm 2 exits at $\hat{t}$, and (3) fully-mixed strategy equilibria in which both firms are indifferent to either staying or leaving in every period from $\hat{t}$ and t^*.

***Proof*:** Since the game is a finite game that ends at t^* given Δ, backward induction applies here. At t^*, the monopoly profits of both firms are zero. At $t^* - \Delta$, there are three types of equilibria in the subgame: two pure-strategy equilibria in which firm 1 (2) exits with probability one, and mixed-strategy equilibria in which each firm is indifferent between the stay and exit. Since the two pure-strategy stage-equilibria violate Lemma 1, only the mixed-strategy equilibrium is possible at $t^*-\Delta$. Similarly, one can show that only the mixed-strategy equilibrium is possible at $t^*-2\Delta$. By backward induction, therefore, there are only three equilibria stated above.

Q.E.D.

The following two corollaries to Proposition 1 examine the exit behavior of firms in the two extreme cases indentified above. Corollary 1 confirms the result in Ghemawat and Nalebuff under the assumption (5) even when the production below full capacity is allowed.

Corollary 1

Suppose $C_i(q_i, K_i) = rK_i$. Then, if $K_1 > K_2$, the unique subgame perfect equilibrium of the exit game is that firm 1 exits at $\hat{t}_1$ and firm 2 exits at t_2^* as $\Delta \to 0$ (note that $\hat{t}_1 < t_2^*$).

Proof: Given Proposition 1, it is sufficient to show that $t_1^* < t_2^*$ and $\hat{t}_1 \leq \hat{t}_2$ when $K_1 > K_2$.

(1) $t_1^* < t_2^*$: Note $\pi_i^m(t, K_i) = \underset{q_i \leq K_i}{\text{Max}} \{p(q_i, t)q_i - rK_i\}$. If $\partial\pi_i^m(t, K_i)/\partial K_i \geq 0$, then $\pi_i^m(t, K_i) > 0$. Thus, if $\pi_i^m(t, K_i) \leq 0$, then $\partial\pi_i^m(t, K_i)/\partial K_i < 0$. Therefore, $t_1^* < t_2^*$ when $K_1 > K_2$ for Δ short enough.

(2) $\hat{t}_1 \leq \hat{t}_2$: Since $q_1^d = q_2^d$, $\pi_1^d[\hat{t}_2, K_1, K_2] = p(q_1^d, q_2^d, \hat{t}_2)q_1^d - rK_1 \leq p(q_1^d, q_2^d, \hat{t}_2)q_2^d - rK_2 = 0$ since $q_1^d = q_2^d$. Therefore, $\hat{t}_1 \leq \hat{t}_2$.

Q.E.D.

The above corollary shows that the larger firm exits earlier than the smaller firm if the operating costs are negligible, that is, $C_i(q_i, K_i) = rK_i$. However, it is also possible that the smaller firm exits first in equilibrium. When the cost function satisfies (6), which is another extreme case of (4), one gets the following Corollary.

Corollary 2

Define $\bar{t}^* \equiv \{t \in \mathbb{R} \mid \pi^m(t, \infty) = 0\}$.

Suppose $C_i(q_i, K_i) = \begin{cases} F + mq_i & \text{if } q_i \leq K_i. \\ \infty & \text{if } q_i > K_i \end{cases}$

Then, if $K_1 > K_2$, the unique subgame perfect equilibrium of the exit game is that firm 2 exits at $\hat{t}_2$ and firm 1 exits at t_1^* as $\Delta \to 0$ (note that $\hat{t}_2 < t_1^*$) if $K_2 < q_2^m(\bar{t}^*, K_2)$.

Proof: When the opportunity cost of capital is zero, there is no cost of keeping excess capacity once the capital is sunk. Even though the excess capacity does not affect the duopoly profits, the firm with excess capacity may have more profits if it becomes a monopolist since the output is constrained by its capacity. Since $\pi_1^m(t, K_1) \geq \pi_2^m(t, K_2)$ and $\pi_1^d(t, K_1, K_2) \geq \pi_2^d(t, K_1, K_2) \forall t \in \{1, 2, \ldots, \infty\}$ when $K_1 > K_2$, $t_1^* \geq t_2^*$ and $\hat{t}_1 \geq \hat{t}_2$. From $K_2 < q_2^m(\bar{t}^*, K_2)$, we know that $t_1^* \neq t_2^*$. Therefore, it follows from Proposition 1 that firm 2 exits at $\hat{t}_2$ and firm 1 exits at t_1^*.

Example **1:** Assume

$$p(q,t) = e^{-t}(\alpha - \beta q)$$

$$C_i(q_i, K_i) = \begin{cases} F + mq_i & \text{if } q_i \leq K_i, \\ \infty & \text{if } q_i > K_i \end{cases}$$

$$K_1 = (\alpha - m)/2\beta > K_2 = (\alpha - m)/3\beta$$

$$2(\alpha - m)^2 / 9\beta < F < (\alpha - m)^2 / 4\beta.$$

In this case, one can easily check $\pi_1^d(t) = \pi_2^d(t) < 0 \ \forall t \in [0, \infty)$, $\pi_2^m(0) < 0$ and $\pi_1^m(0) > 0$. Only the larger firm earns positive monopoly profits at time 0 because of the larger capacity and, therefore, the smaller firm is the one that exits immediately. When m is large, the larger firm survives longer even though economies of scale are not significant. Therefore, when the capital is sunk, that is, the opportunity costs of capital is negligible, the larger firm survives longer since the profits are higher when it becomes a monopolist.

The aforementioned corollaries show that the smaller firm survives longer if the operating costs are small relative to the opportunity costs of capital and that the larger firm survives longer if the opportunity costs of capital are small relative to the opportunity costs of capital. Therefore, it is the relative size of two costs that determines the exit behavior in declining industries. Based on this result, on can explain two contradicting pieces of evidence: Ghemawat and Nalebuff (1985) and Lieberman (1989) show that the larger firms are the first to exit the industry, while Lieberman (1989), Evans (1987), Dunne, Roberts and Samulson (1989), Deily (1988), and Londregan (1988) show that the smaller firms are the first to exit the industry.

Furthermore, the results of Corollary 2 are striking since firms are able to commit themselves to the industry by having a large capacity that is sunk if it is profitable to do so. In this case, it is conceivable that the capacity be used as a means of commitment in some declining industries where the decline is very slow. This issue, however, is beyond the coverage of this paper.

IV. Conclusions

In order to implement industrial or trade policy in a declining industry, policy makers should be aware which firm is the first to exit the market without government intervention. For example, if a domestic firm can survive without protection, the government does not have to levy tariffs to protect the domestic firm. Brainard (1989) assumes the results in Ghemawat and Nalebuff (1985) in analyzing the effects of government intervention through tariffs on social welfare and the order of exit in a globally declining industry.

It is shown, however, that Ghemawat and Nalebuff's conclusion cannot be generalized if the capacity is sunk. It turns out that it is the size of firms' operating costs relative to their opportunity costs of capital that determines the pattern of exit in declining industries. It is shown that a larger firm survives longer than a smaller firm if the operating costs dominate the opportunity costs of capital, which occurs when investment in capacity is sunk. It is conceivable that the policy implication has to be modified according to the new finding.

The result implies that firms may be able to induce the opponent firm to exit the market through a large capacity, which is contrary to the existing literature. The result can explain the empirical findings that the smaller firms exited earlier than the larger firms in some industries, that was not explained in any existing literature.

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