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CAPACITY, ENTRY AND FORWARD INDUCTION

by

Kyle Bagwell and Garey Ramey*

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*Northwestern University and University of California, San Diego. For helpful comments we are grateful to Vince Crawford, Avinash Dixit, Drew Fudenberg, John Panzar and Rob Porter, as well as seminar participants at the University of California, San Diego, Northwestern University, University of Western Ontario and the Econometric Society 1989 Winter Meetings. Bagwell thanks the National Science Foundation for research support under grant SES-8900856.

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We introduce avoidable fixed costs into the capacity and entry model of Dixit (1980) to produce a coordination problem among multiple postentry equilibria. Elimination of weakly dominated strategies makes it possible for the entrant to play a knockout strategy, consisting of a large capacity commitment which selects the entrant's preferred postentry equilibrium and drives the incumbent from the market. The incumbent must respond to the knockout threat by using judo tactics, involving a reduction in its capacity commitment. In subgame perfect equilibria which are robust to elimination of weakly dominated strategies, the incumbent must accept a market share smaller than the entrant's if avoidable fixed costs are sufficiently high, or cede the market to the entrant if avoidable fixed costs are higher still.

1. Introduction

The nature of strategic rivalry between incumbent firms and potential entrants depends heavily upon the conjectures which firms hold about the reactions of their rivals. In the early limit pricing models proposed by Bain (1956), Modigliani (1958) and Sylos-Labini (1962), prospective entrants believe that incumbent output will be maintained in the event of entry. Later analysts questioned the credibility of output maintenance as a threat against potential entrants, and focused instead on irreversible investments through which incumbents could make binding commitments. The work of Dixit (1980) exemplifies this view: he assumes that an incumbent can manipulate postentry conditions through capacity investment. After observing the capacity investment, the entrant correctly anticipates the output level that

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maximizes the incumbent's profits in the event of entry. In essence, the entrant solves the postentry game and then, inducting backwards, decides whether to enter.

The key conclusion of this literature is that the ability to make sunk investments conveys a strategic advantage to first movers, allowing them to maintain favorable market positions and perhaps to deter entry entirely. This remains true even if second movers are also allowed to make strategic commitments, as in Ware (1984). In this paper we take a closer look at this conclusion. In particular, we ask whether first mover advantages persist when there are significant fixed costs which may be avoided by shutting down. The presence of avoidable fixed costs leads to a coordination problem in choosing postentry outputs: alongside the equilibria in which the firms share the market there may exist "natural monopoly" equilibria in which one firm produces output so large that the other responds optimally by shutting down.

The existence of this coordination problem dramatically alters the strategic balance between first and second mover. Consider the situation facing the incumbent and entrant after the incumbent has made its capacity commitment. Suppose the entrant responds with a very large capacity investment. The incumbent must then ask itself, what does this mean about postentry competition? If the entrant could not recoup its capacity investment with its postentry market-sharing quantity, the incumbent can only infer that the entrant will respond with a larger output, near its natural monopoly level, as only such quantities could possibly justify the entrant's capacity choice. More specifically, the incumbent observes the entrant's capacity choice, eliminates capacity and quantity combinations which represent weakly dominated strategies for the entrant, and thereby inducts forward to deduce the entrant's possible postentry quantity.[1] Given this inference, the incumbent responds optimally to the large entrant capacity by shutting down.

Thus, the combination of avoidable fixed costs and the entrant's ability to make sunk investments allows the entrant to play a knockout strategy involving high capacity investment. Credibility of the knockout strategy follows from the fact that the incumbent uses forward induction to form strategic inferences, and thus it cannot escape the logic which leads to the entrant's natural monopoly equilibrium.

If avoidable fixed costs are sufficiently high, there is no response available to the incumbent which allows it to escape the knockout strategy, and the incumbent's only recourse is to cede the market to the entrant by choosing zero capacity. For smaller levels of avoidable fixed cost, however, the incumbent can avoid being knocked out by reducing its initial capacity investment, in order to lower its endogenous avoidable fixed costs as well as to make the market-sharing equilibrium more attractive for the entrant; thus, the incumbent uses judo tactics to defend itself against the knockout strategy. Interestingly, the incumbent's commitment to the market is maintained only by taking actions which restrict its market share. Moreover, market share must be restricted by a greater amount as avoidable fixed costs rise. This stands in contrast to the usual first-mover tactics of strengthening commitment to the market by preemption of the entrant's market share, being more reminiscent of the behavior of the entrant in Gelman and Salop's (1983) model.

Our work has been inspired by the recent game-theoretic papers of Ben-Porath and Dekel (1987) and van Damme (1989), which resolve the problem of coordination among multiple Nash equilibria by allowing players to engage in "public money burning." Both papers employ stronger notions of forward induction than that used here: Ben-Porath and Dekel apply multiple rounds of elimination of weakly dominated strategies, while van Damme develops his own concept of forward induction. These authors give examples which show that the last player to burn money is able to select his preferred equilibrium, i.e. strategic communication conveys second mover advantages. Our model adds the feature that the first mover can use his precommitment ability to offset the communication power of the second mover, by using the judo tactics described above. This effect arises from the fact that precommitment alters the set of postentry equilibria and the second mover's payoffs in these equilibria.

The next section reviews the model of capacity and entry originated by Dixit and amended by Ware, and section three introduces our assumptions as to avoidable fixed costs. In sections four and five we develop the knockout strategy, and section six explains the incumbent's inability to use such a strategy. Section seven demonstrates the incumbent's judo tactics. A parameterized example is analyzed in section eight, and connections with the extended literature are discussed in section nine. Section ten concludes the text. The appendix describes more formally the reduced game obtained by elimination of weakly dominated strategies, and discusses the existence of subgame perfect equilibria of that game.

2. Dixit's Model and Ware's Critique

Dixit (1980) introduced the following model of large-scale entry. There are two firms, an incumbent and an entrant. These are referred to as Firm 1 and Firm 2, respectively. The model has two stages. In the first stage Firm 1 chooses its capacity k_1. In the second stage Firm 1 choooses a quantity of output q_1, and it may expand its capacity. Simultaneously, Firm 2 chooses capacity and quantity, k_2 and q_2. Inverse demand is given by $p = a - b(q_1 + q_2)$. For Firm 1, stage two production costs are:

$$c_1(q_1 | k_1) = \begin{cases} cq_1, & q_1 \leq k_1 \\ cq_1 + r(q_1 - k_1), & q_1 > k_1 \end{cases}$$

As long as output is below the precommitted capacity, Firm 1 pays only the variable cost c. For larger output, however, Firm 1 must pay an additional r per unit to expand capacity. For Firm 2, combined production and entry costs are:

$$c_2(q_2) = \begin{cases} 0, & q_2 = 0 \\ (c + r)q_2 + f, & q_2 > 0 \end{cases}$$

where f represents the fixed component of sunk entry costs.[2]

(Figure 1 here)

Stage two reaction functions for the firms, conditional on k_1, are shown in Figure 1. The vertical kink in Firm 1's reaction function represents the fact that its variable costs rise discretely if it must expand capacity.

Decisions in this model are presumed to be consistent with the notion of backward induction rationality, which is roughly defined as follows: when forecasting future behavior, the firms anticipate that behavior will be rational in any subgame that may arise.[3] In essence, the game is analyzed from back to front by inductively solving for Nash equilibria of subgames. Here, the subgames correspond to choices of k_1 which initialize the second stage, and based on backward induction rationality the firms anticipate Nash equilibria of the second stage, given by intersection of the reaction functions, for any choice of k_1.

Thus, by manipulating k_1 in the first stage, Firm 1 may affect the stage two outcome by shifting the Nash equilibrium. It will clearly be in Firm 1's interest to expand capacity beyond the symmetric Cournot quantity. It may allow entry and act as a Stackelberg leader, or deter entry entirely by choosing $k_1 = q_1^D$. Of course, Firm 1's strategic leadership depends on the sunkness of capacity investment, since its reaction function actually shifts only to the extent that the capacity investment is unrecoverable.

(Figure 2 here)

Ware (1984) has proposed an extension of Dixit's model wherein Firm 2 is allowed to make a sunk capacity investment after Firm 1 does, but prior to the choice of outputs in stage two. Figure 2 illustrates a situation in which Firm 1 has opted to attempt entry deterrence by choosing $k_1 = q_1^D$. By making a sunk investment of k_2, Firm 2 introduces a horizontal kink in its own reaction function, and it may thereby select as the Nash equilibrium any point between A and B on Firm 1's reaction function. An isoprofit curve for Firm 2 is also illustrated in the figure, and in this case Firm 2's preferred post-entry equilibrium is at A. It follows that, based on backward induction rationality, Firm 1 will anticipate Firm 2's optimal capacity choice and adjust its choice of k_1 accordingly. Firm 1's strategic advantage is reduced, but certainly not eliminated, when commitment power is given to Firm 2.

3. Avoidable Fixed Costs

While sunk costs are evidently important in many industries, it is often true that a significant portion of fixed costs are recoverable if a firm chooses to shut down operations; these are called avoidable fixed costs. To consider the role of avoidable fixed costs, we propose to alter the framework of the preceding section as follows. First, we assume there is a nonnegligible avoidable fixed cost which is independent of capacity. For notational ease, we will let the sunk cost f now represent this avoidable fixed cost; while this distinction is immaterial from the entrant's point of view, it has an important effect on the incentives of the incumbent. We will assume throughout that f is sufficiently small to make monopoly viable.[4] Second, we suppose that part of capacity investment may be avoided by shutting down. In particular, either firm may recover proportion α of its capacity investment by choosing to produce no output in the second stage.

The latter assumption is justified to the extent that capacity investment has a "putty-clay" character: when a firm increases capacity, it may plan its investment to acheive any desired output level, but once the investment is in place costs may be recovered only by shutting down capacity in discrete lumps. Maintenence and heating costs, for example, are variable at the capacity planning stage, but may turn into lumpy fixed costs once operations commence. This principle also applies to resale of capacity. For example, a firm may shop for a piece of real estate which exactly fits its needs, but once purchased the real estate may be resalable only in parcels of some minimum size. For simplicity we assume the most basic form of lumpy recoverability, i.e. costs are recoverable only by shutting down completely.

(Figure 3 here)

Figure 3 illustrates the new second-stage reaction function of Firm 1, when it has chosen capacity k_1' in stage one. If $\alpha = 1$, Firm 1 may recover all of its capacity investment by shutting down, and this is indeed the optimal decision whenever $q_2 \geq q_2'$. For smaller values of α, the exit-inducing level of q_2 is larger.[5] It should be noted that capacity investment still allows Firm 1 to commit to a tougher response for any situation in which it remains in the market.

(Figure 4 here)

Suppose now that Firm 1 chooses $k_1 = q_1^D$, and Firm 2 responds with $k_2 = k_2'$ which is so large that Firm 1 would prefer to shut down if Firm 2 were to operate at full capacity. We then have the situation depicted in Figure 4. There are now two postentry equilibria: one market-sharing equilibrium at point A, and one natural monopoly equilibrium at B, in which Firm 1 opts to cede the market to Firm 2. This introduces a coordination problem in determining the postentry outputs: Firm 1 would prefer to play according to equilibrium A, whereas equilibrium B is better for Firm 2. Of course, backward induction rationality gives no basis for favoring one equilibrium over another, and either may serve as the anticipated postentry outcome. If the firms anticipate that equilibrium A will obtain, then k_2' will certainly be a suboptimal strategy for Firm 2; in fact, if avoidable fixed costs are low enough so that market sharing gives a postentry equilibrium when $k_1 = q_1^D$ and $k_2 = k_2'$ (as depicted in Figure 4), then the outcome predicted by Ware will result. Thus, first-mover advantages are consistent with backward induction rationality, even in the presence of avoidable fixed costs.

4. Elimination of Dominated Strategies

Suppose, however, that the firms think a little harder about the implications of their rival's behavior. Since each knows that the other is a rational profit-maximizer, it should not be believed that the rival firm takes actions which are manifestly unprofitable. In particular, a firm should never conjecture that the rival operates according to a weakly dominated, or inadmissible, strategy, that is, a strategy which is unambiguously inferior to some other strategy.[6]

To discuss weakly dominated strategies, we must introduce notation to represent the firms' strategies. For Firm 1, strategies are denoted by:

$$s_1 = (k_1, q_1(k_2))$$

where the dependence of q_1 on k_2 indicates the fact that the firms choose outputs after capacities are determined. Let S_1 be the set of all strategies available to Firm 1. Similarly, Firm 2's strategies are of the form:

$$s_2 = (k_2(k_1), q_2(k_1))$$

and S_2 gives Firm 2's strategy set. Finally, payoffs for the firms are:

$$\Pi_1(s_1,s_2) = \begin{cases} (a - b(q_1(k_2) + q_2(k_1)) - c))q_1(k_2) - r\max\{q_1,k_1\} - f, & q_1(k_2) > 0 \\ -(1 - \alpha)rk_1, & q_1(k_2) = 0 \end{cases}$$

$$\Pi_2(s_1,s_2) = \begin{cases} (a - b(q_1(k_2) + q_2(k_1)) - c))q_2(k_1) - r\max\{q_2,k_2\} - f, & q_2(k_1) > 0 \\ -(1 - \alpha)rk_2, & q_2(k_1) = 0 \end{cases}$$

where we have suppressed the dependence of k_2 on k_1.[7]

A strategy $s_1 \in S_1$ is <u>weakly dominated</u> by $s_1' \in S_1$ if, for all $s_2 \in S_2$:

$$\Pi_1(s_1',s_2) \geq \Pi_1(s_1,s_2)$$

and there exists $s_2' \in S_2$ such that:

$$\Pi_1(s_1',s_2') > \Pi_1(s_1,s_2')$$

Thus, Firm 1 should not select s_1, as s_1' gives superior profitability over the entire range of possible Firm 2 strategies. We will henceforth refer to a weakly dominated strategy simply as <u>dominated</u>. s_1 is called <u>undominated</u> if it is not dominated by any s_1'. We let S_1^U denote the set of undominated strategies for Firm 1. S_2^U is defined analogously for Firm 2.

