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ENTRY-DETERRENCE EXTERNALITIES AND RELATIVE FIRM SIZE

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Most models of entry deterrence through preemptive investment consider either a monopolist or a cartel. This suppresses an important question: how does threat of entry affect capital choices of several noncolluding incumbents. There are two opposing forces. Expanding capital to deter entry generates a public good to other incumbents, but also increases the expanding firm's share of market output. We address the trade off in a model of sequential entry with foresight, where in the first stage capital choices are made sequentially and in the second stage the output interaction is Cournot or competitive. Under competitive interaction, we prove that the first entrant either admits all other potential entrants or deters all – it never allows partial entry. Under Cournot, we find (using simultaneous) some rather surprising patterns: easier entry can make the first entrant's capital larger or smaller; the first entrant can be smaller than the second but is never less profitable; the first entrant's profit is always reduced by increased entry threat but profits of other entrants can be increased.

1. Introduction

There is a long literature, dating back at least to Kaldor (1935), suggesting that incumbent firms in concentrated industries can deter large-scale entry by choosing greater capital. The underlying idea is that it is relatively costly to adjust certain inputs so that through its choice of such inputs, 'capital', a firm can commit itself to a short-run marginal cost function that will make it a tougher competitor. This reduces expected profit to potential entrants.

Until recently, the formal models of entry deterrence through capital choice have considered a single incumbent – a monopolist or a perfect cartel – facing a single potential entrant [e.g., Wenders (1971), Spence (1977), Dixit (1980), Eaton and Lipsey (1981)]. This leaves an open question: how does threat of entry affect the equilibrium when capital choices are made by several noncolluding incumbents? The question is relevant since generally

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there are multiple potential entrants and an initial monopolist can easily find it unprofitable to deter them all [Dixit (1980), Schwartz and Thompson (1986)]. The equilibrium, therefore, may have several incumbents facing threat of further entry.

With several incumbents, deterring entry is a public good. This aspect might induce each incumbent to try to saddle others with the task of expanding capital. An opposite force is that expanding capital typically implies expanding output, so given the need for *some* firm to expand capital any firm might prefer to do so itself rather than see a rival's output expand. We study the interplay between these opposing incentives in a framework of sequential entry with perfect foresight [e.g., Hay (1976), Prescott and Visscher (1977)].

Our model considers a homogeneous good produced using two inputs, labor and capital. Production exhibits constant returns and variable proportions between the two inputs (the marginal product of each input increasing continuously with the amount of the other input). There is also a fixed cost of entering the industry, making the industry a natural monopoly as in most entry-deterrence discussions. There are two stages. Firms enter and choose capital stocks sequentially in the first stage, foreseeing how equilibrium outputs and profits will be determined in the second stage given the short-run marginal cost functions implied by the capital choices. The number of entering firms is therefore determined endogenously. Entry deterrence takes the form of choosing a higher capital stock: under our variable-proportions technology, choosing higher capital reduces a firm's marginal cost at any output thereby lowering expected profits to potential entrants.

Precisely how capital choices affect profits depends on the nature of the second-stage interaction. We first consider competitive interaction, with equilibrium price determined where industry demand intersects the horizontal sum of marginal cost curves of the entering firms. (Recall that there is a fixed entry cost so the number of entrants will be finite and profits positive.) Such an output interaction appears, for example, in Spence (1977) and Dixon (1985), though their capital selection stage differs from ours. Under such competitive output interaction, we prove that the first entrant chooses a capital stock that either deters all other potential entrants or lets all enter: the first entrant never allows partial entry.

The intuition for this result is as follows. Constant returns to scale enable one firm to mimic the cost structure of an industry of multiple firms – by choosing the same aggregate capital stock one firm obtains the same marginal cost function as the industry. Such 'technology mimicking' is generally *not* sufficient for a single firm to deter an entrant as efficiently as several firms could, since an entrant might expect a single firm to respond quite differently than would several non-colluding firms. Under competitive interaction, however, there is *strategic mimicking*: a single firm responds to entry in the same way that several noncolluding firms would. Thus, the first mover can deter entry alone as effectively as could several firms and therefore prefers not to share the deterrence task. As we discuss in the Conclusion, the principle of strategic mimicking helps explain some other deterrence results in the literature.

An output interaction that does not yield strategic mimicking is Cournot. Solving the two-stage game analytically is difficult given Cournot interaction and our variable-proportions technology, so we proceed numerically. Holding other parameters fixed, we compare the equilibria for different levels of the entry cost. The results should be interpreted as a comparison across industries characterized by different entry conditions not as a time series in one industry, since in the model firms choose capital only once.

Some intriguing patterns emerge. Increased entry threat can induce an early mover to choose more capital in order to deter entry or choose less and rely on later movers to share in the deterrence task. Such sharing can result in later movers emerging larger than early ones. When larger, however, later movers are still less profitable. This might suggest that sharing in entry deterrence is always a burden, but this characterization is not accurate. Later movers sometimes benefit from increased sharing in entry deterrence, and therefore from an increase in entry threat that induces increased sharing. In contrast, the first mover is always harmed by increased entry threat.

