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*The RAND Journal of Economics*, Vol. 22, No. 2 (Summer, 1991), 155-172.

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# Oligopoly limit pricing

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*We expand Milgrom and Roberts' (1982) limit pricing model to allow for multiple incumbents. Each incumbent is informed as to the level of an industry cost parameter and selects a preentry price while a single entrant observes each incumbent's preentry price. We find that incumbents are unable to coordinate deception, which results in a separating equilibrium in which preentry prices are not distorted. Further, introducing the refinement of unprejudiced beliefs, we show that the no-distortion equilibrium is the only refined separating equilibrium. Plausible pooling equilibria fail to exist or involve downward distortions in preentry prices.*

## 1. Introduction

■ The basic notion of limit pricing involves an incumbent firm choosing a low price and thereby convincing a potential entrant that entry would be unprofitable. This informal idea becomes a complete theory when two further issues are addressed. First, the linkage between the preentry price and the postentry profits of the entrant must be made explicit. Second, true monopolies are certainly the exception, and any useful model of limit pricing must be consistent with the existence of multiple, uncoordinated incumbents.

Past literature has studied two kinds of linkages. The early work of Bain (1956), Modigliani (1958), and especially Sylos-Labini (1962) proposed a commitment linkage, whereby the incumbent is able to commit to sustain its output level if entry occurs. This idea has been extended to commitment of a wider class of strategic variables, such as capacity, and to commitments by multiple incumbents, made either simultaneously or sequentially.<sup>1</sup> Mil-

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We thank Joe Harrington, Ken Judd, Mark O'Donnell, Rob Porter, an anonymous referee, seminar participants at the University of California, San Diego, the University of Chicago, the University of Michigan, Stanford University, Washington State University, and the 1989 Summer Econometric Society meetings, and especially Steve Matthews for helpful comments. Bagwell thanks the National Science Foundation for research support under grant SES-8909856.

<sup>1</sup> See Gilbert and Vives (1986) and Waldman (1987) for multiple-incumbent models in which output is committed before entry. Vives (1988) explores this model with sequential output choices. Dixit (1980), Eaton and Lipsey (1980), Fudenberg and Tirole (1983), and Spence (1977) construct models with strategic capacity choices. Related models with multiple incumbents and a dynamic structure are studied by Bernheim (1984), Eaton and Ware (1987), Kamien and Schwartz (1975), and McLean and Riordan (1989). Finally, the entry-detering role of product proliferation is analyzed by Bonanno (1987), Eaton and Lipsey (1979), Judd (1985), Prescott and Visscher (1977), and Schmalensee (1978).

grom and Roberts (1982) introduced the idea of an informational linkage, in which the incumbent reduces its price in order to signal to the entrant that entry prospects are unfavorable. Despite the distortion to preentry pricing, entry decisions are exactly the same as under complete information.

This information-based approach to limit pricing has been extended in several directions,<sup>2</sup> yet the fundamental extension to multiple incumbents remains seriously incomplete. The primary work in this area is an article by Harrington (1987). Building on his earlier work (Harrington, 1986), he assumes that an entrant expects its costs to be the same as those of the incumbent firms. Intuitively, there is then an incentive for incumbents to distort price *upward* in order to signal high costs. Harrington shows that this intuition is in fact correct, under the assumptions that incumbents with common, privately known costs simultaneously choose preentry output and that the entrant observes only the resulting market price.

While provocative, this work ignores an essential aspect of oligopoly behavior. In particular, it seems most plausible that an entrant would be able to observe individual behavior of each incumbent separately, as opposed to a single, summary statistic of all incumbents' behavior. We show below that this difference is of fundamental importance in understanding oligopoly limit pricing behavior.

Our model takes the following form. An industry cost parameter determines the costs incurred by each active firm. This parameter can be either high or low.<sup>3</sup> For simplicity, we assume there are two incumbent firms, each of which knows whether costs are low or high in the industry. The firms choose prices in a differentiated product market. Both prices are observed by the entrant, who then tries to infer industry costs. Higher costs correspond to lower profits, so incumbents would like to signal high costs.

One might expect that prices would tend to be distorted upward. We argue, however, that a very robust equilibrium exists in which the incumbents simply play as if there were complete information, or equivalently, no entry threat! Prices are not distorted in either direction, and entry takes place exactly when it is profitable. Although the latter conclusion is consistent with previous single-incumbent models, the former is not and points to a significant difference between multiple- and single-incumbent models.

The key point is that when incumbents select observable signals simultaneously, non-cooperative behavior implies that they are unable to coordinate deception. In other words, when a low-cost incumbent attempts to feign high costs by raising its price, the entrant is not fooled because the rival low-cost incumbent continues to select its equilibrium price. This in turn means that it is possible to credibly signal high costs with no distortions at all. We refer to such an outcome as a *no-distortion equilibrium*.

As is usually the case in signalling models, there may exist many other signalling equilibria, involving a wide variety of possible distortions. We show that for a large class of entry situations, the no-distortion equilibrium uniquely satisfies a pair of refinements that eliminate unreasonable inferences by the entrant.

The first kinds of equilibria we consider are *two-sided separating equilibria*, in which each incumbent plays a separating pricing strategy (the no-distortion equilibrium fits into this category). For these equilibria we introduce the refinement of *unprejudiced beliefs*, which requires the entrant to take into account the number of price deviations that would

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<sup>2</sup> See, for example, Bagwell and Ramey (1988, 1990) for the possibility of signalling costs and demand with price and advertising expenditures, Cho (1987) for a careful analysis of the single-crossing property, Matthews and Mirman (1983) for a model in which price is observed with noise, Ramey (1987) for an analysis that includes a capacity choice, and Roberts (1987) for a survey of an extended literature.

<sup>3</sup> This does not mean that the incumbents have identical costs, only that each incumbent incurs lower costs when the cost parameter is low rather than high. We may thus refer to low-cost (high-cost) incumbents when the industry cost parameter is low (high).

be needed to generate a deviant price pair. In particular, unprejudiced beliefs satisfy a minimality rule, whereby the entrant infers a particular industry cost type if under that type the deviant price pair can be rationalized with the fewest number of deviations from the equilibrium strategies. We argue that this rule will be satisfied provided the entrant is not “prejudiced” in believing that any one price deviation is infinitely more likely than any other.

The requirement that beliefs be unprejudiced eliminates all two-sided separating equilibria except the no-distortion equilibrium. The essential point is that unprejudiced beliefs enable a high-cost incumbent to choose a deviant price closer to its reaction curve, resting assured that the separating price of the rival incumbent will reveal high costs. This informational free-riding will occur unless there are no gains available from deviating. The no-distortion equilibrium is the only two-sided separation equilibrium that eliminates all such gains.<sup>4</sup>

We also consider *one-sided separating equilibria*, in which one of the incumbents plays a pooling strategy, and *pooling equilibria*, in which both play pooling strategies. Requiring unprejudiced beliefs need not have force in such equilibria, since informational free-riding is impossible when the rival incumbent pools. Assumptions are given, however, under which a straightforward adaptation of the intuitive criterion of Cho and Kreps (1987) ensures elimination of all equilibria with pooling. In this case, the no-distortion equilibrium is the only equilibrium that can be supported by unprejudiced and intuitive beliefs.