5. <u>The Knockout Strategy</u>

It is possible to give a precise characterization of the sets of undominated strategies, S_1^U and S_2^U, and we do this in the appendix. Our purpose in this section is to illustrate one very important implication of the elimination of dominated strategies: by choosing a sufficiently large capacity level, the entrant can force the incumbent to accept the entrant's natural monopoly outcome and exit the market, despite the existence of other outcomes which the incumbent prefers. This in turn implies that when avoidable fixed costs are present, the entry-deterrence equilibrium identified by Dixit may fail to be consistent with forward induction rationality. We assume until the end of the section that $\alpha < 1$. Let $q^M \equiv (a - c - r)/2b$ denote the monopoly output when capacity costs are included, and $\bar{q}^M \equiv (a - c)/2b$ the analogous output when capacity costs are ignored.

First, it is relatively simple to show that strategies which specify extremely large capacity levels must be dominated. In particular, consider the set of capacity choices k_2 which are so large that Firm 2 could not possibly recoup its capacity costs, even if Firm 1 were to cede the market by choosing $q_1 = 0$; such capacity choices guarantee that Firm 2 earns nonpositive profits no matter what Firm 1's strategy is. Note that $k_2 > q^M$ for every element in this set, as we have assumed that the firms would earn strictly positive profits as monopolists. For given $k_2 > q^M$, consider the quantity which maximizes Firm 2's profit when Firm 1 chooses $q_1 = 0$. If $q_2 = 0$ is the maximizer, then maximized profits are $-(1 - \alpha)rk_2$, which is strictly negative. Suppose $q_2 = 0$ is not the maximizer. If $k_2 \leq \bar{q}^M$, then $q_2 = k_2$ is Firm 2's best quantity choice, since once $k_2 > q^M$ it does not pay to expand capacity; if $k_2 > \bar{q}^M$, then the best quantity for Firm 2 is $q_2 = \bar{q}^M$, as this would be optimal even if capacity were infinite. It follows that $q_2 = \min\{k_2, \bar{q}^M\}$ is Firm 2's best response to $q_1 = 0$, and thus Firm 2 obtains nonpositive maximized profits if:

$$(a - b \min\{k_2, \bar{q}^M\} - c)\min\{k_2, \bar{q}^M\} - rk_2 - f \leq 0 \tag{1}$$

Since Firm 2's maximized profits can only be lower if $q_1 > 0$, it follows that k_2 is in the set of capacity choices which guarantee nonpositive profits for Firm 2 if and only if k_2 satisfies (1). The smallest element in the set, denoted $\bar{k}_2$, is defined by:

$$(a - b(\min\{\bar{k}_2, \bar{q}^M\}) - c)\min\{\bar{k}_2, \bar{q}^M\} - r\bar{k}_2 - f = 0$$

and it is easy to see that (1) holds for every $k_2 \geq \bar{k}_2$.

Now, suppose the Firm 2 strategy $s_2 = (k_2(k_1),q_2(k_1))$ has $k_2(k_1') \geq \bar{k}_2$ for some k_1'; that is, when Firm 2 plays s_2, it responds to k_1' by choosing $k_2 \geq \bar{k}_2$. By (1), s_2 would yield nonpositive profits if Firm 1 were to play any s_1 with $k_1 = k_1'$, and profits would be strictly negative if s_1 also specified $q_1(k_2(k_1')) > 0$. We can construct a strategy s_2' which dominates s_2, as follows:

$$s_2' = \begin{cases} (k_2(k_1),q_2(k_1)), & k_1 \neq k_1' \\ (0,0), & k_1 = k_1' \end{cases} \tag{2}$$

i.e. s_2' gives the same responses as does s_2 if $k_1 \neq k_1'$, but puts $k_2 = q_2 = 0$ in response to $k_1 = k_1'$. It follows that $\Pi_2(s_1,s_2) = \Pi_2(s_1,s_2')$ as long as s_1 has $k_1 \neq k_1'$, while $\Pi_2(s_1,s_2) \leq \Pi_2(s_1,s_2') = 0$ for s_1 with $k_1 = k_1'$, with strict inequality if $q_1(k_2(k_1')) > 0$. s_2' therefore dominates by s_2. Thus, if s_2 is undominated, then it must specify capacity responses strictly less than $\bar{k}_2$, for every k_1.

Second, while all strategies with $k_2 \geq \bar{k}_2$ are dominated, it is also true that for every $k_2 < \bar{k}_2$ there is some undominated strategy which specifies that k_2. In particular, consider strategies in which k_2 is slightly below $\bar{k}_2$, with q_2 again set to maximize profits given the choice of k_2 and $q_1 = 0$; we may define such a strategy s_2 by $k_2(k_1) = \bar{k}_2\text{-}\varepsilon$ and $q_2(k_1) = \min\{\bar{k}_2\text{-}\varepsilon,\bar{q}^M\}$ for every k_1, for some small $\varepsilon > 0$. Since (1) does not hold for $k_2 < \bar{k}_2$, Firm 2's profits will be strictly positive under s_2 if Firm 1 responds to $\bar{k}_2\text{-}\varepsilon$ by choosing $q_1 = 0$. Note that s_2 cannot be weakly dominated by any s_2', for suppose s_2' specifies $k_2'(k_1') \neq \bar{k}_2\text{-}\varepsilon$ or $q_2'(k_1') \neq \min\{\bar{k}_2\text{-}\varepsilon,\bar{q}^M\}$ (or both) for some k_1'. Let s_1 be given by $k_1 = k_1'$ and:

$$q_1(k_2) = \begin{cases} q_1', & k_2 < \bar{k}_2\text{-}\varepsilon \\ 0, & k_2 \geq \bar{k}_2\text{-}\varepsilon \end{cases}$$

where q_1' is very large. It is easy to see that when Firm 1 plays s_1, s_2 gives strictly greater profits to Firm 2 than does s_2'. It follows that s_2' cannot dominate s_2, and since this argument applies for any $s_2' \neq s_2$, we have $s_2 \in S_2^U$. This establishes that for any k_1, there exists an undominated strategy in which $k_2(k_1) = \bar{k}_2-\varepsilon$.

Third, undominated strategies which set $k_2(k_1) = \bar{k}_2-\varepsilon$ are not at the same time free to specify the output level arbitrarily, for negative profits would be guaranteed if $q_2(k_1)$ were far from the profit-maximizing monopoly quantity. More specifically, suppose s_2 sets $k_2(k_1')$ $= \bar{k}_2-\varepsilon$ for some k_1', but also fixes $q_2(k_1')$ so far from $\min\{\bar{k}_2-\varepsilon,\bar{q}^M\}$, which is the best response to $q_1 = 0$, that profits would be negative even if $q_1 = 0$. As above, s_2 will be dominated by s_2' which sets $k_2 = q_2 = 0$ in response to k_1', but otherwise agrees with s_2. Thus, for $s_2 \in S_2^U$ with $k_2(k_1) = \bar{k}_2-\varepsilon$, it is necessary that $q_2(k_1)$ not lie too far from $\min\{\bar{k}_2-\varepsilon,\bar{q}^M\}$. In other words, once we rule out the possibility that Firm 2 plays dominated strategies, then the only quantities which can be associated with the capacity $\bar{k}_2-\varepsilon$ are those which fall near $\min\{\bar{k}_2-\varepsilon,\bar{q}^M\}$. It is easy to see, moreover, that the distance between $q_2(k_1)$ and $\min\{\bar{k}_2-\varepsilon,\bar{q}^M\}$ must approach zero as ε approaches zero.[8]

(Figure 5 here)

Let us now consider the situation shown in Figure 5.[9] Firm 1 chooses $k_1 = q_1^D$ where $q_1^D \in (q^M,\bar{q}^M)$, indicating that entry deterrence is a possible equilibrium, but one which requires capacity to be set above the full-cost monopoly output, q^M. Firm 2 would cede the market to Firm 1 if postentry equilibrium A were anticipated; in this case we have the entry-deterrence eqilibrium identified by Dixit, in which Firm 1 earns strictly positive profits. Firm 1 would exit, however, if Firm 2 output were in excess of q_2^D. Observe that any strategies giving rise to postentry outcome A must have $k_1 = q_1(0) = q_1^D$ and $k_2(q_1^D) =$ $q_2(q_1^D) = 0$.

We now consider whether A might still arise as the outcome of a subgame perfect equilibrium of the new, reduced game obtained by elimination of dominated strategies. In the reduced game the original strategy sets are replaced by the sets S_1^U and S_2^U. Suppose Firm 2 deviates to $\bar{k}_2$-ε after observing $k_1 = q_1^D$. Such a deviation is possible in the reduced game, as the second point above shows that S_2^U contains at least one s_2 with $k_2(q_1^D) = \bar{k}_2-\varepsilon$. Further, since Firm 2's strategy must now be an element of S_2^U, the third point indicates that the deviant strategy s_2' necessarily sets $q_2'(q_1^D)$ close to $\bar{q}^M$, and $q_2'(q_1^D) > q_2^D$ is implied for small enough ε. Thus, Firm 1 must anticipate that Firm 2's quantity will exceed q_2^D in the subgame of the reduced game initialized by $k_1 = q_1^D$, $k_2 = \bar{k}_2-\varepsilon$, and Firm 1 necessarily responds with $q_1(\bar{k}_2-\varepsilon) = 0$ in any subgame perfect equilibrium.

But with this restriction, the entry-deterrence outcome A is no longer a subgame perfect equilibrium: Firm 2 earns zero profits in the equilibrium, but by the definition of $\bar{k}_2$ it would obtain strictly positive profits by deviating to a strategy s_2' which sets $k_2'(q_1^D) = \bar{k}_2-\varepsilon$ and $q_2'(q_1^D) = \bar{q}^M$.[10] It follows that Firm 1's preferred equilibrium is no longer viable when strategies are required to be undominated. The elimination of dominated strategies forces Firm 1 to conclude that a large capacity commitment by Firm 2 must be accompanied by a large quantity of output, for otherwise the capacity commitment would be irrational. Firm 1 would then prefer to exit the market to recover its fixed costs. Since Firm 2 is aware of this calculation, it can be assured of knocking the incumbent out of the market by choosing large capacity, and it will prefer to do so if the incumbent attempts to deter entry. Hence, the presence of avoidable fixed costs allows the entrant to play a knockout strategy, by making a large capacity commitment.[11]

It is clear that the knockout strategy will be successful for a range of k_2 below $\bar{k}_2$: as k_2 declines, the set of q_2 which could possibly give positive profits, and thus could appear as part of an undominated strategy, expands in a continuous way around $\bar{q}^M$ (this is explained further in the appendix). The optimal knockout strategy from the entrant's point of view involves the smallest capacity level which would still guarantee that only quantities $q_2 > q_2^D$ could possibly give positive profits in conjunction with the capacity choice k_2. The minimum over this set of capacities, which we denote by k_2^O, is defined by:

$$(a - bq_2^D - c)q_2^D - rk_2^O - f = 0$$

Any s_2 with $k_2(k_1) = k_2^O$ and $q_2(k_1) \leq q_2^D$ is dominated. Thus, observing k_2^O convinces the incumbent that $q_2 > q_2^D$, and the incumbent exits. If the incumbent observes $k_2 < k_2^O$, however, then it could still infer that $q_2 < q_2^D$ even after dominated strategies are removed, and knockout would not be successful.

