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A Sequential Entry Model with Strategic Use of Excess Capacity

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DISCUSSION PAPER #835

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Abstract: A model of sequential entry with Leontief costs is studied in which demand is iso-elastic. Some or all firms may hold excess capacity in the perfect equilibrium to the entry game. Firms with a first mover advantage trade off the positioning value of a large investment in capacity, leading to a large market share, against the possible costs of bearing the burden of entry deterrence through holding excess capacity in equilibrium.

Introduction

In a recent article, Bulow, Geanakoplos, and Klemperer (BGK(1985)) demonstrate using a two-firm, two-stage game that excess capacity can serve as a credible entry deterring strategy when demand is iso-elastic. Their result is in sharp contrast to the majority of capital commitment models of entry deterrence (Dixit (1980), Eaton and Lipsey (1981), Eaton and Ware (1987), Gilbert (1986), Spulber (1981), and Ware (1984)), in that in entry deterrence equilibrium the BGK incumbent holds excess capacity which is idle and would be utilized to expand output only in the event of entry. In many respects the BGK results are more consistent with the empirical evidence on the strategic use of excess capacity, reported for example, by Esposito and Esposito (1974), Cossutta and Grillo(1986), Reynolds (1986), Lieberman (1987), and Barham (1989).

In this paper we present a sequential entry model of investment[1] with the BGK framework of iso-elastic demand. Our purpose is to investigate the way in which excess capacity is used as strategic instrument in a framework of multiple incumbent firms. Broadly speaking, two forces govern the equilibrium level of investment of a typical firm in a sequential entry framework. First, investment has a *positioning* component: it may give the firm some strategic advantage over its rival firms in the market. Second, each firm's investment contributes to *entry deterrence*: it creates strategic barriers to the profitable entry of firms.

In contrast to the two-firm game, investment in entry deterrence has a public good aspect in a multiple firm framework. Each firm's investment in entry deterrence will benefit all incumbent firms equally, but the costs must be incurred privately. Two features of this non-

[1] The sequential entry methodology permits the number of firms and their size distribution to be determined endogenously as part of the equilibrium (see e.g. Eaton and Ware (1987)). This is accomplished by assuming the existence of a large but finite number of firms, more than could profitably enter the industry, each making an investment choice in sequence. These investments must be sunk, otherwise they would have no strategic value. The initial sequence or *identity* of the firms is arbitrary. Each firm makes its choice knowing the choices of its predecessors and with complete information about the structure of the game. A choice of zero in capacity is effectively a choice not to enter. A market equilibrium (Cournot in this paper) is then realized in the final stage, conditioned on the sequence of sunk investments, and so involving only those firms with positive capacities.

cooperative nature of investment in entry deterrence which have been discussed in other work are *delegation* and *underinvestment*.[2] Delegation refers to the incentive of early entrants in the sequence of investment not to do their full share of entry deterrence in the knowledge that later entrants will be forced to pick up the slack, because these later entrants have a strong incentive to deter further entry. Underinvestment occurs when this process of coordination breaks down, in a classic prisoner's dilemma fashion. As a result, the collective entry deterrence efforts of the incumbent firms, acting individually and non-cooperatively, amount to less than a jointly optimal amount of investment, based on cooperative investment decisions.

Our model adopts the BGK framework of constant elasticity demand and Leontief costs, and extends it to a sequential entry model in which firms with identical technologies invest, in an arbitrary sequence, in capacity.[3] The final stage of the game is a (constrained) Cournot equilibrium in quantities. We show the existence of equilibria in which some or all producing firms hold excess capacity as an instrument of entry deterrence. Delegation also occurs with early entrants forcing later movers to incur a greater than equal share of excess capacity costs. Investment has a positioning value as well as making a contribution to entry deterrence. Thus, in some cases positioning opportunities outweigh delegation opportunities, and the earlier entrant holds all of the entry deterring capacity. We have not generated examples of underinvestment in this model; it remains, however, a theoretical possibility.

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[2] See Gilbert and Vives (1986), McLean and Riordan (1989), Waldman (1987) and (1988), and Tirole(1988).

[3] In contrast to Dixit (1980) and BGK (1985), we treat the investment stage as distinct in a strategic timing sense from the quantity game. The distinction, although of qualitative significance, is important. See Ware (1984) for an analysis of this issue.