We show by parameterized example that pooling equilibria will satisfy the intuitive criterion when entry deterrence is sufficiently important relative to preentry profits. This will occur, for example, in a rapidly growing market. The interesting point is that the pooling equilibria which now satisfy the intuitive criterion will typically involve *downward distortions* to preentry prices, in contrast to Harrington’s results. Thus, the distortions first demonstrated by Milgrom and Roberts (1982) emerge here in the form of intuitive pooling equilibria, which exist when market growth is sufficiently rapid.

The plan of the article is as follows. Section 2 describes the basic model and defines a sequential equilibrium for our setting. Sections 3, 4, and 5 consider no-distortion equilibria, two-sided separating equilibria, and equilibria with pooling, respectively. Section 6 presents our parameterized example. Section 7 gives brief comments concerning some extensions of our model, and Section 8 concludes.

## 2. Model

■ Consider the following situation. There are two incumbent firms, Incumbent 1 and Incumbent 2, and one potential entrant firm that compete in a two-period market. In the first period the incumbent firms alone produce the product. At the outset of the second period, the potential entrant may choose to enter the market, and in the second period the market may have either two or three sellers. The key feature of this market is that the incumbent firms possess information about production costs that the entrant cannot observe prior to making its entry decision.

This market will be modelled by means of the following three-stage game:

*Stage 1.* Incumbents 1 and 2 observe a cost parameter  $C$  and choose prices  $P_1$  and  $P_2$ . The set of possible  $C$  is given simply by  $\{L, H\}$ .  $P_1$  and  $P_2$  are chosen noncooperatively from nondegenerate intervals  $[0, \bar{P}_1]$  and  $[0, \bar{P}_2]$ , respectively.<sup>5</sup>

<sup>4</sup> A public good problem is thus associated with entry deterrence. Incumbents would like to deter entry by signalling high costs with collusive prices, but free-rider effects result in signalling at lower prices. This “underinvestment” in entry deterrence is similar to results found by Harrington (1987) but opposite to those found by Gilbert and Vives (1986).

<sup>5</sup> We may think of  $\bar{P}_i$  as giving the “choke price” for Incumbent  $i$ ’s product when consumers buy zero units of Incumbent  $j$ ’s product. Any  $P_i > \bar{P}_i$  is then payoff-equivalent to  $\bar{P}_i$ .

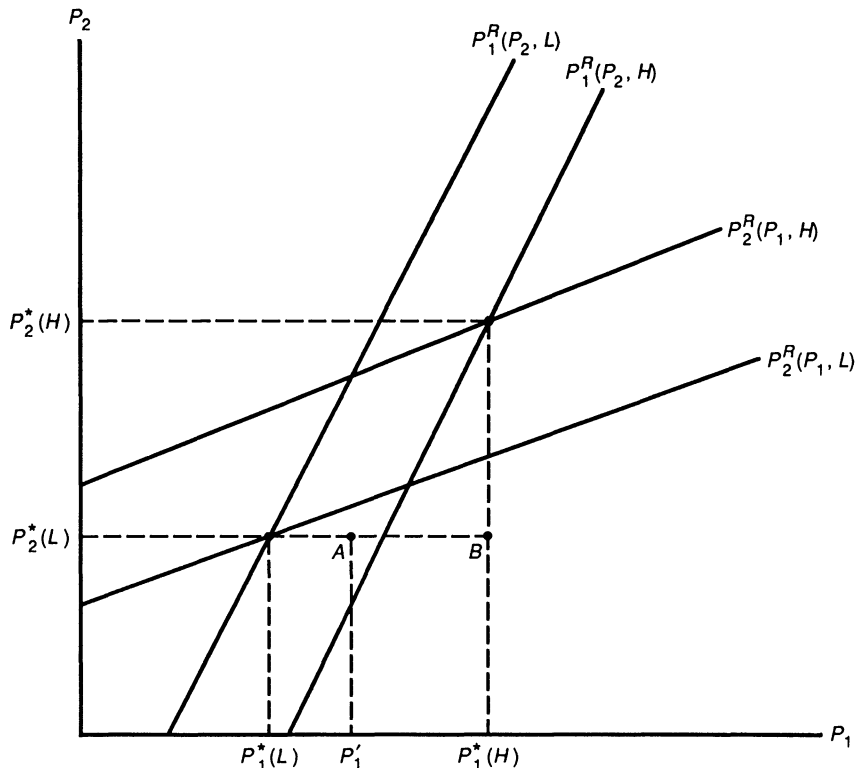
*Stage 2.* The entrant observes  $P_1$  and  $P_2$ , but not  $C$ , and makes an entry decision  $D \in \{0, 1\}$ , where 0 denotes no entry and 1 denotes entry.

*Stage 3.* The firms play a second-period oligopoly game whose structure depends on the entry decision.

We abstract from the details of second-period interaction and simply specify payoffs conditional on the entry decision. Let  $i = 1, 2$  be an index for incumbent firms; we shall also sometimes use the index  $j$  when a distinction between the two incumbents is required. Similarly, the index  $e$  is employed for the entrant. We now use  $\Pi_i^N(C)$  to denote the second-period profit of Incumbent  $i$  when entry does not occur ( $D = 0$ ) and the cost parameter is  $C$ , and we let  $\Pi_i^E(C)$  denote second-period profit for this incumbent when entry does occur ( $D = 1$ ). To capture the fact that incumbents always prefer no entry, we assume  $\Pi_i^N(C) > \Pi_i^E(C)$  for all  $C$ . For the entrant,  $\Pi_e^E(C) > \Pi_e^N(C) = 0$  gives the second-period profit if entry occurs and if not, respectively. When entry does occur, a sunk entry cost of  $K \geq 0$  is incurred; we will suppose that the value of  $K$  is the private information of the entrant. Finally,  $C = L$  is associated with lower production costs and thus higher profits than is  $C = H$ ; we therefore assume  $\Pi_i^N(L) > \Pi_i^N(H)$ ,  $\Pi_i^E(L) > \Pi_i^E(H)$ , and  $\Pi_e^E(L) > \Pi_e^E(H)$ .

For the incumbents, first-period profits are given by  $\Pi_i(P_i, P_j, C)$ ,  $i, j = 1, 2, i \neq j$ , which are assumed to be continuous functions of the prices. For each  $P_j$  and  $C$ ,  $\Pi_i$  is uniquely maximized by  $P_i^R(P_j, C)$ , which is a reaction function that is continuous, strictly increasing in  $P_j$  and such that  $\bar{P}_i > P_i^R(P_j, H) > P_i^R(P_j, L)$ . We assume that there is a unique static Nash equilibrium in prices for each  $C$ , given by  $(P_1^*(C), P_2^*(C))$ . Figure 1 illustrates these assumptions.

FIGURE 1



As our solution concept we employ Kreps and Wilson's (1982) sequential equilibrium, which gives restrictions on strategies as well as beliefs of players. The firms' strategies are given by  $\hat{P}_i(C)$  for Incumbent  $i$  and  $\hat{D}(P_1, P_2, K)$  for the entrant.  $C$  and  $K$  are chosen by "Nature" via randomization. Let  $\rho \in (0, 1)$  give the probability that  $C = L$ , and suppose that  $K$  is drawn from nondegenerate  $[0, \bar{K}]$  according to the strictly positive density  $f(K)$ . The entrant's beliefs when it makes its entry decision are given by  $\hat{\rho}(P_1, P_2)$ , the posterior probability of  $C = L$  when  $(P_1, P_2)$  has been observed. To ensure that there is positive probability of entry being unattractive, assume  $\bar{K} > \Pi_e^E(H)$ .

