Entry, Sunk Costs and Renegotiation in Duopoly

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ABSTRACT. – In this paper we examine the relationship between sunk costs, market structure and welfare in a dynamic duopoly model. We consider a model in which two firms make sequential capacity choices and then play a continuous time game in outputs. It is assumed that the equilibria in the quantity choice stage of the game are renegotiation-proof, and study two polar extremes in this set. It is assumed that either firm one or firm two receives all the *ex post* rents. In both cases we find, in contrast to most previous studies, that low sunk costs are associated with low welfare.

Entrée, coûts fixes et renégociation en situation de duopole

RÉSUMÉ. – On examine dans cet article la relation entre les coûts fixes, la structure du marché et le bien-être, dans le cadre d'un modèle dynamique de duopole où les deux entreprises commencent par un choix séquentiel de capacité, puis jouent en temps continu sur les niveaux de production. On suppose que les équilibres à l'étape du choix de capacité sont robustes à la renégociation et on étudie deux cas polaires extêmes parmi ces équilibres. Dans le premier cas, l'entreprise 1 reçoit tous les profits futurs. Dans le second, c'est l'entreprise 2 qui reçoit toutes les rentes. Contrairement aux études antérieures, on trouve que le niveau de bien-être croît avec les coûts fixes.

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The authors would like to thank the Social Sciences and Humanities Research Council of Canada for financial support. The second author is also grateful for the financial support provided by the Dirección General de Investigación Cientifica y Técnica of Spain during a visit to the Universitat Autònoma de Barcelona.

1 Introduction

A question that has received relatively little attention in the literature studying market structure is the relationship between investment decisions and the potential for collusion in concentrated industries. Though it has long been recognized that market conduct [1] and structure are intimately related, recent theoretical work has tended to study one of two questions. [2]

Beginning with the seminal work on limit pricing due to BAIN [1956], MODIGLIANI [1958], and SYLOS-LABINI [1962], there is a large literature that studies the effect of conduct on market structure. In this literature one begins with a model of conduct or price behaviour, and then analyses the consequences for entry deterrence. This work has advanced greatly with the introduction of the concept of perfectness due to SELTEN [1985].

The recent work on conduct uses the theory of repeated games, and begins with the assumption that there is a fixed number of firms. For example the work of FRIEDMAN [1971], and more recently the important work of ABREU [1983], studies the conditions under which cooperative outcomes are perfect equilibria in a dynamic game. [3] The basic result is that when the future is important, or there is some asymmetric information, then there are many possible cooperative equilibria.

In contrast the recent literature which integrates conduct and structure supposes that conduct is the consequence of playing a well defined game, either in prices or quantities. [4] The outcome of this game is usually uniquely defined for any configuration of investment decisions by firms. In equilibrium firms will anticipate the outcome of the conduct game, and make strategic investment decisions that will affect the equilibrium in the conduct game. One of the most important lessons of this literature is that the ability of firms to sink costs *ex ante*, can result in non-competitive market structures. The recent work on contestable markets goes even further to claim that the lack of sunk investments will result in competitive behaviour, even in the presence of large fixed costs. [5]

Though this work is in many respects complementary, whether one stresses conduct or structure in a model can have important policy implications. The work on market structure tends by and large to support the view that a lowering of entry barriers will result in a more competitive and efficient market structure. This view has been at the heart of the deregulation process that is presently being carried out in many countries. The work on

1. By market conduct we mean industry behaviour for a given market structure.
2. For an extensive discussion of these issues see SCHERER [1980].
3. See FUDENBERG and TIROLE [1987] for a comprehensive survey.
4. This literature is now very large. Some prominent examples relevant to our study are BERNHEIM [1984], BULOW, GEANAKOPOLIS, and KLEMPERER [1985], DIXIT [1980], EATON and WARE [1987], GILBERT and VIVES [1986], and WARE [1984].
5. See BAUMOL, PANZAR and WILLIG [1982].

conduct suggests that there are many possible outcomes, some more efficient than others. The implication of these models is that firms left to their own devices will be able to agree upon self enforcing contracts that will result in high prices and supernormal profits. Policy responses to this possibility have included laws against the formation of cartels and price fixing, as well as the public ownership of natural monopolies.

The purpose of this paper is to introduce a simple model to study the relationship between sunk investments and market conduct. One of the first papers to consider this issue is GHEMAWAT and CAVES [1986]. They argue informally that the introduction of conduct into a model with investment decisions would substantially alter the accepted intuition. Essentially, the potential for cooperative behaviour would result in more sunk investment by all firms, rather than entry deterrence. However the major thrust of that paper was not theoretical, but rather to provide some empirical evidence supporting this conclusion.

In a model similar to the one studied here, BENOIT and KRISHNA [1987] analyze a dynamic duopoly with a simultaneous investment decision in the first period, followed by a repeated game in prices. They characterize the set of equilibria for this model, and show that in equilibrium there will generally be excess capacity in the market. However this work does not address the issue of sunk costs, and the way this affects the set of equilibria. Furthermore, the use of a price setting game in the second stage not only limits the ability of firms to share the market in an arbitrary fashion, but is also sensitive to the assumed rationing scheme when the low priced firm is unable to serve the entire market.

The effect of sunk costs on market structure is explicitly analyzed in MACLEOD [1987]. The model considered in that paper is a dynamic oligopoly model with constant marginal costs and fixed entry costs. The major innovation is to characterize the set of equilibria as a function of the fraction of fixed costs which are sunk upon entry. In contrast to the literature on entry deterrence, it is found that increasing the level of sunk costs will increase the set of possible equilibria, and in particular more firms will be able to enter the market in equilibrium when sunk costs are high.

In this paper we will include several features not addressed in the previous papers. We will study a dynamic duopoly in which firms choose capacities in the first period, and play a continuous time game in quantities in the second stage. This approach has several advantages. First, a major issue will be the effect of sunk costs. Like DIXIT [1980], and in contrast to MACLEOD [1987], it will be assumed that sunk costs will affect the marginal cost of production *ex post*. Firms will pay for a capacity decision in the first stage, and then pay a fixed cost per unit up to the capacity limit in the second period. Using a parameterization of costs due to EATON and WARE [1987], sunk costs will be the fraction of costs paid up front during the capacity choice.