The Structure of the Sequential Entry Model

Costs

All firms possess identical Leontief cost functions $C(x_i , k_i) = f + c(\alpha k_i + (1 - \alpha)x_i)$, where $x_i \leq k_i$. α is a parameter which captures the proportion of unit production costs which are sunk before production takes place. Leontief costs are assumed in order to keep the focus of attention on excess capacity which is literally unused. With a variable proportions technology, firms may overinvest in capacity in order to increase their market share, but this is excess capacity only in the sense that it is not cost minimizing, not in the sense of being unused in equilibrium.[4]

It is common in models based on a Cournot equilibrium to assume the *Hahn-Novshek condition*: that each firm's marginal revenue is decreasing in the output of rival firms.[5] In symbols, $p' + x_i p'' < 0$, where $p(\bullet)$ is the inverse demand function. Generally, this condition serves the purpose of ensuring the existence of a Cournot equilibrium. However, in capacity commitment models, it also guarantees that it would never pay any firm to hold excess capacity as a barrier to entry. The reason is that, for any given capacity, new entry would lower the marginal revenue of all incumbent firms, and hence any capacity unused in the pre-entry equilibrium would certainly be unused in the post-entry game. While the Hahn-Novshek restriction has convenient analytical properties, it removes from consideration the particular focus of this paper, the possibility of sequential equilibrium involving excess capacity used as a weapon to deter entry.

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[4] Brander and Spencer (1983), Reynolds (1986), and Schwartz and Baumann (1988) are examples of models with variable proportions technologies, and which exhibit non-cost minimizing capacity investment in equilibrium.

[5] The first comprehensive discussion of this issue, so far as we are aware, is by Carl Shapiro in his excellent survey of Oligopoly Theory, Shapiro (1989).

Demand

We work with a family of demand functions, constant elasticity, which do not satisfy the Hahn-Novshek condition. Over some range of quantities, each firm's output is *increasing* in market output. This raises the possibility that excess capacity might be held as a barrier to entry, because the incumbent can credibly threaten to increase output after entry. Bulow, Geanakoplos, and Klemperer first demonstrated this point through an example in their 1985 note. This paper can be seen as an extension of their work to a full sequential entry equilibrium, incorporating the correct timing structure of investment and quantity choices.

Inverse demand is given by the function

$$P = A\,X^{-\frac{1}{\epsilon}} \tag{1}$$

Figure 1 depicts a firm i's reaction function given an investment in capacity k_i , and our demand and cost assumptions. Note how the reaction function is positively sloped over some range of output of a rival firm or entrant, denoted as q_j. It is firm i's credible potential for expanding output along the positively sloped portion of its reaction function that makes it possible for excess capacity to be held in a deterrence equilibrium. The entrant's reaction function is also shown in the figure. Given the investment of k_i by firm i, suppose the entrant were to choose a capacity corresponding to point B, its best output response to an incumbent's output of $x_i=k_i$. Absent entry, firm i would produce a monopoly quantity at point A. Entry raises its marginal revenue, and induces it to expand output to point B. If the entrant's profits at point B are non-positive, entry will be deterred, and the incumbent will hold excess capacity in equilibrium.[6]

[6] This brief description of the workings of the model ignores for the sake of simple exposition, the possibility that the entrant's best choice will not be at B, given k_i. In fact, in the case illustrated, the entrant would choose a capacity level less than that at B, so that both incumbent and entrant would produce less in the post-entry equilibrium. Capacity k_i would then not necessarily be sufficient to deter entry, and in any case, would be an excessive investment, since not all of it would be utilized even *after* entry.

Properties of the Perfect Nash Equilibrium

Eaton and Ware (1987) showed that, in a sequential entry model with Leontief Costs, and where demand satisfies the Hahn-Novshek condition, firms do not hold excess capacity in equilibrium.[7] In the model we study here, firms can hold excess capacity in equilibrium; hence, entry deterrence involves a real cost to any such firm. As such, that firm would like to delegate the task of entry deterrence, possibly even to an entrant which it could deter, at some cost. This cost incentive to delegate makes determining specific equilibria more difficult, but also provides a rich range for exploring positioning versus delegation possibilities.

Eaton and Ware also introduce a useful distinction between *blockaded* and *strategic* equilibria to sequential entry games. A blockaded equilibrium for n firms is one in which the n producing firms make their capacity choices *independent* of the possibility of further entry.[8] In a *strategic* equilibrium the incumbents have to invest strategically in order to deter further entry. The following property is immediate.

