Entry, Collusion, and Capacity Constraints*

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I. Introduction

It is arguably true that no single topic has held more of a fascination for students of Industrial Organization than the issue of entry deterrence. This issue has been analyzed from many perspectives, including: the role of advertising and imperfect information in deterring entry [1; 14; 18; 19]; incentives confronting a monopoly seller of durable goods [3; 4]; incentives in the context of sequential entry [2; 9]; dynamic aspects of entry deterrence [10; 13]; and the role of excess capacity in deterring entry [22; 23].

Dixit [5; 6] discussed the incentives for an incumbent firm to deter entry in the presence of sunk costs. In his models, a firm must sink some capital prior to entering the industry, and this sunk cost creates an entry barrier. Any potential entrant must pay the sunk costs prior to entering, and the incumbent can deter entry by reducing the stream of profits sufficiently so that the entrant's post entry profit flow cannot cover its sunk cost. Ware [24] adapted Dixit's work by allowing for a three-stage game: following the incumbent's decision, the entrant decides upon entry in stage two, paying the sunk costs at that time; in stage three (if entry occurred) the firms play a quantity choosing game.¹

Formby and Smith [7] argue that rather than deterring entry, the incumbent firm often has an incentive to allow entry and then collude with the entrant. In this context, the post-entry cartel is asymmetric, with the incumbent producing the larger amount and realizing the higher profits.²

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1. Ware argues that this should be a three stage problem because there should be a lag between the time that the entrant decides to enter and the time she first produces. Note that this approach abstracts from an important possibility. By design, the incumbent is not allowed to alter his capital in the second stage, even as the entrant is choosing her capital. It would seem that the incumbent could choose the monopoly level of output and capital prior to entry, and then expand upon entry, much as the incumbent might accelerate the pace of its research and development efforts if another firm enters the patent race as in Gilbert and Newbery [11]. By contrast, in Dixit's models [5; 6], there is no time lag between the entry decision and the time of production. In the model below, we adopt Dixit's interpretation of the entry deterrence game.

2. Such behavior may be consistent with the experience in one of the most famous Sherman Act anti-trust cases. During the early part of this century, U.S. Steel continually allowed entry, and then invited the entrant to participate in the infamous "Gary Dinners," where steel prices were collusively fixed. The possibility that an incumbent may prefer to present an accommodating appearance to the entrant is considered in a more general context in Fudenberg and Tirole [8].

In such a scenario, stability of the post-entry cartel is an important concern. Indeed, following entry the entrant may have a strong incentive to threaten dissolution unless the terms of the cartel are not renegotiated. If the entrant's initial share of cartel profits is small, and there is no institutional feature which limits the entrant's ability to expand output following entry, this threat may well be credible. If, on the other hand, there is some mechanism by which the entrant can credibly limit his production, then the post-entry cartel is more likely to prove stable.³

Our goal in this paper is to establish conditions under which it pays the incumbent to allow entry and then collude. We find that the incentive to allow entry is negatively related to the incremental cost of a unit of capacity. Spulber [23] showed that the credibility of holding excess capacity in an attempt to deter entry was in doubt unless the opportunity cost of capital was low. Thus, our result indicates that an incumbent firm is likely to allow entry and negotiate a cartel under conditions when holding excess capacity to deter entry is likely to be credible.

II. Deterrence vs. Collusion

Throughout the paper, we attempt to mimic the framework and notation used by Dixit [5; 6]. We therefore consider at first a market characterized by linear demand and constant marginal costs. There is an incumbent firm and one prospective entrant, both of whom have access to the same technology. The incumbent has a first-mover advantage, and so knows the entrant will behave as a Cournot firm. For example, the incumbent may be able to commit to an output level by signing medium- or long-term contracts prior to entry. Entry requires bearing some sunk cost, S . We will use q_j to denote the output of firm j , where $j = 1$ for the incumbent and $j = 2$ for the entrant. The market demand curve is

$$P = a - b(q_1 + q_2). \quad (1)$$

Since marginal costs are constant, one can interpret the parameter (a) as the demand intercept net of marginal costs, and so we assume without loss of generality that marginal costs are zero. Then monopoly output is $a/2b$, monopoly price is $a/2$, and monopoly profits are $\pi_M = a^2/4b$. Within a duopoly setting, Cournot-Nash profits are $\pi_N = a^2/9b$ for each player; at the Stackelberg equilibrium, the leader earns $\pi_1^L = a^2/8b$, and the follower earns $\pi_2^F = a^2/16b$. Since the entrant must pay S to enter the industry, she will not enter unless post-entry profits are larger than S . Thus to successfully deter entry, the incumbent must produce at least an amount q_1^d (which depends on S), where the entrant's best response to this choice would just earn her post-entry profits of S , and hence pre-entry profits of 0. If the incumbent produces q_1^d then firm 2 will not enter, so that market price will equal $a - bq_1^d$. One can then show that deterrence profits are

$$\pi_1^D = -4S + 2a[S/b]^{1/2}, \quad (2)$$

and that they are positive and increasing in S so long as entry is not blockaded.⁴

