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The Role of Sunk Costs in Entry Deterrence in a Mixed Oligopolistic Market

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ABSTRACT. – In this paper we clarify the role of strategic precommitment in a mixed oligopolistic market. We consider a model in which both the public incumbent and the private entrant determine capacity in the long run. In the short run the firms compete according to a capacity restricted Cournot game. We prove that the necessity to invest prior to the output decision restricts a public firm in entry deterrence. Moreover, it is shown that fixed set-up costs can be in favor of the entrant. Although the public firm is solely interested in output, taking into account its budget constraint, the public firm realizes profits and deviates from average–and marginal–cost pricing in equilibrium.

Le rôle du préengagement stratégique dans un marché oligolitique mixte

ABSTRACT. – Cet article clarifie le rôle du préengagement stratégique dans un marché oligolitique mixte. On considère un modèle dans lequel une entreprise publique sur place et un entrant privé déterminent leur capacité à long terme. Dans le court terme, les entreprises se font concurrence suivant un jeu de Cournot avec restriction de capacité. Cet article démontre que la nécessité d'investir avant de décider du volume de production restreint les possibilités de l'entreprise publique pour empêcher l'entrée du concurrent. De plus, on montre que, les coûts d'installation fixes peuvent favoriser l'entrant. Bien que l'entreprise publique ne s'intéresse qu'au volume de production sous sa contrainte budgétaire, elle obtient un profit et ne fixe pas le prix en fonction du coût moyen et marginal.

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1 Introduction

In mixed oligolistic markets at least one private and one public firm are in competition. Mixed oligopolies can actually be observed in practice. The car industry in France and the market for air-travel in Germany being only two examples. It has only been in recent years that the theoretical analysis of this market form has receved greater attention in the literature (HARRIS and WIENS [1980], BEATO and MAS-COLELL [1984], WARE [1986], De FRAJA and DELBONO [1989], CREMER, MARCHAND and THISSE [1989] and FERSHTMAN [1990]) [1]. Most of these papers are concerned with the question of whether nationalization or privatization, two sides of one coin, improves the market allocation from a welfare theoretic viewpoint. However, in this paper we clarify the role of strategic precommitment in a mixed duopoly. By strategic precommitment we mean any irreversible long-run decision of a firm which decisively influences its subsequent behavior. A specific kind of precommitment is a long-run capacity investment of a firm. This kind of strategic decision is analyzed in the present paper.

Privately and publicly owned firms are distinguished by their objective functions. As is standard in microeconomic theory, private firms are assumed to maximize profits. This behavioral assumption is plausible at least for small enterprises, where the owner is simultaneously the leading manager of the firm. Public firms typically are thought to pursue different objectives. In the existing literature on mixed oligopoly the assumption is generally made that a benevolent politician completely controls the performance of a public firm. Thus, a public firm is considered to maximize welfare. In partial equilibrium models of oligopoly the assumption is generally made that the public firm maximizes the sum of consumer and producer surplus. This reflects a rather extreme view. On the one hand, it assumes that the politician pursues social interests, on the other hand, the manager's influence is considered to be negligible. Thus, from an economic point of view welfare maximization is a normative benchmark model.

In this paper we take a more positive view. We assume that a public firm maximizes output while facing a zero-profit constraint. If the public firm cannot fulfill the profit constraint it minimizes losses, that is, it behaves like a profit maximizer to fulfill the budget constraint as closely as possible. The output maximizing behavior has already been applied in the analysis of public monopolies, for instance by REES [1984b]. Its justification results from the argumentation that the manager of a public firm has the possibility of pursuing his own objectives which may not necessarily be those of the owners. There are several reasons for this hypothesis. Supervision and control are either too expensive or not possible. On the one hand, public firms are typically large, with respect to the number of employees and sales. On the other hand, politicians as the representatives of the

1. For a survey see De FRAJA and DELBONO [1990] and NETT [1991].

owners, have only a low incentive to control the managers. They face the uncertainty of reelection. Thus are high costs associated with the expected return of investment of acquiring information about the firm. Moreover, the benefits a politician can expect to reap from any specific performance of the public firm are not very high compared with the transaction costs incurred. As the manager or bureaucrat typically is interested in status, prestige etc. [2] these objectives are highly correlated with output.

In reality, we often observe that markets which were once monopoly domains of a public firm are often opened for private market entry. Thus in this analysis we focus on a situation, in which we assume that a public firm is the incumbent and a private firm is the potential market entrant. Both firms have fixed capacity in the long run. In contrast to the DIXIT [1980] model we assume that capacity is not variable in the short run. The public firm, the incumbent, moves first in fixing its capacity. After knowing the capacity of the incumbent, the private firm chooses its capacity. After this has been done, in a second-round decision, the incumbent has the possibility to revise his capacity decision. We assume here that a public firm is then constrained by bureaucratic restrictions which prohibit capacity from being varied in this transitional period. Both firms have complete knowledge with respect to the capacity of the other. This seems to be a rather plausible view for several industries, especially in the transport sector. For example, typically any airline can observe the number of airplanes each company in the market owns and airplanes determine the number of passengers each company is able to transport.

One main aspect of this paper is to show how sunk costs influence the behavior of a firm. The capacity investment costs are sunk when firms decide on output. If a firm maximizes profits, sunk costs do not have any impact on the strategic decisions of the firm. However, this conclusion strongly depends on the specific objective function as we will see in what follows. Since we assume that the public firm faces a budget constraint, the results in this paper differ from the conclusions of WARE [1986] and FERSHTMAN [1990] [3].