The collection  $\{\hat{P}_1(C), \hat{P}_2(C), \hat{D}(P_1, P_2, K), \hat{\rho}(P_1, P_2)\}$  forms a sequential equilibrium for our game if the following three conditions are satisfied:

Sequential rationality of the entrant strategy:

$$\hat{D}(P_1, P_2, K) = 1 \quad \text{if and only if} \\ \hat{\rho}(P_1, P_2)\Pi_e^E(L) + (1 - \hat{\rho}(P_1, P_2))\Pi_e^E(H) - K \geq 0. \quad (1)$$

Sequential rationality of incumbent strategies:

For  $i, j = 1, 2, \quad i \neq j, \quad \text{and} \quad C = L, H,$

$$\hat{P}_i(C) \in \operatorname{argmax}_{P_i} \left\{ \Pi_i(P_i, \hat{P}_j(C), C) + \Pi_i^N(C) \right. \\ \left. + (\Pi_i^E(C) - \Pi_i^N(C)) \int_0^{\bar{K}} \hat{D}(P_i, \hat{P}_j(C), K) f(K) dK \right\}. \quad (2)$$

Bayes-consistency of beliefs:

$$\begin{aligned} (\hat{P}_1(L), \hat{P}_2(L)) \neq (\hat{P}_1(H), \hat{P}_2(H)) \quad \text{implies} \quad & \hat{\rho}(\hat{P}_1(L), \hat{P}_2(L)) = 1 \\ & \text{and} \quad \hat{\rho}(\hat{P}_1(H), \hat{P}_2(H)) = 0. \\ (\hat{P}_1(L), \hat{P}_2(L)) = (\hat{P}_1(H), \hat{P}_2(H)) \quad \text{implies} \quad & \hat{\rho}(\hat{P}_1(L), \hat{P}_2(L)) = \rho. \end{aligned} \quad (3)$$

Thus, sequential equilibrium requires strategies to be best responses and beliefs to satisfy Bayes' rule along the equilibrium path, for both separating

$$((\hat{P}_1(L), \hat{P}_2(L)) \neq (\hat{P}_1(H), \hat{P}_2(H)))$$

and pooling  $((\hat{P}_1(L), \hat{P}_2(L)) = (\hat{P}_1(H), \hat{P}_2(H)))$  equilibria. The concept imposes no restrictions for beliefs for price pairs off the equilibrium path in our game.

### 3. No-distortion equilibria

■ In the limit pricing theory of Milgrom and Roberts, the fact that price is a signal of cost forces the incumbent to depart from its complete-information optimal pricing. There, in order to convince the entrant that incumbent costs are low and entry is unprofitable, an incumbent must select a preentry price that it would be unwilling to choose were its costs high. The low-cost incumbent thus distorts its price downward so as to sacrifice profit and prove its efficiency. Of course, for such a distortion to occur in an equilibrium framework, some form of a "single-crossing property" must be assumed; i.e., the low-cost incumbent must be willing to reduce its preentry price more than would the high-cost incumbent, in exchange for a given reduction in the probability of entry.

In this section we show that the previous emphasis on distorted pricing as a sacrifice that enables signalling is inappropriate for our multiple-incumbent game. Rather, we argue that signalling is made possible by the inability of noncooperative incumbents to coordinate deception (the sending of false signals). This new emphasis on the role of coordination

gives rise to equilibria in which signalling occurs without distortions in preentry pricing and without a single-crossing property.

Our focus is on a class of sequential equilibria called *no-distortion equilibria* (NDE), in which  $\hat{P}_i(C) = P_i^*(C)$  for all  $i$  and  $C$ . Here, complete-information Nash prices are played by incumbents for each cost type. Note that under our assumptions, multiple NDE arise only to the extent that the entrant's reactions may differ for off-equilibrium-path prices.

*Proposition 1.* NDE exist.

The proof is as follows. Let  $\hat{P}_i(C) = P_i^*(C)$  for all  $i$  and  $C$  and put  $\hat{\rho}(P_1^*(L), P_2^*(L)) = 1$  and  $\hat{\rho}(P_1^*(H), P_2^*(H)) = 0$ . These beliefs satisfy (3). Next, the entrant's decision rule,  $\hat{D}(P_1, P_2, K)$ , is defined to satisfy (1) for the given beliefs. A consequence is that entry is more likely to occur when the low-cost equilibrium price pair is observed.

The interesting step is to show that the proposed pricing strategies satisfy (2). It is sufficient to focus on Incumbent 1. As illustrated in Figure 1,  $P_1^*(H)$  maximizes preentry profit for the high-cost Incumbent 1, given the rival price  $P_2^*(H)$ . Furthermore, the pair  $(P_1^*(H), P_2^*(H))$  gives the lowest possible probability of entry. It follows that the high-cost Incumbent 1 has no incentive to deviate, that is,  $P_1^*(H)$  satisfies (2). If instead Incumbent 1 has low costs, then once more preentry profits are sure to decline if a deviant price is selected, since  $P_1^*(L)$  is a best response to  $P_2^*(L)$ . A deviation might be attractive to this incumbent, however, if it "fools" the entrant and lowers the probability of entry.

Figure 1 illustrates the deviations available to the low-cost Incumbent 1. By selecting a deviant price  $P'_1$ , with  $P'_1 \neq P_1^*(H)$ , a price pair corresponding to point  $A$  is generated. We may exploit the arbitrariness of beliefs for off-equilibrium-path prices and impose  $\hat{\rho}(P'_1, P_2^*(L)) = 1$ , thereby eliminating any incentive for the low-cost Incumbent 1 to deviate to this price. The other possibility is to deviate to the price  $P_1^*(H)$ . Here, the low-cost Incumbent 1 mimics the price that it would select were costs high. This deviation generates a price pair corresponding to point  $B$ . Clearly, if we require that  $\hat{\rho}(P_1^*(H), P_2^*(L))$  be close (but not necessarily equal) to unity, then this deviation is also unattractive. Thus,  $P_1^*(L)$  also satisfies (2) and the proof is complete.

The essential difference between this result and that of Milgrom and Roberts is that, with multiple incumbents, noncooperative pricing prohibits the incumbents from coordinating their defections from the equilibrium prices. To mimic the high-cost price pair and thereby lower the probability of entry, both low-cost incumbents would have to deviate to higher prices. This inability to coordinate deception enables high-cost incumbents to signal high industry costs without sacrificing profits through pricing distortions.<sup>6</sup>

Two important issues remain. First, NDE are reasonable only to the extent that the corresponding belief specification is plausible. Second, NDE form a focal equilibrium class provided that other equilibria with plausible belief specifications do not exist. The next two sections are devoted to the development of standards of plausibility for beliefs that suggest that NDE are a reasonable and focal equilibrium class.