3. Such instability may have characterized the repeated, and unsuccessful, attempts to limit oil production in the 1920s and 1930s. The salient features of these attempted cartels from our perspective were asymmetry of outputs and profit shares, and the observation that smaller firms repeatedly broke ranks when their shares were too small.

4. As the entrant's reaction curve is $q_2 = R_2(q_1) = a/2b - q_1/2$, if the incumbent produced q_d in period 1 the entrant would respond by producing $a/2b - q_d/2$. Given these choices, the entrant's period 1 profits would be

By contrast, should the incumbent choose to allow entry, he would earn profits of π_1^L as a Stackelberg leader. Whether the incumbent decides to deter or allow entry turns on the magnitude of the sunk entry costs, S . When S is larger than some critical level of sunk costs, S' , $\pi_1^D > \pi_1^L$ and entry is effectively impeded. When S is smaller than S' , entry is ineffectively impeded.

A natural alternative to deterring entry by precommitting to a large output might be to allow entry, and then construct a cartel [7]; we shall refer to this as the collusion strategy in the remainder of the paper. One might base such an analysis on the premise that any mutually beneficial alteration to the pre-entry regime ought to be adopted. In particular, if the incumbent can realize profits larger than both leader profits and deterrence profits, and at the same time the entrant can earn profits larger than follower profits, then it pays to allow entry and collude. The post-entry cartel is asymmetric whenever sunk costs are large enough as to yield effectively impeded entry.

We believe there are two flaws in this approach. First, if the incumbent can pre-commit his output for the purposes of deterrence, then his post-entry output is fixed. Of course, he could offer to "subcontract" some of his output to the entrant; even so, industry output would be pegged at the level to which the incumbent has committed, which will generally not equal the monopoly level. Second, it is unreasonable to believe that the entrant will accept her share of the cartel for very long. Since the incumbent's advantage over the entrant is that he has paid the sunk cost and chosen his output, the initial arrangement cannot persist for very long; the original terms of the cartel may be dynamically unstable.

This is most readily demonstrated in a two-period model where the incumbent can commit to his period 1 output prior to entry. In the first period, the entrant's share of the collusive pie can be consistent with the profits she would earn at her best response to the incumbent's period 1 output. However, since the incumbent's first-mover advantage does not persist into the second period, there is every reason to expect the entrant to threaten dissolution of the cartel. Further, the entrant's threat is credible unless her portion of cartel profits at least equal those she would earn at the non-cooperative equilibrium. Ultimately, the smallest cartel profits the entrant will accept are not S , but rather the Cournot-Nash profits.⁵

Our formal model of the incumbent's decision as to collude or deter entry is thus couched in a two period model, where the incumbent can commit to his period 1 output (but not his period 2 output) prior to entry, and where the incumbent can subcontract part of his period 1 output to the entrant if he desires.⁶ The timing of our model is as follows. Prior to the start of period 1, the incumbent has sunk his entry cost (i.e., his presence in the industry is an "initial condition"). In the first period there are two stages: First, the incumbent chooses a strategy—he can "deter",

$(a - bq_d)^2/4b$ and her discounted flow of profits would be $\pi_2^d = (a - bq_d)^2/4b + \delta a^2/9b$. This implies that

$$q_d = a/b - 2[bS - \delta a^2/9]^{1/2}/b$$

will successfully deter entry. We note for future reference that this gives firm one's period 1 deterrence profits as

$$\pi_1^d = 2[bS - \delta a^2/9]^{1/2} \{a - 2[bS - \delta a^2/9]^{1/2}\}/b.$$

5. This presumes that following disagreement, the market reverts to the Cournot/Nash equilibrium. Using the non-cooperative Nash equilibrium as the "disagreement point" is common in the bargaining literature [17: 16]. Smith [21] takes a similar approach to modeling the interaction of oil producers extracting from a common pool.

6. This is not simply a hypothetical practice. For example, Wyoming coal producers can, and often do, opt to have their rivals fill part of their deliveries to utilities. An alternative assumption, which would yield equivalent results, is to allow side payments.