In particular the subsequent analysis verifies the following economic suggestion: a public manager associated with an objective as specified above is interested in capturing the whole market or a high market share in the presence of an opponent. However, a public firm which wants to offer a specific output, previously has to install an appropriate capacity. The higher the capacity the higher the necessary investment which has to be captured by sales. Therefore a high capacity implies that the public firm, which has to cover the costs, is less flexible in its behavior. This is a main restrictive component with respect to the behavior of a public manager.

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2. See NISKANEN [1971].
3. These authors considered market entry within the DIXIT [1980] framework. The papers differ with respect to the cost functions of the firm.

We choose a specification of the demand and cost functions which allows for a direct comparison to the situation of the Cournot Paradox [4]. This allows us to directly observe whether the necessity of strategic precommitment of the public firm makes market entry of a private firm possible. The analysis also allows us to show to the extent to which a public firm is able to reach a high market share if it faces competition by a potential entrant.

The paper is organized as follows: first we present the formal description of the mixed duopoly game and demonstrate why a public firm cannot always deter market entry. We describe the subgame perfect equilibria of the game, assuming identical constant per-unit costs, and discuss the impact of a fixed set-up cost and cost asymmetry. Next we discuss the effects of the move structure in capacity on equilibrium. Finally we examine our results in light of the suggestions found in the standard literature about the role of sunk costs in entry deterrence either on pure private and mixed oligopolistic markets.

2 The Model

We consider two firms, firm 1 is an incumbent public enterprise and firm 2 is a privately owned potential entrant [5]. The structure of the game is as follows: first the incumbent sets his capacity, x_1. Knowing the capacity of firm 1, the private firm then makes its decision on whether to enter the market or to stay out of it. If it enters, it chooses a capacity, $x_2 > 0$. The capacity of the entrant is also observed by the incumbent. Next, both firms simultaneously offer output z_i, $i = 1, 2$, which is restricted by the respective capacity constraints $(z_i \leq x_i,\ i = 1,\ 2)$. Given the output of each firm, a Walrasian auctioneer determines the market clearing price with respect to total demand. Hence, the last stage of the game is a capacity-restricted Cournot model. The capacities given in this stage have been determined sequentially and endogenously in previous stages. Demand is assumed to be linear and represented by $\mathrm{P}(z) = 1 - z$. Each firm faces a cost function, $\mathrm{K}_i(x_i)$, which we specify as follows:

$$\mathrm{K}_i(z_i,\, x_i) = c\, x_i, \qquad z_i \leq x_i, \qquad i = 1,\, 2.$$

Hence, we assume that both firms have the same constant costs c per unit of capacity and that output up to capacity is costless. As usual we assume

4. In the case of Cournot competition between a private and a public firm, if both firms face symmetric concave cost functions in output, the equilibrium outcome is characterized by a public monopoly.

5. Of course, it is also interesting to analyze the reverse structure, which will be presented later on. However, in reality we often observe a deregulation policy admitting market entry of private firms.

that the private firms are profit maximizers. The profit function of a firm is given by:

$$\Pi_i(z_1, z_2, x_i) = (1 - z_1 - z_2) z_i - c x_i, \qquad i = 1, 2,$$

provided that aggregate output is less than maximal demand.

The public manager wants to maximize output under a zero-profit constraint. Since we analyze a multistage game, there are subgames in which the public firm has no possibility of avoiding net losses. To describe out-of-equilibrium behavior we assume that if the public firm cannot realize a non-negative profit, given the output offer of the private firm, it will minimize losses to satisfy the budget constraint as closely as possible. This managerial behavior may be caused by the fear of ruin of the firm. The higher the losses, the more likely it is that the manager will be fired. If the manager loses his job, he is worst off. Given a particular output z_2 of the private firm, the behavior of the public firm can be described as:

$$r_1(z_2) = \begin{cases} \arg\max\limits_{z_1} z_1 \text{ s.t. } \Pi_i \geq 0 \\ \qquad\qquad\qquad \text{if the set } \{z_1 | \Pi_1(z_1, z_2, x_1) \geq 0\} \text{ is not empty} \\ \arg\max\limits_{z_1} \Pi_1(z_1, z_2, x_1) \text{ otherwise.} \end{cases}$$

Looking at a game in extensive form with almost perfect information, we are interested in the existence and properties of subgame perfect equilibria. Such an equilibrium is a Nash equilibrium of each subgame. Since the structure of the game and the objective functions of the agents are common knowledge, each agent is able to anticipate subsequent behavior or strategy choices and the induced payoff. The game has to be solved by backward induction. In our model we first have to analyze the Nash equilibrium of the capacity-restricted COURNOT duopoly model.

3 The Market Subgame

In this subgame each firm has already chosen capacity which is known to both. Now each firm decides to offer a particular output $z_i \leq x_i$ such that the respective payoff is maximized. Since capacities have been determined by previous decisions and there are no variable costs, the only costs faced by the respective firms are sunk costs. Foregone costs, however, do not influence the private firm's output choice. Therefore the private firm maximizes revenue with respect to the capacity constraint,

$$\max_{z_2} (1 - z_1 - z_2) z_2 \quad \text{s.t. } z_2 \leq x_2.$$

In describing the behavior of a public firm we have to distinguish between two cases. First, given z_2, if any feasible strategy of the public firm induces a loss, the incumbent maximizes revenue. In that case the public firm obviously behaves like a private firm. However, if for given z_2 at least one strategy exists which leads to a non-negative profit for the public firm, the public enterprise maximizes output with respect to the capacity, taking account of the zero-profit constraint.

$$\max_{z_1} z_1 \quad \text{s.t. } z_1 \le x_1$$
$$(1 - z_1 - z_2)\, z_1 \ge c\, x_1.$$

Therefore, the *Nash equilibrium* $(z_1^*,\, z_2^*)$ has to fulfill the following conditions:

(i) $(1 - z_1^* - z_2^*)\, z_2^* \ge (1 - z_1^* - z_2)\, z_2$ for every $z_2 \le x_2$ and $z_2^* \le x_2,$

(ii) $(1 - z_1^* - z_2^*)\, z_1^* \ge (1 - z_1 - z_2^*)\, z_1$ for every $z_1 \le x_1,\ z_1^* \le x_1$ and $(1 - z_1^* - z_2^*)\, z_1^* < c\, x_1$

or $z_1^* = \arg \max_{z_1} z_1$ s.t. $z_1 \le x_1$ and $(1 - z_1 - z_2^*)\, z_1 \ge c\, x_1$.