#### 4. Two-sided separating equilibria and unprejudiced conjectures

■ In this model, a separating equilibrium arises whenever

$$(\hat{P}_1(L), \hat{P}_2(L)) \neq (\hat{P}_1(H), \hat{P}_2(H)).$$

Because there are two incumbents in possession of the cost information, there are two sorts of separating equilibria. *Two-sided separating equilibria* (TSE) occur when both incumbents

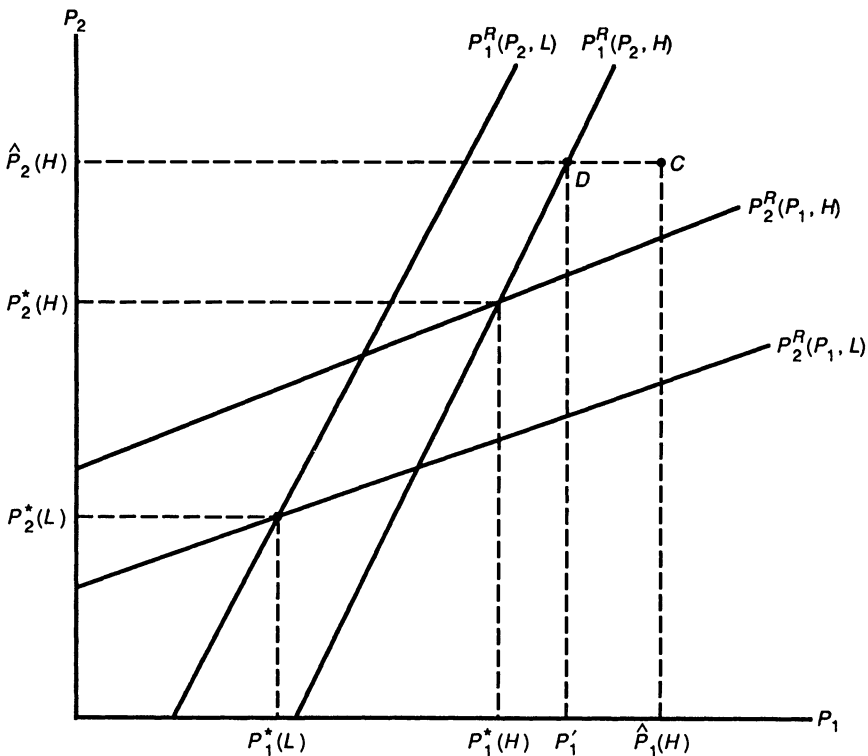
<sup>6</sup> Kalai and Rosenthal (1977) make a related point in an arbitration game, where two agents share information that is unavailable to the arbitrator. By requiring the agents to announce their information simultaneously, the arbitrator is able to elicit information without inducing a distortion. Uniqueness arguments do not apply in that setting, however.

play separating strategies, i.e.,  $\hat{P}_i(L) \neq \hat{P}_i(H)$ ,  $i = 1, 2$ . In TSE, the entrant can learn the cost parameter by observing the price of either incumbent alone. By contrast, *one-sided separating equilibria* (OSE) are found when  $\hat{P}_i(L) \neq \hat{P}_i(H)$  but  $\hat{P}_j(L) = \hat{P}_j(H)$ . Here, the entrant can learn the cost parameter only by observing the price of Incumbent  $i$ . In this section we shall develop a refinement of sequential equilibrium that greatly reduces the set of possible TSE. We consider OSE in the next section.

First, it should be noted that in any separating equilibrium  $\hat{P}_i(L) = P_i^*(L)$  for  $i = 1, 2$ , i.e., the pricing of the low-cost incumbents is never distorted. This is because equilibrium pricing for a low-cost Incumbent  $i$  in a separating equilibrium leads to the largest possible entry, so that there is no punishment that can deter this incumbent from deviating to  $P_i^R(\hat{P}_j(L), L)$ . But the threat of increased entry can induce a wide range of pricing behavior by the high-cost incumbents. We shall argue that threats that lead to pricing distortions in TSE are based on unreasonable inferences by the entrant.

The argument is most easily developed with reference to Figure 2. The point  $C$  corresponds to a possible high-cost price pair for a class of TSE. Observe that if Incumbent 1 deviates to its reaction curve (the price  $P_1'$ ), the point  $D$  is induced. This deviation increases Incumbent 1's preentry profits when costs are high; thus, for such TSE to exist, the entrant's beliefs must put a large weight on the possibility of low costs when the price pair associated with point  $D$  is observed. Is this a plausible belief? We don't think so. The key insight is that the entrant can rationalize observation of the price pair at point  $D$  with either the hypothesis that industry costs are high and a single deviation (by Incumbent 1) occurred or the hypothesis that both incumbents deviated and industry costs are low. Provided that the entrant favors the rationalization that requires the fewest number of deviations, the deviation to point  $D$  must be associated with high industry costs. But under this interpretation the high-cost Incumbent 1 deviates and the equilibrium fails.

FIGURE 2



This reasoning suggests the following formalization of our belief restriction. Suppose  $(P_1, P_2)$  is a disequilibrium price pair in that  $(P_1, P_2) \neq (\hat{P}_1(C), \hat{P}_2(C))$  for  $C = L, H$ . Let  $N(C)$  denote the number of deviations required to generate  $(P_1, P_2)$  if industry costs are of type  $C$ . Thus,  $N(C)$  takes value one (if  $P_i = \hat{P}_i(C)$  and  $P_j \neq \hat{P}_j(C)$ ) or value two (if  $P_i \neq \hat{P}_i(C)$ ,  $i = 1, 2$ ). With this, we say that beliefs are *unprejudiced* if

For any disequilibrium price pair  $(P_1, P_2)$ ,  $\hat{\rho}(P_1, P_2) = 1(0)$  if and only if

$$N(L) < N(H) \text{ (} N(L) > N(H)\text{)}. \quad (4)$$

A collection of strategies and beliefs then forms an *unprejudiced sequential equilibrium* if (1)–(4) are satisfied.

This restriction has two effects. First, a minimality rule is implied whereby the entrant is required to believe that industry costs are of the type that rationalizes the deviant price pair with the fewest deviations.<sup>7</sup> This rule is used above in associating the point  $D$  with high industry costs. Second, a further restriction is implied when the number of deviations required to rationalize a deviant price pair is the same for both cost types, i.e.,  $N(L) = N(H)$ . In this case, the entrant is required to exhibit open-mindedness, by not believing that either cost type is certain. This latter restriction is actually quite weak, allowing any  $\hat{\rho}(P_1, P_2) \in (0, 1)$ .

Like the sequential equilibrium concept itself, the notion of unprejudiced beliefs can be motivated in two ways. The most direct interpretation is that the entrant, upon seeing a deviant price pair, forms some alternative hypothesis about the strategies the incumbents are using. What we are adding is that the entrant uses a minimality rule and exhibits open-mindedness in ranking the alternative hypotheses. This seems a very plausible restriction, given that our noncooperative framework does not allow correlated deviations.

As Kreps and Wilson (1982) discuss, sequential equilibrium beliefs can also be interpreted as the limiting beliefs formed by “perturbing” the equilibrium strategies. Here, one thinks of “fully mixed” strategies that converge to the given equilibrium strategies. Since all prices are selected with positive probability along the sequence, Bayes’ rule may be applied. This generates a sequence of beliefs, and it is required that any final specification of beliefs can be obtained as the limit of some such sequence.<sup>8</sup> Now, for our game and most other signalling games, the two approaches to defining sequential equilibrium are equivalent; neither imposes structure on beliefs for prices off the equilibrium path. One might consider, however, adding the restriction that along the converging strategy sequence, all deviant prices are selected with a common order of probability. In effect, this forces the entrant to have “unprejudiced” beliefs in the perturbed game, believing that no one deviation is infinitely more or less likely than any other. As we argue elsewhere (Bagwell and Ramey, 1989), (4) is a consequence of this added restriction.<sup>9</sup>

<sup>7</sup> A rule with similar flavor is used by McLennan (1985). He holds that beliefs at any information set should place positive probability only on those nodes that can be reached with the fewest useless actions, where an action is useless if it is inferior in every sequential equilibrium. McLennan’s rule has little bite in our game, however, because a plethora of pooling sequential equilibria ensures that most (if not all) prices are useful for both incumbent cost types.