(Figure 6 here)

Figure 6 depicts the possibilities for knockout strategies under a particular parameterization of a, b, c and r. It is presumed that the incumbent attempts entry deterrence by choosing $k_1 = q_1^D$ or, if entry is blockaded, $k_1 = q^M$, and that the knockout strategy has the entrant choosing $k_2 = k_2^O$. In Region 1, the value of f is so small that q_1^D exceeds the monopoly output which Firm 1 would choose if it ignored capacity costs (i.e., $q_1^D > \bar{q}^M$). In this case, entry deterrence is nonviable in Dixit's original model, as the incumbent has no incentive to actually produce the entry-deterring quantity. A similar effect arises in Region 2: avoidable fixed costs are so low that $\bar{q}^M$ would not serve to knock out the incumbent, and consequently there is no knockout strategy available to the entrant. Thus, the preemptive and knockout strategies share the feature that capacity investment is a credible threat only when it is fully utilized.

In the remainder of the diagram the knockout strategy is viable, and it gives strictly higher profits to the entrant than would any other postentry outcome.[12] Here, avoidable fixed costs are high and the traditional entry-deterring strategy is inconsistent with elimination of dominated strategies. In Region 3 the entrant knocks out the incumbent by expanding capacity beyond its monopoly level q^M, but in Region 4 knockout is accomplished by simply choosing the monopoly capacity q^M; in the latter case, avoidable fixed costs are so high that the incumbent is knocked out by a very low level of output.

Figure 6 suggests a reinterpretation of Bain's classification of entry-deterring strategies: for low avoidable fixed costs, capacity commitment implies an "ineffective knockout," and the entrant must accept the incumbent's presence in the market. Larger avoidable fixed costs place us in the region of "effective knockout," where the entrant must expand capacity to drive out the incumbent. Finally, when avoidable fixed costs are very high, the entrant can ignore the incumbent's presence and still drive it out; the incumbency position is "blockaded."

Note finally that the knockout strategy is not successful if $\alpha = 1$, since the incumbent may then conjecture $q_2 = 0$ even when k_2 is large. It follows that knockout requires at least some degree of sunkness on the part of the capacity investment.

6. Strategic Ambiguity of Precommitment

In using the knockout strategy, the entrant employs its capacity commitment to unambiguously communicate its intent to pursue a high-output strategy. One might wonder whether the incumbent can make similar use of its capacity precommitment. The important point is that incumbent capacity choices do not have the same communicative power as do those of the entrant, as the strategic position of the incumbent is more ambiguous: the strategic implications of a given capacity precommitment depend on the entry response which the incumbent expects, and this dependence on expectations makes it harder to draw clear inferences as to the incumbent's rational output choice.

Consider the set of undominated strategies for Firm 1 under the assumption $\alpha < 1$. Of course, strategies with very large k_1 are eliminated; if $\bar{k}_1$ is defined in a manner analogous to $\bar{k}_2$, it follows that no $s_1 \in S_1^U$ has $k_1 \geq \bar{k}_1$. For every $k_1 < \bar{k}_1$, however, we will show that there is an undominated s_1 in which k_1 is chosen, and in which the incumbent responds to entry by shutting down. Henceforth, let $q_2^D(k_1)$ denote the minimum level of q_2 which makes exit an optimal response by Firm 1:

$$\max_{q_1>0} [(a - b(q_1 + q_2^D(k_1)) - c)q_1 - r \max\{q_1,k_1\}] - f = -(1 - \alpha)rk_1$$

On the left-hand side we have the highest profits which Firm 1 could obtain by choosing positive output, given its previous choice of k_1, i.e. this is the profit it would obtain if there were no avoidable fixed costs. The right-hand side gives the profits Firm 1 obtains by shutting down. Since equality holds at $q_2 = q_2^D(k_1)$, it follows that Firm 1 would prefer positive output if $q_2 < q_2^D(k_1)$, and shutdown would be preferred if $q_2 > q_2^D(k_1)$. Note that in Figure 5, q_2^D would now be denoted by $q_2^D(q_1^D)$.

Consider the strategy s_1 defined by $k_1 < \bar{k}_1$ and:

$$q_1(k_2) = \begin{cases} \max\{q^M,\min\{k_1,\bar{q}^M\}\}, & k_2 = 0 \\ 0\,, & k_2 > 0 \end{cases}$$

Thus, s_1 specifies a positive output response if and only if Firm 2 chooses $k_2 = 0$. $q_1(0) = \max\{q^M,\min\{k_1,\bar{q}^M\}\}$ gives Firm 1's profit-maximizing output under the chosen level of k_1, when Firm 2 produces $q_2 = 0$. To see why this is true, note that if $k_1 > \bar{q}^M$, then marginal cost is simply c over the relevant range, and so $\bar{q}^M$ is optimal. If instead $k_1 < q^M$, then capacity must be expanded, making marginal cost equal to c + r; the optimal quantity is now q^M. Finally, if $k_1 \in [q^M,\bar{q}^M]$, then capacity will not be expanded ($k_1 \geq q^M$) nor will output be reduced below k_1 ($k_1 \leq \bar{q}^M$), and so optimal quantity is k_1.

We now demonstrate that s_1 is undominated. No s_1' which sets $k_1' = k_1$ and $q_1'(k_2') > 0$ for some $k_2' > 0$ will dominate s_1, since s_1 gives strictly greater profit when Firm 2's strategy specifies $k_2(k_1) = k_2'$ and $q_2(k_1) > q_2^D(k_1)$. Further, s_1' also fails to dominate s_1 when $k_1' = k_1$ and $q_1'(0) \neq \max\{q^M, \min\{k_1, \bar{q}^M\}\}$, since s_1 is strictly better against s_2 with $k_2(k_1) = q_2(k_1) = 0$. Finally, if s_1' specifies $k_1' \neq k_1$, then s_1 is strictly better when Firm 2's strategy has $q_2(k_1) = 0$ and $q_2(k_1') > q_2^D(k_1)$. We conclude that $s_1 \in S_1^U$. Thus, even after dominated strategies are eliminated, there is no capacity precommitment which allows the incumbent to communicate that it will respond to entry with large (or even positive) output.

The incumbent is unable to communicate its intent because the profitability of its capacity precommitment depends on its conjecture of the entry response, and there is no mechanism which allows the incumbent to communicate its conjecture. Thus, when the entrant observes large k_1, it can think to itself, "This is a profitable strategy for the incumbent because it expects me to choose zero capacity. But I will instead choose positive capacity, and the incumbent will shut down." Eliminating dominated strategies does not prevent the entrant from drawing such an inference.[13] Capacity choices by the entrant do have communicative power, however, precisely because their implications for rational output choice are quite clear.

7. Judo Tactics

From the preceding discussion, it is evident that establishing commitment to the market may be rather difficult for the incumbent, since it must contend with the prospect of being knocked out. We have seen that expanding capacity investment does not allow the incumbent to signal that it will choose a large output level in postentry competition. In fact, we will show that capacity expansion actually places the incumbent in a worse situation.

(Figure 7 here)

Consider Figure 7, in which Firm 1 chooses $k_1' > q_1^D$. Since avoidable fixed costs rise by $\alpha(k_1' - q_1^D)$, Firm 2 can knock out the incumbent with the lower output level $q_2' \equiv q_2^D(k_1')$. This makes the knockout strategy more profitable for Firm 2, as q_2 is moved closer to q^M. Further, the larger level of k_1 reduces the attractiveness of market sharing for Firm 2: when $k_1 = q_1^D$, Firm 2 can induce a market sharing postentry equilibrium anywhere along ABC; however, with the larger k_1' equilibria along BC are removed and replaced by equilibria in which q_1 is larger. Thus, once k_1 is raised, the entrant's profits in postentry market sharing equilibria can only be lower. This makes the knockout strategy even more attractive. It follows that larger k_1 makes the knockout strategy easier to implement and relatively more profitable for the entrant.

The incumbent will be able to remain in the market only if it *reduces* its capacity investment from the entry-deterring level, which serves to degrade the feasibility and attractiveness of the knockout strategy and thereby to encourage the entrant to choose a market sharing strategy. Such *judo tactics* take two forms. First, it is easy to see that the incumbent's position will be safe if $q_2^D(k_1) > \min\{\bar{k}_2, \bar{q}^M\}$, so that the knockout strategy is either dominated or fails to be credible. One can show that $q_2^D(k_1)$ decreases in k_1 if k_1 is not too small.[14] By reducing k_1, Firm 1 may be able to drive $q_2^D(k_1)$ above $\min\{\bar{k}_2, \bar{q}^M\}$, thereby neutralizing the knockout threat. We can call this the *neutralization tactic*. Alternatively, capacity reduction may make market sharing sufficiently profitable to the entrant that it prefers sharing to knockout; this we call the *accommodation tactic*.

(Figure 8 here)

Figure 8 illustrates these two kinds of tactics. First, choosing k_1 slightly below k_1' neutralizes the knockout strategy if $q_2^D(k_1') = \bar{q}^M$, and k_1' is the supremum over the capacity choices which do this. If however we have $q_2^D(k_1') = q_2'$ (e.g., α is a bit larger), then capacity levels close to k_1' would be too large for neutralization to be successful, and further reductions would be required. In general, if the maximum of $q_2^D(k_1)$ lies below $\min\{\bar{k}_2, \bar{q}^M\}$, then there is no capacity reduction large enough to neutralize the knockout threat.

Second, suppose now that q_2' gives the minimum level of k_2 at which the knockout strategy is successful when the incumbent's capacity is k_1' (i.e., k_2^0 for $k_1 = k_1'$). Since $q_2' \in (q^M, \bar{q}^M)$, q_2' also gives the optimal quantity for the entrant when the incumbent is knocked out. In Figure 8, the isoprofit curve through the point $q_1 = 0$, $q_2 = q_2'$ gives the set of outcomes in which $q_2 = k_2$ and in which the entrant's the profits are the same as in the knockout outcome at point A. Note that the entrant is indifferent between the profits from knockout and its preferred market-sharing outcome at point B; further, any capacity level larger than k_1' would induce the entrant to play knockout, as long as $q_2^D(k_1)$ is a decreasing function at $k_1 = k_1'$.[15] This makes k_1' the incumbent's optimal accommodation tactic.

Of course, it may be that under no circumstances will the entrant choose to accommodate the incumbent. As an illustration of this, assume that k_1'' in Figure 8 gives the unique value of k_1 which maximizes $q_2^D(k_1)$ (as explained in note 14), and suppose q_2'' gives the minimum k_2 which induces knockout when $k_1 = k_1''$; thus any $k_2 \geq q_2''$ induces knockout for all k_1. As depicted in Figure 8, the entrant's profits from knockout exceed those available in the entrant's best possible sharing equilibrium, which is at point C (in which Firm 2 acts as Stackelberg leader). It follows that the entrant will respond to any $k_1 > 0$ by inducing knockout, and so the best the incumbent can do is to cede the market to the entrant.

This analysis calls into question the commonly-held view concerning the role of capacity investment in establishing commitment to the market, which states that expansion of capacity strengthens commitment by increasing the incentive to produce large amounts of output. In the presence of avoidable fixed costs, capacity investment may turn into a liability if it makes shutdown even more attractive than large output. As demonstrated above, the focus must then fall on strategies which establish commitment via reduction of investment, which seek to discourage rivals from exploiting the avoidable fixed cost liability.

Our prediction that the incumbent might be forced to cede the market to the entrant raises the question of whether our model deals adequately with the underlying factors that determine strategic advantage. While it may be true in some cases that the timing of investment decisions is beyond the firms' control, under most circumstances it seems plausible that timing would be influenced by firms' decisions; in particular, a firm with an opportunity to move first may be able to surrender its position by delaying its investment (as considered by Mailath (1988), for example). With high avoidable fixed costs, our results suggest that when the timing of moves is endogenized, the firms would compete to obtain the more desireable second position, and entry into the market would take the form of a waiting game.[16]

8. Parameterized Example

In this section we study the set of subgame perfect equilibria which arise after weakly dominated strategies are removed, for a particular parameterization of the model. First, though, it is necessary to establish that subgame perfect equilibria exist in the first place; this is accomplished in the appendix, under the condition that Firm 2's strategy set S_2^U is expanded slightly to allow it to choose strategies which give zero profit in response to Firm 1 strategies which specify shutdown. The appendix demonstrates existence by constructing the equilibrium which maximizes the incumbent's profits over the set of subgame perfect equilibria (including equilibria which involve mixed strategies), and it is this equilibrium which we consider here.

(Figure 9 here)

Figure 9 summarizes the equilibrium outcomes as functions of α and f, for given values of the other parameters. For low α and f, the outcome lies in Region 1, in which the incumbent's optimal capacity choice involves the neutralization tactic. In this case, the tactic takes the form of rendering the knockout threat incredible, i.e. $q_2^D(k_1) > \bar{q}^M$. In subregion 1a this is automatically accomplished at the Stackelberg leader capacity, and the entrant responds optimally by choosing the Stackelberg follower capacity. In subregion 1b, however, the incumbent must reduce capacity from this level in order to neutralize the knockout threat: larger α and f make $q_2^D(k_1)$ smaller for every level of k_1, so that neutralization becomes more difficult.