The second stage game is a continuous game in output. Though the precise formulation is complex, BERGIN [1988] has shown that the set of equilibria can be easily characterized. In this model the folk theorem for repeated games holds, that is all individually rational payoffs are potential equilibria. Since we are explicitly allowing for collusion, this set is further refined to include only those equilibria that are renegotiation-proof.[6] Viewing the set of equilibria in the market as self-enforcing contracts between firms naturally suggests that they will choose the most efficient equilibrium. Though there are methodological problems with this concept. BERGIN and MACLEOD [1989] have shown that regardless of how one defines this concept for continuous games, it will consist of the full Pareto frontier.

To examine the effect of conduct on market structure we study market structure for two polar cases. In the first case firm 1 receives all the *ex post* rents, while the second case reverses this assumption. In the first case there will always be excess capacity when sunk costs are low, with firm 1 having the largest market share. In fact we find that for both cases, when sunk costs are zero the market will be completely monopolized by the firm receiving the *ex post* rents. Therefore in contrast to much earlier work on market structure, we find that low sunk costs do not imply that the market is more competitive. Furthermore, when sunk costs are low, market structure will be very sensitive to conduct. This suggests that the lowering of entry barriers does not necessarily imply a more competitive market.

The agenda for the paper is as follows. In the following section the basic model is presented. Section 3 studies the continuous time quantity setting game and characterizes the set of renegotiation-proof outcomes. Section 4 analyzes the effect of conduct on market structure, while section 5 contains our concluding comments.

2 The Model and Preliminary Results

The duopoly game is defined as follows. Firm 1 will first choose a capacity level k_1, followed by firm 2's choice of capital, k_2. After capacity choices have been made firms will at each time $t \in [0, \infty]$ choose output $q(t) = \{q_1(t), q_2(t)\}$. At time t, each firm can observe all past output and capacity choices. The output will determine the current price in the market via the inverse demand curve, $p(t) = \mathrm{P}(q_1(t) + q_2(t))$. It will be assumed that $\mathrm{P}(.)$ is continuous and downward sloping. Furthermore, we assume that with $\mathrm{R}(\mathrm{Q}) = \mathrm{QP}(\mathrm{Q})$, there is a unique Q^* such that $\mathrm{R}(\mathrm{Q}^*) = \sup \mathrm{R}(\mathrm{Q})$ and for $\mathrm{Q} < \mathrm{Q}' < \mathrm{Q}^*$, $\mathrm{R}(\mathrm{Q}) \leqslant \mathrm{R}(\mathrm{Q}')$.

The cost of capital for firm i will be $a \cdot c \cdot k_1$. Investment of k_i will allow firm i to produce output $q_i \leqslant k_i$ each period at a cost $(1-a) \cdot c \cdot q_i$. If the firm produces at capacity each period then total costs per period will be

6. See PEARCE [1987], FARRELL and MASKIN [1987] and BERGIN and MACLEOD [1989a] for a discussion of renegotiation proofness in repeated games.

$c \cdot k_1$. Thus the parameter c represents the marginal cost of output *ex ante* when the firm operates at capacity. The parameter a will represent the fraction of these costs that are sunk. When $a=0$, then expanding capacity is free, and there are no sunk costs. For larger a a greater fraction of a firm's costs must be sunk *ex ante.* This structure of costs is identical to the example studied by EATON and WARE [1987].

Given this cost structure and a capital-output path, $s=\{k_1, q_1(.), k_2, q_2(.)\}$, and interest rate r, the profits of firm i will be given by:

$$\Pi_i(s) = r \int_0^{\infty} (P(q_1(\tau)+q_2(\tau)) - (1-a)c)\, q_i(\tau)\, e^{-\tau r}\, d\tau - a \cdot c \cdot k_i$$

For notational convenience profits will be given as a flow. The discounted present value will simply be $\Pi_i(s)/r$. The formal definition of strategies and histories for this continuous time game is beyond the scope of the present paper. A detailed discussion of continuous time models and the proofs of the results used in this paper may be found in BERGIN [1988] and BERGIN and MACLEOD [1989]. Intuitively, the continuous time formulation implies that firms will be able to respond instantly to their competitors actions. Though technically complex, the continuous time model will result in a very simple characterization of the set of equilibrium payoffs.

Given capacity choices for the firms, the payoff structure is time invariant and therefore we will study equilibria in which output is not varying over time. A stationary allocation is given by $x=(k,q)\in\mathbb{R}^4_+$, where $k=(k_1,k_2)$ and $q=(q_1,q_2)\leqslant k$.[7] Using slightly abusive notation, the profits per period of firm i at allocation x will be given by:

$$\Pi_i(x) = (P(q_1+q_2) - (1-a)c)\, q_i - a.c.k_i$$

As has been stressed by several authors (particularly DIXIT [1980] and EATON and WARE [1987]), it is important to model firms making optimal decisions at every point in time. Therefore, we will focus exclusively on equilibria which are sub-game perfect. Formally the concept of sub-game perfection requires that at every point in time, t, and for any possible combination of past moves, the equilibrium strategies will form a Nash equilibrium from time t onward. In the next section we will characterize the effect of capital choice on the set of perfect equilibria in the quantity choice game.

3 The Effect of Capital on Conduct

In investment games, such as this one, the choice of capital stocks by firms will affect the set of perfect equilibrium outputs in the second stage

7. If $x, y \in \mathbb{R}^n$, $x \leqslant y$ means $x_i \leqslant y_i$, for all $i=1, \ldots, n$.

of the game. It does so by affecting the ability of firms to punish each other when there is a defection from an agreed upon output path. In fact ABREU [1983] has shown that the set of perfect equilibria are completely characterized by the output paths that provide the most severe punishment to a defecting firm. For general quantity setting games the explicit construction of these punishments can be very complex. However, for certain classes of continuous time games characterizing the set of perfect equilibria is very simple. In the present model essentially "all" outcomes can be supported by some perfect equilibrium.