A reaction function determines the firm's best response to any output of the other firm. The Nash equilibria of each subgame are given by the intersection of the reaction functions of both firms. Before we derive the equilibria of the subgames let us first have a closer look at the respective reaction functions. Obviously the reaction function $r_2(z_1)$ of the private firm has the following structure:

$$r_2(z_1) = \min\left(x_2,\, \frac{1 - z_1}{2}\right).$$

Graphically the reaction function is illustrated in Figure 1.

If the capacity decision is binding with respect to the optimal response to a given output of the incumbent, given z_1 the entrant offers x_2 since the revenue is a concave function in z_2. Otherwise the reaction function is equivalent to that in a COURNOT model where the costs are zero. Notice that all costs are sunk (fixed) costs in this stage. In particular, if $x_2 \ge \frac{1}{2}$, the capacity choice is not binding with respect to the revenue-maximizing behavior of the private firm. As we can see, the reaction function of the private firm is independent of c, and hence independent of the sunk costs induced by the capacity choice.

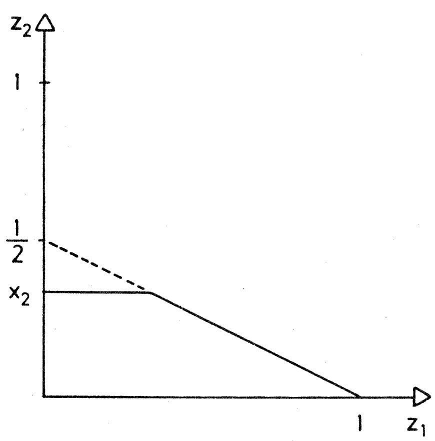

FIGURE 1

Let us next turn to the reaction function of the public firm. We have to distinguish the following cases. First, z_2 is so low that the public firm can offer $z_1 = x_1$ without incurring losses. Second, z_2 is so high that the firm cannot earn a revenue which covers costs. In this case it still attempts to maximize revenue. If z_2 lies somewhere in between, the public firm offers the maximum output which yields zero profits.

If c is greater than $\frac{1}{2}$, irrespective of the specific value of z_2 and x_1, revenue maximizing coincides with output maximizing in the last stage. In this case the market is "tight" in the sense that less profit can be earned in this market. Therefore market entry of the private firm induces destructive competition. If $c < \frac{1}{2}$, the behavior of the public firm coincides with that of the private firm as long as $x_1 \leq c$. The reason is as follows: if $z_2 \leq 1-c-x_1$ the public firm can utilize its full capacity without incurring losses. In this range $x_1 \leq \frac{1-z_2}{2}$ also holds. Given a higher output z_2, any strategy of the incumbent induces a loss because the revenue-maximizing output $\min\left(x_1, \frac{1-z_2}{2}\right)$ in greater than $1-c-z_2$, for any $z_2 > 1-c-x_1$, if $x_1 \leq c$. In this case since the profit-maximizing strategy of the public firm leads to an equilibrium price lower than the costs per unit of capacity, this is obviously true. This can be seen in the following Figure 2 *a*.

As a consequence the public firm's reaction function $r_1(z_2)$ is symmetric to that of the private firm, namely

$$r_1(z_2) = \min\left(x_1, \frac{1-z_2}{2}\right).$$

On the other hand, if $c < \frac{1}{2}$ and $x_1 > c$, the reaction function of the public firm is

$$r_1(z_2) = \begin{cases} \frac{1-z_2}{2} & \text{if} \quad z_2 \geq 1-2\sqrt{cx_1} \\ \frac{1-z_2}{2} + \sqrt{\frac{(1-z_2)^2}{4} - cx_1} & \text{if} \quad z_2 \in (1-c-x_1,\, 1-2\sqrt{cx_1}) \\ x_1 & \text{otherwise.} \end{cases}$$

This reaction function is illustrated in Figure 2 *b*.

If z_2 is lower than $1-c-x_1$, the public firm can utilize its full capacity without incurring losses. However, z_2 greater than $1-2\sqrt{cx_1}$ implies that any output choice of the public firm leads to a revenue lower than the investment costs associated with the given capacity, so the public manager maximizes revenue. If z_2 lies somewhere between these critical values, the public firm chooses the maximum output which yields a zero profit. Note that the reaction function of the public firm depends decisively on per-unit capacity costs, which are sunk costs in the last stage. The capacity decision does not only truncate the reaction function which results when there is no binding capacity constraint, but also determines the shape of the entire reaction function. Within the range where the public firm operates on its