In Region 2 the incumbent's optimal capacity choice involves the accommodation tactic: knockout is feasible, but the entrant prefers the market sharing outcome. In subregion 2a knockout is so costly that the entrant prefers the Stackelberg follower outcome to knockout, but in the rest of Region 2 the incumbent must reduce capacity from the Stackelberg leader level in order to accommodate the entrant. In subregion 2b these reductions still leave the incumbent with larger postentry market share, but in subregion 2c the incumbent must choose capacity so small that the entrant has larger postentry market share; accommodation forces the incumbent to accept an inferior market position.

Finally, for larger α and f we enter Region 3, in which the incumbent can neither neutralize the knockout strategy, nor accommodate the entrant. The incumbent's optimal strategy is then simply to cede the market to the entrant. We see that the benefits of choosing capacity first are linked to the extent and nature of avoidable fixed costs. In general, as these costs rise, the incumbent must reduce its capacity commitment in order to protect itself from knockout. When avoidable fixed costs are sufficiently high, the incumbent is forced to cede the market even in its preferred equilibrium.

9. Related Literature

This paper builds on a large literature which studies strategic investment by incumbent firms. Two strands of work relate most closely to our analysis. First, the role of avoidable fixed costs in creating coordination problems has been recognized by Dixit (1979) and Arvan (1986). Arvan argues that reputation plays a role in the equilibrium selection process, and he shows that the incumbent may gain the advantage in equilibrium selection by exploiting private information about its costs. Second, Schmalensee (1983) and Fudenberg and Tirole (1984) discuss circumstances under which exercising strategic power may lead an incumbent to choose a less aggressive strategy, in order to exploit strategic complementarity (the "puppy dog ploy"). Our accommodation tactic is related to this notion in that in both instances, a reduction in the incumbent's aggressiveness makes it more profitable for the entrant to play a strategy which is beneficial to the incumbent.

Our paper contributes to a growing body of work which analyzes the strategic power which accrues to second movers. This research is conveniently divided into three categories. First, second movers may be able to capture the market through displacement of first movers, due to the presence of avoidable fixed costs. Eaton and Lipsey (1980) give a very clear illustration of this principle. In their model, the incumbent's capital is indivisible and must be replaced after a certain interval of time. As time passes, the sunk cost of capital investment turns gradually into the avoidable cost of capital replacement. The incumbent maintains its commitment to the market by keeping its avoidable fixed cost below a certain level, which is accomplished by early replacement of its capital. In a similar vein, the literature on contestable markets (e.g., Baumol and Willig (1981)) emphasizes that incumbency advantages arise only to the extent that fixed costs are sunk as opposed to avoidable.

More recent literature makes a similar point. In a dynamic game of exit, Ghemawat and Nalebuff (1985) show that firms having larger avoidable fixed costs exit first. Judd

(1985) argues that a multiproduct firm selling substitute products can be displaced from one of its markets by an entrant, provided exit costs (e.g., severance pay) are not too high. In a sense, the low prices that entry induces upon the incumbent's product line act like a fixed cost, which can be avoided if the incumbent exits the entered market. Maskin and Tirole (1988) consider a model in which short-term commitments to output are used to deter entry. If output is too small, the entrant knocks out the incumbent. This accumulation of research points to a basic dichotomy: sunk costs convey strategic power to first movers, while avoidable costs convey strategic power to second movers.

Second, a literature has developed that illustrates second mover advantages in environments with learning externalities. Ramey (1988) shows that a "wait and see" approach to product innovation can be preferred if the probability of successful innovation is correlated across firms. Jovanovic and Lach (1989) argue that late entrants benefit from free-riding off of the learning-by-doing of early entrants. First mover disadvantages are shown by Gal-Or (1987) to occur if the existence of private information gives rise to signaling distortions; Mailath (1988) demonstrates that such distortions may induce the first mover to voluntarily give up its first mover status.

Third, a firm may prefer second mover status in markets with strategic complementarities. For example, Gal-Or (1985) observes that second mover profits are higher than first mover profits in a Stackelberg game of price competition. Here, the first mover adopts a less aggressive price than the second mover in order to reduce rivalry. Of course, a first mover advantage remains to the extent that both firms do better in the Stackelberg game than in a simultaneous move game. In total, this research demonstrates that whether the first or second mover possesses the strategic edge may hinge on many aspects of the economic environment.

10. Conclusion

In the past twenty years, the merger of Industrial Organization and Game Theory has produced a plethora of theories but few broad conclusions. One conclusion which has been robust to a variety of models, however, is that there is a preemptive advantage to moving first when costs are sunk. This conclusion is well illustrated by Dixit's model of entry deterrence, wherein the sunk nature of capital expenditures enables an incumbent firm to commit to an aggressive postentry posture. Extensions of this line of reasoning have led to completely new theories of the evolution of market structure (Eaton and Ware (1987), McLean and Riordan (1989)).

Our fundamental point in this paper is that the first mover advantages associated with incumbency fail to hold - and indeed may be reversed - when there are multiple equilibria in the postentry game. In our model, the fact that the entrant chooses capacity second, after the incumbent, affords the entrant a tremendous advantage. The incumbent may be forced to acquiesce to the entrant by choosing zero capacity, or practice judo economics by selecting a nonthreatening, small capacity. The former possibility is more likely the higher are avoidable fixed costs.

This analysis calls into question the conclusion that first movers must benefit due to their ability to preempt. Rather, in the context of the capacity-and-entry model, when sunk costs are large relative to avoidable costs the strategic advantage does lie with the incumbent, but when the reverse holds the advantage goes to the entrant. This conditional aspect of first mover advantages may provide some explanation for the poor performance of the received model in the few empirical studies that have been done. For example, Bulow, Geanakopolos and Klemperer (1985) have shown that for a variety of demand functions the incumbent in Dixit's model will choose to hold excess capacity in order to deter entry. Lieberman (1987), however, finds little evidence of such behavior. Similarly, Smiley (1988) finds excess capacity to be a relatively unpopular mode of deterrence in his survey of product managers.

In our model, the incumbent responds to the second mover advantage by reducing capacity investment, but one can conceive of other strategies which might be available to the incumbent. First, through choice of technology the incumbent may have some control over the sunk vs. avoidable components of fixed costs. The incumbent's defensive tactics may then take the form of a distortion in favor of technologies which are relatively inflexible with respect to the range of products which can be produced.[17] Second, the incumbent might render the knockout strategy nonviable through choice of organizational form. In particular, the knockout strategy would fail if the incumbent could commit to choosing quantity prior to observing the entrant's capacity. Such a commitment may restore first mover advantages even if the entrant is unable to observe the incumbent's quantity, i.e. the incumbent may gain from "silent commitment power." Organizational forms which are relatively inflexible and bureaucratic may be useful for this purpose.

APPENDIX

Subgame Perfect Equilibrium of the Reduced Game

In this appendix we first characterize the sets S_1^U and S_2^U, and then discuss the existence of subgame perfect equilibria of the game in which the strategy sets S_1 and S_2 are replaced by S_1^U and S_2^U. The assumption $\alpha < 1$ is maintained throughout the appendix.

Let $q_1^R(q_2|k_1)$ denote Firm 1's reaction correspondence in the postentry game, when Firm 1 has chosen capacity k_1. We know that $q_1^R(q_2|k_1)$ is weakly decreasing in q_2, and $q_1^R(q_2|k_1)$ gives a continuous function for all q_2 except $q_2 = q_2^D(k_1)$, at which point Firm 1 is indifferent between its positive best response and shutdown. Note further that in postentry competition the firms will never produce outputs which exceed their best responses when the rival produces zero quantity. For Firm 1 this upper bound output is given by:

$$q_1^0(k_1) \equiv \max\{q^M, \min\{k_1, \bar{q}^M\}\}$$

as was explained in the text. $q_2^R(q_1|k_2)$, $q_1^D(k_2)$ and $q_2^0(k_2)$ are defined analogously; note that $q_1^D(0)$ corresponds to the q_1^D of the text.

Let us now characterize the set S_2^U. Consider first the Firm 2 output choices which are dominated by virture of guaranteeing nonpositive profits. For any $k_2 > 0$, we can define $q_2^H(k_2)$ and $q_2^L(k_2)$ to be the upper and lower solutions, respectively, to the following:

$$(a - bq_2 - c)q_2 - r\max\{k_2, q_2\} - f = 0 \tag{3}$$

Thus, for $q_2 \geq q_2^H(k_2)$ or $q_2 \leq q_2^L(k_2)$, Firm 2's profits given its choice of k_2 are nonpositive even if $q_1 = 0$.

(Figure 10 here)

$q_2^H(k_2)$ and $q_2^L(k_2)$ are illustrated in Figure 10. Note that $q_2^H(k_2) \leq \bar{k}_2$ and $q_2^L(k_2) \in (0,\bar{q}^M]$ for all k_2, where $q_2^L(k_2) > 0$ is a consequence of $f > 0$.

S_2^U is characterized in the following:

Lemma 1: S_2^U is exactly the set of all $s_2 = (k_2(k_1),q_2(k_1))$ such that, for every k_1:

(a) $k_2(k_1) < \bar{k}_2$;

(b) $q_2(k_1) \in (q_2^L(k_2(k_1)),q_2^0(k_2(k_1))]$ whenever $q_2(k_1) > 0$; and

(c) $k_2(k_1) = 0$ whenever $q_2(k_1) = 0$.

Proof: Suppose $s_2 \in S_2^U$. From the text we know that $k_2(k_1) < \bar{k}_2$, so it remains to verify that (b) and (c) are satisfied. If there existed k_1' such that $q_2(k_1') > 0$ and $q_2(k_1') \notin (q_2^L(k_2(k_1')),q_2^H(k_2(k_1')))$, then s_2 would be dominated by s_2' defined as in (2). Further, if s_2 set $q_2(k_1') > q_2^0(k_2(k_1'))$, then we could define s_2' to agree with s_2 except for putting $q_2'(k_1') = q_2^0(k_2(k_1'))$, and s_2' would dominate s_2. Since $q_2^0(k_2) < q_2^H(k_2)$ for all $k_2 < \bar{k}_2$, we have (b). If s_2 puts $q_2(k_1') = 0$, then Firm 2's profits are $-(1 - \alpha)k_2(k_1')$ when Firm 1 chooses k_1', and s_2 would be dominated unless $k_2(k_1') = 0$; this gives (c).

Now suppose that s_2 satisfies (a), (b) and (c), but $s_2 \notin S_2^U$. Then there must be some s_2' which dominates s_2, and for some k_1' we will have $(k_2(k_1'),q_2(k_1')) \neq (k_2'(k_1'),q_2'(k_1'))$. Suppose first that $k_2(k_1') \neq k_2'(k_1')$, and consider s_1 which sets $k_1 = k_1'$ and:

$$q_1(k_2) = \begin{cases} 0, & k_2 = k_2(k_1') \\ q_1', & k_2 \neq k_2(k_1') \end{cases}$$

Since $q_1(k_2(k_1')) = 0$ and $q_2(k_1') \in (q_2^L(k_2(k_1')),q_2^H(k_2(k_1')))$, s_2 gives strictly positive profits as a response to this s_1, while s_2' must yield nonpositive profits if q_1' is sufficiently large; thus, $\Pi_2(s_1,s_2) > \Pi_2(s_1,s_2')$, and s_2' cannot dominate s_2.

Suppose next that $k_2(k_1') = k_2'(k_1')$, so that $q_2(k_1') \neq q_2'(k_1')$. Since $q_2(k_1') \in [0,q_1^0(k_2(k_1'))]$, we can find q_1' such that when Firm 1 chooses q_1', $q_2(k_1')$ gives strictly higher profits in postentry competition than does $q_2'(k_1')$) (for example, we might have $q_2^R(q_1' | k_2(k_1')) \leq q_2(k_1') < q_2'(k_1')$). Thus s_2 is strictly better than s_2' against s_1 which sets $k_1 = k_1'$ and $q_1(k_2(k_1')) = q_1'$, and s_2' cannot dominate s_2. Q.E.D.

(Figure 11 here)

Figure 11 illustrates the sets S_2^U for the possible configurations of $\bar{k}_2$ and $\bar{q}^M$. The shaded areas indicate the values which $q_2(k_1)$ may assume in an undominated strategy, for $k_2 = k_2(k_1)$. As k_2 rises, both the upper and lower bounds of possible quantity responses rise. Moreover, the infimum over allowable positive quantity reponses is not itself allowable.