Recent articles that have independently addressed the issue of noncooperative entry deterrence include McLean and Riordan (forthcoming), Eaton and Ware (1987), and Gilbert and Vives (1986). McLean and Riordan first consider an abstract environment where firms enter sequentially and choose between two technologies. They characterize formally how profits must depend on technology choices in order for early entrants to delegate to later entrants the task of deterring still later potential entrants (the delegation being accomplished noncooperatively through the initial technology choice). They then illustrate delegation in a Cournot example where one technology yields a higher fixed cost but lower, constant marginal cost than the other. By solving the Cournot case numerically we forego formal results, but can admit a richer menu of technology choices and illustrate additional phenomena.

Eaton and Ware also consider sequential capital choices and Cournot output interaction, but have a different cost structure. They assume that marginal cost is constant up to a maximum output and infinite there, with capital determining the maximum output but not affecting marginal cost elsewhere. This cost structure could reflect fixed proportions between capital and other inputs. Eaton and Ware establish some useful results, notably that a firm can enter profitably if and only if its profit is positive calculated assuming that later movers stayed out (Proposition 6). This 'myopic' entry rule, shown to be rational even though later movers might enter, extends to our cost structure. But we show that some of their other results, e.g., that no firm holds excess capacity, hinge on capital not affecting marginal cost. We defer the discussion of Gilbert and Vives (1986) to the conclusion.

2. The model

Consider a homogeneous good industry where price is a decreasing function of aggregate output, $p'(\sum q)<0$. A firm must incur a fixed entry cost, F, representing various overhead expenses, such as those involved in learning the production technology and in establishing one's credibility with suppliers and customers. Production satisfies

$$q=f(L,k), \qquad f_L, f_k>0, \quad f_{LL}, f_{kk}<0, \quad f_{Lk}>0, \tag{1}$$

where f subscripts denote partial derivatives and f exhibits constant returns. Given fixed input prices, w and r, long-run average production cost is constant which makes the industry a natural monopoly (recall the fixed entry cost). This natural monopoly assumption is standard in entry deterrence discussions and is broadly consistent with empirical evidence for concentrated industries.

The input k, 'capital', can initially be chosen at any level but this level then becomes fixed. Output q then varies only with the input L. The short-run cost function is

$$C(q,k)\equiv\min_{L}(wL+rk) \quad \text{subject to} \quad f(L,k)\geqq q.$$

The short-run marginal cost function, $C_q(q,k)=w/f_L(L,k)$, satisfies

$$C_q(q,k)>0, \qquad C_{qq}(q,k)>0, \quad C_{qk}(q,k)<0 \quad \text{for all} \quad q,k>0. \tag{2}$$

That is, short-run marginal is positive, increases with output and is lower the higher is the firm's capital.

Although all firms face the same technology, they move sequentially in some exogenous order denoted $1,2,\dots,n$. A move involves deciding whether to enter (incur F) and, if so, with what level of k. Once incurred, the costs F and rk are sunk. Given the irreversibility of these investment decisions, a sequential-move representation seems appropriate. Although entry is sequential, we assume that the lag between entry dates is short enough that any profit earned during such 'disequilibrium' periods is inconsequential. A firm therefore bases its entry decision on the equilibrium outputs that will prevail once all entering firms have made their capital choices.

In the cases we consider the (second-stage) output game possesses a unique equilibrium for any set of marginal cost functions implied by the (first stage) capital choices $\underline{k}=(k_1,\dots,k_n)$. Therefore firm i's *gross profit*, π_i, is a function of capital choices,

$$\pi_i=p\left(\sum_j q_j(\underline{k})\right)q_i(\underline{k})-C(q_i(\underline{k}),k_i),$$

and a firm enters only if its gross profit exceeds the entry cost F. Since capital choices are sequential the equilibrium vector $\underline{k}$ can be found through backward induction, with firm 1's capital choice ultimately determining others' choices. The equilibrium generally will not be symmetric as firms will choose different levels of capital depending on their order of entry.

3. Output interaction is competitive

We first consider the case where, given the marginal cost functions implied by capital choices, price and outputs are determined as a (short-run) competitive equilibrium. A firm's profit in competitive equilibrium can be expressed as an implicit function of total industry capital, K, and the firm's capital, k, where K includes k:

$$\pi = g(K, k). \tag{3}$$

Intuitively, since all firms face the same constant-returns technology, the industry marginal cost curve is determined by K (regardless of how K is distributed). Given competition, industry marginal cost determines price (regardless of the number of firms). Since k determines the firm's short-run cost function, together K and k determine profit. [A formal derivation appears in Schwartz and Baumann (1986).] The following properties of g are important:

$$\frac{\partial g(K,k)}{\partial K} < 0, \quad \frac{\partial g(K,k)}{\partial k} > 0 \quad \text{for all} \quad K, k > 0. \tag{4}$$

The first property holds because increasing K while holding k fixed means that rivals are expanding. The second property holds because holding K fixed while increasing k implies an offsetting contraction by rivals, and under constant-returns such capital reshuffling would benefit a firm.

For any capital level k^0 define the mapping

$$k^*(k^0) \equiv \arg\max_k g(k^0 + k, k).$$

The mapping k^* applies to all firms since all face identical technology. Since we have placed only weak restrictions on demand and marginal costs (e.g., demand need not be concave) it is conceivable that k^* is a correspondence rather than a function. To allow for this, with a slight abuse of notation we will denote by $g(k^0 + k^*(\bar{k}), k^*(\bar{k}))$ any element of the set $\{g(k^0 + k', k') \mid k' \in k^*(\bar{k})\}$, where k^0 and $\bar{k}$ are given. There is a unique capital level $\bar{k}$ defined by

$$g(\bar{k}+k^*(\bar{k}),k^*(\bar{k}))=F.^1 \tag{5}$$

That is, if prior movers choose total capital $\bar{k}$ a firm's gross profit will equal the entry cost, F, if the firm chooses its optimal response to $\bar{k}$ and later movers stay out. The following result establishes the rationality of a very simple entry rule.