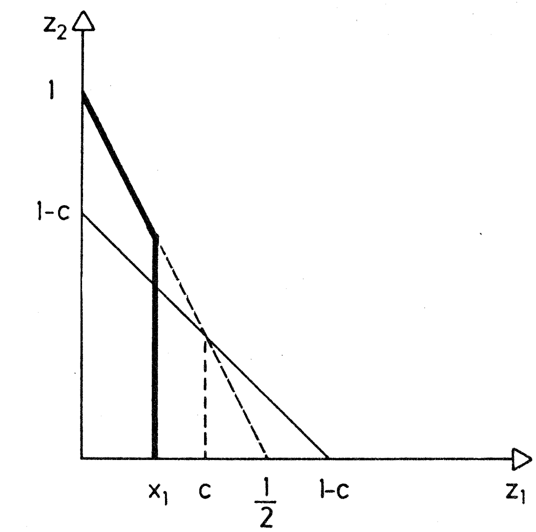

FIGURE 2*a*

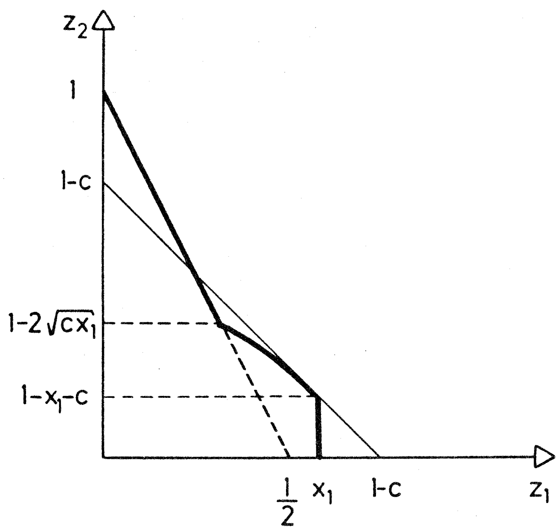

FIGURE 2*b*

zero profit line, the slope of the reaction function is influenced by the fixed cost term. Furthermore, the critical levels where the public firm changes the kind of behavior depend decisively on c and x_1.

Next let us consider how the flexibility of the public firm is affected by a higher capacity x_1. By definition, a reaction function of a firm is termed more flexible than another reaction function if, for any given output of the opponent, the reaction function suggests a higher response in output than the other one. Sunk costs do not influence the reaction function of a profit-maximizing firm. Therefore, in the range in which initially the capacity constraint was binding, higher capacity induces more flexible behavior of a private firm. According to our previous discussion the same is valid for a public firm if the market is "tight" $\left(c \geq \frac{1}{2}\right)$ or $x_1 \leq c$ and $c \leq \frac{1}{2}$.

However, let us assume values of c and x_1 which imply a reaction function as illustrated by the dashed line in Figure 3. This is the case if $c \in \left(0, \frac{1}{2}\right)$ and $x_1 \geq c$. If the public firm increases its capacity up to x_1', the reaction function approximates the reaction function described in Figure 4. We observe that for $z_2 \leq z_2'$ the public firm reacts more flexible because the initial capacity constraint is no longer binding. As a consequence of the higher fixed costs the public firm responds to any output $z_2 \in (z_2'; 1 - 2\sqrt{cx_1})$ with a lower output in order to satisfy the budget constraint or to minimize losses. Thus within this range greater capacity causes less flexible behavior. This restricts a public firm from attempting to deter entry.

As the market equilibrium is determined by the intersection of the private and the public firm's reaction function, the qualitative properties of the equilibrium depend decisively on the relationship between c and x_1. It is, of course, possible that multiple equilibria occur. Especially if both firms choose a rather high capacity and c is sufficiently low, a private firm's reaction function may intersect the public firm's reaction function within any given interval [6]. At the most we may observe three equilibria. In the case of multiple equilibria we select the equilibrium which leads to the highest output of the incumbent. Since we are interested in the extent to

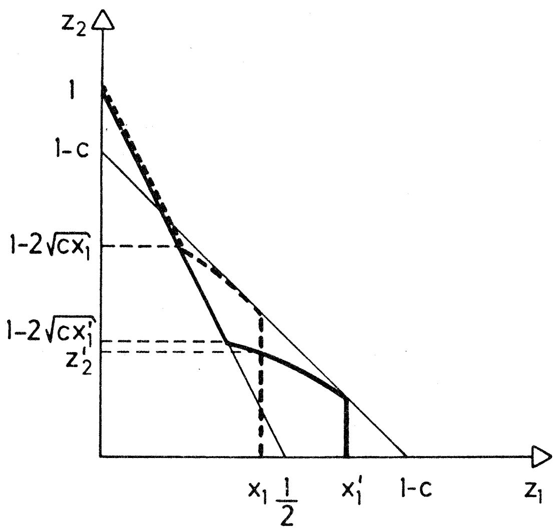

FIGURE 3

6. The parameter constellation $x = 1 - 2c$, $x_2 = \frac{1}{2}$ and $c = \frac{1}{8}$ leads to such a situation.

which the public firm can capture the market, we do not impose restrictions on the public firm by an equilibrium selection in favor of the public firm. At this point we give no explicit description of the market equilibria for all specific parameter values. The algebra is standard, however, the many case distinctions make it quite tricky [7].

4 A Characterization of Equilibrium Allocations

In this section we will characterize the subgame perfect equilibria. Note that firms, in choosing their capacity, anticipate the subsequent behavior of themselves as well as of their competitors and especially the market outcome. First, let us consider the situation in which the market is "tight" $\left(c \geq \frac{1}{2}\right)$ and assume that the public firm sets a capacity equal to $1 - c$. In this case the public firm's reaction function looks like that illustrated in Figure 4. Regardless of the capacity chosen by the private firm, the equilibrium allocation is located on this reaction function. We can see that any allocation which leads to a positive output of the private firm induces an equilibrium price lower than the variable costs. This is due to the fact that destructive competition results if the private firm enters in a market which is "tight". Consequently, the private firm stays out off the market. Since $1 - c$ is the maximum capacity which the public firm can utilize in a monopolistic situation, the public firm chooses just this capacity in equibrium.