We next consider S_1^U. Let $q_1^H(k_1)$ and $q_1^L(k_1)$ be defined by analogy to $q_2^H(k_2)$ and $q_2^L(k_2)$, and let $q_1^H(k_1,\alpha)$ and $q_1^L(k_1,\alpha)$ be the upper and lower solutions, respectively, to:

$$(a - bq_1 - c)q_1 - r\max\{k_1,q_1\} - f = -(1 - \alpha)rk_1$$

This is similar to (3) except that it reflects the fact that Firm 1 no longer has the option of recovering all fixed costs once k_1 is chosen. Thus, Firm 1 is less willing to shut down; we have $q_1^H(k_1,\alpha) > q_1^H(k_1)$ and $q_1^L(k_1,\alpha) < q_1^L(k_1)$ for all $k_1 > 0$. Note that $\lim_{\alpha\to 1} q_1^L(k_1,\alpha) = q_1^L(k_1)$ and $\lim_{\alpha\to 1} q_1^H(k_1,\alpha) = q_1^H(k_1)$. S_1^U is characterized in:

<u>Lemma 2</u>: S_1^U is exactly the set of all $s_1 = (k_1,q_1(k_2))$ such that:

(a) $k_1 < \bar{k}_1$;

(b) For all k_2, $q_1(k_2) \in (q_1^L(k_1,\alpha),q_1^0(k_1)]$ whenever $q_1(k_2) > 0$; and

(c) There exists k_2 such that $q_1(k_2) \in (q_1^L(k_1),q_1^0(k_1)]$ whenever $k_1 > 0$.

Proof: Suppose $s_1 \in S_1^U$. We already know that (a) is implied. If $q_1(k_2) \in (0,q_1^L(k_1,\alpha)]$, then Firm 1 weakly prefers the response $q_1'(k_2) = 0$, and strictly prefers it if $q_2(k_1) > 0$. If $q_1(k_2) > q_1^0(k_1)$, then Firm 1 prefers the response $q_1'(k_2) = q_1^0(k_1)$. In either case, the preferred response may be used to construct a strategy s_1' which dominates s_1; this gives (b). If $k_1 > 0$ and $q_1(k_2) \notin (q_1^L(k_1),q_1^H(k_1))$ for all k_2, then the strategy s_1' which sets $k_1' = q_1'(k_2) = 0$ for all k_2 is weakly preferred for any s_2, and strictly so if $q_2(k_1) > 0$. Combining this with (b) gives (c).

Now suppose s_1' dominates s_1 which satisfies (a), (b) and (c). First consider $k_1 > 0$ and $k_1 \neq k_1'$. By (c) there exists k_2' such that $q_1(k_2') \in (q_1^L(k_1),q_1^0(k_1)]$. Let s_2 satisfy $k_2(k_1) = k_2'$, $q_2(k_1) = 0$, and $k_2(k_1') = q_2(k_1') > q_2^D(k_1')$, in which case $\Pi_1(s_1,s_2) > 0 \geq \Pi_1(s_1',s_2)$. Next consider $k_1 = 0$ and $k_1 \neq k_1'$, and let s_2 continue to satisfy the preceding. Using (b) we have $\Pi_2(s_1,s_2) \geq 0 > \Pi_2(s_1',s_2)$. Finally, for $k_1 = k_1'$ we must have $q_1(k_2') \neq q_1'(k_2')$ for some k_2', and since $q_1(k_2') \leq q_1^0(k_1)$ we may find q_2' such that when Firm 2 chooses $q_2(k_1) = q_2'$, $q_1(k_2')$ gives strictly higher profits in postentry competition than does $q_1'(k_2')$; q_2' may be used to specify s_2 such that $\Pi_1(s_1,s_2) > \Pi_1(s_1',s_2)$. Q.E.D.

Note that Lemma 2.c captures precisely the strategic ambiguity of precommitment for the incumbent: when $k_1 > 0$, the entrant infers only that $q_1(k_2) > 0$ for some k_2, whereas Lemma 1.c shows that observing $k_2 > 0$ leads the incumbent to infer $q_2(k_1) > 0$ for every k_1.

(Figure 12 here)

The shaded areas of Figure 12 depict the restrictions on Firm 1 quantity responses which must hold for every k_2 in an undominated strategy. The figure makes clear the key difference between S_1^U and S_2^U, being that the response $q_1 = 0$ is not eliminated no matter what level of k_1 is chosen.

Now that the reduced game has been characterized, we can give conditions needed for existence of subgame perfect equilibria. There are three kinds of postentry outcomes which might arise in a subgame initialized by k_1 and k_2:

1. Preempt Equilibrium - $q_1 > 0$, $q_2 = 0$. When $k_2 = 0$, this equilibrium exists if and only if $q_1^0(k_1) \geq q_1^D(k_2)$. We know from Lemma 1 that this equilibrium is inconsistent with dominant strategy elimination if $k_2 > 0$.

2. Knockout Equilibrium - $q_1 = 0$, $q_2 > 0$. For any k_1 and k_2, this kind of equilibrium exists if and only if $q_2^0(k_2) \geq q_2^D(k_1)$.

3 Share Equilibrium - $q_1 > 0$, $q_2 > 0$. To consider this class of postentry equilibria we need to look more carefully at the reaction functions in the reduced game. As for Firm 1, it is easy to see that $q_1^L(k_1,\alpha) < q_1^R(q_2|k_1) \leq q_1^0(k_1)$ for any q_2 such that $q_1^R(q_2|k_1) > 0$, so we may simply take the restriction of $q_1^R(q_2|k_1)$ to $(q_2^L(k_2),q_2^0(k_2)]$. The same holds true for Firm 2 if $k_2 = 0$. For $k_2 > 0$, however, we could have $q_2^R(q_1|k_2) < q_2^L(k_2)$ for some q_1 (this occurs if Firm 2 would not want to enter expecting the response q_1, but once it has entered it would not want to exit). In this case Firm 1's best response in the reduced game might not be defined.

(Figure 13 here)

The problem is illustrated in Figure 13. The allowable quantity responses for the subgame initialized by k_1 and k_2 are given by the shaded area together with the segment AB along which $q_1 = 0$. For $q_1 \in [q_1', k_1]$ Firm 2's profits continue to increase as q_2 is reduced toward $q_2^L(k_2)$, but the limit is not an allowable response. We remedy this problem by expanding set S_2^U slightly to include responses $q_2^L(k_2)$; we denote this set by $\hat{S}_2^U$. With this we can define Firm 2's reaction function for every subgame; in Figure 13, for example, the segment CD now gives the reactions for $q_1 \in [q_1', k_1]$. Note that with this modification the reaction functions of Firm 2 will always be continuous functions of q_1 when $k_2 > 0$, as no strategy in $\hat{S}_2^U$ allows Firm 2 to jump to $q_2 = 0$.

This modification of our reduced game is supportable from two perspectives. First, we can define our subgame perfect equilibrium as a limit of outcomes which specify ε-equilibria in every subgame as $\varepsilon \to 0$. Second, note that when this problem leads to nonexistence of postentry equilibria for a given pair of capacity choices, we may specify q_1 such that Firm 2 would prefer $k_2 = q_2 = 0$ over its capacity choice no matter what quantity it picked in the subgame. Thus the nonexistence problem only arises at irrelevant branches of the game.

We now let $q_2^R(q_1 | k_2)$ denote Firm 2's reaction function in the modified game. In the $k_2 > 0$ case, a share equilibria of a subgame exist if and only if $q_2^R(q_1 | k_2)$ intersects $q_1^R(q_2 | k_1)$ from below before $q_1^R(q_1 | k_2)$ jumps to zero; further, at most one share equilibrium will exist. We can be sure that a share equilibrium exists if $q_2^D(k_1) \geq q_2^0(k_2)$, as in this case both reaction functions may be restricted to strictly positive quantities; this case is illustrated in Figure 13. It follows that nonexistence of a knockout equilibrium is sufficient for existence of a share equilibrium. Similar observations apply for $k_2 = 0$, except that when $q_2^D(k_1) \geq q_2^0(k_2)$ we know there exists either a share equilibrium or a preempt equilibrium (or both).

(Figure 14 here)

Now suppose $q_2^D(k_1) < q_2^0(k_2)$, and let $q_1^R(q_2^D(k_1) | k_1) = \{0, q_1'\}$, i.e. q_1' is the positive output level which Firm 1 produces at the point where $q_1^R(q_2 | k_1)$ jumps to zero. Then a share equilibrium exists if and only if $q_2^R(q_1'|k_2) \leq q_2^D(k_1)$, for this is necessary and sufficient for the reaction functions to cross at some $q_1 \geq q_1'$. In Figure 14 we have an instance in which share equilibria do not exist for this reason.

We now construct a subgame perfect equilibrium of the game obtained by replacing the strategy sets S_1 and S_2 by S_1^U and S_2^U. The idea behind the construction is that for each subgame initialized by k_1 and k_2, we will choose as postentry equilibrium the equilibrium which gives Firm 1 the greatest profit, unless we are forced to do otherwise in order to ensure that a profit maximizing capacity choice exists for Firm 2.

We first consider the choices of k_2 for which share equilibria of the subgame exist. Note that $q_2^L(k_2)$ is a positive constant for $k_2 \leq q^M$; this places a lower bound on Firm 2's quantity in share equilibria when k_2 is small. Note further that share equilibrium profits vary continuously as k_2 varies, so long as the share equilibrium continues to exist.

Next consider the k_2 which make knockout equilibria the unique equilibria of the subgame. In this case we have either $k_2 > 0$ and $q_2^L(k_2) > q_2^D(k_1)$, or $q_2^R(q_1'|k_2) > q_2^D(k_1)$ where q_1' is the positive best response to $q_2^D(k_1)$ (i.e., the situation depicted in Figure 14); note that Firm 2's profits in the knockout equilibria are continuous in k_2. If either condition holds with equality, then both share and knockout equilibria may exist, but specifying the share equilibrium may be inconsistent with existence of a profit maximizing choice of k_2, as Firm 2 may be able to induce the knockout equilibrium through a slight increase in k_2. If this is true, we specify the knockout equilibrium. Otherwise we specify the share equilibrium for every subgame with $k_2 > 0$, and if $k_2 = 0$ we specify Firm 1's most preferred equilibrium. It follows that for every k_1, there exists a capacity choice $k_2^R(k_1)$ which maximizes Firm 2's profits.[18] If Firm 2 is indifferent between two or more values of k_2, then it chooses the one which makes Firm 1's profits the highest.

Now consider Firm 1's profits as a function of k_1, given $k_2^R(k_1)$ and the indicated postentry equilibria. There are two reasons why profits may be discontinuous at a point k_1':

(1) Firm 2 shifts $k_2^R(k_1)$ discontinuously to move between postentry equilibria, but at k_1' Firm 2 is indifferent between these equilibria. We have indicated that in this case Firm 2 selects the equilibrium most preferred by Firm 1. (2) A perturbation of k_1' eliminates a class of equilibria for every k_2. $k_2^R(k_1)$ might then shift discontinuously between equilibria among which Firm 2 is not indifferent at k_1'. If the preempt equilibrium is eliminated, we know that it still exists at $k_1 = k_1'$, as a consequence of the fact that the reaction functions have closed graphs; thus profits could only jump upward at this point. Similarly, if perturbing k_1 would eliminate the share equilibria for every k_2, then one or more share equilibria would exist at $k_1 = k_1'$ and again only upward jump discontinuities would be possible.

Finally, perturbations from k_1' will determine the existence of knockout equilibria for all k_2 if and only if $q_2^D(k_1') = \min\{\bar{k}_2, \bar{q}^M\}$ (this is the neutralization tactic). It is then true that $q_2^D(k_1') \geq q_2^0(k_2)$ for all $k_2 < \bar{k}_2$ (recall that $\bar{k}_2 > q^M$), and so there exists a share equilibrium for every k_2. Since given k_1' Firm 2 is unable to induce the knockout equilibrium, our specification requires the share postentry equilibrium to be played. Thus, Firm 1's profits can only jump upward at k_1'.

From this discussion it follows that Firm 1's profits are uppersemicontinuous in k_1, and by specifying a profit-maximizing choice of k_1 we complete the construction. Note that if we make a different specification of postentry equilibria, then Firm 2's capacity choice is affected only if it chooses to induce a postentry equilibrium which gives it greater profits. But this necessarily lower's Firm 1's profits. It follows that the above construction maximizes Firm 1's equilibrium profits over the set of subgame perfect equilibria of the reduced game.

Finally, there will not be any equilibria with mixed strategies in which the incumbent earns higher profit. Note first that in the post-entry subgame, neither firm will mix among positive quantities, as a consequence of the strict concavity of the profit function in own quantity. Thus, if $k_2 > 0$ Firm 2 must choose a pure quantity strategy, and Firm 1 will then mix only if $q_2 = q_2^D(k_1)$; Firm 1 is indifferent among such outcomes. If $k_2 = 0$, there are two reasons why Firm 2 might mix: (1) $q_1 = q_1^D(k_2)$. In this case the preempt equilibrium exists, and it gives Firm 1 greater profits than any of the mixed outcomes. (2) Firm 1 mixes. In this case Firm 1's expected postentry profits are $-(1 - \alpha)rk_1$, which are no greater than in the outcome specified above. Thus, replacing the specified postentry outcomes with mixed outcomes can only reduce Firm 1's profits. Further, mixed choices of k_2 will only reduce the incumbent's profits, as we have specified that if Firm 2 is indifferent, it chooses the capacity which makes Firm 1's profits the greatest.