Lemma 1. Firm i enters if and only if $\sum_{j<i} k_j < \bar{k}$, $j, i = 1, 2, \ldots, n$.

Proof. Let $\sum_{j<i} k_j \equiv k^0$. Firm i enters iff $g(k^0+k_i+\sum_{m>i}\hat{k}_m, k_i) > F$ for some $k_i > 0$ where $\hat{k}_m$ denotes firm m's optimal choice given prior choices and foresight about how its choice affects subsequent choices. If $k^0 \geqq \bar{k}$, then for any $k_i, \hat{k}_m \geqq 0$ we have

$$\begin{aligned} g(k^0+k_i+\sum_{m>i}\hat{k}_m, k_i) &\leqq g(k^0+k_i, k_i) && \text{(by (4))} \\ &\leqq g(k^0+k^*(k^0),\ k^*(k^0)) && \text{(by optimality of } k^*) \\ &\leqq g(\bar{k}+k^*(k^0),\ k^*(k^0)) && \text{(by (4) since } k^0 \geqq \bar{k}) \\ &\leqq g(\bar{k}+k^*(\bar{k}),\ k^*(\bar{k})) = F && \text{(by optimality of } k^* \text{ and (5))} \end{aligned}$$

Thus, firm i cannot profitably enter if $k^0 \geqq \bar{k}$.

To prove that firm i does enter if $k^0 < \bar{k}$, we consider two exhaustive cases and show that firm i has a profitable strategy (not necessarily its optimal one) in each case. Consider an element k' of $k^*(\bar{k})$. If k^0 is such that $k^0+k' \geqq \bar{k}$ then firm i can choose k' thereby keeping out firms $m>i$ and earnings profit $g(k^0+k',k') > g(\bar{k}+k',k') = F$, the inequality by (4) given $k^0 < \bar{k}$ and the equality by (5). If k^0 is such that $k^0+k' = \bar{k} - \Delta$ where $\Delta > 0$, firm i can choose $k'+\Delta$. Industry capital is then $\bar{k}$, keeping out firms $m>i$, and firm i's profit is $g(\bar{k}, k'+\Delta) > g(\bar{k}+k',k') = F$, the inequality by using both parts of (4). Q.E.D.

That $\sum_{j<i} k_j < \bar{k}$ is *necessary* for i's entry is obvious, since further entry can only harm a firm under competitive output interaction. *Sufficiency* also is intuitive but a bit less obvious. We had to rule out the possibility that a firm is profitable if no further entry occurs but (for any feasible capital choice of

[1]To see that there can be at most one value for $\bar{k}$, suppose there were two values satisfying (5). Denoting these $k_b > k_a$ we obtain a contradiction: $F = g(k_a+k^*(k_a),\ k^*(k_a)) \geqq g(k_a+k^*(k_b),\ k^*(k_b)) > g(k_b+k^*(k_b),\ k^*(k_b)) = F$, where the weak inequality follows from the optimality of $k^*(k_a)$ given k_a and the strict inequality follows from (4). That there exists a level $\bar{k}$ follows since all functions occurring are continuous and assuming the market can support at least one firm.

the firm) becomes unprofitable if further entry does occur – while this foreseen, later entry is itself profitable.

Proposition. If the output interaction is competitive the equilibrium number of entrants is either 1 *or n. That is, the first entrant either deters all other firms or admits all – it never allows partial entry.*

Proof. Consider a hypothesized equilibrium with m entrants, $1<m<n$, choosing total capital $K^e=\sum k_i^e$, and producing total output Q^e. Firm 1's gross profit in this hypothesized equilibrium is $g(K^e, k_1^e)$. In order to show that this is not an equilibrium, it is sufficient to show that firm 1 has a capital choice different from k_1^e that earns it greater profit and deters all further entry.

Since in the hypothesized equilibrium at least one firm does not enter, $m<n$, we know $K^e \geqq \bar{k}$ (Lemma 1, sufficiently part). Suppose that instead of choosing k_1^e firm 1 had chosen K^e. Then no firm $j>1$ would have entered (Lemma 1, necessity part). If firm 1 then produced output Q^e its gross profit would be

$$g(K^e, K^e)=\sum g(K^e, k_i^e)>g(K^e, k_1^e),$$

the equality by constant returns and the inequality since for every entering firm i, $g(K^e, k_i^e)>F>0$. Q.E.D.

The ability of firm 1 to mimic profitability any situation in which several firms deter further entry explains why firm 1 never allows *partial* entry. This argument fails to rule out allowing *all* entry because doing so might enable the industry to reduce capital below $\bar{k}$, an option firm 1 does not have if it wishes to deter even a single potential entrant (by Lemma 1). Thus, the equilibrium has firm 1 deterring all others or letting all enter, depending on which yields it higher profit.