Figure 1. Extensive Form

“collude”, or “lead.” The choice of strategy implies a period 1 output choice to which he commits. Second, and based on the incumbent’s first stage choice, the entrant decides whether to enter or stay out. Entry entails sinking the entry cost, and selecting an output. In period 2, the firms simultaneously select quantities if entry has occurred; if entry hasn’t occurred, the incumbent operates as an unfettered monopolist.⁷

Figure 1 presents the extensive form for our model. In this diagram, decision nodes are depicted by rectangles, with the decision maker identified by their initial (I or E). In delineating the interactions, we have subsumed the choice process in period 2 for all combinations of period 1 actions except for the collusive choices (q_1^c, q_2^c) . If the firms don’t initially collude, the period 2 equilibrium is Cournot (if entry has occurred). If the firms collude in period 1, there are two potential outcomes in period 2: continued collusion or Cournot. This underscores the requirement that firm two’s period 2 profits cannot be less than her Cournot profits. We note that the collusive arrangement in the continuation game will generally differ from the arrangement in period 1. To emphasize this potential difference, we use $\hat{q}_i$ to represent firm i ’s cartel output in period 2, and $\hat{\pi}_i$ to represent firm i ’s collusive profits in period 2.

The values at the various branches give discounted payoffs for the incumbent and entrant, in

7. This is the one aspect of our model which is not robust with respect to the length of the game. If the industry were infinitely-lived, the incumbent would have to commit to q_{it} in each period (so as to always deter entry), and hence he would perennially earn π_1^d . This complication would not alter the fundamental insight of our analysis.

that order. For example, if the incumbent selects q_1^c in period 1 and the entrant chooses her best response, $R_2(q_1^c)$, her profit flow includes period 1 profits, written as π_2^d in Figure 1; Cournot profits from period 2, π_2^N ; and subtracts off the entry cost. Similarly, the incumbent's profit flow includes period 1 profits, π_1^a in Figure 1; and Cournot profits from period 2. If instead the entrant chose not to enter, her profit flow would be zero. The incumbent's flow would then consist of $\pi_1^{M'}$ in period 1 and unconstrained monopoly profits, π_1^M , in period 2.

Some rankings of the values in Figure 1 are implied by our model. Since in general q_1^c is not the monopoly output, $\pi_1^{M'} < \pi_1^M$. If the entrant responds non-cooperatively to q_1^c , the incumbent loses: $\pi_1^c > \pi_1^a$. The incumbent's cartel profits exceed his leader profits: $\pi_1^c > \pi_1^L$. If firm two enters following the incumbent's choice of q_1^d or q_1^c he earns less than he would as a leader. The worst of these three events from the incumbent's perspective is entry following q_1^d : $\pi_1^{L'} < \pi_1^a < \pi_1^L$. Finally, the entrant's best response to q_1^c earns her more than her best response to q_1^L : $\pi_2^d > \pi_2^F$. Also, her profit flow associated with the period 1 combination ($q_1^L, R_2(q_1^L)$) is strictly positive: $\pi_2^F + \delta\pi_2^N - S > 0$. It follows then that $\pi_2^d + \delta\pi_2^N - S > 0$.

Comparing values allows us to identify the various sub-game equilibria. Consider first the outcome if firm one selects q_1^d in period 1. By definition this output is large enough that firm two's discounted flow of profits, net of entry cost, is just zero, or equivalently: $\pi_2^d + \delta\pi_2^N = S$. Hence if one selects q_1^d , two will select to not enter, and one will earn $\pi_1^d + \delta\pi_1^M$. On the other hand, if one selects q_1^L , two will elect to enter, and one will earn $\pi_1^L + \delta\pi_1^N$. Entry is effectively impeded if

$$\pi_1^d + \delta\pi_1^M > \pi_1^L + \delta\pi_1^N. \quad (3)$$

If inequality (3) fails, entry is ineffectively impeded. (If $q_1^d \leq q_1^L$, then two wouldn't enter in either regime; entry is blockaded.)

Consider next the case where firm one selects q_1^c in period 1. There are three sub-cases: (i) two selects q_2^c in period 1 (the firms collude); (ii) two selects her best response, $R_2(q_1^c)$; and (iii) two selects not to enter. Assuming entry is not blockaded, we may rule out the third sub-case.