NOTES

1. Throughout this paper our criterion of forward induction requires only the elimination of weakly dominated strategies. More sophisticated notions of forward induction, such as those surveyed by Kohlberg (1989), are not required for our analysis.

2. These cost functions incorporate the fact that neither firm will in the second stage expand capacity beyond the chosen output, which would clearly be a strictly dominated strategy.

3. More specifically, games of this sort have been analyzed using the concept of <u>subgame perfect equilibrium</u>, developed by Selten (1975). Kreps and Wilson (1982) discuss broader notions of backward induction rationality.

4. Specifically, we assume $f < (a - c - r)^2/4b$.

5. In Figure 3, the minimum exit-inducing quantity q_2' satisfies:

$$\max_{q_1} (a - b(q_1 + q_2') - c)q_1 - r \max\{q_1, k_1'\} - f = 0$$

where the the solution satisfies $q_1 \leq k_1'$ since in the figure Firm 1 would not choose to expand capacity beyond k_1' for any q_2. The minimum q_2 which induces the response $q_1 = 0$ when $k_1 = 0$ is defined by:

$$\max_{q_1} (a - b(q_1 + q_2) - c - r)q_1 - f = 0$$

Since for any q_2 the left-hand side of the latter expression is greater that of the former when q_2' is replaced with q_2, it follows that the latter minimum exit-inducing quantity is greater than q_2', as shown in Figure 3. Note that these quantities would be the same if k_1 did not exceed the monopoly quantity. For $\alpha = 0$, in contrast, the minimum exit-inducing quantity when $k_1 = k_1'$ is defined by:

$$\max_{q_1} \; (a - b(q_1 + q_2) - c)q_1 - r \max\{q_1, k_1'\} - f = -rk_1'$$

and clearly this gives a larger minimum exit-inducing quantity than under $k_1 = 0$.

6. This criterion is discussed by Luce and Raiffa (1957) and, more recently, by Kohlberg and Mertens (1986).

7. For simplicity our model is specified in terms of pure strategies, although our analysis extends to mixed strategies in a straightforward way. The possibility of mixed strategies is incorporated into the parameterized example of section eight.

8. See Lemma 1 of the appendix for a detailed demonstration of the latter point.

9. All qualitative properties depicted in Figure 5 and described in the text hold for the parameterization $a = b = 1$, $c = 0$, $r = 0.25$, $f = 0.0325$ and $\alpha = 0.4$.

10. It is important to understand this point. By selecting $\bar{k}_2$-ε, Firm 2 ensures that Firm 1 shuts down precisely because <u>only</u> values of q_2 which exceed q_2^D can be undominated in conjunction with the capacity choice $\bar{k}_2$-ε. One particular quantity of this type is $\bar{q}_M$; furthermore, the choices $k_2 = \bar{k}_2$-ε, $q_2 = \bar{q}_M$ give strictly positive profits to Firm 2 when q_1

= 0. Thus, Firm 2 would actually deviate to these choices.

11. While $q_1(\bar{k}_2-\varepsilon) = 0$ is implied when subgame perfection is imposed following the elimination of dominated strategies, it is also true that $q_1(\bar{k}_2-\varepsilon) = 0$ must hold in any Nash equilibrium which survives two rounds of dominated strategy elimination. Thus our result may be derived solely from forward induction inference, as is done by Ben-Porath and Dekel (1987) and van Damme (1989).

12. Recall that different choices of k_2 lead to different postentry equilibria based on shifting the entrant's reaction function. Under the parameterization of Figure 6, the entrant prefers the knockout strategy to any postentry equilibrium which could be induced by some choice of k_2, and which would involve positive output for Firm 1. Among the equilibria with positive Firm 1 output, Firm 2 in this example prefers the equilibrium in which it shares the market with Firm 1.

13. One may wonder whether more rounds of dominated strategy elimination might sharpen the incumbent's communicative abilities. For example, in Figure 5 it may be that more rounds discriminate between an "aggressive" strategy, $k_1 = q_1(k_2) = q_1^D$ for all k_2, and a "bluffing" strategy, $k_1 = q_1^D$ and $q_1(k_2) = 0$ for all $k_2 > 0$. Indeed this is the case, but it is the agressive strategy which is removed; to see this, recall from note 11 that two rounds of dominated strategy elimination ensure $q_1(\bar{k}_2-\varepsilon) = 0$.

14. This may be seen as follows. Note that when $q_2 = q_2^D(k_1)$, Firm 1's reaction correspondence contains two points, zero quantity and a strictly positive quantity which we may denote by q_1'; thus, at $q_2^D(k_1)$ Firm 1's best response jumps from $q_1' > 0$ to zero. One can show that there exist capacity levels k_1^a and k_1^b, depending solely on exogeneous

parameters and satisfying $0 < k_1^a < k_1^b$, such that: (1) For $k_1 > k_1^b$, we have $q_1' < k_1$ and $q_2^D(k_1)$ is strictly decreasing in k_1; in this case, q_1' lies on the upper negatively sloped segment of Firm 1's reaction function. (2) For $k_1^a \leq k_1 \leq k_1^b$, we have $q_1' = k_1$, $q_2^D(k_1)$ is strictly decreasing in k_1 if $f < bk_1^2$, and it is strictly increasing if $f > bk_1^2$; here q_1' is on the vertical segment. (3) For $k_1 < k_1^a$, we have $q_1' > k_1$ and $q_2^D(k_1)$ is strictly increasing in k_1; q_1' is now on the lower negatively sloped segment, corresponding to the full-cost reaction function. As depicted in Figures 7 and 8, $k_1' > k_1^b$ holds, and so any $k_1 > k_1'$ satisfies $q_2^D(k_1) < q_2^D(k_1')$.

15. For this to be true we must have $f \leq bk_1'^2$; see note 14.

16. Results from Ramey (1988) may be at once applied to this question. Consider the following game. In each of the periods t = 1,2,..., two firms decide whether to enter or stay out. If both stay out, the game starts again in the next period. If only one firm enters, it observes that the other firm has stayed out and chooses its capacity, while the other firm observes this capacity choice and chooses its own capacity in the next period; this corresponds to the game considered in the present paper. If both enter, then they play some symmetric equilibrium (perhaps in mixed strategies) in which capacities and then quantities are chosen simultaneously. It follows that in a symmetric entry equilibrium, entry is delayed if the first mover's profits are positive but lower than the second mover's (in the parameterized example of section eight, this is Region 2c of Figure 9), and the market fails completely if the first mover is forced to cede the market (Region 3 of Figure 9).

17. We thank Lanny Arvan for this suggestion. Here we have a variation of the investment strategy discussed by Eaton and Lipsey (1981): rather than excessive durability, the incumbent chooses excessive inflexibility.

18. When a preempt equilibrium is specified for $k_2 = 0$, existence of $k_2^R(k_1)$ is assured as a consequence of the behavior of Firm 2's profits in the neighborhood of $k_2 = 0$. For suppose small upward perturbations of k_2 induce share equilibria in which profits are positive; in this case Firm 2's share profits will be independent of k_2 for k_2 sufficiently small. If upward perturbations induce knockout equilibria, then Firm 2's profits will also be independent of k_2 for k_2 sufficiently small. Thus, even though a downward jump discontinuity exists at $k_2 = 0$, profits do not continue to rise as k_2 is reduced toward zero.

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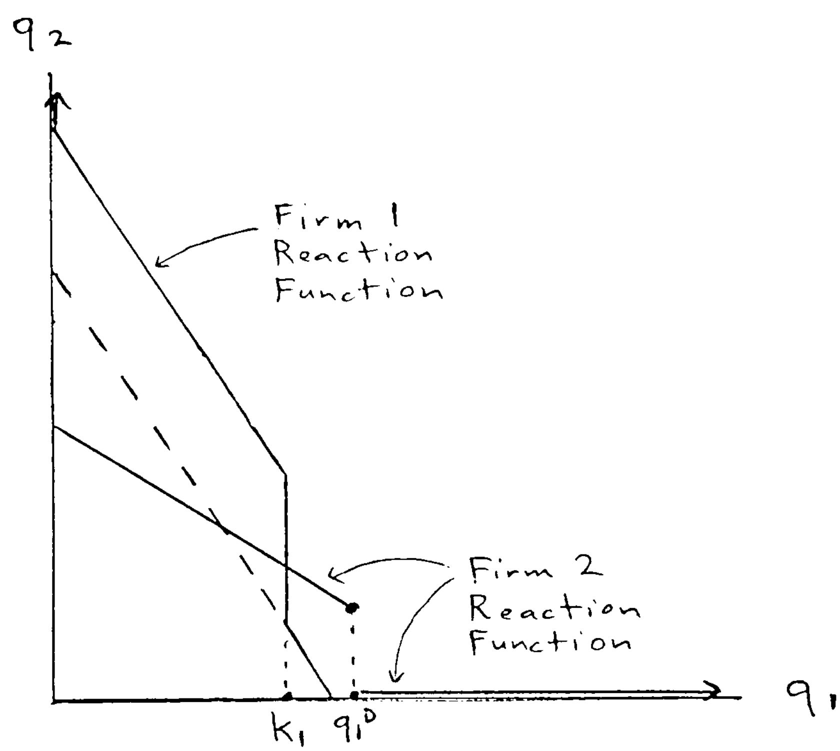