The most favourable scenario for allowing entry is with two firms and $F=0$. (The latter follows because deterrence requires a greater deviation of capital from the simple-monopoly capital the lower is F.) Assuming linear demand and the production function $q=(2Lk)^{\frac{1}{2}}$, described further in section 4 below, we found numerically that even for $F=0$ deterring the single potential entrant was three times more profitable than letting it enter. Fig. 1 illustrates such a deterrence equilibrium. Firm 1 has excess capacity, produces an output below that at minimum average cost given k_1, but earns positive profit since it produces the monopoly output. Firm 2 stays out because if it entered firm 1 would supply along its marginal cost curve since, by assumption, the interaction would be competitive.

Competitive output interaction therefore yields rather implausible predic-

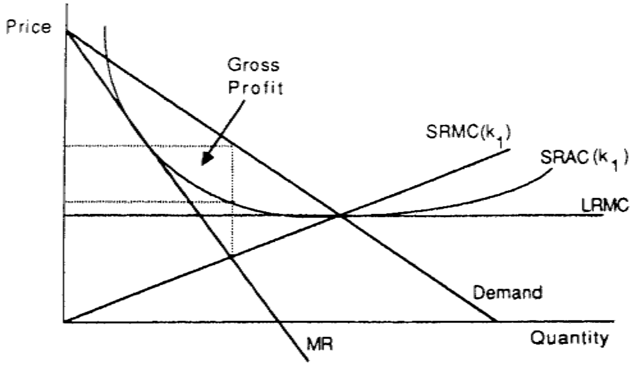

Fig. 1. Profitable deterrence when $F=0$.

tions: that entry deterrence is all-or-none and that it is profitable even with no scale economies. These implausible predictions confirm prior intuition – that the output interaction is unlikely to be competitive when the product is homogeneous and the number of active firms is as small as two. A more plausible interaction in this context is Cournot.

4. Output interaction is Cournot

Given that short-run marginal cost is not constant but increasing in output and decreasing in the (given) level of capital, it is difficult to solve the two-stage entry game analytically. We compute the equilibrium numerically, assuming linear inverse demand

$$q=(2Lk)^{\frac{1}{2}},$$

and a particular Cobb–Douglas production function

$$q=\tfrac{1}{2}(L^{\frac{1}{2}}k^{\frac{1}{2}}).$$

Given input prices w and r, the short-run cost function is

$$C(q,k)=\frac{wq^2}{2k}+rk$$

implying the short-run marginal and average cost functions

$$C_q(q,k)=\frac{wq}{k},\qquad \frac{C(q,k)}{q}=\frac{wq}{2k}+\frac{rk}{q}.$$

We chose the parameter values $a=15$, $b=1$, $w=1$, $r=12.5$, for which the simple-monopoly solution is $k=1$, $q=5$. Since demand and short-run marginal cost are linear in output, there is a unique Cournot equilibrium for any vector of capital choices [see, e.g., Szidarovski and Yakowitz (1977), Friedman (1983)].

Understanding our subsequent results is helped by recognizing how a firm's capital choice affects Cournot equilibrium values.

Lemma 2. Assume inverse demand $p(Q)=a-bQ$ and consider m firms with marginal cost functions wq_i/k_i, $i=1,\dots,m$ where $a,b,w>0$ and $Q\equiv\sum q_i$. Given a vector of capital stocks $\underline{k}=(k_1,\dots,k_m)\gg 0$, the Cournot equilibrium outputs q_i^c and gross profits π_i^c satisfy

$$\text{(i)}\ \frac{\partial Q^c}{\partial k_j}=\frac{w(a-bQ^c)^2}{a(bk_j+w)^2}>0, \qquad \text{(ii)}\ \frac{\partial q_i^c}{\partial k_j}=\frac{-bk_i}{(bk_i+w)}\frac{\partial Q^c}{\partial k_j}<0, \qquad \text{(iii)}\ \frac{\partial q_j^c}{\partial k_j}>0,$$

$$\text{(iv)}\ \frac{\partial^2 q_j^c}{\partial k_j^2}<0, \qquad \text{(v)}\ \frac{\partial \pi_i^c}{\partial k_j}=\left[p'(Q^c)q_i^c\frac{(2bk_i+w)}{(bk_i+w)}\right]\frac{\partial Q^c}{\partial k_j}<0.$$

Proof. Cournot outputs q_i^c are the solutions to the following maximization problems

$$\max_{q_i} \pi_i=p(Q)q_i-C(q_i;k_i),$$

where each firm i assumes $\partial q_j/\partial q_i=0$, for all $j\neq i$. Given our functional forms, the first order conditions evaluated at the solution outputs yield

$$q_i^c=(a-bQ^c)k_i(bk_i+w)^{-1}, \tag{6}$$

where $Q^c=\sum_{j=1}^m q_j^c$.

(i) Summing both sides of (6) over i yields

$$Q^c=(a-bQ^c)\sum_{i=1}^m k_i(bk_i+w)^{-1}.$$

Partially differentiating with respect to k_j and rearranging gives (i).

(ii) The expression for $\partial q_i^c/\partial k_j$ follows from (6) and the sign from (i).

(iii) $\partial q_j^c/\partial k_j=\partial Q^c/\partial k_j-\sum_{i\neq j}(\partial q_i^c/\partial k_j)$, which is positive by (i) and (ii).