EQUILIBRIUM PROPERTY 1: *Blockaded equilibria never involve excess capacity. Strategic equilibria may or may not involve excess capacity.*

The intuition of this result is clear from the fact that excess capacity is held only to make the threat of expanding output credible *in the event of entry.* Since blockaded equilibria effectively contain no threat of entry, incumbent firms have no reason to hold excess capacity.

EQUILIBRIUM PROPERTY 2: *Equilibria which do not involve excess capacity consist of the smallest number of firms which can deter further entry.*

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[7] Eaton and Ware (1987), Proposition 4, p5.

[8] More formally, in a blockaded equilibrium the solution to a game with n firms imposed exogenously is identical to the equilibrium in which the number of firms is determined as part of the solution.

Proof: The proof is a straightforward adaptation of the proof of Proposition 7 in Eaton and Ware (1987).

We are particularly interested in perfect equilibria which do involve excess capacity. Since this unused capacity will be used only *after* entry, any firm holding it must satisfy the increasing marginal revenue condition i.e. at the equilibrium capacities and quantities that firm's marginal revenue must be increasing in market output. By differentiating marginal revenue, we see that the increasing marginal revenue condition requires that

$$x_i \geq \epsilon(\sum_{\substack{j=1 \\ j \neq i}}^{n} x_j) \tag{2}$$

If market demand is elastic, the above condition implies immediately that only one firm, the largest firm, can hold excess capacity in perfect equilibrium. With inelastic demand, several firms can hold excess capacity in the equilibrium, but note also that the restriction

$$n\epsilon \geq 1 \tag{3}$$

is a necessary condition for the existence of Cournot equilibrium with inelastic demand.[9]

Having established these preliminary results, we are ready to investigate further the properties of equilibria involving excess capacity. In the ensuing analysis, we work with an explicit parameterization of the model, involving inelastic demand, in order to illustrate the factors determining equilibrium. In particular, we show, both diagrammatically and by means of a numerical simulation, how delegation gives way to a positioning advantage for firm 1, as fixed costs are increased, and the limit output falls.

The basic parameters of the simulation are: A = 1000.0, c = 10.0. We adopt an elasticity value of 0.6 as convenient; it allows two firms to produce in Cournot equilibrium, but

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[9] The condition guarantees that, in a symmetric equilibrium, each firm *perceives* demand to be elastic.

equilibria display clear patterns of delegation and positioning. Our derivation of equilibrium is constructive: first we check that at least two firms are needed to deter further entry. We must also check that two firms can credibly produce sufficient output (*after* entry) that a third firm can be deterred.

Figure 2 depicts the variable cost reaction functions for firms 1 and 2; that is, the solution to the equation

$$MR_i(x_i, x_j) = (1 - \alpha)\, c$$

Recall that α is the proportion of unit production costs that must be sunk in the form of capacity investment. The procedure for solving for a particular perfect equilibrium to the model can now be described. The *Limit Output* (LO) is derived as a function of f, the fixed costs of entry. Note that limit output must be defined a bit more carefully than in models which satisfy the Hahn-Novshek condition; limit output is the output which if credibly produced by the incumbents *after entry* would just drive the entrant's profits to zero. In computing the limit output, we also obtain the potential entrant's most efficient output level, conditioned on the Limit Output, $k_3^*(LO)$. In Figure 2, the *sum* of these is drawn in as the equation

$$k_1 + k_2 + k_3 = LO(f) + k_3^*(LO) \qquad (4)$$

where firm 3's output is shown in the figure added to that of firm 1. A dashed line is also drawn representing the limit output itself, i.e. the equation

$$k_1 + k_2 = LO(f) \qquad (5)$$

We know that an entry deterring equilibrium will involve excess capacity, because this dashed line passes to the right of the intersection point of the two reaction functions (point C in the figure). Total output corresponding to C is the most that two firms can produce without additional entry. In the equilibrium firm 1 delegates as much excess capacity to firm 2 as possible: the limit to this delegation is found where firm 2's variable cost reaction function cuts line (4) above, i.e. point E in the figure. The equilibrium capacity choice for firm 1 is the point vertically below point E on line (5), so that between them firms 1 and 2 have total capacity equal to the limit output. The choice for firm 1 also involves excess capacity in entry deterring duopoly equilibrium - this can be verified in the figure because 1's capacity choice lies above point C.