<sup>8</sup> The description provided here of “consistent beliefs” is exact when the set of possible prices is finite. As we show elsewhere (Bagwell and Ramey, 1989), a related notion of consistency can be defined for our game, where the number of prices is infinite. The key difficulty is that Bayes’ rule must be defined on small intervals of prices rather than individual prices (which are zero-probability events).

<sup>9</sup> It is intuitive that the minimality rule is implied. Two deviations are of the same order of likelihood as one deviation only if one of the former deviations is of higher order (infinitely more likely) than the latter deviation. This is not allowed under unprejudiced beliefs, and so one deviation is always associated with a higher order of likelihood than two deviations. Finally, since we are only requiring that deviations share a common order of probability, the converging sequence of strategies can be specified so that  $\hat{\rho}(P_1, P_2)$  takes any value in the open interval  $(0, 1)$  when  $N(L) = N(H)$ .

The discussion above indicates that the TSE associated with point *C* fail to be unprejudiced equilibria. In fact, an exactly related argument eliminates all TSE in which  $\hat{P}_i(H) \neq P_i^R(\hat{P}_j(H), H)$  for some *i*. This is because there always exists  $P_i \neq \hat{P}_i(L)$ , with  $P_i$  close (or equal) to  $P_i^R(\hat{P}_j(H), H)$ , to which the high-cost Incumbent *i* could deviate. It follows that the only possible unprejudiced TSE are NDE.

TSE other than NDE fall victim to what might be called informational free-riding. For example, when in Figure 2 the high-cost Incumbent 1 deviates to  $P_1 \neq \hat{P}_1(L)$ , it does so knowing that the entrant will nevertheless observe the equilibrium high-cost price,  $\hat{P}_2(H)$ , from the rival incumbent. In this sense, the high-cost Incumbent 1 can deviate and free-ride on the signalling of the rival Incumbent 2. In TSE, this sort of free-riding is sure to occur unless both incumbents' prices are best responses.

It remains to show that unprejudiced NDE exist. This is a simple matter to confirm, since the NDE class constructed in the previous section has unprejudiced beliefs. The point *A* in Figure 1 can be generated by one deviation (by Incumbent 1) under low costs, while two deviations are required if costs are high. The minimality rule therefore requires  $\hat{\rho}(P_1, P_2^*(L)) = 1$ . Similarly, the point *B* can be rationalized by one deviation under either cost state, and so open-mindedness allows  $\hat{\rho}(P_1^*(H), P_2^*(L))$  close to (but below) one.

We now summarize with

*Proposition 2.* The only TSE that are unprejudiced are NDE.

Thus, NDE are reasonable in the sense that they can be supported with unprejudiced beliefs. They are also therefore focal over the class of TSE, since no other TSE can be supported in this sense.

### 5. Equilibria with pooling and intuitive conjectures

■ In this section we consider equilibria in which there is pooling by one or both incumbents. We focus first on OSE, in which only one incumbent pools. Suppose we have a class of OSE in which  $\hat{P}_i(L) \neq \hat{P}_i(H)$  but  $\hat{P}_j(L) = \hat{P}_j(H)$ . In such equilibria the high-cost Incumbent *i* can no longer informationally free-ride on Incumbent *j*, since Incumbent *j*'s strategy no longer signals the cost level. Correspondingly, there may exist unprejudiced OSE. An example is given in Figure 3, in which  $\hat{P}_2(L) = \hat{P}_2(H)$ , but separation occurs because  $\hat{P}_1(L) \neq \hat{P}_1(H)$ . The high-cost Incumbent 2 could free-ride on separation by Incumbent 1, but since  $\hat{P}_2(H) = P_2^R(\hat{P}_1(H), H)$ , there is no need to deviate. The high-cost Incumbent 1 could increase preentry profits by deviating, but Incumbent 2's pricing does not ensure separation; observing  $(P_1, \hat{P}_2(H))$  can be rationalized by one deviation under either state, and thus unprejudiced beliefs can put sufficiently large weight on the possibility of low costs to support OSE. The key point here is that when Incumbent 2 is not separating, the probability of entry may be affected by a deviation in Incumbent 1's price.

The equilibrium of Figure 3 has a property that seems suspicious, however: Incumbent 1 chooses a lower price when it has higher costs. It seems more likely that a firm would wish to choose higher prices when it had higher costs. We can be sure that higher-cost firms differentially prefer higher prices if we make the following single-crossing assumption:

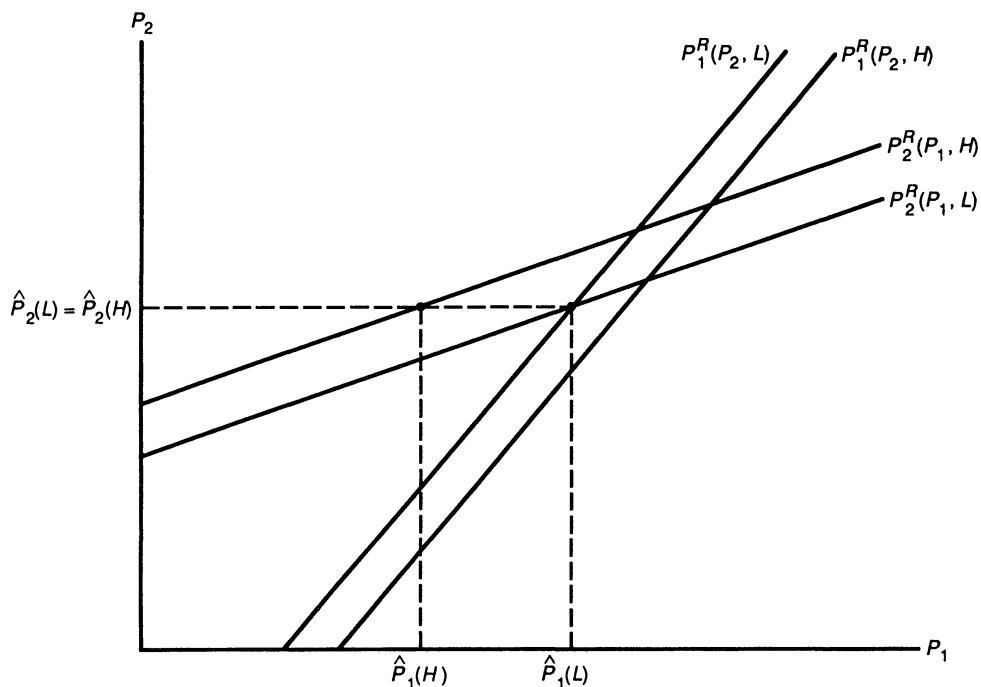
*Assumption 1.* For all  $P_i, P_j$ ,

$$-\frac{\frac{\partial}{\partial P_i} \Pi_i(P_i, P_j, H)}{\Pi_i^E(H) - \Pi_i^N(H)} > -\frac{\frac{\partial}{\partial P_i} \Pi_i(P_i, P_j, L)}{\Pi_i^E(L) - \Pi_i^N(L)}$$

This states that the marginal rate of substitution of price increases for reductions in the probability of entry is greater under higher costs.<sup>10</sup>

<sup>10</sup> See Cho (1987) and Ramey (1987) for more on the importance of the single-crossing property in the limit-pricing context.