In the first sub-case, for collusion to persist in period 2 it must be that firm two's period 2 collusive profits, $\hat{\pi}_2^c$, satisfy

$$\pi_2^c + \delta\hat{\pi}_2^c \geq \pi_2^c + \delta\pi_2^N, \quad (4)$$

i.e., that $\hat{\pi}_2^c \geq \pi_2^N$. Otherwise, firm two's best action in period 2 would be to dissolve the cartel. Hence when firm one offers cartel terms to firm two following entry, the terms will include $\hat{\pi}_2^c = \pi_2^N$.⁸

In the second sub-case, firm two's discounted profits are $\pi_2^d + \delta\pi_2^N$, where π_2^d are her follower profits if she responds non-cooperatively to q_1^c . Thus, for the cartel to be acceptable to firm two, it must be that

8. Thus, we envision the incumbent offering the entrant a "take-it-or-leave-it" package, with non-cooperative behavior occurring if the incumbent's offer is declined. This part of our model is included for concreteness, though it can be rationalized as a subgame-perfect equilibrium in a bargaining game of repeated offers if there are very high costs of delaying agreement or if the time horizon is quite short [16]. Alternative constructs, where the collusive pie is shared in accordance with Nash's [15] bargaining model or the risk-dominance concept discussed in Chapter 6 of Harsanyi and Selten [12], could be included in our model. Again this would not radically alter our results, although it would greatly complicate the analysis.

$$\pi_2^c + \delta \hat{\pi}_2^c \geq \pi_2^a + \delta \pi_2^N. \quad (5)$$

Since $\hat{\pi}_2^c = \pi_2^N$, this implies $\pi_2^c \geq \pi_2^a$ if the cartel is to be acceptable to firm two. In light of footnote 8, firm one offers cartel terms to firm two of $\pi_2^c = \pi_2^a$ and $\hat{\pi}_2^c = \pi_2^N$. Correspondent to firm two's collusive profits, firm one's share of the cartel yields him profits of π_1^c in period 1 and $\hat{\pi}_1^c$ in period 2. This allows calculation of firm one's discounted flow of profits as $\pi_1^c + \delta \hat{\pi}_1^c$ if he selects q_1^c .

We note that firm one will always prefer q_1^c to q_1^l . There are two reasons for this. First, firm one's period 2 collusive profits exceed his Cournot profits. Second, collusion in period 1 implies a smaller output, and hence a higher price, than in the Stackelberg regime; it follows that industry profits are larger. But, firm two's period 1 profits are the same, and so firm one's period 1 profits must exceed the leader profits. Thus, firm one gains in both periods. It follows that collusion is the preferred strategy when entry is ineffectively impeded.

It is also possible that the incumbent will prefer to allow entry and collude when entry is effectively impeded. To facilitate collusion, the incumbent would commit to an output significantly less than the entry-deterrence level, and subcontract some of his production. Correspondingly, industry profits are again larger when the incumbent chooses to collude than when he deters. However, the incumbent must share these larger profits, so his collusive profits will only exceed deterrence profits when his share of the collusive pie is sufficiently large, relative to deterrence profits. Consider first a parameterization with sunk costs just barely large enough to induce effectively impeded entry. In this context, deterrence profits are marginally larger than leader profits. Since the incumbent could collude by selecting the leader output, and we showed above that collusive profits in such a regime are discretely larger than leader profits, it follows that collusion is preferred to deterrence for sufficiently small sunk costs. As one considers larger sunk costs however, deterrence profits increase. Past some level, they will exceed the incumbents collusive profits, and deterrence will be preferred.⁹

We note that the profit flows from the "collude" and "lead" strategies are well-defined, and independent of sunk costs. Similarly, the period 2 profits firm one earns if he successfully deters entry, π_1^M , are independent of S . Correspondingly, S affects the incumbent's strategy selection only through its affect on period 1 deterrence profits. Specifically, if we define

$$V_c = \pi_1^c + \delta \hat{\pi}_1^c - \delta \pi_1^M, \quad (6)$$

9. The critical value of sunk cost at which the incumbent is just indifferent between deterrence and leadership, S' , can be calculated by equating the two profit flows: $\pi_1^c + \delta \pi_1^N = \pi_1^d + \delta \pi_1^M$. It is straight forward to verify that period 1 leader profits are $a^2/8b$, Cournot/Nash profits are $a^2/9b$, and monopoly profits are $a^2/4b$; deterrence profits are given in footnote 4. Combining these observations allows us to derive the critical level of sunk costs as