At any point in time the present value of the flow profits of a firm is bounded below by the individually rational payoff. This is the profit that firm i would get when firm j attempts to lower firm i's profit as much as possible. In the case of the Cournot model this will occur when firm j chooses the largest possible output. More formally, given capital stocks, firm i's individually rational outcomes is given by:

$$v_i(k) = \max\{\Pi_i(k, q) \mid q_i \in [0, k_i], \text{and } q_j = k_j\}$$

The set of feasible individually rational outcomes for given capital stocks will be defined by:

$$F(k) = \{\Pi_i(k, q), \Pi_2(k, q) \mid \Pi_i(k, q) \geqslant v_i(k),\ i = 1, 2, q \in [0, k_1] \times [0, k_2]\}$$

(Note that in this model, both $v_i(k)$ and $F_i(k)$ depend on a. This is important to note as we vary a over [0, 1] later. However, for simplicity of notation this dependence will not be made explicit.) Capital choices made in the first stage of the game will affect the outcome in the output stage of the game via their effect on the individually rational outcomes. This dependence follows immediately from the following proposition due to BERGIN [1988].

PROPOSITION 1: Given the capital choice k, $x = (k, q)$ will form a perfect equilibrium outcome if and only if $\{\Pi_1(k, q), \Pi_2(k, q)\} \in F(k)$.

This is a version of the well known folk theorem for repeated games. [8] It states that every individually rational outcome can be supported by some equilibrium strategy (see for example FUDENBERG and MASKIN [1986]). In particular both the Cournot-Nash equilibrium and the joint profit maximizing outcomes are potential equilibria. Therefore the requirement that firms play equilibrium strategies places few restrictions on the behaviour of firms.

When there exist multiple equilibria in the post entry game, and firms are assumed to play one of these equilibria, it must be the case that they

8. In our formulation there is less tension between price setting and quantity setting games. In capacity constrained games such as this one the use of price as the strategic variable necessarily involves a rationing scheme. If the rationing schemes rations agents with a low reservation price first then the individually rational payoffs in the quantity game and the price game will be the same. Since this is the most pessimistic rationing scheme for the firm being punished, this implies that for all other rationing schemes the individually rational payoffs should be higher.

have correct expectations about their competitors actions. Normally the process by which expectations are made consistent is not modeled, though it is often supposed that there is some form of preplay communication that will allow firms to coordinate their actions *ex post*. In this paper let us suppose that communication is always possible, although it will not be modeled explicitly. This assumption will place some restriction on the set of equilibria that one would expect rational firms to choose.

If firms can communicate then one would expect them to choose the most efficient equilibrium (where one firm cannot be made better off without worsening the position of another) from the set of possible perfect equilibria. A great deal of competition law is in fact predicated on the assumption that firms in a concentrated industry if left to their own devices will collude. Therefore it is reasonable to ask what market structure and performance will be like under such an assumption.

Unfortunately simply requiring firms to select an efficient equilibrium is not necessarily a consistent criterion. For example consider a Bertrand price setting game that is played repeatedly. If firms have constant marginal costs then all the perfect equilibrium outcomes can be supported by strategies that punish firms by moving to marginal cost pricing after cheating has occurred. However if firms can communicate then they will have an incentive to move back to a more cooperative equilibrium that will make both firms strictly better off. In this case assuming that firms are rational, in the sense that they will always choose efficient strategies, will make the threats used to support the cooperative equilibrium not credible.

Recently, Farrell and Maskin [1987] and Pearce [1987] have introduced a restriction on the set of perfect equilibrium for repeated games called *renegotiation-proofness*. This restriction takes account of the fact that agents may have the incentive to renegotiate to better continuation payoffs' (the present values of the payoff streams over the remainder of the game), following some histories – in which case the corresponding equilibrium ought not to be considered immune to renegotiation. Subgame perfect equilibria that incorporate the incentives agents have to renegotiate are called *renegotiation-proof*. There is not full agreement on a formal definition of renegotiation-proofness, in part because of problems in finding a definition compatible with existence of renegotiation-proof equilibria. However in the present continuous time framework there is a natural candidate. A set of strategies will be called *renegotiation-proof* if for any possible history of the game, and at any time, there does not exist another set of equilibrium strategies that Pareto dominate the current continuation payoff (*i.e.* the continuation payoffs under the candidate strategies at the history and time period in question). Any outcome (or payoff vector) determined by a set of renegotiation-proof strategies will be called a renegotiation-proof outcome (or renegotiation-proof payoff vector). In general there will not exist equilibria that are renegotiation-proof by this definition. In the case of continuous time games Bergin and MacLeod [1989] have a generic existence result. This result will not be formally developed here, we will simply apply this result to the current game. A necessary condition for renegotiation-proofness is that the corresponding outcome be Pareto efficient, as the following result states, this will also be a sufficient condition.

PROPOSITION 2: Given the vector of capital stocks k, an outcome x will be renegotiation-proof if and only if it is Pareto efficient in the *ex post* quantity game. Namely $\{\Pi_1(k,q), \ \Pi_2(k,q)\} \in \Phi(k)$, where $\Phi(k) = \{\pi \in F(k) \mid \text{there does not exist } \pi' \in F(k), \text{ such that } \pi' \geqslant \pi, \ \pi' \neq \pi.\}$.

This result shows that the individually rational payoffs on the Pareto frontier in the continuous time game are all renegotiation-proof. Therefore, if firms "agree" upon an equilibrium with payoffs in $\Phi(k)$, then if cheating occurs the cheater will be punished with a strategy that is itself efficient. Hence once "agreement" is reached there will never be any incentive to renegotiate.

For the present game even the concept of renegotiation-proofness does not select a unique equilibrium. The choice of a particular equilibrium outcome may be interpreted as defining market conduct. Thus even when firms can communicate, and hence choose only renegotiation-proof outcomes, market conduct will affect market structure. To understand the relationship between conduct and structure in this model we will consider two extreme cases.

The first is that firm 1 has a first mover advantage that is used to select the equilibrium most favourable to firm 1. Under this assumption firm 2 will only get the individually rational payoff $v_2(k)$ – call this assumption A. The second possibility involves the first mover obtaining the individually rational payoff $v_1(k)$. We will call this assumption B. To indicate the persepctive behind these polar assumptions consider the first possibility. This assumption is interesting in that it gives firm 2 the most pessimistic level of profits upon entry, and therefore if firm 2 enters in this case, it will enter in all the other equilibria of the game.