The situation, however, is completely different if $c \leq \frac{1}{2}$. Again assume that the public firm chooses the maximum capacity which a monopolist can utilize without making losses, namely, $x_1 = 1 - c$. In this case the reaction function of the public firm is as illustrated in Figure 5*a* [8]. The shaded area reflects the tuples of output allocations which induce an equilibrium price higher than the variable costs. Therefore if an equilibrium allocation lies within this set and a firm utilizes its capacity, this firm earns a positive profit. Line AB reflects the private firm's reaction function if its capacity is not binding. A lower capacity x_2 modifies this reaction function, as shown in Figure 1. The equilibrium allocation is determined by the intersection of the reaction functions of both firms. Therefore, by choosing its capacity, a private firm can induce any allocation on the public firm's reaction function where $z_2 \leq \frac{1}{3}$. Since in equilibrium the private firm utilizes its capacity,

7. The interested reader is invited to refer to the discussion paper which is available on request.

8. The figure is drawn for $c = \frac{1}{3}$.

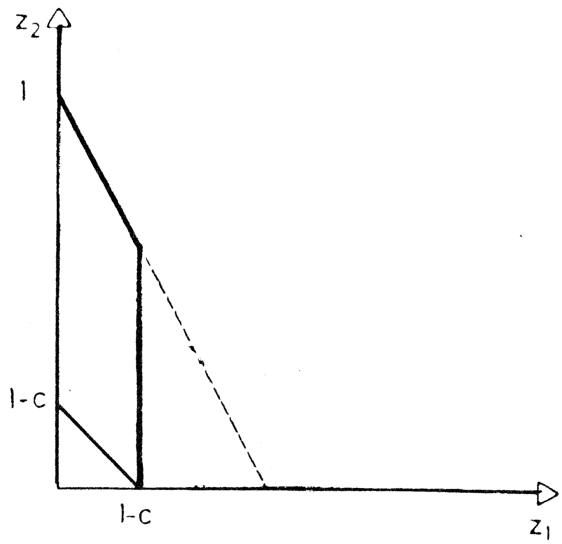

FIGURE 4

market entry is profitable for the private firm if $x_1 = 1 - c$. [9]. If the public firm chooses a lower capacity, the public firm's reaction function changes as illustrated in Figure 3. Therefore, there is still a part of the public firm's reaction function which is located within the shaded area of Figure 5*a*. Obviously market entry is profitable in such a situation. In this case, by choosing $x_2 = \dfrac{1 - c - x_1}{2}$ (the Stackelberg-follower strategy), which leads to an equilibrium in which both firms utilize their capacity, the entrant can always realize a positive profit. Since the public firm's reaction function for $z_2 \geq 1 - 2\sqrt{c\,(1-c)}$ does not change, a higher capacity than $1 - c$ does not prevent market entry.

Let us next illustrate the subgame perfect equilibrium allocation graphically. Any allocation along the line $z_1 + z_2 = 1 - c$ induces a market price equal to constant per-unit capacity costs. If the equilibrium allocation lies below this line, a firm earns a positive profit if it utilizes capacity. The bold line in Figure 5*b*, reflects the reaction function of the

9. It can be shown that the private firm's profit decreases along the zero-profit part of the public firm's reaction function. Since

$$x_2 = \frac{1}{2} - c = \arg\max\left(1 - x_2 - \frac{1 - x_2}{2}\right)x_2 - cx_2 > 1 - 2\sqrt{c\,(1-c)},$$

given $x_1 = 1 - c$ in equilibrium the private firm chooses just this capacity.

public firm. We assume that $x_1 = \overline{x}_1$ and $c = \frac{1}{3}$ [10]. The line AB reflects the revenue-maximizing behavior of the entrant if there is no capacity constraint. The line CD illustrates the Stackelberg follower behavior. If both firms hold no idle capacity in equilibrium, this line indicates the best capacity choice of the entrant. As discussed previously, the entrant can induce any allocation on the public firm's reaction function which lies below G. We can this draw an isoprofit line for which it is implicitly assumed that the entrant utilizes his capacity. If the public firm chooses $\overline{x}_1$, the isoprofit line includes both E and F. Consequently, the entrant is indifferent between choosing a Stackelberg-follower strategy and setting a capacity equal to $1 - 2\sqrt{c\overline{x}_1}$ which induces the allocation in F. This implies that $\overline{x}_1$ is implicitly defined by

$$\frac{(1 - x_1 - c)^2}{4} = \left[\frac{1 - \max\left(\frac{1}{2} - c,\, 1 - 2\sqrt{cx_1}\right)}{2} - c\right] \times \max\left(\frac{1}{2} - c,\, 1 - 2\sqrt{cx_1}\right).$$

In F, however, the public firm does not utilize its capacity.

We can conclude that the public firm does not choose a capacity lower than $\overline{x}_1$. Next assume that the public firm sets a capacity which is higher than $\overline{x}_1$. The incumbent's reaction function consequently changes, as indicated by the dashed line. Since the isoprofit line of the private firm does not change, the private firm will induce the equilibrium allocation in F$'$. This implies that the public firm holds idle capacity. More precisely for any capacity higher than $\overline{x}_1$ the entrant chooses $x_2 = \max\left(1 - 2\sqrt{cx_1},\, \frac{1}{2} - c\right)$. Although z_1 may increase in x_1 for values higher than, $\overline{x}_1$, it can be shown that it is always lower than $z_1 = \overline{x}_1$. Thus $\overline{x}_1$ is the equilibrium capacity. It is the critical level where the private firm changes its behavior from a Stackelberg follower to setting a capacity where the public firm operates while holding idle capacity. In equilibrium, both firms utilize their capacity. Since the equilibrium price is higher than c, both form's earn positive profits. Thus, in contrast to our intuition in equilibrium the public firm which is only interested in a high output earns positive profits and deviates from marginal-cost pricing.