(iv) $\partial^2 q_j^c/\partial k_j^2=\partial^2 Q^c/\partial k_j^2-\sum_{i\neq j}(\partial^2 q_i^c/\partial k_j^2)$. And $\partial^2 Q^c/\partial k_j^2<0$ while $\partial^2 q_i^c/\partial k_j^2>0$, by inspection of (i) and (ii).

(v) Let $Q_{-i}^c\equiv Q^c-q_i^c$ and define

$$\pi_i^c=\pi_i(q_i^c,Q_{-i}^c;k_i)\equiv p(Q^c)q_i^c-C(q_i^c;k_i).$$

Since q_i^c is optimal given Q_{-i}^c,

$$\frac{\partial \pi_i^c}{\partial k_j} = \frac{\partial \pi_i}{\partial Q_{-i}^c} \frac{\partial Q_{-i}^c}{\partial k_j} = p'(Q^c) q_i^c \left(\frac{\partial Q^c}{\partial k_j} - \frac{\partial q_i^c}{\partial k_j} \right) = \left[p'(Q^c) q_i^c \frac{(2bk_i + w)}{(bk_i + w)} \right] \frac{\partial Q^c}{\partial k_j} < 0,$$

using (i) and (ii) and recalling that $p' < 0$. Q.E.D.

Properties (i), (ii) and (iii) follow because increasing a firm's capital reduces its marginal cost. Holding rivals' capital constant, this leads the firm to expand output in Cournot equilibrium and rivals to contract, but by a smaller total amount. The effect is to reduce profit to each rival, as stated in (v). Thus, a firm can make entry less profitable by choosing greater capital. But doing so tends to create excess capacity since, by (iv), a firm's Cournot output expands at a decreasing rate as it expands capital.

The expression for $\partial \pi_i^c / \partial k_j$ in (v) yields an important implication: that entry deterrence is greatest when capital is distributed equally among incumbent firms. Since the magnitude of $\partial \pi_i^c / \partial k_j$ depends on the magnitude of $\partial Q^c / \partial k_j$ and the latter is decreasing in k_j, from (i), if capital were reshuffled from a larger incumbent to a smaller one, an entrant's profit would decrease for any capital choice. Thus, given m incumbents, $1 < m < n$, and total capital K, the lowest entry cost F for which entry can be deterred is reached when K is distributed evently.[2] Alternatively, if firm $m+1$ is deterred when K is distributed unevenly, it can be deterred with some $K' < K$ when K' is distributed evenly. Since a single-firm industry is the limiting case of a multi-firm industry with uneven capital distribution, the above discussion implies that a single firm cannot deter entry as effectively as can several firms. In contrast, under competitive output interaction (rather than Cournot) an entrant's profit depended only on rivals' total capital, not its distribution, so one firm could deter as effectively as several.

We compute the equilibria for different values of F.[3] Recalling that this

[2]Consider a vector of capital choices $(k_1, \ldots, k_m)$ and denote the minimum value k_a and the maximum value k_b, where $k_a < k_b$. Denote the gross profit to potential entrant $m+1$ by $\pi_{m+1}(k_1, \ldots, k_m; k_{m+1}^*)$ where k_{m+1}^* is optimal given $(k_1, \ldots, k_m)$. Consider the effect on π_{m+1} of a small reshuffling of capital from firm b to firm a, i.e., $dk_b/dk_a = -1$. Then $df_{m+1}/dk_a|_{(k_a+k_b)} = \partial \pi_{m+1}/\partial k_a - \partial \pi_{m+1}/\partial k_b + (\partial \pi_{m+1}/\partial k_{m+1}^*)\ (dk_{m+1}^*/dk_a)$. The last term is zero since k_{m+1}^* was optimal. By Lemma 2 part (v), $\partial \pi_{m+1}/\partial k_a < \partial \pi_{m+1}/\partial k_b \Leftrightarrow \partial Q^c/\partial k_a > \partial Q^c/\partial k_b$, and the latter inequality holds by Lemma 2 part (i), given $k_a < k_b$. Hence $d\pi_{m+1}/dk_a|_{(k_a+k_b)} < 0$. So if initially firm $m+1$ was deterred for all $F \geqq F^0$, following the capital reshuffling $m+1$ is deterred for all $F \geqq F^1$, where $F^1 < F^0$.

[3]In determining whether further entry would occur given a vector of prior capital choices we make use of Eaton and Ware's (1987) 'myopic' entry rule, whereby a firm enters if and only if its profit is positive computed assuming that later movers stay out. The 'only if' part obviously extends to our technology. If firm i cannot be profitable given $(k_1, \ldots, k_{i-1})$, then it cannot enter period, since further entry would only harm it (Lemma 2 part (v)). Showing the 'if' part is somewhat harder but Roger Ware has supplied a proof, available on request. In any case, we verify that any entering firm's profit does remain positive in our equilibria whenever further entry occurs. Details about the computation algorithm are available on request.

should be interpreted as a cross-sectional experiment across industries, the results are presented graphically in figs. 2 through 4. The figures are not to scale, in order to magnify the regions of interest. Fig. 2 shows capital choices and fig. 3 shows capital utilization rates, the ratio of a firm's actual output to the output that minimizes short-run average cost. A ratio below 1 implies inefficient production due to excess capacity. Fig. 4 shows gross profits. How consumer surplus and total surplus vary with F is discussed in Schwartz and Baumann (1986).[4]

4.1. Capital choices

Fig. 2 shows the equilibrium capital choices for values of F between 10 and 1. For $F>9.2$ entry is naturally blockaded in that firm 1's simple-monopoly capital prevents positive profit to firm 2. As F falls below 9.2, firm 1 expands capital to deter entry but this causes the capital utilization rate to slump, as seen in fig. 3. At $F=5.3$, firm 1 lets firm 2 enter and reduces k_1 substantially. The gain to firm 1 derives from the sharp increase in its capacity utilization rate (shown in fig. 3). It is no accident that firm 1 eventually allows entry. Under Cournot interaction a single incumbent can find it impossible to forestall an entrant, since expanding capital does not commit the incumbent to supplying a corrspondingly high output [Schwartz and Thompson (1986) provide some examples].