FIGURE 3



The key implication of Assumption 1 is that if a low type prefers a higher price with its corresponding entry response to a lower price with its entry response, then a high type must strictly prefer the higher price. Then, under Assumption 1 the situation depicted in Figure 3 cannot satisfy (2), as the high-cost Incumbent 1 would deviate to  $\hat{P}_1(L)$ . Since all OSE must be of this form, it follows that all OSE are eliminated under Assumption 1.<sup>11</sup>

We now consider pooling equilibria, in which  $(\hat{P}_1(L), \hat{P}_2(L)) = (\hat{P}_1(H), \hat{P}_2(H))$ . In pooling equilibria the entrant learns nothing from observing the preentry price, and so the entrant's posterior belief in a pooling equilibrium is that costs are low with probability  $\rho$ . Requiring unprejudiced beliefs has no real force in pooling equilibria because neither incumbent can free-ride on separation by the other. (I.e.,  $N(L) = N(H) = 1$  when a single incumbent deviates from a pooling equilibrium.)

Consider the situation of a high-cost Incumbent  $i$  in a pooling equilibrium. Since low-cost firms differentially prefer lower prices, this incumbent might be able to find some price  $P_i > \hat{P}_i(L)$  that it would never choose if costs were low, even under the most favorable entry response. Surely a reasonable entrant would place little weight on the prospect that a low-cost Incumbent  $i$  would choose such a price. Choosing  $P_i$  would then allow the high-cost Incumbent  $i$  to separate without having to free-ride on Incumbent  $j$ .

This is the idea that underlies the intuitive criterion of Cho and Kreps (1987). For-

<sup>11</sup> Our results would change if NDE were not TSE. For example, if dissipative advertisements were the only signal available, then NDE have pooling at no advertising. TSE are then impossible when beliefs are unprejudiced, due to informational free-riding. Under a single-crossing property, OSE would exist, with the usual, large distortion from the advertising firm.

Matthews and Fertig (1989) analyze such a model, under the alternative assumptions that senders choose advertising levels sequentially and disagree about the preferred inference for the receiver to draw. They show OSE exist under unprejudiced beliefs in which an arbitrarily small distortion in the first signal is sufficient to separate because of the second sender's threat to "counteract" any false signalling with a large, disconfirming second signal, and in which the first sender pools at zero advertising and the second sender distorts in the usual fashion. These arguments only require the single-crossing property to hold for the second sender.

malizing this criterion in our setting will require a few new definitions. Let us first write the equilibrium probability of entry,  $X$ , as a function of the entrant's beliefs:

$$X(\hat{\rho}) = \int_0^{\hat{\rho}\Pi^E(L)+(1-\hat{\rho})\Pi^E(H)} f(K)dK.$$

Note that the probability of entry is increasing in  $\hat{\rho}$ . Next, a selection by Incumbent  $i$  of  $P_i$  when costs are type  $C$  is said to be *equilibrium admissible* if

$$\begin{aligned} \Pi_i(P_i, \hat{P}_j(C), C) + X(0)(\Pi_i^E(C) - \Pi_i^N(C)) \\ \geq \Pi_i(\hat{P}_i(C), \hat{P}_j(C), C) + X(\hat{\rho}(\hat{P}_i(C), \hat{P}_j(C)))(\Pi_i^E(C) - \Pi_i^N(C)). \end{aligned}$$

That is, by choosing  $P_i$  when costs are type  $C$ , Incumbent  $i$  could improve on its equilibrium payoff, or at least do no worse, if the entry response were sufficiently low. Any deviations that are not equilibrium admissible are called *equilibrium dominated*.

Under the usual application of the intuitive criterion, equilibrium-dominated strategies are eliminated from the game, which forces the entrant to consider only the possibility of equilibrium-admissible selections. Of course, such extreme inferences may violate open-mindedness as well as the minimality rule. We provide here a modified intuitive criterion, designed to strengthen the open-mindedness condition without giving rise to prejudiced beliefs. In particular, when the minimality rule is inapplicable (i.e., when  $N(L) = N(H)$ ), we shall assume that the entrant attaches a much (but not infinitely) greater likelihood to equilibrium-admissible than equilibrium-dominated deviations.<sup>12</sup>

This motivates the following definition. For given  $\epsilon \in (0, 1)$ , beliefs are said to be  $\epsilon$ -*intuitive* if

Consider any disequilibrium price pair  $(P_1, P_2)$  for which  $N(L) = N(H)$ , and suppose that  $P_i$  is equilibrium dominated for Incumbent  $i$  if and only if costs are low (high) and that  $P_j$  is equilibrium admissible for Incumbent  $j$  when costs are high (low). Then

$$\hat{\rho}(P_1, P_2) < \epsilon(\hat{\rho}(P_1, P_2) > 1 - \epsilon). \quad (5)$$

Under this definition, when  $N(L) = N(H)$ , the entrant places small weight on a cost type when a price is equilibrium dominated for one incumbent of that type, and the respective prices are equilibrium admissible for both incumbents of the other type. A set of strategies and beliefs forms an  $\epsilon$ -*intuitive sequential equilibrium* if (1)–(3) and (5) hold.<sup>13</sup>

Applying the  $\epsilon$ -intuitive criterion requires further strengthening of our assumptions. First, it must be the case that pooling equilibria do not involve prices that are very close to  $\hat{P}_i$ , or else there would be too little scope for upward price deviations. To rule out this possibility we assume

<sup>12</sup> For a more rigorous discussion of these issues, see Bagwell and Ramey (1989).

<sup>13</sup> We may use the  $\epsilon$ -intuitive criterion to eliminate OSE under assumptions somewhat weaker than Assumption 1. Assume first that whenever  $P'_i > P_i$ , we have

$$\Pi_i(P'_i, P_j, L) - \Pi_i(P_i, P_j, L) < \Pi_i(P'_i, P_j, H) - \Pi_i(P_i, P_j, H),$$

and second, for all  $P_i, P_j$  with  $P_i < \hat{P}_i$ , there exists  $P'_i > P_i$  such that

$$\Pi_i(P'_i, P_j, L) < \Pi_i(P_i, P_j, L).$$

Now, the separating firm in OSE can find  $P'_i > \hat{P}_i(H)$  such that the low type prefers  $\hat{P}_i(H)$  with minimum entry to  $P'_i$  with minimum entry, whereas the high type has the opposite preferences. But the equilibrium conditions then imply that  $P'_i$  is equilibrium dominated for the low-cost Incumbent  $i$ , so in an  $\epsilon$ -intuitive equilibrium, the high-cost Incumbent  $i$  will deviate to  $P'_i$  if  $\epsilon$  is sufficiently small. Mark O'Donnell has suggested to us a second possibility: If the incumbent's preentry profits are strictly concave in own price and the separating low type strictly prefers  $P'_i(L)$  to  $\hat{P}_i(H)$ , then  $\hat{P}_i(H) + \delta$  will be equilibrium dominated when costs are low and equilibrium admissible when costs are high, for  $\delta$  sufficiently small.