$$S' = x'^2/b + \delta \pi_2^N,$$

where $x' = a[1 - (1/2 + 5\delta/9)^{1/2}]/4$. The value of sunk cost at which the incumbent is just indifferent between collusion and deterrence, S'' , can be calculated by equating the two profit flows: $\pi_1^c + \delta \hat{\pi}_1^c = \pi_1^d + \delta \pi_1^M$. It can be shown that firm one's optimal pre-entry output is $q_1^c = 3a/5b$, which gives $\pi_1^c = a^2/5b$. Then noting that $\hat{\pi}_1^c = \pi_1^M - \pi_2^N$ and $\pi_2^N = a^2/9b$, we infer that $\pi_1^d = a^2/5b - \delta a^2/9b$ when sunk costs equal S'' . Then using the characterizations in footnote 4, we obtain:

$$S'' = x''^2/b + \delta a^2/9b,$$

where $x'' = a[1 - (1/5 + 4\delta/9)^{1/2}]^{1/2}$

Figure 2. Deterrence vs. Collusion

then the collusion strategy is preferred to the deterrence strategy whenever S is such that $V_c > \pi_1^d$. Similarly, if we define

$$V_L = \pi_1^L + \delta\pi_1^N - \delta\pi_1^M \quad (7)$$

entry is effectively impeded when $V_L < \pi_1^d$.

These observations facilitate a graphical analysis of the incumbent's incentives, contained in Figure 2. This diagram includes the entrant's static best response function, labeled as $R_2(q_1)$ and running from $(0, M_2)$ to $(C_1, 0)$. Because of the incumbent's first-mover advantage, this curve predicts the combination of period 1 outputs if the firms do not collude. Further, since the entrant must anticipate covering her sunk costs if she is to enter, there is a point on her reaction function at which she would no longer enter. This point is denoted by B in our graph; the associated x -coordinate, B_1 , is the smallest level of output to which firm one must pre-commit to deter entry. We note that the location of B depends on S : as larger values of sunk costs facilitate entry deterrence, B lies farther up firm two's reaction curve the larger is S . (This part of our diagram is essentially identical to the analysis in [5].) Figure 2 also includes two iso-profit contours for firm one, with dollar values V_c and V_L (as defined by eqs. (6) and (7)). These iso-profit contours strike the x -axis at outputs $\tilde{q}_{1c}$ and $\tilde{q}_{1L}$, respectively. The interpretation of these outputs follows [5]: firm one can earn profits of V_L in period 1 by producing $\tilde{q}_{1L}$, if the entrant produced zero. Since he can produce a smaller output (which is closer to his monopoly level) and still deter entry, he prefers deterrence to leadership: entry is effectively impeded. On the other hand, to earn period 1 profits of V_c , he would have to produce $\tilde{q}_{1c}$ and have the entrant produce zero. Since this is below the entry-barring level, he cannot earn period 1 profits as large as V_c if he chooses to deter entry. It follows that he prefers the collusion strategy to the deterrence strategy. Of course, as sunk costs rise, the point at which the entrant chooses to not enter moves up her reaction curve, and the value B_1 moves towards the monopoly level. For some level S'' of sunk costs, B_1 and $\tilde{q}_{1c}$ coincide and the incumbent is indifferent between the collusion and deterrence strategies. With larger sunk

costs he would prefer deterrence, while with lower sunk costs he would prefer collusion. These observations may be summarized in:

PROPOSITION 1. *There is a range of sunk costs for which entry is effectively impeded and the incumbent prefers to allow entry and then collude.*

It is interesting to note that the entrant is strictly better off when the incumbent chooses the collusion strategy. This follows since her cartel profits equal $\pi_2^a + \delta\pi_2^N$, which exceed sunk costs from remarks above. Correspondingly, for values of S only slightly larger than S'' , firm two's potential gain from collusion outweighs the profits firm one would sacrifice by not deterring. In such a scenario the entrant would like to forge a cartel with terms less attractive to her. But since such an offer would not be credible, in that the entrant's best action would be to cheat on the cartel once she has entered, the rational incumbent would not agree to such terms.

The foregoing discussion suggests that one constraint on the successful implementation of a cartel is the inability of the entrant to credibly limit her period 2 output. One is then lead to ask: are there structural conditions under which the entrant can credibly limit the level of profits she would obtain as part of the cartel? For example, if production were subject to capacity constraints, as in Spence [22] or Dixit [6], the entrant's ability to expand output following entry would be limited, and she might be able to credibly limit her share of the cartel. Since this would insure that the incumbent received a proportionately larger share of the cartel, it might make the collusion strategy more attractive.