Over the range $3.9<F<5.3$ the optimal capital choices of firms 1 and 2 ignoring 3 suffice to deter 3. Not surprisingly, $k_1>k_2$ as firm 1 claims a larger share of the output market. The novel results are for $F\leqq 3.9$, where noncooperating oligopolists face threat to entry.

Initially it is the first mover that expands to deter entry. As F drops below 3.9, initially k_1 increases. The reason is that at $F=3.9$ firm's 1's capital is at its optimal level given 'myopic interaction' with firm 2. A small increase in k_1 therefore reduces 1's profit less than allowing expansion by another firm, whether entry by 3 or expansion by 2 to deter 3. [A formal demonstration appears in Schwartz and Baumann (1986), note 4]. This logic is quite general. For any F where entry is just deterred given 'myopic' capital choices, there is a neighborhood $F-\varepsilon$ where firm 1 expands to deter entry. (Thus, firm 1 also expands initially to deter firm 4, near $F=1.9$.)

As entry threat increases, the first mover delegates an increased share of the

[4]Briefly, output and hence consumer surplus increase as F decreases in ranges where entry is not naturally blockaded (and remain unchanged in the other ranges). Interestingly, output barely increases following firm 3's entry since firms 1 and 2 greatly reduce their capital. Total surplus sometimes increases and other times decreases, reflecting the tradeoff between increased industry output and increased excess capacity. Where additional entry occurs, by firm 2 at $F=5.3$ and firm 3 at $F=1.9$, total surplus increases. The beneficial effects of increased output and, more importantly, decreased excess capacity (due to capital cutback by the previously-deterring incumbents) outweigh the wasteful duplication of entry costs.

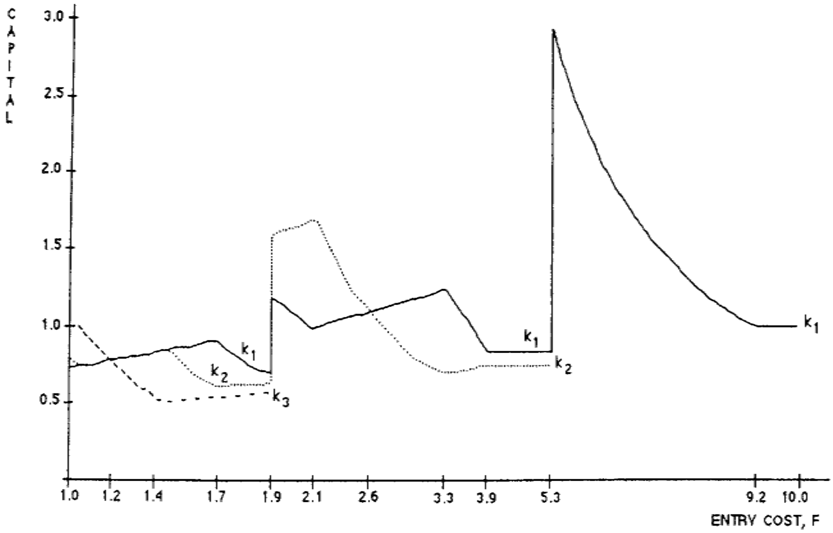

Fig. 2. Capital choices.

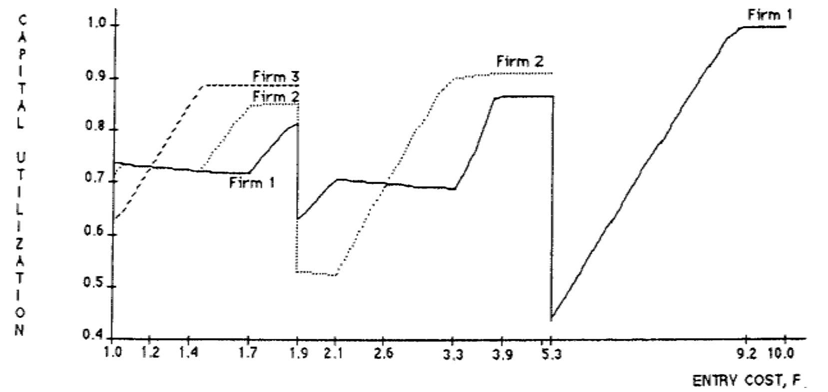

Fig. 3. Capital utilization rates (Ratio of actual output to the output that minimizes short-run average cost).

entry-deterrence task. From $F=3.9$ to $F=3.3$ k_1 increases but at $F=3.3$ a reversal occurs: k_1 decreases and k_2 increases. In effect, firm 1 is delegating to firm 2 an increased share of the task of forestalling firm 3 as F drops from 3.3 to 2.1. (The second reversal at $F=2.1$ is discussed shortly.) The above patterns recur as F drops below 1.9 and the threat of entry by firm 4 intensifies. Initially firm 1 expands to deter 4, then it delegates the task to firm 2, which itself delegates it to firm 3 (at $F=1.4$).