For parameter values $c \in \left(\frac{1}{3}, \frac{1}{2}\right)$ we have thus determined the subgame perfect equilibrium. The characterization, however, strongly depends on the fact thay any public firm's reaction function intersects the unrestricted revenue maximizing function of the private firm at least once, either at

10. Multiple equilibria do not occur because when $c \geq \frac{1}{3}$ the public firm's reaction function never intersects the revenue maximizing function of the private firm for $z_1 \geq \frac{1}{3}$.

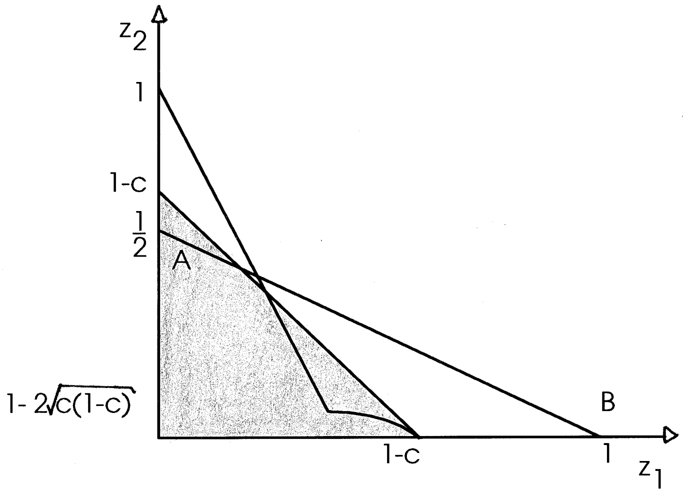

FIGURE 5*a*

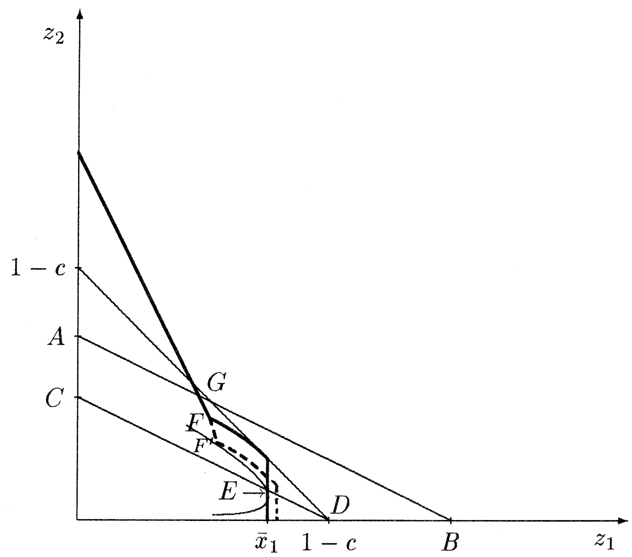

FIGURE 5*b*

$\left(x_1, \dfrac{1-x_1}{2}\right)$ or at $\left(\dfrac{1}{3}, \dfrac{1}{3}\right)$. This implies that for $x_1 > \dfrac{1}{3}$, any point on the public firm's reaction function in which $z_2 < \dfrac{1}{3}$ can be induced by the respective capacity choice of the private firm. This, however, is not valid in general. For example, assume that $c < \dfrac{1}{2} - \dfrac{\sqrt{5}}{6}$. In this case the unrestricted revenue maximizing function of the private firm and the public firm's reaction function intersect either at $(z_1, z_2) = \left(x_1, \dfrac{1-x_1}{2}\right)$ if $x_1 \leq 1 - 2c$ or at $(z_1', z_2') = \left(\dfrac{1}{2} + \sqrt{\dfrac{1}{4} - 2cx_1}, \dfrac{1}{2} + \sqrt{\dfrac{1}{4} - 2cx_1}\right)$. In this case multiple equilibria will not occur. If $x_1 < 1 - 2c$ the private firm can only induce an equilibrium in which the public firm utilizes its capacity. Thus the private firm behaves like a Stackelberg follower in this case setting $x_2 = \dfrac{1 - x_1 - c}{2}$. For larger values of x_1 the private firm can induce any allocation on the public firm's reaction function where $z_2 \leq z_2'$ holds. Since the private firm's profit decreases in z_1 along the part where the public firm operates on its zero profit line, the private firm either sets $x_2 = z_2'$ or $x_2 = \dfrac{1 - x_1 - c}{2}$. Again there is a critical level, call it $\hat{x}_1$, which is implicitly defined by:

$$\frac{(1 - c - x_1)^2}{4} = (1 - z_1' - z_2')\, z_2' - z_2'.$$

This represents the maximum capacity a public firm can utilize. As before for higher values c this determines the equilibrium. The qualitative properties still remain.

Four intermediate values of c the analysis is more complicated, especially, because of the presence of discontinuities and the existence of multiple equilibria. However, also in this case, the qualitative properties hold. The output allocation in equilibrium is shown in Figure 6.

We initially posed the question as to extent to which a public firm is able to obtain a high market share if it faces competition by a private firm. The answer can be given by means of the following Figure 6 in which we draw the market share of the private firm [11]. For intermediate values of c a private entrant achieves a non-negligible market share of up to 24 percent. Furthermore, in the next section we prove that a symmetric fixed set-up cost may increase the private firm's market share. Comparing the equilibrium outcome to the situation which is associated to the Cournot paradox we conclude that the necessity to fix capacity in the long run restricts a public firm in deterring market entry. It is just the requirement of precommitment for the public firm which makes market entry attractive to a private firm.