Figure 1

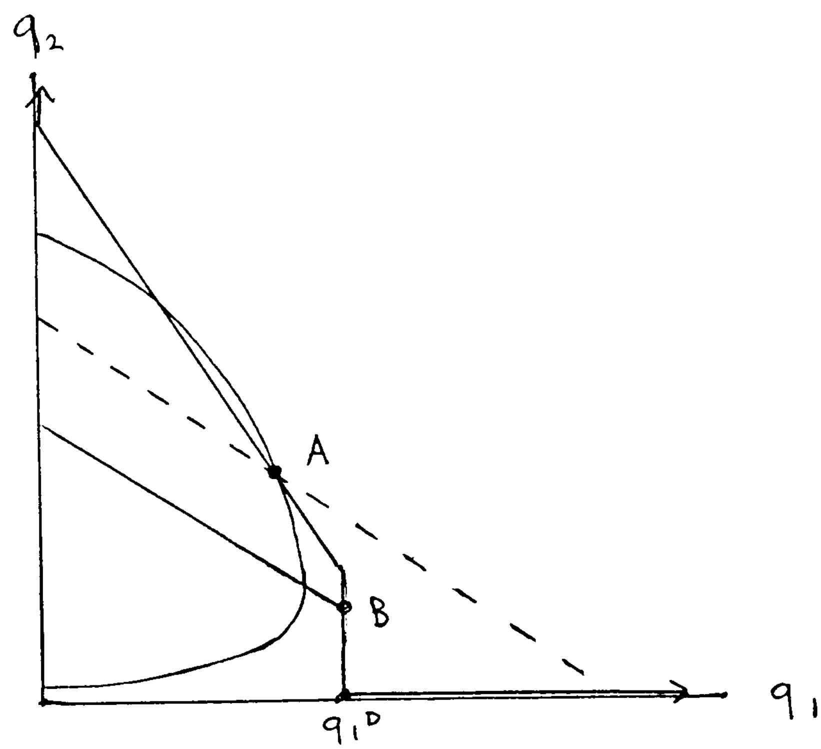

Figure 2

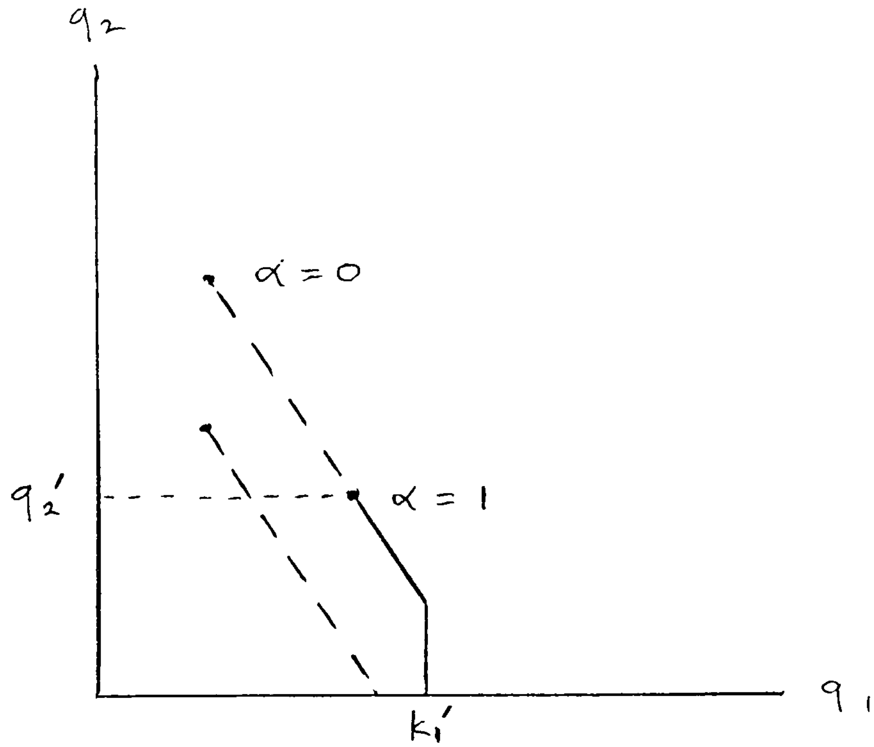

Figure 3

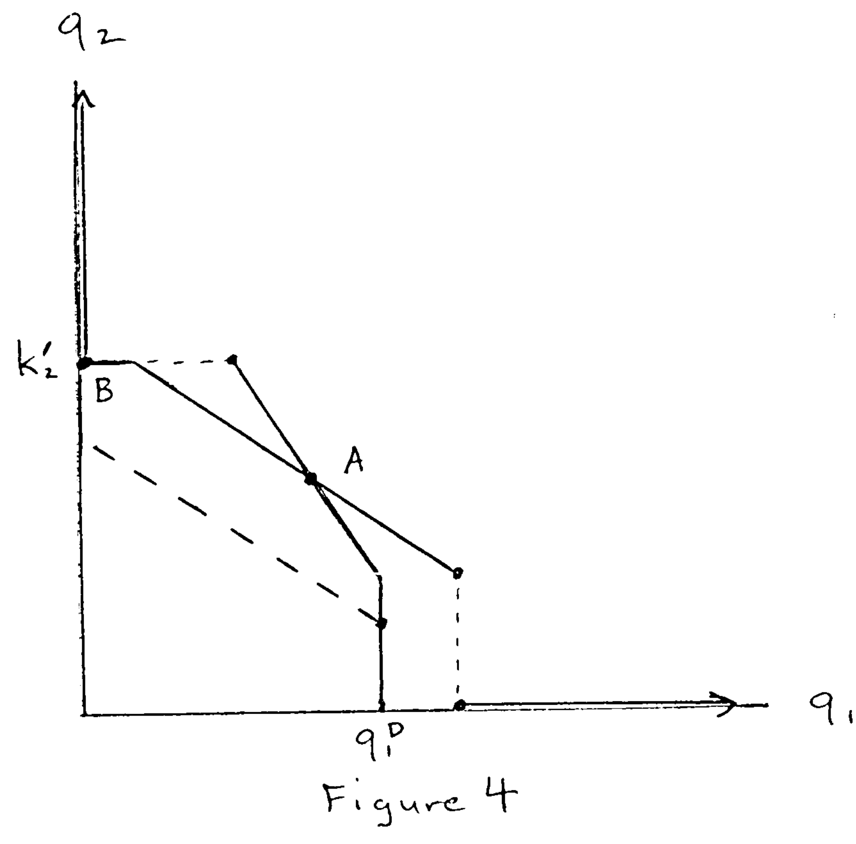

Figure 4

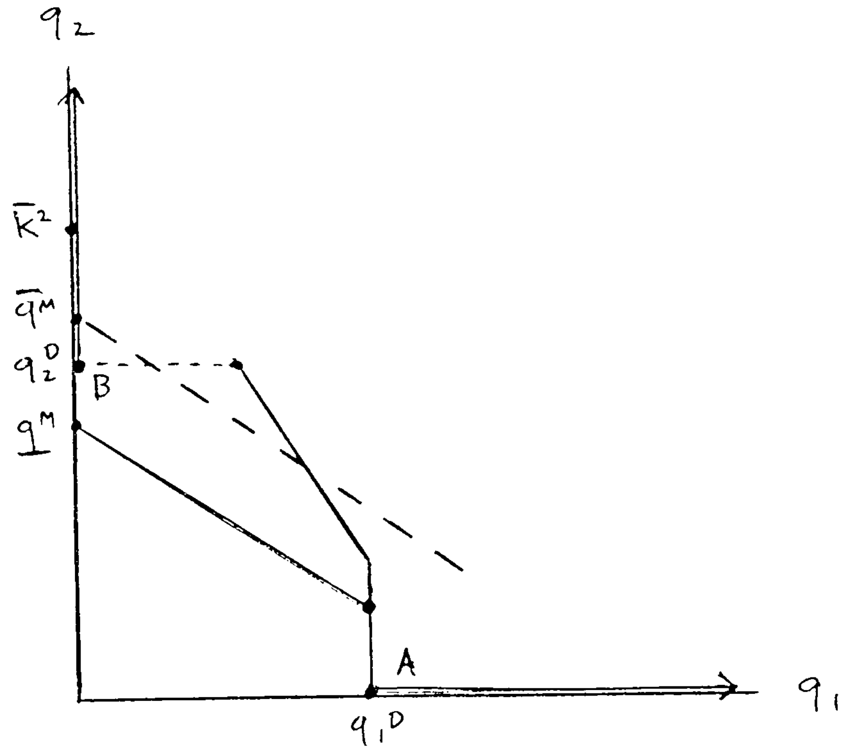

Figure 5

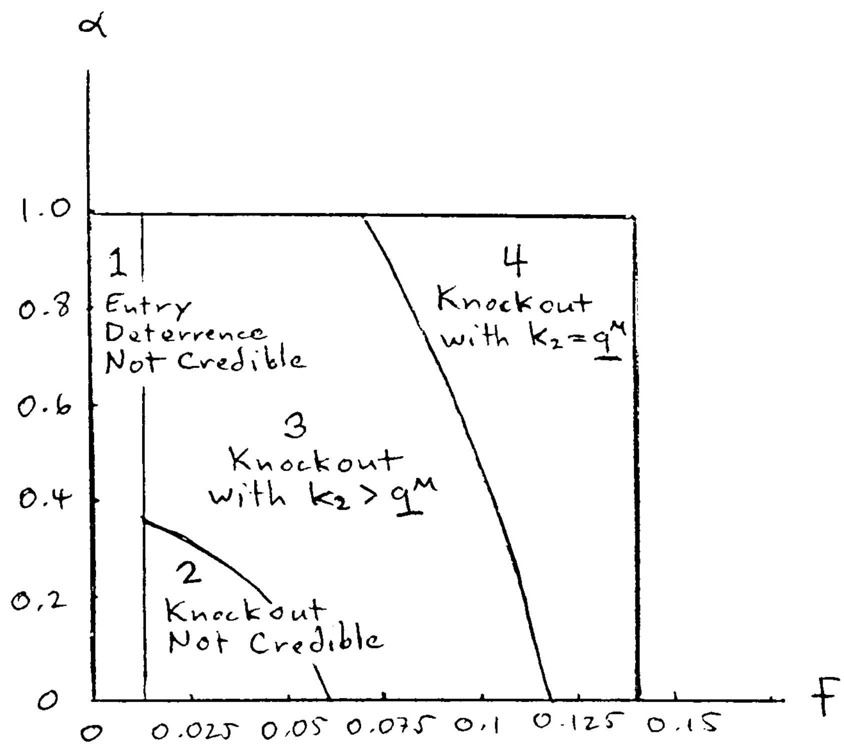

Figure 6

Parameterization: a = b = 1, c = 0, r = 0.25

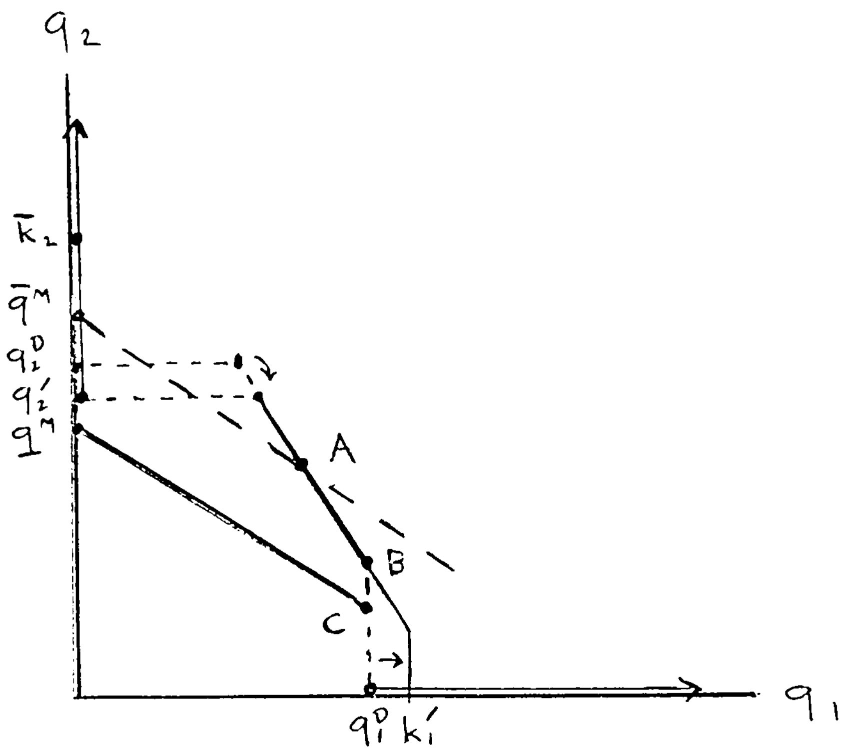

Figure 7

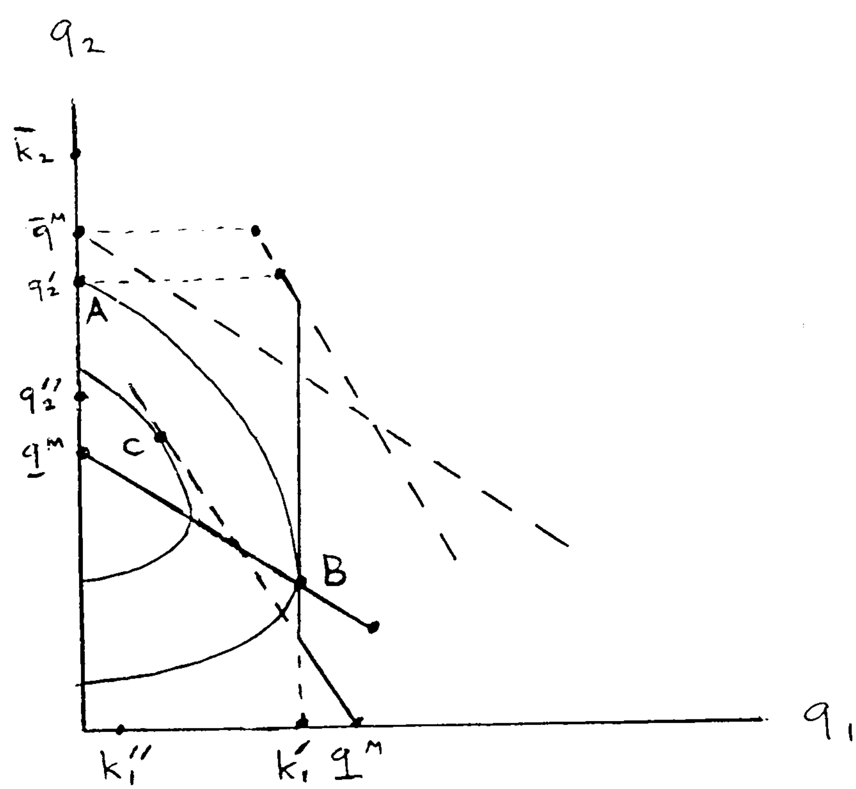