Secondly this assumption will allow us to evaluate the consequences of encouraging one firm to become in essence an industry leader. On the other hand, the behaviour implied by the second assumption gives the incumbent the most pessimistic assessment of its deterrence power. If the incumbent successfully deters entry in this case, it will deter entry in any case. Thus we may view these two cases as the polar extremes of behaviour within the set of renegotiation-proof equilibria. These two possible assumptions are more formally:

ASSUMPTION A: Given k, the equilibrium payoffs will be given by,

$$(\pi_1^A(k), \pi_2^A(k)) \equiv \pi^A(k) \equiv \underset{\pi \in \Phi(k)}{\operatorname{argmax}} \, \pi_1.$$

ASSUMPTION B: Given k, the equilibrium payoffs will be given by

$$(\pi_1^B(k), \pi_2^B(k)) \equiv \pi^B(k) \equiv \underset{\pi \in \Phi(k)}{\operatorname{argmax}} \, \pi_2.$$

The properties of $\pi^A(k)$ and $\pi^B(k)$, and the resulting market structure will be discussed in the following section. Finally it should be noted that we apply the concept of renegotiation-proofness to the second stage only, and not to the full game. While it is possible that firms cooperate over the choice of capacity, it is more in keeping with the separation between conduct and structure to view the first stage as occurring with no explicit coordination. Since the second stage involves a long term relationship, then it is more reasonable to suppose that some coordination, either explicit or implicit, occurs at this time.

4 Market Structure

Let us begin by noting that under both assumptions A and B, an equilibrium will exist. Note that $\pi^{M}(k)$, $M \in \{A, B\}$, is a continuous function of k. Furthermore firms will never choose $k_i > \bar{Q}$, for some $\bar{Q} < \infty$ and therefore capacity choice will be from the compact set $[0, \bar{Q}]$.[9] Under these assumptions we have the following proposition which follows directly from a theorem of Hellwig and Leininger (1987).

PROPOSITION 3: For both assumptions A and B there exists a subgame perfect equilibrium for the market game. That is there exists a capitcal stock k_1^M and a function $k_2^M(k_1)$, such that:

$$k_1^M \in \underset{k_1}{\operatorname{argmax}}\, \pi_1^M(k_1, k_2^M(k_1)) \text{ and,}$$

$$k_2^M(k_1) \in \underset{k_2}{\operatorname{argmax}}\, \pi_2^M(k_1, k_2) \quad \text{for all } k_1.$$

The following propositions will provide some characterization results. One of the important issues in the analysis of market structure is the ability of incumbent firms to deter further entry. Under assumption A, it is relatively easy for firm 1 to deter entry by firm 2.

4.1. Market Structure under Assumption A

Let us now consider that effect that assumption A will have on market structure. Under assumption A, firm 1 will collect all the *ex post* surplus in the output market. This will in general make entry deterrence quite easy.

PROPOSITION 4: A necessary and sufficient condition for firm 1 to deter entry under assumption A is that firm 1 produces sufficient capacity to force the market price below c, the marginal cost. More formally $k_2(k_1) = 0$, if and only if $P(k_1) \leqslant c$.

Proof: Under assumption A the profit of firm 2 is given by $k_2(P(k_1 + k_2) - c)$. By the continuity of $P(.)$, if $P(k_1) > c$, then firm 2 will

9. Since $a > 0$ and instantaneous revenue is bounded, there is some $\bar{Q}$ such that if $K_i > \bar{Q}$, $\Pi_i(s) < 0$. Thus K_i will never be choosen larger than $\bar{Q}$.

make strictly positive profits for some $k_2 > 0$. Clearly, if $P(k_1) \leqslant c$ then firm 2 will always set $k_2 = 0$. □

Notice that the level of sunk costs does not affect the level of capacity needed to deter entry. However these costs will affect the costs of entry deterrence. For example suppose that $a=0$, that is capacity is free, then the firm will always chose sufficient capacity to deter further entry. Though this result is immediate in the present framework, it is counter intuitive. Most work on market structure stresses the role of sunk costs in deterring entry. For example EATON and WARE [1987] have an example with the same cost structure as we use here, however they find that when a is small this will encourage entry and there is no excess capacity. In this model we have exactly the opposite result as summarized in the following proposition.

PROPOSITION 5: Under assumption A, when there are no sunk costs, ($a=0$), entry is always deterred, and there is excess capacity in equilibrium.

If costs are completely sunk upon entry this will imply that under certain conditions there will always be further entry.

PROPOSITION 6: Suppose that $a=1$, then for c sufficiently large (but less that $\bar{p}$), firm 2 will always choose to enter.

Proof: To show this result choose $c \geqslant P(Q^*)$, where Q^* is the output that maximizes *ex post* revenue, *i.e.* $Q^* = \operatorname{argmax} QP(Q)$. Let $\bar{K}$ satisfy $P(\bar{K})$. Since $P(Q^*) \leqslant c$, this implies $\bar{K} \leqslant Q^*$. To deter entry, firm 1 must choose $K_1 \geqslant \bar{K}$. If entry is deterred then $K_1 \geqslant \bar{K}$ and firm 1 solves $\max_{q \leqslant K_1} QP(Q) - cK_1$. Suppose $\tilde{Q}$ solves this problem. Note that $\tilde{Q} = K_1$ if $K_1 < Q^*$, otherwise $\tilde{Q} = Q^*$. Firm 1's profit is $(P(\tilde{Q}) - c)\tilde{Q} - c(K_1 - \tilde{Q})$. Since $P(\tilde{Q}) \leqslant c$ and $K_1 \geqslant \tilde{Q}$, profit is not positive. Accommodating firm 2 will result in an equilibrium at which both firms earn strictly positive profits. Therefore firm 1 will not deter entry. □

In the following discussion we focus on the case of linear demand – thus $P(Q) = d - bQ$. Recall that $v_1(k_1, k_2)$ denotes the individually rational payoff to player i for fixed capital stocks. Consider first the case where the incumbent takes all the surplus and the follower obtains his individually rational payoff (assumption A). To determine the values of (k_1, k_2) and (q_1, q_2), observe that if firm 1 chooses k_1 then since 2 (the follower) will obtain his individually rational level, the choice of k_2 is determined by solving $\max_{k_2} v_2(k_1, k_2)$. This determines a function $k_2(k_1)$. Hence we see that $v_2(k_1, k_2(k_1)) = \max_{k_2} [(d-c) - b(k_1 + k_2)] k_2$. For fixed values of k_1 and k_2, efficiency requires that q_1 and q_2 be chosen to solve:

$$\max_{q_i \leqslant k_i} \{ [d - b(q_1 + q_2)](q_1 + q_2) - c[(1-a)(q_1 + q_2) + a(k_1 + k_2)] \}.$$

Thus to determine the values of the four variables we solve the program:

$$\max_{k_1}\Big\{ \max_{\substack{q_1 \leqslant k_1 \\ q_2 \leqslant k_2(k_1)}} \{[d-b(q_1+q_2)](q_1+q_2)-c[(1-a)(q_1+q_2) + a(k_1+k_2)]\} - v_2(k_1, k_2(k_1))\Big\}.$$

This program has the following solution.