III. Capacity Constraints and Collusion

In this section, we investigate the effect of capacity constraints on the incumbent's choice between the deterrence strategy and the collusion strategy. The model we utilize is a two-period variant of the model of entry deterrence in the presence of capacity constraints in Dixit [6]. The essential feature is cost asymmetry: as the incumbent's capacity is already in place, his marginal costs are nil for outputs at or below capacity. On the other hand, the entrant must build from scratch, and so her marginal costs explicitly include the marginal cost of an additional unit of capacity. This asymmetry affects the nature of both cooperative and non-cooperative equilibria following entry, and the entry-barring equilibrium.

In the discussion which follows, we will denote the marginal cost of an additional unit of capacity by r and firm j 's capacity by k_j , where again $j = 1$ for the incumbent and $j = 2$ for the entrant. As is common in the literature, we choose units of capacity to equal units of output. Thus, our capacity constraint may be written as $q_j \leq k_j$.

It is straightforward to show that the asymmetric static Cournot-Nash equilibrium entails production of $(a + r)/3b$ by the incumbent and $(a - 2r)/3b$ by the entrant, and that Cournot-Nash profits for the entrant are equal to¹⁰

$$\pi_2^{N'} = (a - 2r)^2/9b. \quad (8)$$

10. Since the incumbent's marginal costs are zero, his static reaction function is $q_1 = R_1(q_2) = a/2b - q_2/2$. On the other hand, the entrant has marginal costs of r , so her static reaction function is $q_2 = R_2(q_1) = (a - r)/2b - q_1/2$. Combining these results produces the values given in the text. Further, this yields market price of $P^N = (a + r)/3$; noting that $\pi_2 = (P^N - r)q_2$ gives eq. (8).

As in section II, if the incumbent is to deter entry, he must select some output $q_1^{d'}$ so large that the entrant's best response earns her zero profits *ex ante*. In this event, the incumbent earns deterrence profits $\pi_1^{D'}$; as in section II these profits are increasing in S within the relevant range.¹¹

Also as in section II, there exists a range of sunk costs for which entry is effectively impeded and the incumbent prefers to allow entry and then collude. Because of the cost asymmetry, the combination of outputs corresponding to a collusive regime will be more complex than the corresponding collusive frontier developed in section II. In particular, the collusive frontier in this section's model will be non-linear; moreover, if one rules out side payments any post-entry cartel cannot maximize industry profits.¹²

The main result of this section is that increases in r reduce the attractiveness of the collusion strategy. Equivalently, when entry is effectively impeded, allowing entry and colluding is more likely to be adopted for smaller values of r , and correspondingly, smaller cost asymmetries.

PROPOSITION 2. $\partial(\pi^c - \pi^d)/\partial r < 0$.

The proof of this proposition is neither enlightening nor straightforward, and so we relegate it to an appendix.

At first blush, this result is somewhat surprising. By inviting entry and then colluding, the incumbent's optimal capacity level is significantly reduced, so that his capacity costs are much lower if he colludes. Based on this incentive, one would expect the likelihood of adoption to be positively related to the relative cost of capacity. There is, however, a competing incentive which the incumbent must consider. This second incentive is that the discounted flow of revenues earned by choosing deterrence will rise more rapidly than the discounted flow of collusive revenues as r increases.¹³ Based on this second incentive, one would expect the likelihood of adoption to be negatively related to the relative cost of capacity. The proposition suggests that this second incentive is more important than the first: increases in the unit cost of capacity raise deterrence revenues more than they raise the incumbent's revenues as part of a cartel; this difference in added revenues is larger than the cost savings he would realize from colluding rather than deterring entry.

The above result is particularly striking when related to Spulber's Proposition 4 [23, 511]. He showed that deterring entry by holding excess capacity was unlikely unless capacity costs are low. Taken together with our results, this suggests that when holding excess capacity to deter entry is credible, it is frequently preferable to adopt the collusion strategy.

11. Using the information in footnote 10, the entrant's period 1 follower profits can be calculated as $(a - r - bq_1)^2/4b$. This gives her discounted profits of $\pi_2^d = (a - r - bq_1)^2/4b + \delta(a - 2r)^2/9$. It follows that the incumbent can deter entry by producing

$$q_1^{d'} = (a - r)/b - 2[bS - \delta(a - 2r)^2/9]^{1/2}/b$$

in period 1. For any S such that entry is not blockaded, $q_1^{d'}$ exceeds the monopoly output. Since $q_1^{d'}$ is decreasing in S , increases in S raise deterrence profits.