Figure 8

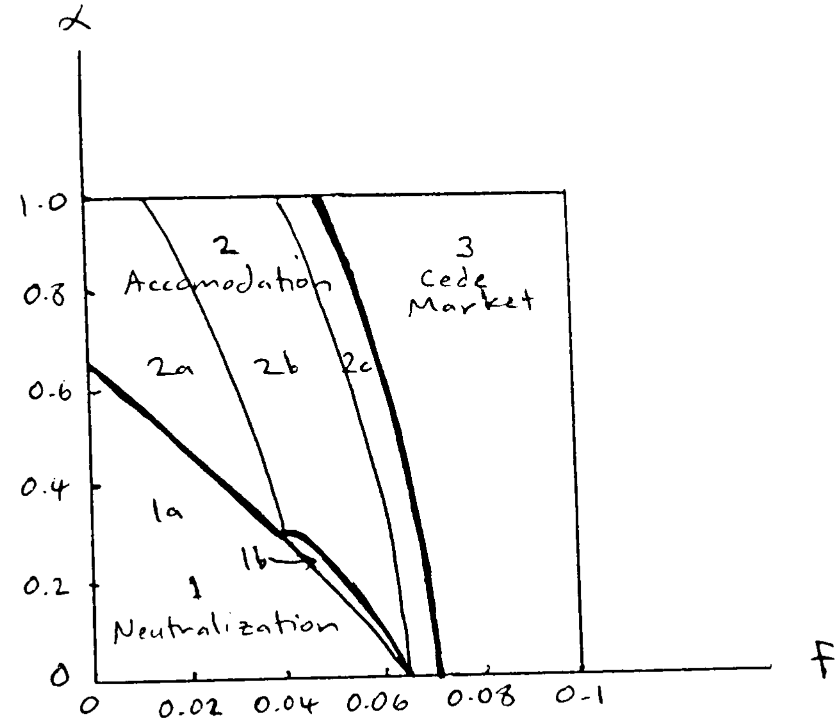

Figure 9

Parameterization: a = b = 1, c = 0, r = 0.25

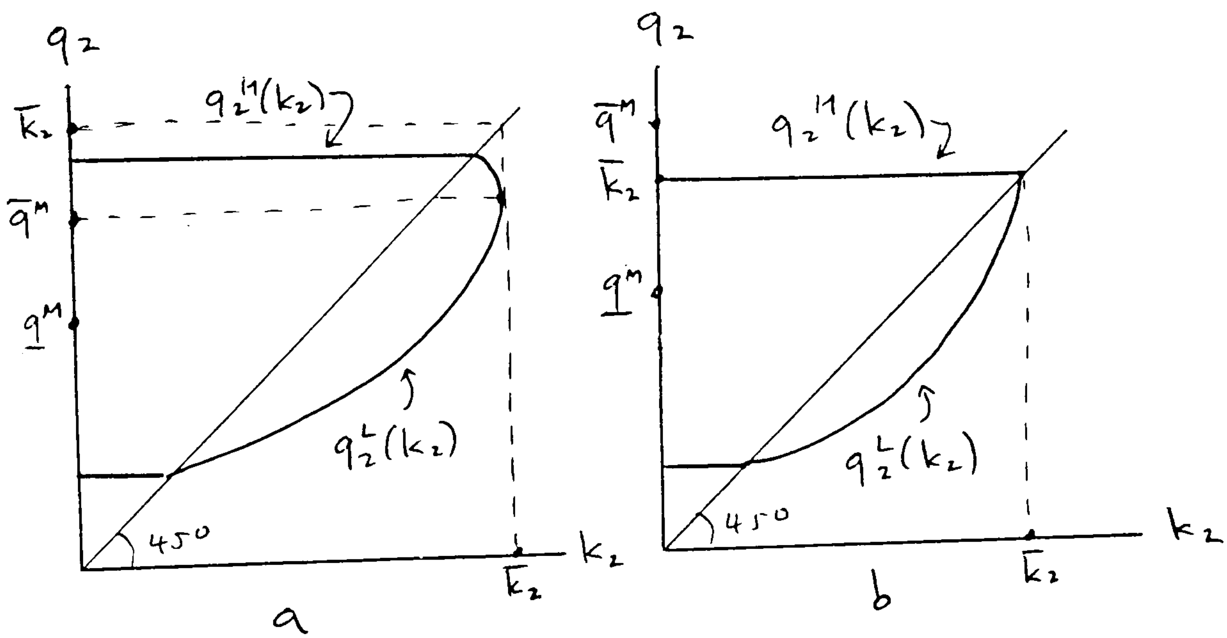

Figure 10

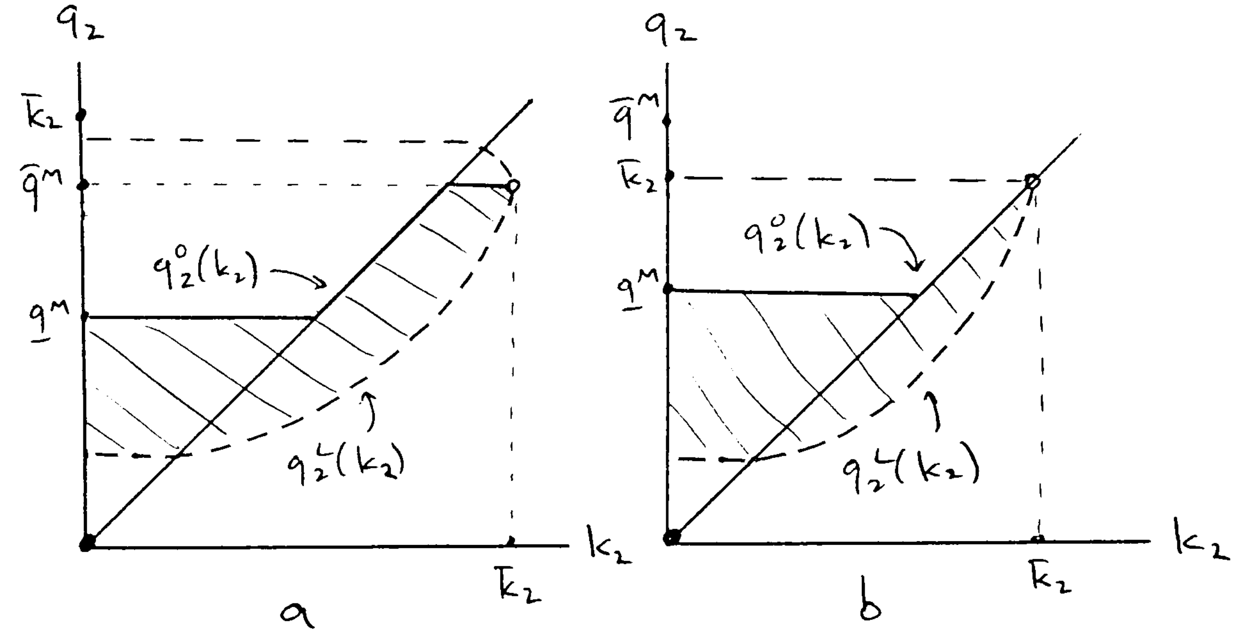

Figure 11

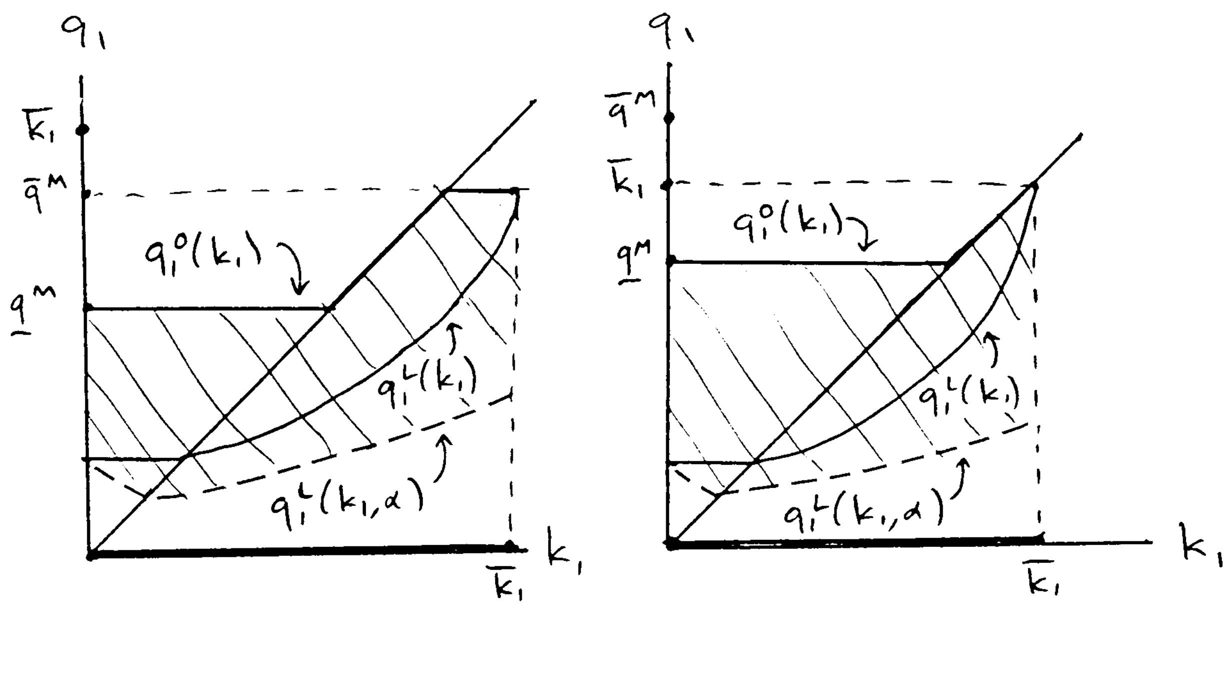

Figure 12

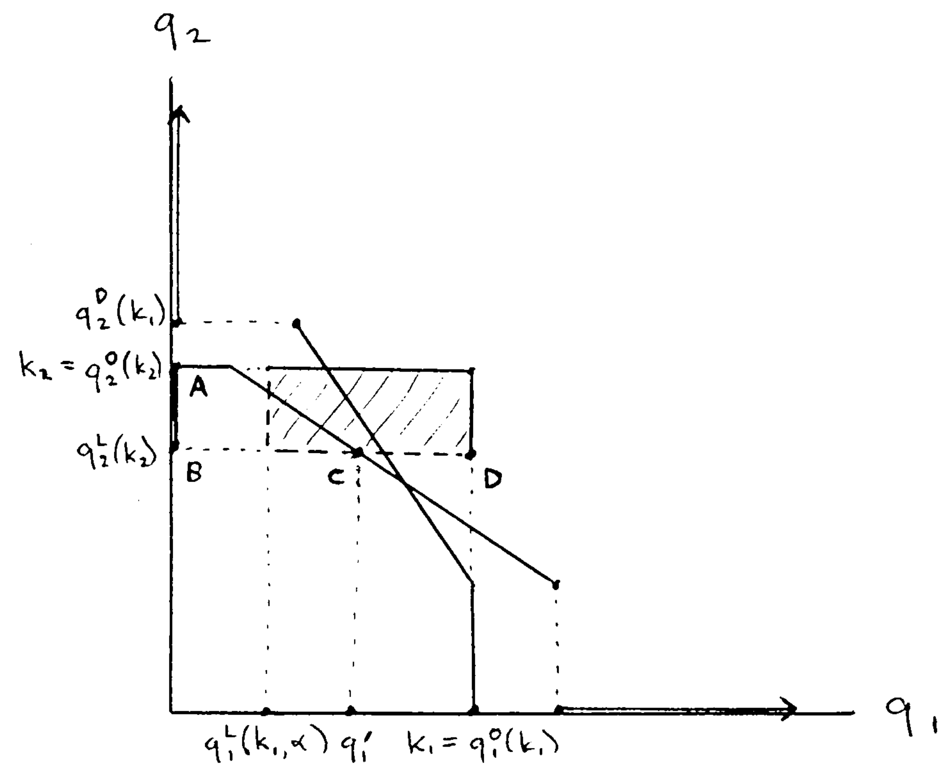

Figure 13

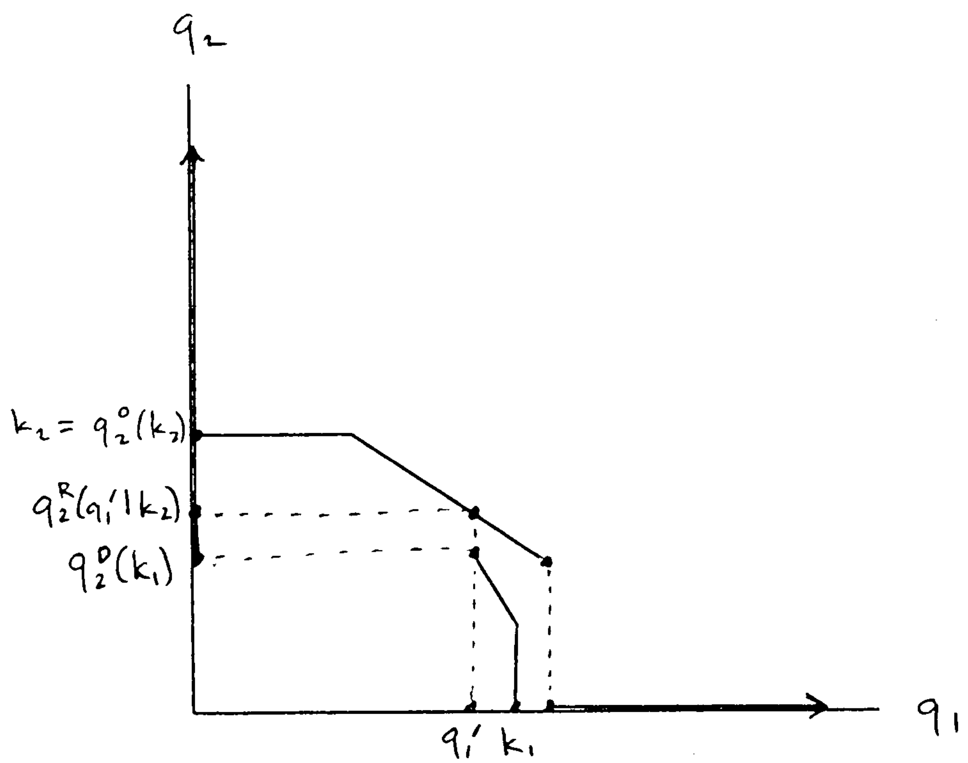

Figure 14