Case 1: $(d-c)-2\,ca>0$.

$$k_1=\frac{(d-c)-ca}{b},\qquad q_1=\frac{1}{2b}\left(\frac{[(d-c)+ca]^2-3\,c^2a^2}{(d-c)+ca}\right)$$

$$k_2=\frac{ca}{2b},\qquad q_2=\frac{3}{2b}\left(\frac{c^2a^2}{(d-c)+ca}\right).$$

The equilibrium profits are given by:

$$\pi_1=\frac{1}{4b}\{[(d-c)-ca]^2+c^2a^2\}\qquad\text{and}\qquad \pi_2=\frac{1}{4b}\{c^2a^2\}.$$

Case 2: $(d-c)-2\,ca\leqslant 0$.

In this case both firms are capacity constrained. The values of the capital stocks are:

$$k_1=q_1=\frac{(d-c)}{2b},\qquad k_2=q_2=\frac{(d-c)}{4b}.$$

The corresponding profit levels are:

$$\pi_1=\frac{1}{8}\frac{(d-c)^2}{b}\qquad\text{and}\qquad \pi_2=\frac{1}{16}\frac{(d-c)^2}{b}.$$

Note that these are the Stackleberg quantities! For c sufficiently small we will be in case 1. In this case, in contrast to the results of EATON and WARE [1987] and VIVES [1987], there will be excess capacity in the market regardless of the level of sunk costs.

In the example considered by EATON and WARE [1987] one has $a=2$, $b=1$ and $c=1$. Here we consider the same example for $c=1.5$ and 0.5. Market structure as a function of sunk costs when $c=0.5$ is shown in Figure 1. When sunk costs are low then it is not costly for the first firm to invest in excess capital that will lower the profits of firm 2. As sunk costs rise the cost of this entry deterring strategy rises, which has the effect of allowing more entry by firm 2, and lowering the amount of excess capacity in the market.

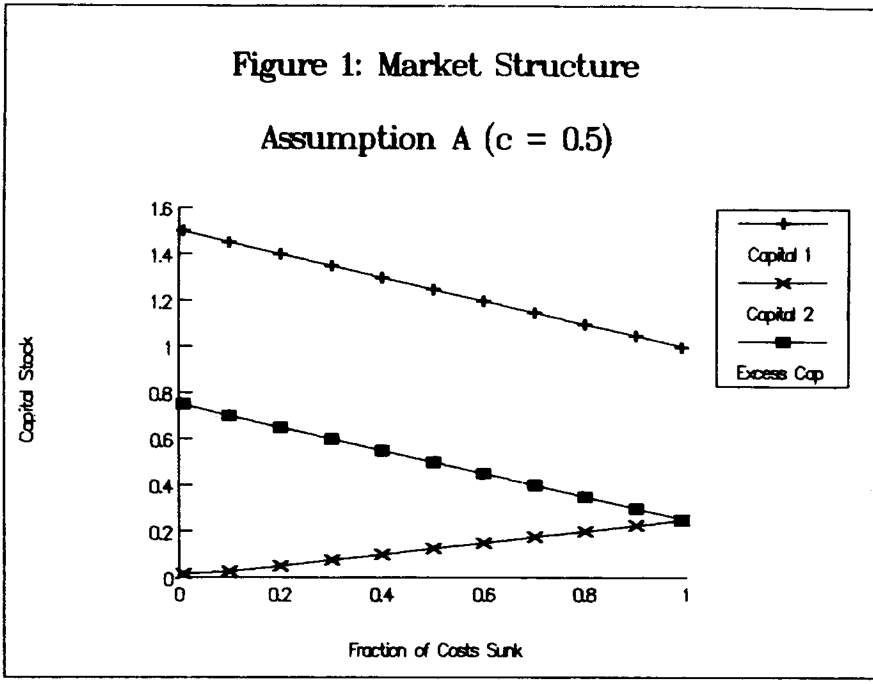

FIGURE 1

Market Structure

In Figure 2 it is shown that raising sunk costs has the effect of first lowering and then eventually raising welfare.[10] As sunk costs rise total profits fall, which combined with the effect of welfare results in consumer surplus rising with sunk costs. The case of $c = 1.5$ is shown in figures 3 and 4. In this case as sunk costs are increased one quickly approaches the Stackleberg equilibrium.

In all cases firm one is larger than firm two in equilibrium. Further, low sunk costs will in general imply lower total welfare in the market.

4.2. Market Structure Under Assumption B

The other extreme possibility we consider is that where the incumbent receives his individually rational level in the quantity subgame – after the levels of capital stock are chosen (assumption B). In this case firm 2 receives all the surplus in the quantity setting stage of the game. Even though firm

10. Welfare is simply the standard sum of producer and consumer surpluses. If Q* and K* are the total output and capital stock respectively then welfare is given by $W = \int_0^{Q*} P(q)\,dq - c(aK^* + (1-a)Q^*)$.