Why is firm 1 unable to delegate still more excess capacity to firm 2? Consider a small reduction in firm 1's capacity choice. Even if firm 2 were to increase its own capacity choice by an equal amount, the additional capacity commitment would not be credible since it would not be used in the event of entry. Thus a minimum of k_1^* is required in order for entry deterrence to be feasible.

As we increase the value of f, the limit output decreases, and both lines (4) and (5) in the figure shift to the left. The equilibrium is constructed in exactly the same way, with the equilibrium point in the figure shifting down firm 2's variable cost reaction function towards point C. As f is increased, firm 1's excess capacity decreases faster than that of firm 2, until a value, f_2, is reached such that firm 1 holds no excess capacity at all in equilibrium. For even larger values of f, the equilibrium is constructed in the same way, only now firm 1 will be capacity constrained in equilibrium; firm 1's equilibrium output is less than the Cournot duopoly output (point C) in this region.

Note that for all f values in a neighbourhood greater than f_2, firm 1 produces less output in equilibrium than firm 2. Firm 1 may still be more profitable, because it does not have to bear the cost of excess capacity. At some value, f_3, the profits of firms 1 and 2 in equilibrium will be the same, even though the equilibrium is asymmetric. For still larger values of f, firm 1 will force a *switching* of roles i.e. it will prefer to hold the excess capacity and be the larger firm in equilibrium, while firm 2 chooses just enough capacity to make up the limit output, and is capacity constrained in equilibrium. In Figure 2, the equilibrium is constructed after this switch point by using firm 1's variable cost reaction function in exactly the same way as firm 2's was used in the first phase of equilibria, switching the entrant's capacity (and output) choice,

k_3 to the k2 axis, so that the whole construction is reversed.

Figure 3, based on a simulation, shows how the equilibria depend on f, the fixed costs of entry, in terms of quantities and excess capacity. The phases of delegation and positioning are clearly identified as functions of f. We define the range $f_1 \leq f \leq f_3$ as the *delegation phase* and the phase $f_3 \leq f \leq f_4$ as the *positioning phase*, where f_1 to f_4 are defined, as follows, for a given value of α.

f_1 = the smallest value of fixed costs such that two firms are still able to deter further entry.

f_2 = the value of fixed costs at which firm 1 no longer holds excess capacity in equilibrium.

f_3 = the largest value of fixed costs such that firm 2 is larger in equilibrium - i.e. for f values above f_3, firm 1 prefers the positioning advantage of being the large firm, as opposed to the advantage of delegating the costs of excess capacity to firm 2.

f_4 = the value of fixed costs such that a single firm can deter entry and the equilibrium becomes a strategic monopoly.

We have computed the critical values, f_1 to f_4, for our simulation model.[10] Equilibrium capacities, quantities, and profits can then be computed within the different intervals of f. A similar comparative statics exercise with respect to α, the capacity cost coefficient, can also be performed. As the sunk capacity cost proportion of production costs rises, so does the cost of holding excess capacity in order to deter entry. This increases the payoff to delegation of entry deterrence by firms moving early in the sequence. At the same time, however, increasing α increases the *positioning* advantage of these same firms, thereby creating more strategic

[10] Details of the simulation are available from the authors.

opportunity to be large, and raising the opportunity cost of delegating entry deterrence (if it involves holding excess capacity) to later entrants. And, thirdly, an effect which is peculiar to models exhibiting excess capacity in equilibrium: the larger is α, *ceteris paribus*, the larger will be equilibrium output which implies lower industry profits with inelastic market demand. The outcome of these trade-offs can only be determined by simulation in specific cases. In any case, a greater degree of sunkness in the technology increases the advantage, and the equilibrium profits, of the first mover. In order to illustrate these observations, Appendix A reports equilibria for a range of f values, and for three illustrative values of α, 0.2, 0.4 and 0.6.