*Assumption 2.* For all  $P_j$ ,

$$\begin{aligned} \Pi_i(\bar{P}_i, P_j, L) + X(\rho)(\Pi_i^E(L) - \Pi_i^N(L)) \\ < \Pi_i(P_i^R(P_j, L), P_j, L) + X(1)(\Pi_i^E(L) - \Pi_i^N(L)). \end{aligned}$$

Under Assumption 2, we must have  $P_i^P < \bar{P}_i$  in a pooling equilibrium, since otherwise Incumbent  $i$  when costs are low would deviate to  $P_i^R(P_j, L)$ .

Further, invoking the  $\epsilon$ -intuitive criterion requires that there exist some price that is equilibrium dominated for a low-cost incumbent. To assure this, we assume

*Assumption 3.* For all  $P_j$ , if  $P_i$  satisfies  $P_i < \bar{P}_i$  and

$$\begin{aligned} \Pi_i(P_i, P_j, L) + X(\rho)(\Pi_i^E(L) - \Pi_i^N(L)) \\ \geq \Pi_i(P_i^R(P_j, L), P_j, L) + X(1)(\Pi_i^E(L) - \Pi_i^N(L)), \end{aligned}$$

then there exists  $P_i' > P_i$  such that

$$\Pi_i(P_i', P_j, L) + X(0)(\Pi_i^E(L) - \Pi_i^N(L)) < \Pi_i(P_i, P_j, L) + X(\rho)(\Pi_i^E(L) - \Pi_i^N(L)).$$

In other words, for any price  $P_i$  that a low-cost Incumbent  $i$  might choose in a pooling equilibrium, there is some  $P_i' > P_i$  that is equilibrium dominated for that incumbent. It is easy to verify that Assumptions 2 and 3 will hold if the value of entry deterrence to a low-cost Incumbent  $i$ ,  $\Pi_i^N(L) - \Pi_i^E(L)$ , is sufficiently small.

We now have

*Proposition 3.* Under Assumptions 1, 2, and 3, the only equilibria that are unprejudiced and  $\epsilon$ -intuitive for every  $\epsilon \in (0, 1)$  are NDE.

The proof of this proposition requires two steps. The first step is to prove that NDE are the only possible equilibria that are unprejudiced and  $\epsilon$ -intuitive. It is here that the assumptions of the proposition are needed. From Proposition 2, it is not necessary to consider TSE. Also, as argued above, OSE are inconsistent with Assumption 1. Consider then a pooling equilibrium in which  $(\hat{P}_1(L), \hat{P}_2(L)) = (\hat{P}_1(H), \hat{P}_2(H)) \equiv (P_1^P, P_2^P)$ . For simplicity, let us focus on the pricing of Incumbent 1. Using Assumptions 2 and 3, we can find  $P_1' > P_1^P$  that satisfies

$$\Pi_1(P_1', P_2^P, L) + X(0)(\Pi_1^E(L) - \Pi_1^N(L)) < \Pi_1(P_1^P, P_2^P, L) + X(\rho)(\Pi_1^E(L) - \Pi_1^N(L)).$$

Moreover, by Assumption 1, we can choose  $P_1'$  so that it also satisfies

$$\begin{aligned} \Pi_1(P_1', P_2^P, H) + X(0)(\Pi_1^E(H) - \Pi_1^N(H)) \\ > \Pi_1(P_1^P, P_2^P, H) + X(\rho)(\Pi_1^E(H) - \Pi_1^N(H)). \end{aligned}$$

Recalling that  $\hat{\rho}(P_1^P, P_2^P) = \rho$  in a pooling equilibrium, we see that  $P_1'$  is equilibrium dominated for Incumbent 1 when costs are low, but  $P_1'$  is equilibrium admissible for this incumbent when costs are high. Of course,  $P_2^P$  is equilibrium admissible for Incumbent 2 under either state. Thus, if beliefs satisfy (5), then  $\hat{\rho}(P_1', P_2^P) < \epsilon$ . In particular,  $\hat{\rho}(P_1', P_2^P)$  can be made arbitrarily small by picking  $\epsilon$  small. For  $\epsilon$  sufficiently small, the second inequality above guarantees a deviation to  $P_1'$  by the high-cost Incumbent 1, destroying the equilibrium. It follows that no pooling equilibrium is  $\epsilon$ -intuitive for all  $\epsilon \in (0, 1)$ , which completes the first step.

Thus, under the assumptions of the proposition, equilibria other than NDE are not focal, since they fail to be unprejudiced and  $\epsilon$ -intuitive. The assumptions provide conditions under which pooling equilibria fail to be  $\epsilon$ -intuitive. Under Assumption 1, high-cost incumbents differentially prefer price increases that lead to entry reductions. The role of Assumptions 2 and 3 is to ensure that there is some price increase that would not be contemplated

under low costs. Together, these conditions enable the high-cost incumbents to benefit from entry-reducing price increases when beliefs are  $\epsilon$ -intuitive, thereby destroying pooling equilibria.

The second step of the proof is to show that unprejudiced NDE exist that are  $\epsilon$ -intuitive. The argument is simple and may be understood with reference to Figure 1. Observe that every  $P_2 \neq P_2^*(H)$  is equilibrium dominated for the high-cost Incumbent 2;  $P_2^*(H)$  both maximizes preentry profit against  $P_1^*(H)$  and minimizes the probability of entry. It follows that  $P_2^*(L)$  is equilibrium dominated for Incumbent 2 if and only if costs are high. Hence, for fixed  $\epsilon \in (0, 1)$ , a belief specification with  $\hat{\rho}(P_1, P_2^*(L)) > 1 - \epsilon$  for all  $P_1 \neq P_1^*(L)$  satisfies (5). In particular, the beliefs described in Section 3, where  $\hat{\rho}(P_1, P_2^*(L)) = 1$  for  $P_1 \neq P_1^*(H)$  (corresponding to point *A*) and

$$\hat{\rho}(P_1^*(H), P_2^*(L)) = 1 - \epsilon/N$$

for  $N$  very large (corresponding to point *B*), satisfy (5).

Unprejudiced NDE that are  $\epsilon$ -intuitive therefore exist. This captures the simple economic point that the high-cost incumbents have no incentive to deviate whatsoever, and so beliefs that associate points like *A* and *B* with a probable low-cost industry are extremely plausible. Since NDE are supported by such beliefs, these equilibria are reasonable. Furthermore, NDE are extremely focal under the assumptions of the proposition, since no other equilibria are then unprejudiced and  $\epsilon$ -intuitive.

The key condition that makes it possible to eliminate pooling equilibria is that the value of entry deterrence for a low-cost incumbent be sufficiently small, for this allows us to find price increases that could never benefit the low-cost incumbent. In fact, if the value of entry deterrence is even smaller, then pooling equilibria will not exist at all, since we can pin the possible equilibrium prices of each type arbitrarily close to their reaction functions. Conversely, when the value of entry deterrence is very large, then not only will pooling equilibria exist for a large range of prices (sustained by severe entry punishments), but it will be impossible to eliminate these equilibria using the  $\epsilon$ -intuitive criterion, owing to nonexistence of price increases that are equilibrium dominated.<sup>14</sup> In the next section we argue that the most robust prospects for  $\epsilon$ -intuitive pooling equilibria involve low prices.