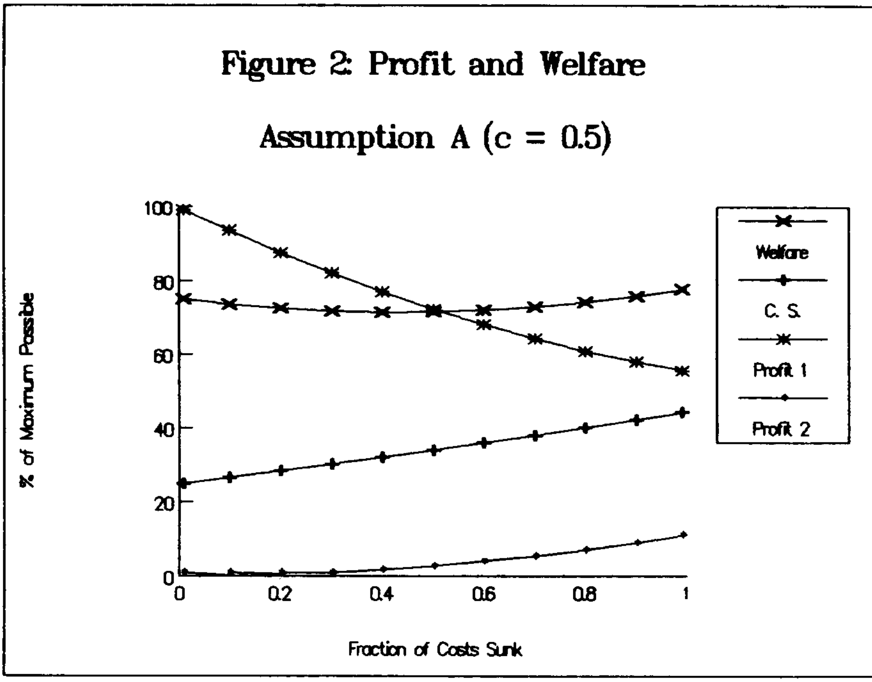

FIGURE 2

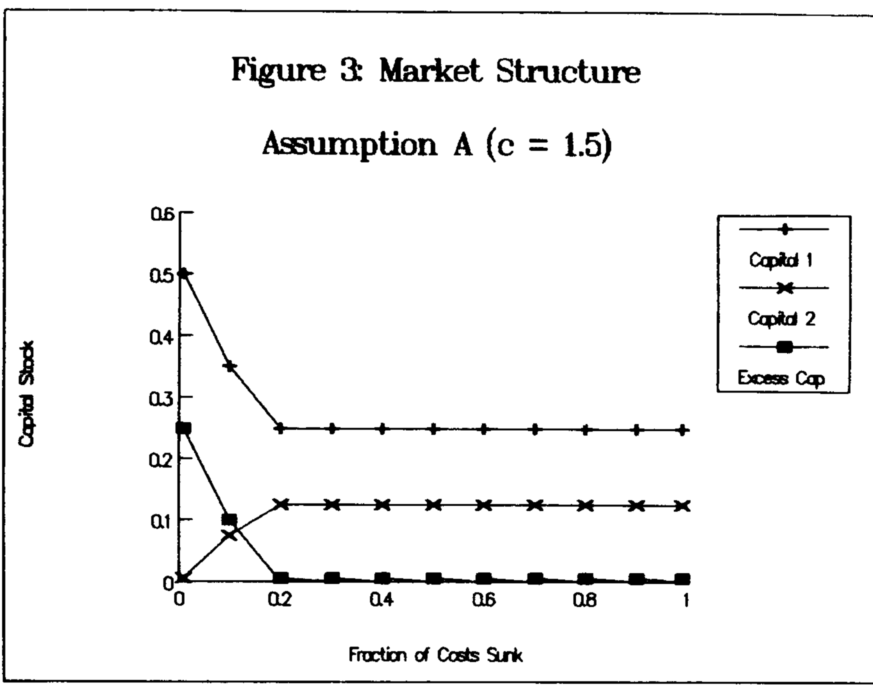

FIGURE 3

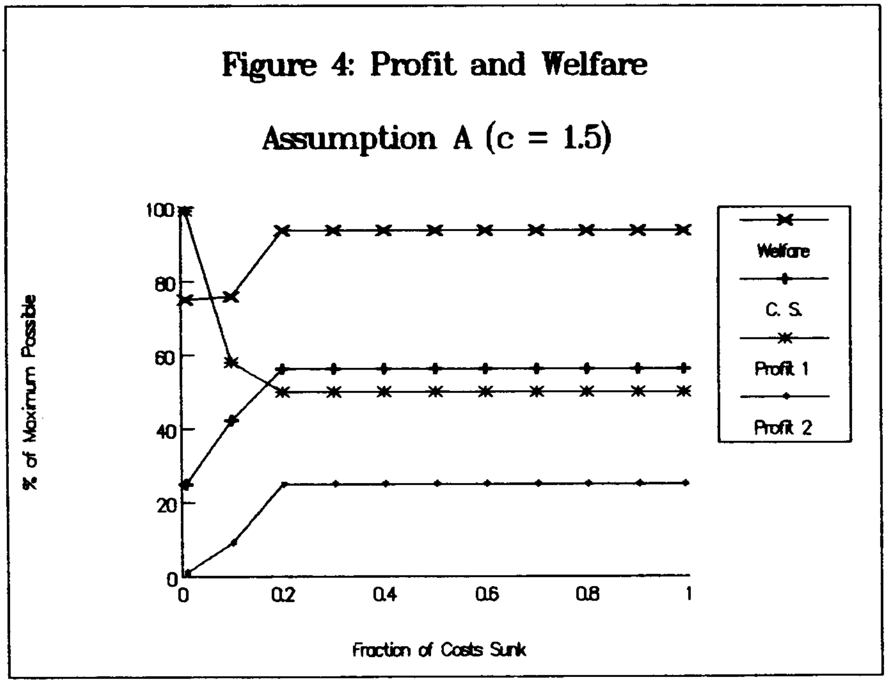

FIGURE 4

Profit and Welfare

1 has the first mover advantage in capital choice, when sunk costs are low firm 2 will be able to effectively keep firm 1 out of the market.

PROPOSITION 7: Under assumption B, if there are no sunk costs, $(a=0)$, then at every equilibrium firm 1 earns zero profit. Furthermore these equilibria are all equivalent to the equilibrium at which firm 1 sets $k_1=0$, and firm 2 sets $k_2=q_2=Q^m$, the monopoly solution.

This result follows directly from the fact that should firm 1 choose a positive level of capital, firm 2 can without cost force firm 1's profits down to less than zero. Therefore firm 1 has no incentive to enter. As long as the set of equilibrium payoffs are continuous in sunk costs (as they are for example in the linear case). then this result states that for low level of sunk costs firm 2 will act as a near monopoly.