Our analysis of the properties of perfect equilibria in the model may be summarized as:

EQUILIBRIUM PROPERTY 3: *Perfect equilibria may have all producing firms (firms holding positive capacity) holding excess capacity, or some subset of the industry only holding excess capacity. Firms holding excess capacity in a Perfect Equilibrium may come at the beginning or the end of the sequence of entering firms.*

It is instructive at this point to relate our results on delegation of entry deterrence and positioning to those of McLean and Riordan (1989, hereafter MR) who first identified the concept of delegated entry deterrence in this class of models. In MR firms make a binary choice of technology, one choice being less profitable but more effective in deterring further entry. Because the choice is discrete, and is defined only in an abstract sense of profitability, an analogy to our concept of positioning cannot be directly found within MR's framework. Thus, firms in our model face a richer tradeoff than in MR, because they make direct capacity and quantity choices from a continuous strategy set. Nevertheless, any *delegation* equilibrium in our model (corresponding to the region indicated in figure 3), must satisfy MR's criteria for a delegation equilibrium also.[11] Moreover, the equilibria to our model in the *positioning* region are analogous to MR's discussion of *partial entry deterrence*, in which the "entry deterring"

[11] McLean and Riordan (1989), pp 7-8.

technology is more profitable than the "normal" technology.[12]

Finally, we considered the possibility of underinvestment in entry deterrence occurring in perfect equilibria to our model. If, as in MR, underinvestment is said to occur among firms 1,...,j when, as a group, these firms could have invested more in entry deterrence and yielded each individual firm a higher payoff, then underinvestment can only occur if demand is inelastic. This follows logically from both the property that when demand is elastic only one firm can credibly invest in excess capacity as well as the principle that free rider problems associated with underinvestment can only arise if it is necessary for two or more firms to coordinate entry deterring behaviour[13] Consider the behaviour of the firms which cannot credibly invest in excess capacity. As in Eaton and Ware (1987), they will invest in capacity up to the maximum output level they can obtain in the Cournot output stage of the game. Only firm one's decision involves a choice concerning entry deterrence, and thus the potential for free-riding is eliminated.

Though we have not generated an example, underinvestment cannot be ruled out in the case where demand is inelastic. Moreover, if it occurs, underinvestment is most likely *ceteris paribus* when demand is not strongly inelastic, capacity costs are high, and/or fixed costs are low; that is, when the decline in revenues resulting from entry are most likely to outweighed by the gains in capacity savings.

Conclusions

Although there has been a proliferation of models of strategic entry deterrence, very few of these have shed any light on the phenomenon of excess capacity which is held as an

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[12] McLean and Riordan (1989), pp 15-16.

[13] see Waldman (1988) or McLean and Riordan (1989).

instrument of entry deterrence. In this paper, working in a sequential entry framework, with constant elasticity demand and Leontief costs, we have shown that equilibria can occur in which some or all of the producing firms hold *idle* capacity as an instrument of entry deterrence. These equilibria all fall within the category described by Eaton and Ware (1987) as strategic equilibria. Moreover, for excess capacity to be a credible entry deterrent, the marginal revenue of the firm holding the excess capacity must be increasing in the output of an entrant. The implied relationship between firm outputs in equilibrium and elasticities is discussed in the paper.

The fact that entry deterrence through holding excess capacity involves a real cost to the firm allows us to examine the sharing of the entry deterrence burden between incumbent firms in a non-cooperative framework. Moreover, since investment in capacity conveys a positioning advantage, giving early movers a larger market share, we are able to examine how this trade-off between positioning and delegation works out in equilibrium. To summarize what turns out to be a fairly complex interaction, the first firm will delegate excess capacity where feasible, unless it is able to deter entry with a large market share, keeping subsequent entrants small. In the latter case, the first firm will be forced to hold any excess capacity required to deter further entry. Even when this configuration is feasible, the first firm may be willing to give up its dominant position if the excess capacity required is too costly.

It is clear that the model is not very restrictive in its predictions. The first step towards empirical clarification of the strategic excess capacity notion should probably be to test the demand side of the model, i.e. the assumption of convex demand. We note that we were only able to obtain equilibria in which multiple firms hold excess capacity in equilibrium, where market demand is inelastic. If these demand configurations were to be rejected by the data, then the search for an empirically plausible model of strategic excess capacity would have to shift to a different class of models.