12. The collusive frontier in our model corresponds to the notion of "market sharing" in Schmalensee [20]. The collusive frontier under market sharing is a quadratic relation, with x-intercept at the low cost monopoly output (which is $a/2b$ in our framework) and y-intercept at the high cost monopoly output (which is $[a - r]/2b$ in our framework). Because the incumbent's marginal costs are lower, movements along the collusive frontier which raise his output while reducing the entrant's output yield increasing in industry profits. In the limit, industry profits are maximized when the incumbent is the only producer. Of course, for the entrant to accept such an allocation, the incumbent would necessarily have to bribe her to keep her output at zero.

13. On the one hand, increases in r enable the incumbent to deter entry with smaller outputs, so that his revenues rise markedly. On the other hand, while increases in r raise the discounted flow of cartel profits, the incumbent does not capture all these gains.

Including capacity constraints complicates the analysis, but not the essential intuition. The decision as to collude or deter entry follows a comparison of the associated profit flows. As before, there exists a value S'' of sunk cost at which the incumbent is indifferent between the two strategies; collusion is preferred for smaller sunk costs. Unlike the variant in section 2, and because of the computational difficulty in deriving the incumbent's period 1 collusive output, it is not possible to characterize S'' in closed form.¹⁴ Instead, we conduct a numerical analysis to demonstrate the effect of capital costs on the desirability of the collusion strategy.

IV. Numerical Analysis

In this section we use a numerical example to demonstrate the impact of an asymmetric cost structure on the willingness of the incumbent to adopt the collusion strategy. For various values of r , one can numerically determine q_1^c , the incumbent's period 1 output associated with the collusion strategy, $\hat{q}_1^c$, the incumbent's period 2 output under collusion, and q_1^d , the period 1 entry deterring output. Based on these numbers, a comparison of the profit flows can be made and a strategy selected. As noted above, the optimal strategy depends on the level of sunk cost, and so we seek the critical value at which the two strategies are equally attractive. Results of the simulation analysis are provided in Table I. The table illustrates the impact of changes in the entrant's marginal cost of capital on output, profit, and entry deterrence. The demand parameters used in the simulation are $a = b = 1$ (which are those used in Schmalensee [20]). Finally, we used a discount factor of 90% ($\delta = .9$).

The first column in Table I gives the unit cost of capacity, ranging from 0 to .20. The pre-entry output selected by the incumbent when he chooses the collusive strategy, q_1^c , is given in column two. The incumbent's period 2 collusive output, $\hat{q}_1^c$, is given in column three. The entrant's collusive outputs, which are q_2^c in period 1 and $\hat{q}_2^c$ in period 2, are listed in columns four and five. The incumbent's discounted collusive profit flow is given in column six, and the entrant's flow is in column seven. Column eight gives the value of sunk cost at which the incumbent is indifferent between collusion and deterrence. The sunk cost at which entry is just effectively impeded is listed in column nine. Finally, the ratio of column eight to column nine is reported in column ten.

Examination of Table I reveals that as the entrant's unit cost of capital increases, the second period cartel output of the dominant firm increases while at the same time the cartel output of the

14. Owing to the added complexity in this section's model, calculation of the critical value of sunk cost at which the incumbent is indifferent between deterrence and leadership, S' , and the value at which he is just indifferent between deterrence and collusion, S'' , is complicated considerably. Following the same logic as in footnote 9, and in Figure 2, one first determines the discounted flow of profits earned by colluding, call it π^c , and by leading, call it π^L . Next, subtract off period 2 monopoly profits net of capacity costs discounted back to period 1, i.e., $\delta(\pi^M - rq_1^d)$. The value of sunk costs which makes period 1 deterrence profits equal to $\pi^c - \delta(\pi^M - rq_1^d)$ is S'' . The value of sunk costs which gives deterrence profits equal to $\pi^L - \delta(\pi^M - rq_1^d)$ is S' . One can express these critical values of sunk costs as

$$S' = (a - bq^*)^2/4b + \delta\pi_2^N, \quad \text{and}$$

$$S'' = \{[(a - r)/b] - q^{**}/2\}^2 + \delta\pi_2^N,$$

where q^* is that value of q_1^d for which the incumbent is just indifferent between leadership and deterrence, and q^{**} is that value of q_1^d for which he is just indifferent between collusion and deterrence. Unfortunately, closed form solutions for q^* and q^{**} are difficult to obtain when $r \neq 0$. Correspondingly, we rely on numerical methods in the analysis below.