Let us now consider the linear case under assumption B. As before efficiency requires that q_1, q_2 satisfy:

$$\max_{q_i \leq k_i} \{ [d-b(q_1+q_2)](q_1+q_2)-c[(1-a)(q_1+q_2)+a(k_1+k_2)] \}.$$

For fixed k_1 the program now becomes

$$\max_{k_2} (\max_{\substack{q_1 \leq k_1 \\ q_2 \leq k_2}} \{ [d-b(q_1+q_2)](q_1+q_2) - c[(1-a)(q_1+q_2)+a(k_1+k_2)] \} - v_1(k_1, k_2)).$$

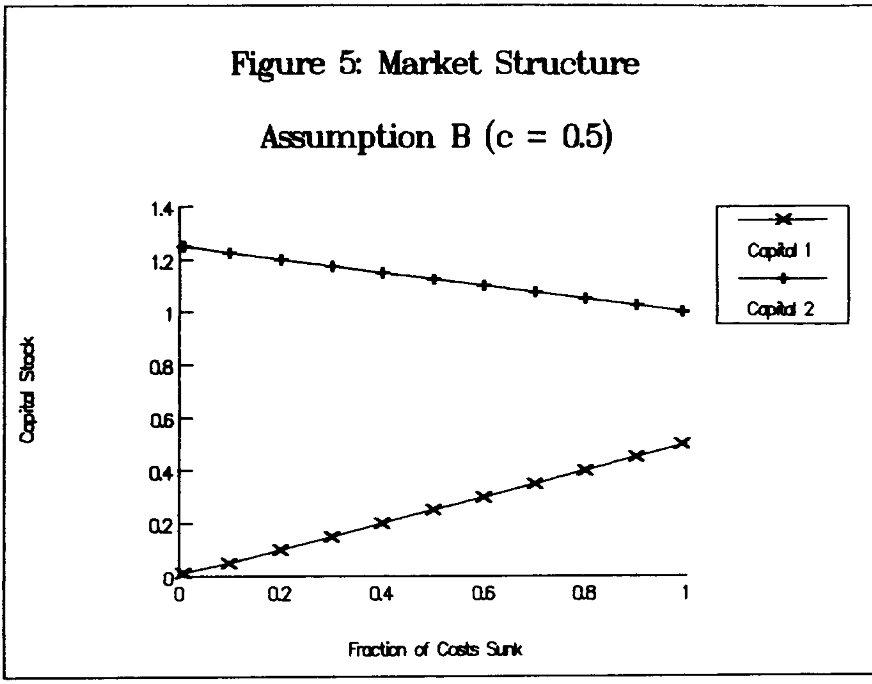

FIGURE 5

Market Structure

This determines k_2 as a function of k_1, $k_2(k_1)$. The solution for k_1 is obtained from the program: $\max_{k_1} v_1(k_1, k_2(k_1))$.

Solving this program yields capacities, quantities and profits as follows:

Case 1: $(d-c) \geqslant 2ca$

$$k_1 = q_1 = \frac{ca}{b}, \qquad k_2 = q_2 = \frac{[d-c(1+a)]}{2b}$$

$$\pi_1 = \left(\frac{[d-c(1-a)]}{2}\right)\left(\frac{ca}{b}\right), \qquad \pi_2 = \left(\frac{[d-c(1-a)]}{2}\right)\left(\frac{[d-c(1+a)]}{2b}\right)$$

Case 2: $(a-c) \leqslant 2ca$

$$k_1 = q_1 = \frac{[d-c]}{2b}, \qquad k_2 = q_2 = \frac{[d-c]}{4b}$$

$$\pi_1 = \frac{[d-c]^2}{8b}, \qquad \pi_2 = \frac{[d-c]^2}{16b}.$$

In figures 5 to 8 the effect of sunk costs on market structure and welfare is displayed for c equal to 0.5 and 1.5. Notice that for the high marginal cost case the equilibrium quickly converges to the Stackleberg outcome, with firm 1 having the largest market share when costs are completely sunk.

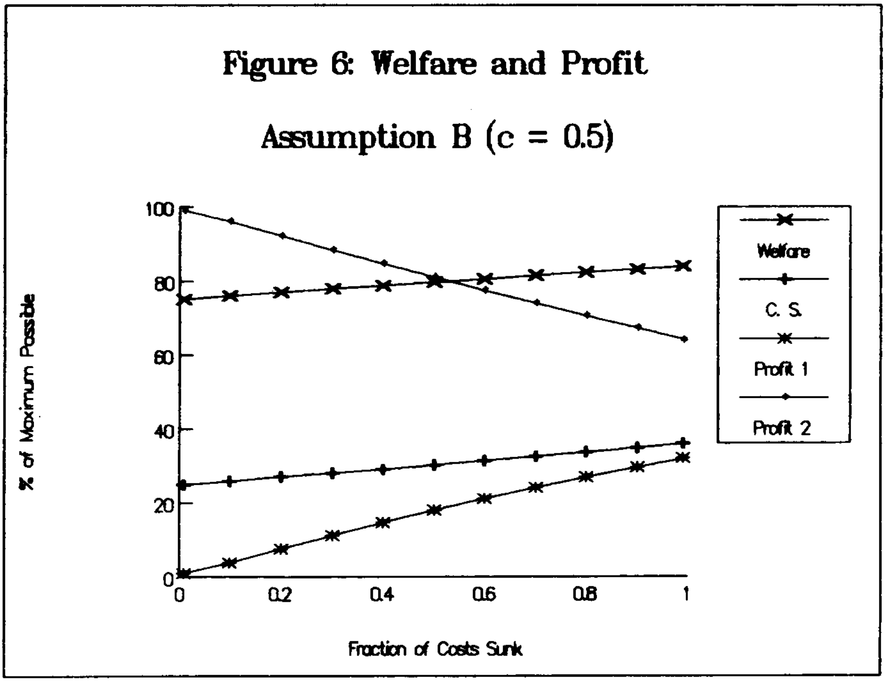

FIGURE 6

Welfare and Profit

In both cases firm 2 is a monopolist when there are no sunk costs, while the size of firm 1's capital increases with increases in sunk costs. In neither case is there excess capacity. The reason is that firm 2 threatens firm 1 with a discrete increase in capacity if firm 1 chooses $k_1 > ac$.

As under assumption A, welfare tends to fall, then rise with sunk costs when $c = 0.5$. For the high level of marginal costs welfare and consumer surplus increase monotonically with sunk costs. In both cases the situation in which costs are completely sunk corresponds to the highest level of welfare.