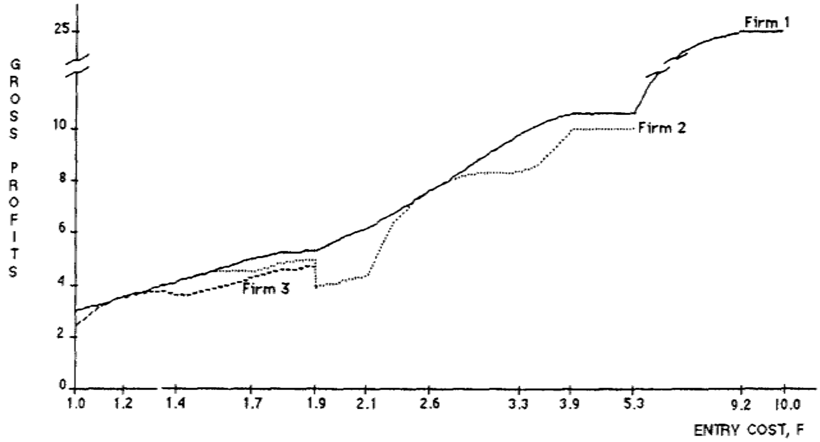

Fig. 4. Gross profits.

Later movers can have larger capital than earlier movers, but only where entry threat is relatively strong. As firm 1 continues delegating to 2 the task of deterring 3, eventually $k_2=k_1$ (at $F=2.6$). As F drops below 2.6, k_2 becomes increasingly larger than k_1. The increased excess capacity of firm 2, reflected in the drop in 2's capital utilization rate (fig. 3), makes it willing to let firm 3 enter at $F=2.1$. Recognizing that firm 2 has reached the end of its rope, firm 1 takes over some deterrence by expanding k_1 until F drops to 1.9. There, it reduces k_1 and lets firm 3 enter. (Interestingly, $\pi_1+\pi_2$ increases after firm 3 enters because to deter 3 firm 1 was choosing a large capital, ignoring the harm that this was imposing on firm 2.) Near $F=1.9$ entry threat by firm 4 is relatively weak, hence capital choices are governed largely by 'myopic' interaction not the entry threat. Correspondingly, $k_1>k_2>k_3$. But as F continues dropping and entry threat intensifies, eventually $k_3>k_2\geqq k_1$ ($F<1.2$), as firm 3 bears the brunt of deterring firm 4.

4.2. *Profits and the burden (?) of entry deterrence*

An early mover's gross profit is never lower than a later mover's, even when the early mover's capital is smaller. In fig. 4, $\pi_1\geqq\pi_2\geqq\pi_3$, with equalities holding only when capital stocks are equal. Note that $\pi_1>\pi_2$ when $k_1<k_2$ ($1.9<F<2.6$) and $\pi_2>\pi_3$ when $k_2<k_3$ ($F<1.2$).

Easier entry (lower F) never benefits the first mover but can benefit later movers. Lowering F reduces π_1 whether it causes additional entry ($F=5.3$, $F=1.9$) or increased threat of entry ($1.9<F<3.9$, $F<1.9$). In contrast, lowering F can increase π_2 and π_3 (even once these firms have entered). For instance, π_2 increases slightly when threat of entry by firm 3 intensifies (as

F drops below 3.3) and when firm 3 is allowed to enter (as F drops below 1.9). Similarly, π_3 increases as F drops below (approximately) 1.35.

Since lowering F makes entry easier, it is not surprising that firm 1's profit is thereby reduced. (Lowering F leaves π_1 unaffected only when entry is naturally blockaded, as in the ranges $F > 9.2$ and $3.9 < F < 5.3$.) In contrast to firm 1, any later mover takes as given F *and* the capital choices of prior movers. Holding prior capital choices constant, lowering F would harm such a later mover because it increases entry threat. However, in response to lower F an early mover may reduce its capital, either to accept additional entry or to cope optimally with the increased entry threat by delegating an increased share of deterrence. It is this reduction in an early mover's capital that can enable later movers to benefit from a lower F. Later movers, however, benefit only over certain ranges.

Later movers benefit from increased sharing in deterrence only when they are smaller. It is suggestive that decreasing F increases π_2 only in ranges of F where $k_1 > k_2$ (examine figs. 2 and 3 around $F = 3.3$ and $F = 1.7$). Intuitively, if k_2 moves towards equality with k_1 as F decreases, the industry faces stronger entry threat but deters this threat more efficiently (see discussion of Lemma 2). The rise in π_2 (near $F = 3.3$ and 2.6) reflects firm 2's capturing some of this efficiency gain. But deterrence is most efficient when $k_2 = k_1$, hence any additional decrease in k_1 and increase in k_2 reduces deterrence efficiency (e.g., as F drops from 2.6 to 2.1). Not surprisingly, increased delegation of entry deterrence once $k_2 \geqq k_1$ reduces firm 2's profit.[5]

Recapping, a later mover's capital is larger than an earlier mover's only where entry threat is strong. Roughly speaking, if it were profitable to have a larger capital solely in order to claim a large share of market output then an early entrant would choose the larger capital.[6] When a larger mover is larger, it is bearing a disproportionate cost of entry deterrence and is consequently less profitable than an earlier mover.