Appendix: Simulation Results

(i) critical values for f

α	f_1	f_2	f_3	f_4
0.2	29.0	36.4	37.0	124.0
0.4	18.0	24.1	26.4	112.0
0.6	6.3	11.2	16.0	98.0

(ii) some illustrative equilibria in α - f space (note: profit figures shown are gross of fixed costs, f)

α \ f	29.0		36.4		37.0	
0.2	$k_1 = 3.772$ $x_1 = 3.092$ $\pi_1 = 116.13$	$k_2 = 3.772$ $x_2 = 3.092$ $\pi_2 = 116.13$	$k_1 = 3.092$ $x_1 = 3.092$ $\pi_1 = 117.53$	$k_2 = 3.772$ $x_2 = 3.092$ $\pi_2 = 116.13$	$k_1 = 3.023$ $x_1 = 3.023$ $\pi_1 = 119.00$	$k_2 = 3.772$ $x_2 = 3.057$ $\pi_2 = 119.00$
0.4	$k_1 = 4.414$ $x_1 = 3.383$ $\pi_1 = 110.22$	$k_2 = 3.150$ $x_2 = 3.150$ $\pi_2 = 106.48$	$k_1 = 4.337$ $x_1 = 2.938$ $\pi_1 = 139.20$	$k_2 = 2.510$ $x_2 = 2.510$ $\pi_2 = 123.71$	$k_1 = 4.330$ $x_1 = 2.903$ $\pi_1 = 141.66$	$k_2 = 2.465$ $x_2 = 2.465$ $\pi_2 = 125.15$
0.6	$k_1 = 5.074$ $x_1 = 3.135$ $\pi_1 = 133.23$	$k_2 = 2.490$ $x_2 = 2.490$ $\pi_2 = 115.07$	$k_1 = 4.902$ $x_1 = 2.581$ $\pi_1 = 168.68$	$k_2 = 1.945$ $x_2 = 1.945$ $\pi_2 = 137.60$	$k_1 = 4.889$ $x_1 = 2.539$ $\pi_1 = 171.80$	$k_2 = 1.906$ $x_2 = 1.906$ $\pi_2 = 139.58$

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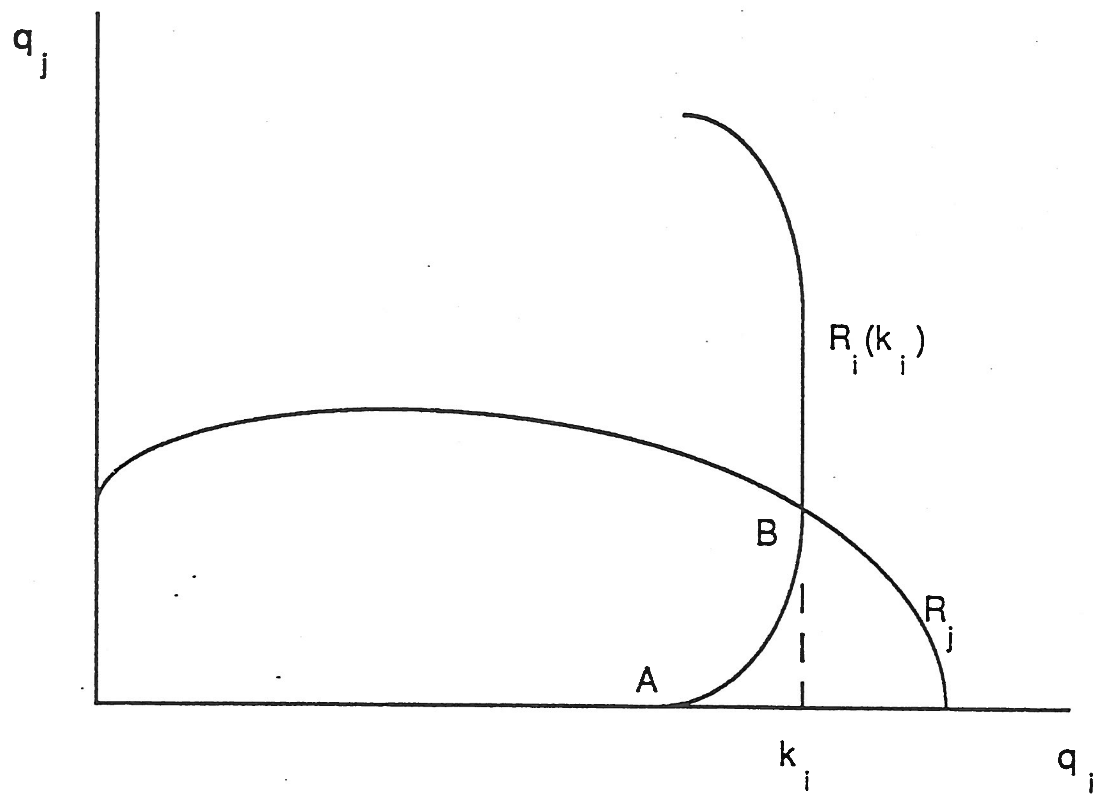
FIGURE 1