The shape of the function which represents the private firm's market share as a function of c can be explained as follows: for any given per unit capacity choice $x_1 \leq c$ (see Figure $2\,a$) the public firm credibly precommits itself to sell an output equal to capacity [12]. In equilibrium the public firm utilizes any capacity lower than or equal to c. This critical capacity decreases in c. The private firm's incentive to set a higher capacity increases with a

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11. For numerical calculations we used GAUSS. As we already mentioned, the public firm operates as a monopolist if the market is "tight" $\left(c \geq \dfrac{1}{2}\right)$.

12. This is of course restricted to the area along the public firm's reaction function which induces a higher market price than the constant per unit costs of capacity.

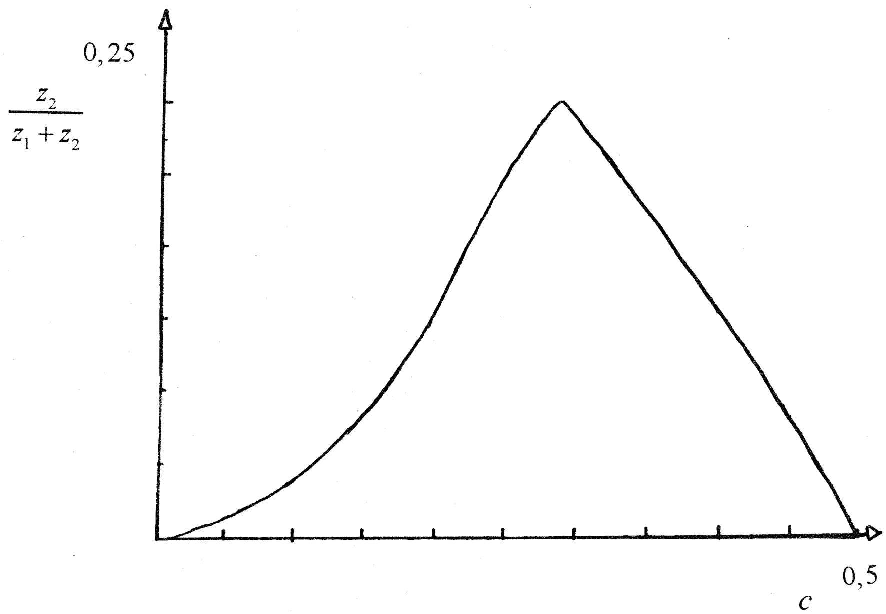

FIGURE 6

lower c. However, there is also another effect: the lower the capacity costs, the more flexible a public firm at any given capacity. Therefore it is less attractive for a private firm to force the incumbent to a loss-minimizing behavior for a given x_1. This effect dominates at a certain value of c, which explains the function illustrated in Figure 6. Consider the extreme of zero capacity costs. By choosing a capacity equal to $1 - c$, in the market subgames the incumbent responds to any output of the private firm in a way that induces a market price equal to zero. Therefore the private firm has no incentive to enter the market.

The equilibria $\left(c \leq \frac{1}{2}\right)$ are characterized as follows:

– The private firm enters the market.

– Each firm utilizes its full capacity. The incumbent gains no advantage from holding overcapacity with the intention to deter entry. Overcapacity only makes him less flexible.

– The public firm offers its output at a price which deviates from the marginal costs.

– Both firms realize positive profits.

– The public incumbent has a higher market share than the private entrant.

5 The Impact of Fixed Set-up Costs

Since fixed costs only reduce profits and do not influence behavior, in the standard literature fixed set-up costs are considered to be barriers to market entry. We are now interested in examining whether this suggestion is valid in a mixed duopoly situation. Assuming that each firm faces fixed costs K_F, we pose the following hypotheses:

– If the fixed set-up costs are lower than the profit of the private firm in the initial equilibrium, the market share of the private entrant and the market price are increasing functions of fixed costs.

– If the fixed set-up costs are rather high, the private firm will not enter the market.

To illustrate that fixed set-up costs may induce a higher market share of the entrant, let us again look at Figure 5 *b*. In contrast to the initial situation, assume that each firm faces positive fixed set-up costs which are lower than the entrant's revenue in G. In this case within the area $z_1 \leq \overline{x}_1$ the incumbent's reaction function qualitatively changes as indicated by the dashed line. Since fixed set-up costs do not influence the behavior of a private firm, the shape of the private firm's isoprofit lines does not change [13]. If the incumbent sets $\overline{x}_1$, the entrant prefers to induce the allocation at F′ and the incumbent does not utilize its capacity. Consequently, the incumbent sets a lower capacity than $\overline{x}_1$ to be more flexible within the relevant range. In equilibrium, we again observe that the entrant is indifferent between behaving like a Stackelberg-follower and choosing $x_2 = \max\left(1 - 2\sqrt{cx_1}, \frac{1}{2} - c\right)$. Since the market share of the entrant along the line CD is decreasing in x_1, the initial equilibrium is characterized by a lower market share of the entrant. Furthermore, the equilibrium price is higher than in the initial situation. This provides a counterexample to the traditional view on the role of fixed set-up costs in market entry.

The second hypothesis needs no illustration. It is quite clear that a fixed set-up cost of, say, $\frac{(1-c)^2}{4}$ (the monopolistic net revenue) will lead to a monopolistic situation of the public firm. Otherwise both firms would make losses.