Table I. Results From Numerical Analysis

r	q_1^c	$\hat{q}_1^c$	q_2^c	$\hat{q}_2^c$	π_1^c	π_2^c	S''	S'	S''/S'
.00	.6000	.2778	.1000	.2222	.3250	.1400	.1031	.1000	1.0310
.01	.5904	.2810	.0999	.2168	.3177	.1360	.0993	.0960	1.0344
.02	.5808	.2843	.0998	.2113	.3106	.1320	.0956	.0922	1.0369
.03	.5712	.2875	.0997	.2060	.3037	.1281	.0919	.0884	1.0396
.04	.5616	.2908	.0996	.2006	.2969	.1243	.0883	.0847	1.0425
.05	.5520	.2940	.0995	.1954	.2904	.1206	.0848	.0810	1.0469
.06	.5424	.2973	.0994	.1901	.2840	.1170	.0814	.0775	1.0503
.07	.5328	.3006	.0993	.1848	.2778	.1134	.0781	.0741	1.0540
.08	.5232	.3040	.0992	.1795	.2719	.1099	.0749	.0708	1.0579
.09	.5136	.3073	.0991	.1744	.2661	.1065	.0717	.0676	1.0607
.10	.5040	.3107	.0990	.1692	.2605	.1032	.0686	.0644	1.0652
.11	.4944	.3140	.0989	.1641	.2550	.1000	.0656	.0614	1.0686
.12	.4848	.3174	.0988	.1590	.2498	.0968	.0627	.0585	1.0730
.13	.4752	.3208	.0987	.1539	.2447	.0937	.0599	.0556	1.0781
.14	.4656	.3243	.0986	.1488	.2399	.0907	.0572	.0529	1.0814
.15	.4560	.3277	.0985	.1438	.2352	.0878	.0546	.0502	1.0869
.16	.4464	.3312	.0984	.1388	.2307	.0849	.0520	.0476	1.0917
.17	.4368	.3347	.0983	.1338	.2264	.0822	.0496	.0452	1.0966
.18	.4272	.3382	.0982	.1289	.2222	.0795	.0471	.0428	1.1008
.19	.4176	.3417	.0981	.1241	.2183	.0769	.0448	.0406	1.1056
.20	.4080	.3453	.0980	.1192	.2145	.0744	.0426	.0384	1.1119

entrant declines. Note also that when $r > 0$, total output of the two firms in period 2 is less than the zero-cost monopoly output, due to the convexity of the collusive frontier. Period 1 output for both firms falls as r rises. As one would expect, collusive profits for the entrant decrease with positive changes in r . The incumbent's collusive profit flow also declines as the unit cost of capacity rises. For while larger values of r increase his advantage, allowing for increases in his discounted flow of revenues, they also increase his capacity costs.

Note too that higher values of r reduce S'' , the crucial level of sunk costs at which the incumbent is indifferent between deterrence and collusion. This is the essence of our proposition: For fixed S , increases in r lower collusive profits more rapidly than they lower deterrence profits; it follows that the level of sunk costs for which deterrence profits just equal collusive profits must shrink. But increases in the unit capacity costs also facilitate deterrence; this is manifested by the decrease in S' , the value of sunk costs at which entry is just effectively impeded, as r rises. It is interesting to note that S' falls more rapidly than S'' . The interpretation is that the range of sunk costs for which entry is effectively impeded and the collusive strategy is preferred, $S' \leq S < S''$, is increasing in the unit cost of capacity. That is, while increases in r render the collusion strategy less attractive in an absolute sense, such increases make it more attractive in a relative sense.

V. Concluding Remarks

This paper has investigated an alternative strategy to entry deterrence: inviting entry and then colluding with the new entrant. We showed that this strategy will be preferred to deterring entry for sufficiently small levels of sunk cost. This holds true even if the incumbent has a cost

advantage because of capacity costs, although higher capacity cost reduce the attractiveness of colluding. We should point out that these results differ in an important respect from Gallini's [9] result that an incumbent may invite entry by one firm so as to deter entry by additional firms. In our analysis, the incumbent faces only one potential entrant, so that allowing entry has no impact on future entrants. Obviously, this limits its applications to observed industrial behavior; it does have the benefit that it makes the analysis considerably less opaque. Here, entry is allowed when an acceptably asymmetric cartel can be formed because relative to deterrence, this allows the incumbent to eliminate costly excess capacity without greatly reducing, and indeed perhaps increasing, his revenues.

It has been argued that the circumstances under which an incumbent might credibly deter entry by holding excess capacity may not be very general [23, 511]. In particular, holding excess capacity to deter entry may only be credible if the cost of capacity is small. To the extent that this is true, our results have added significance: when excess capacity can credibly deter entry, the collusion strategy might commonly be adopted. This suggests that the strategy of holding excess capacity to deter entry has limited theoretical support.

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