REACTION FUNCTIONS FOR CONSTANT ELASTICITY DEMAND



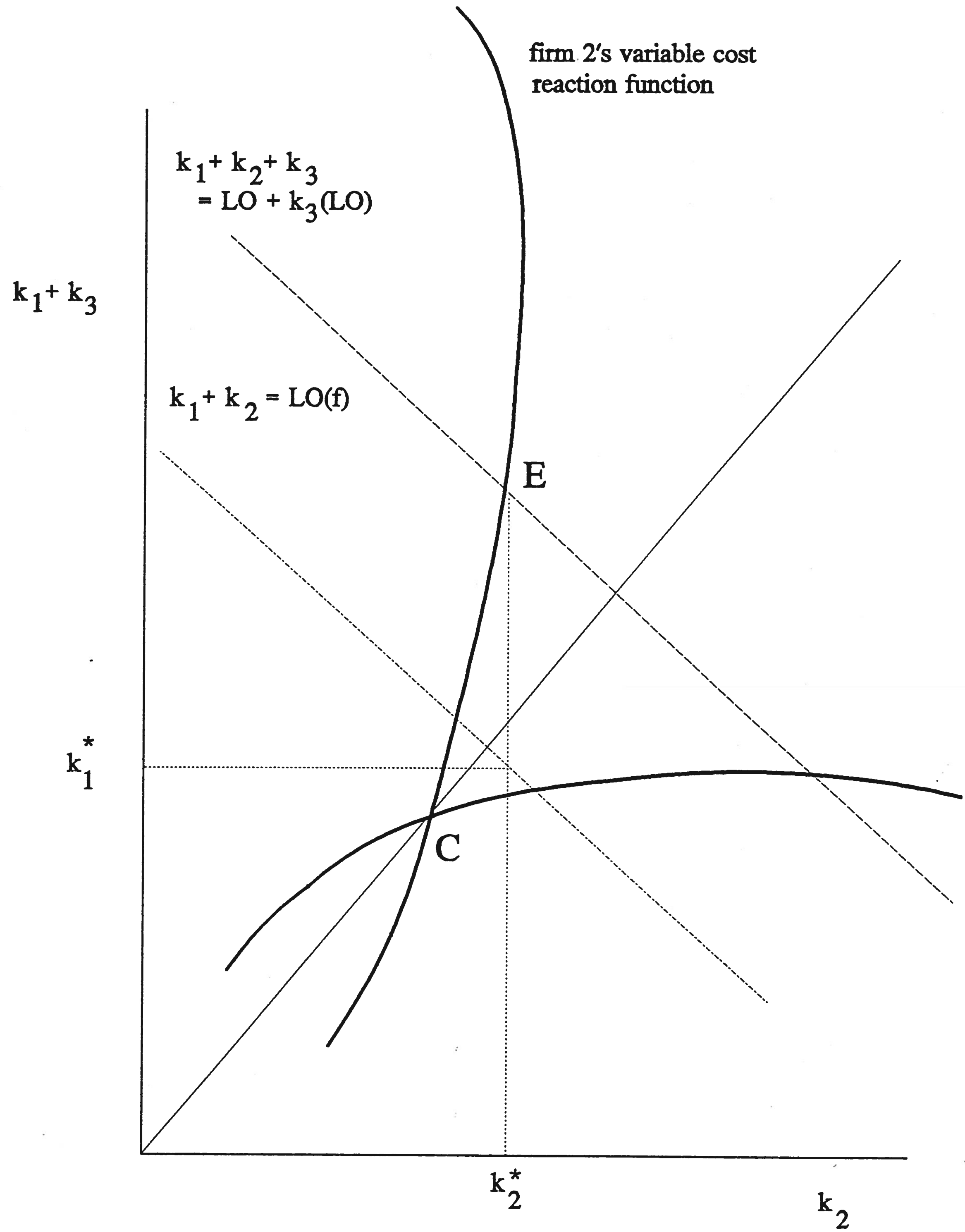


Figure 2: Construction of the perfect equilibrium with two incumbent firms

(model parameters: $\epsilon = 0.6$; $\alpha = 0.4$; $A = 1000.0$; $c = 10.0$)