6 Altering the Move Structure

In this section we examine how the sequence of the capacity decision influences the equilibrium allocation. Let us first assume that the private firm is the incumbent and that it sets its capacity first. Again, by choosing its capacity, the private firm chooses its reaction function which determines its behavior in the last stage. Obviously any subgame perfect equilibrium is

13. However, each allocation leads to a lower profit of the entrant because of the fixed cost term.

located on this reaction function. If the private firm sets a capacity which is lower than $1 - c$ $\left(\text{if } c \geq \frac{1}{2}\right)$ or c $\left(\text{if } c < \frac{1}{2}\right)$, any allocation on the private firm's reaction function which leads to an equilibrium price higher than c implies that the private firm utilizes its capacity (see Figure 2 *a*). Consequently, the public firm sets its capacity equal to $1 - c - x_2$, thus inducing an equilibrium $(z_1, z_2) = (1 - c - x_2, x_2)$ [14]. If the private firm sets a capacity which is higher than c, the allocation along the private firm's reaction function which the public firm prefers most is $(1 - 2c, c)$. At this point the private firm's reaction function intersects the line which reflects the allocations corresponding to an equilibrium price equal to c. Selecting equilibria in its favor, the public firm can induce just this allocation by choosing $x_1 = 1 - 2c$. We conclude that independent of the private firm's capacity choice the equilibrium price is equal to the average cost. Consequently, both firms earn zero profits. Thus a private incumbent would leave the market if government decided to produce the same product. Therefore, there seems to be a distinct first-mover disadvantage with respect to capacity decision. This conclusion is, however, not robust. Let us assume that the private firm's capacity costs are lower than the public firm's cost c by some amount ε. In this asymmetric cost situation, the public firm still behaves as already described in the symmetric case. Obviously if $c \geq \frac{1}{2}$, the private firm deters market entry by setting $x_2 = 1 - c + \varepsilon$. In the second stage it offers the monopoly output $\frac{1 - c + \varepsilon}{2}$. Next, consider the situation in which $c < \frac{1}{2}$. Since the equilibrium price is independent of the private firm's capacity level, the private firm chooses the maximum capacity it can utilize, namely, c. The private firm then realizes a profit equal to $\varepsilon \cdot c$. In comparison to a situation in which the private firm is the entrant, the private incumbent earns a higher market share: however, if ε is arbitrarily small it receives a lower profit. On the other hand, for $1 - 2c$ the equilibrium output of a public entrant is lower than the equilibrium output which a public incumbent realizes in a duopoly in which it is the incumbent ($\overline{x}_1$ or $\hat{x}_1$). Thus if we consider a model in which the capacity decision of the two firms is endogenously determined, an equilibrium results in which the public firm is the first mover in capacity. This also demonstrates that the initial game structure is the correct one.

We should mention that no equilibrium in pure strategies exists if both firms move simultaneously and $c < \frac{1}{2}$. For $c = \frac{1}{3}$ this is illustrated by Figure 7 in which the reaction functions in capacity of both firms are drawn. The shape of the reaction functions has already been explained. Since there is no point of intersection, we have thus proven that our thesis is valid.

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14. Note that we retain the convention of letting the public firm be firm 1 and the private firm be firm 2.

7 A Confrontation with Existing Literature on Strategic Precommitment and Market Entry

A well-known paper concerned with the role of sunk costs in entry deterrence is DIXIT [1980]. In this paper, he considers a model quite similar to our model. The main difference between our models is that he assumes capacity to be variable in the short run. Only the incumbent sets capacity prior to the Cournot-Nash game. This implies that only the incumbent can shift his reaction function. This is done by installing a specific capacity which allows the incumbent to become more flexible in the relevant capacity range. If it sets a high capacity, it signals that it is a " "top dog" (be big and strong to look tough and aggressive) " [15]. " An incumbency advantage (the possibility of early capital accumulation) leads the incumbent firm to accumulate a large capacity (and therefore to charge a low price) in order to limit or deter entry " [16]. It is mainly the irreversibility of the binding commitment of the investment decision which makes an incumbent look like a "top dog". In our model we have seen that sunk costs restrict an

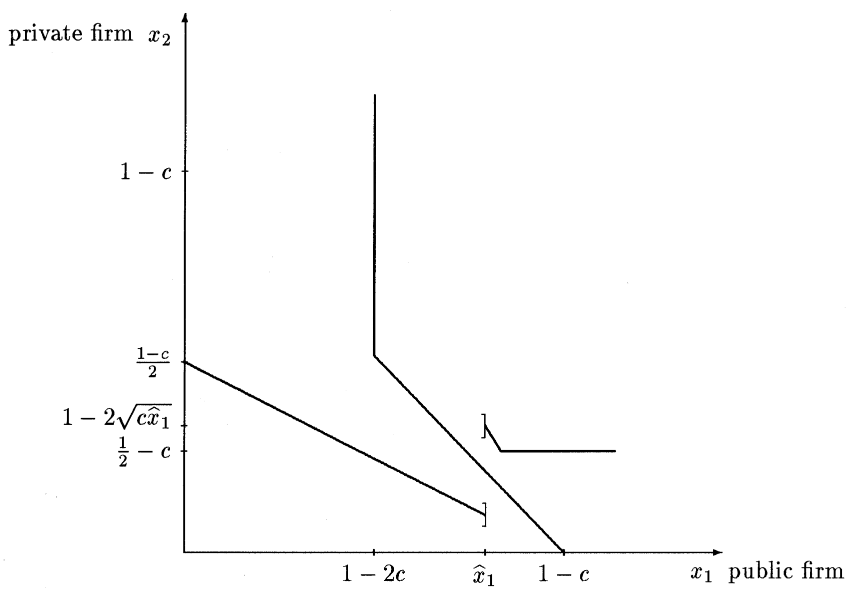

FIGURE 7

15. See TIROLE [1988], p. 328.
16. See TIROLE [1988], p. 306.

output maximizing firm from looking like a "top dog" because if the output maximizing firm becomes too fat, it gets weak. Therefore, in the DIXIT framework, we would choose zero capacity in the first stage in order to be flexible and later capture the whole market. Neither case occurs in our model since we implicitly assume that capacity is not variable in the short run.

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