5 Concluding Discussion

In this paper we have studied the relationship between market structure and conduct behaviour for different levels of sunk costs. As in DIXIT [1980], and EATON and WARE [1987] sunk costs were modeled in terms of their effect on marginal costs of production *ex post*. It is generally believed that sunk costs tend to create non-competitive market structures by giving an

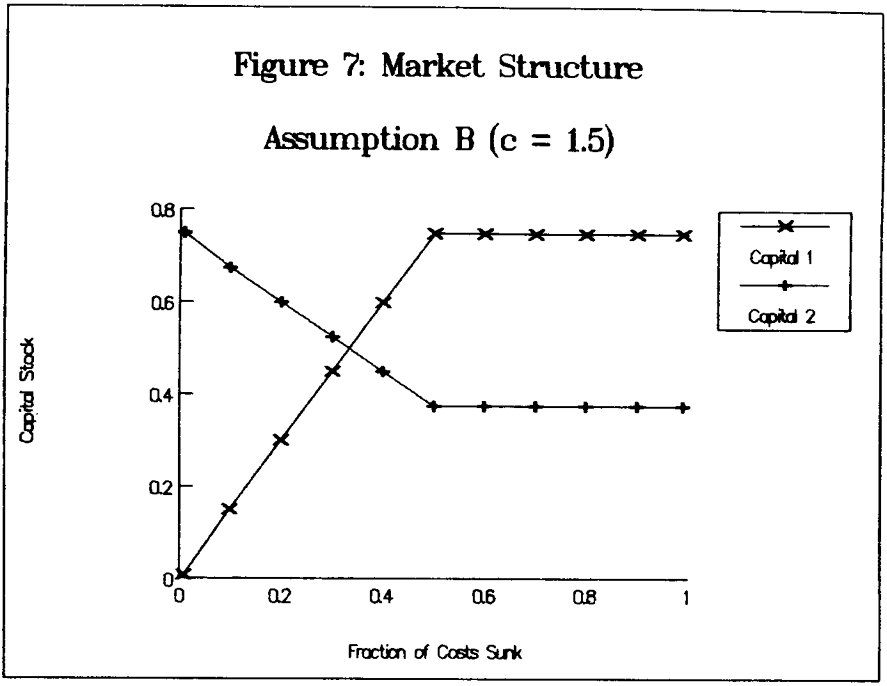

FIGURE 7

Market Structure

advantage to the first mover. We find that even when the first mover can extract all the surplus *ex post* this conclusion is not in general correct. In our examples it is always the case that welfare and consumer surplus were highest when costs were completely sunk. The basic results would be even more striking in a multi firm context. If there were additional entry this would give even more incentive for the firm collecting the *ex post* rents to hold excess capacity, and thereby lower welfare.

One of the lessons of our analysis it that market structure is very sensitive not only to sunk costs, but also to the nature of conduct. If sunk costs are high then in general the first mover has an advantage. Furthermore, we found that when marginal costs and sunk costs were high then conduct had little effect on the market structure and performance. In this case, as we can see from the results of VIVES [1987], increasing the pool of potential entrants will in general be welfare enhancing.

Despite the simplicity of the model, we feel that this work has two interesting implications. First at a theoretical level, if one takes the potential for collusion seriously then one is unlikely to obtain a satisfactory theory of market structure taking only tastes and technology as exogenous.

Secondly, the recent view that low sunk costs imply that the market will be approximately competitive seems to be misguided. In the present model sunk costs, (as in EATON and WARE [1987]), were modeled in terms of the fraction of variable costs that must be sunk up front. We found that in the

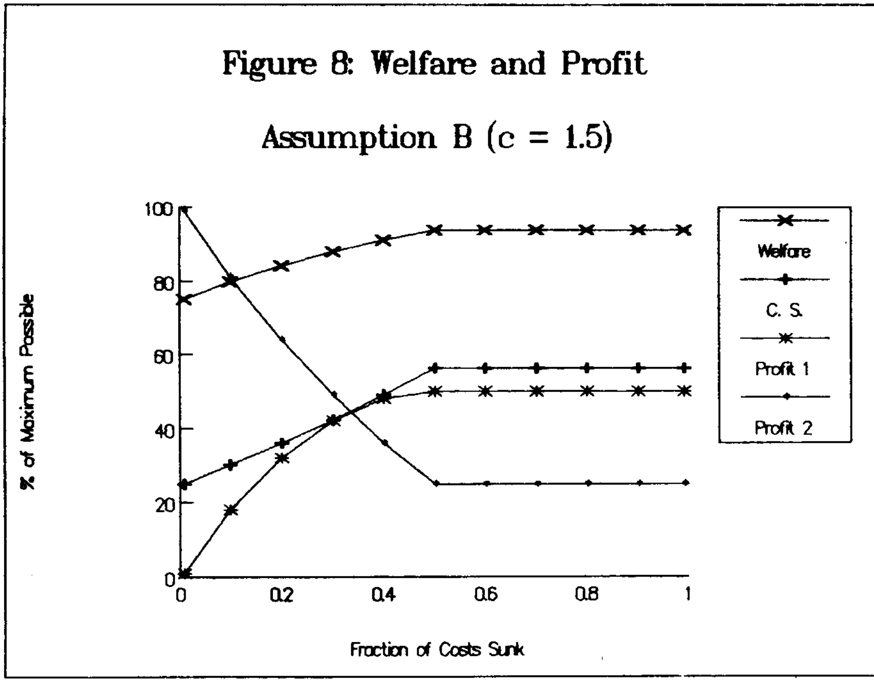

FIGURE 8

Welfare and Profit

presence of low sunk costs, and capital precommitment, the market for in two extreme behavioural assumptions will be close to a monopoly. Allowing further entry will only reinforce this result. These results also tend to support earlier work by MACLEOD [1987] where it is shown that in the presence of fixed costs that are not sunk, monopoly will always be an equilibrium.

The existence of low sunk costs does not by itself imply that the market will be competitive or efficient. Lower sunk costs if anything increase the potential for cooperation, and therefore the size of the rents available to firms who can achieve market leadership. One of the ways this is achieved is through the investment in excess capacity. In such a market competition law directed towards non-competitive conduct may be efficiency enhancing.

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