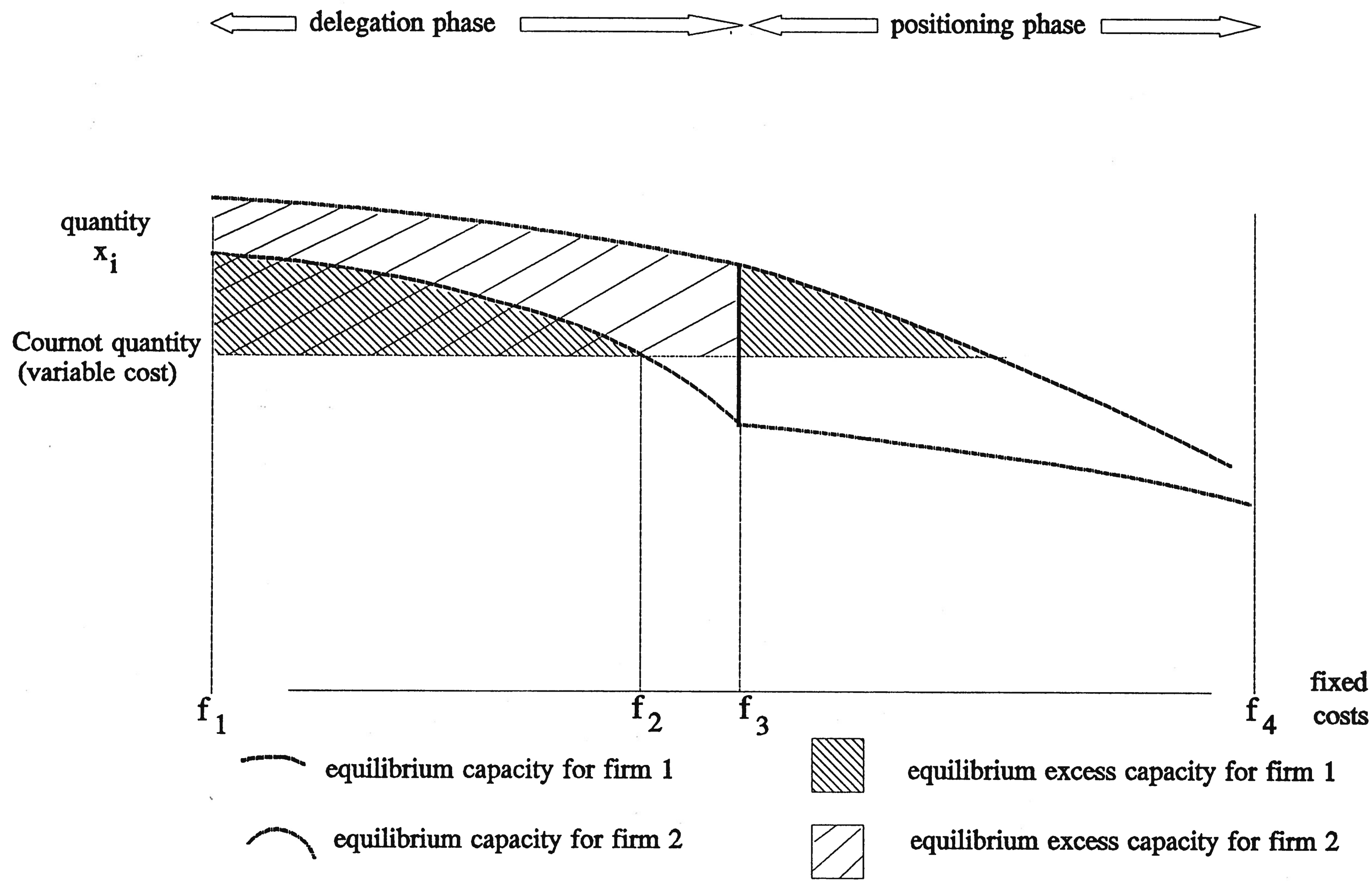


Figure 3: excess capacity and the phases of equilibrium as fixed costs are varied