4.3. Excess capacity

Excess capacity characterizes our equilibrium for any value of F (except where firm 1 is an unconstrained monopolist, $F \geqq 9.2$). Two features of our model yield this excess capacity: the variable-proportions technology and the Cournot interaction. The former implies that increasing capital yields a lower (short-run) marginal cost curve. Since rivals can observe this, their Cournot-

[5]Similar remarks apply when firms 1, 2 and 3 are deterring firm 4 ($F < 1.9$). Firm 3's profit only increases as F decreases from (approximately) 1.34 to 1.2, a range where firms 1 and 2 are delegating the deterrence task to 3 (by reducing k_1 and k_2) *and* $k_3 < k_1 = k_2$.

[6]Eaton and Ware find that the third entrant can be more profitable than the second. While the underlying force is not clear to us, it is possible that the pattern $\pi_1 \geqq \pi_2 \geqq \pi_3$ is specific to our parameter values. However, we are confident of the reasoning why $\pi_1 > \pi_2$ when $k_1 < k_2$.

equilibrium outputs will be lower. There is consequently a gain from increasing capital beyond the level required for productive efficiency.[7]

This effect is absent if adding capital does not reduce marginal cost, which explains many of the differences between our results and those of Eaton and Ware (1987). In their formulation, adding capital increases a firm's feasible output but leaves marginal cost unaffected on intramarginal output. Consequently, they find that in equilibrium no firm holds excess capital (Proposition 5) since eliminating excess capital would leave unaltered other firms' Cournot outputs. The absence of excess capacity implies that the larger firms are also the more profitable, whereas we find no monotonic relation between size and profitability.

Eaton and Ware also find that the number of entering firms is the smallest number which can deter entry by an additional firm (Proposition 7). This result too hinges on capital not affecting marginal cost and is not true in our model. For example, at $F=1.9$ we have three entrants but firms 1 and 2 could have deterred firm 3 (for some neighborhood below $F=1.9$) either by increasing capital or distributing capital more equally. Finally, they find that increased threat of entry reduces the variance of firm sizes, whereas we find that the variance can decrease or increse (see fig. 2).[8]

5. Conclusion

We have shown that incentives to deter entry through expanding capital vary dramatically with how outputs are determined given the short-run cost functions implied by capital choices. If outputs are determined competitively, the first mover prefers not to share the entry deterrence task with any other firm: it either admits all other firms or, more likely, deters all. This is not true when the output interaction is Cournot.

The important feature of competitive interaction is 'strategic mimicking' – a single firm reacts to entry the same as would several firms. It therefore can deter entry as efficiently as several firms and sees no benefit in sharing the deterrence task. Any model that exhibits strategic mimicking (and natural monopoly costs) yields this result. Thus, Gilbert and Vives (1986) find that, despite the public good aspect, there is no free-rider tendency in entry deterrence: each of several initial incumbents prefers to be the one deterring

[7]The Cournot assumption is important. Dixon (1985) shows that if outputs are determined competitively, firms choose too little capital. In equilibrium, each firm then produces where price intersects the rising portion of its marginal cost curve and since profit is positive (for any finite number of firms), this output exceeds that which minimizes average total cost given the firm's capital.

[8]Eaton and Ware represent increased threat of entry in two ways: by reducing (1) the fixed entry cost (like we do) and (2) the fraction of production cost that is assumed sunk (whereas our capital cost is always fully sunk). Holding (2) constant and reducing (1) is the same experiment as ours and they find that this reduces the variance of firm sizes (p. 24).

entry. In their model it is the ability of any incumbent to commit to supplying any output level (there is no distinction between capital and output) that permits strategic mimicking. The same output-commitment ability implies that if entry occurs sequentially and the number of potential entrants is large, the first entrant will forestall all other firms [Omori and Yarrow (1982), Schwartz (1982), Vives (1985)]. In Schwartz and Thompson (1986), strategic mimicking is present because any firm can establish independent competing divisions. Such divisionalization ability makes any one of several incumbents want to forestall all identical-cost entry, whatever the output interaction.

If strategic mimicking is not feasible, as under Cournot interaction, there can be benefits from sharing the entry deterrence task. In deciding whether to increase capital in response to easier entry conditions, an early mover must then weigh two opposing forces. Expanding capital provides a private good by increasing the firm's output, which is preferable to seeing a rival's output increase. Expanding capital also provides a public good by deterring entry, which an early mover would like to see another firm provide.[9] Since the magnitude of these forces under Cournot interaction depends on the initial inequality between capital stocks, variations in entry conditions produced some intriguing patterns.

Our Cournot findings suggest two empirical implications. First, the magnitude of structural entry barriers, such as scale economies, should have no systematic influence on the relative sizes of the leading firms in concentrated industries. This implication arises because increased entry threat sometimes increased the size-inequality of entering firms and other times decreased it. Second, the larger firms in an industry need not be the more profitable ones since they may be bearing a disproportionate share of the cost of entry deterrence.

[9]Vickers (1985) provides an illuminating analysis of a similar tradeoff in the incentives of incumbent firms to form joint ventures for R&D. From the standpoint of denying a technology to a potential entrant, R&D is a public good. But from the standpoint of securing a technology superior to that of other incumbents, R&D is a private good.

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