## 6. Example

■ In this section we analyze the plausibility of our added assumptions by means of a simple differentiated-product oligopoly model proposed by Shubik and Levitan (1980). The example demonstrates that when the assumptions break down, the distortions associated with pooling equilibria will tend to involve price *reductions* by the incumbent firms.

Suppose there is a representative consumer, who in a given period  $t$  maximizes the expression

$$U_t = \frac{\alpha_t \sum_{i=1}^n q_i}{\beta} - \frac{(\sum_{i=1}^n q_i)^2}{2\beta} - \frac{\sum_{i=1}^n \sum_{j=1}^n (q_i - q_j)^2}{4\beta(1 + \gamma)} - \sum_{i=1}^n P_i q_i,$$

where  $n$  is the number of firms,  $P_i$  is Firm  $i$ 's price,  $q_i$  gives the number of units of Firm  $i$ 's product purchased by the consumer in the period, and  $\alpha_t, \beta, \gamma$  are positive parameters. profits for each firm are given by

$$\Pi_i = (P_i - C)q_i.$$

<sup>14</sup> The relationship between the informativeness of equilibria and the value of entry deterrence is discussed in Ramey (1987), where it is shown that all equilibria become arbitrarily close to fully informative when the value of entry deterrence becomes small, while only pooling equilibria exist when the value is large.

For our purposes, there are two periods to consider. In period one we have  $n = 2$  and  $\alpha_i = \alpha_1$ . Here, Firm  $i$  corresponds to Incumbent  $i$ , where  $i = 1, 2$ . For period two,  $\alpha_i = \alpha_2 > \alpha_1$ , with the growth in demand leading to the prospect of entry by a third firm. The value of  $n$  in period two is either two or three, depending on the entry decision. If entry does occur, then we may understand Firm 3 to be the entrant. The parameters  $\beta$ ,  $\gamma$ , and  $C$  are constant across the two periods.  $C$  may assume the values  $L, H$ , with

$$0 < L < H < \frac{\alpha_1}{\beta}.$$

Finally,  $\bar{P}_i = \alpha_1/\beta$ , i.e., the upper bound of possible prices is taken to be the lowest price at which Firm  $i$  is guaranteed to sell no units, no matter what prices are chosen by rival firms. It is easy to check that the assumptions of Section 2 are satisfied by this example.

Let us consider Assumption 1. For Incumbent  $i$ , given  $P_j$ , the lowest price at which period-one sales are zero, i.e., the period-one “choke price,” is

$$P_i^C(P_j) = \frac{[\alpha_1/\beta + \gamma P_j/2]}{1 + \gamma/2}.$$

Because in this example the profit functions are strictly concave in own price, Assumption 1 clearly holds for  $P_i^R(P_j, L) \leq P_i \leq P_i^R(P_j, H)$ . For  $P_i^R(P_j, H) < P_i < P_i^C(P_j)$ , the assumption is equivalent to

$$\frac{\alpha_1/\beta - 2(1 + \gamma/2)P_i + \gamma P_j/2 + (1 + \gamma/2)H}{\alpha_1/\beta - 2(1 + \gamma/2)P_i + \gamma P_j/2 + (1 + \gamma/2)L} < \left( \frac{\alpha_2 - \beta H}{\alpha_2 - \beta L} \right)^2.$$

The right-hand side of the above expression is less than one, reflecting the fact that reducing the probability of entry is differentially beneficial to the low-cost incumbents. At  $P_i = P_i^R(P_j, H)$  the left-hand side is zero, but it increases as  $P_i$  rises. It is possible that the expression fails to hold for large  $P_i$ . Similarly, Assumption 1 may fail for small  $P_i < P_i^R(P_j, L)$ . The assumption cannot hold when  $P_i \geq P_i^C(P_j)$ .

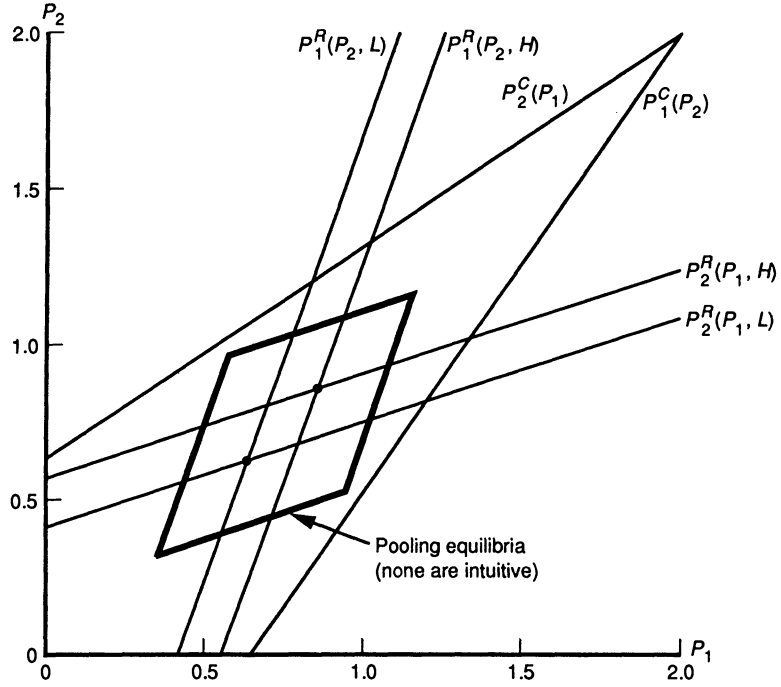
As discussed above, the existence of pooling equilibria which are  $\epsilon$ -intuitive for every  $\epsilon \in (0, 1)$  hinges on the comparison between preentry and postentry profits. If the former are relatively important, pooling equilibria will lie close to the incumbents’ reaction functions, and small price increases will be equilibrium dominated for the low-cost incumbent; Assumption 1 can then be invoked to find price increases that overturn the equilibria. If the latter are relatively important, then the low-cost incumbent might be willing to accept any price increase in order to reduce the probability of entry from  $X(\rho)$  to  $X(0)$ ; that is, all price increases might be equilibrium admissible for the low-cost incumbent. Alternatively, price increases that are large enough to be equilibrium dominated under low costs will be equilibrium dominated under high costs, owing to failure of Assumption 1.

Whether preentry or postentry profits are more important depends on the amount by which demand grows between the two periods, which in this setting is determined exogenously. But the comparison also depends endogenously on the preentry pricing policies of the incumbent firms. Choosing low prices serves to reduce the preentry profits, and pooling equilibria may therefore be intuitive precisely because pooling occurs at very low prices.

These points are illustrated in the parameterized examples in Figures 4–6.<sup>15</sup> In the examples, the densities  $f(K)$  are chosen to generate large gains from entry deterrence. As  $\alpha_2$  rises, the range of intuitive pooling equilibria rises; for sufficiently large  $\alpha_2$  all price pairs give intuitive pooling equilibria. Short of the latter case, intuitive pooling equilibria are

<sup>15</sup> The shape of the set of pooling equilibria is easily understood. For each incumbent and cost type, one can imagine a band about  $P_i^R(P_j, C)$  capturing the prices at which this incumbent would be willing to pool. The intersection of all such bands then gives the set of pooling equilibria, which has a diamond shape as shown in Figure 4. The diamond is distorted partially in Figures 5 and 6, because under these parameterizations the band about the high-cost Incumbent  $i$ ’s reaction curve hits the choke price, meaning that this incumbent will pool at the choke price and hence any higher price.

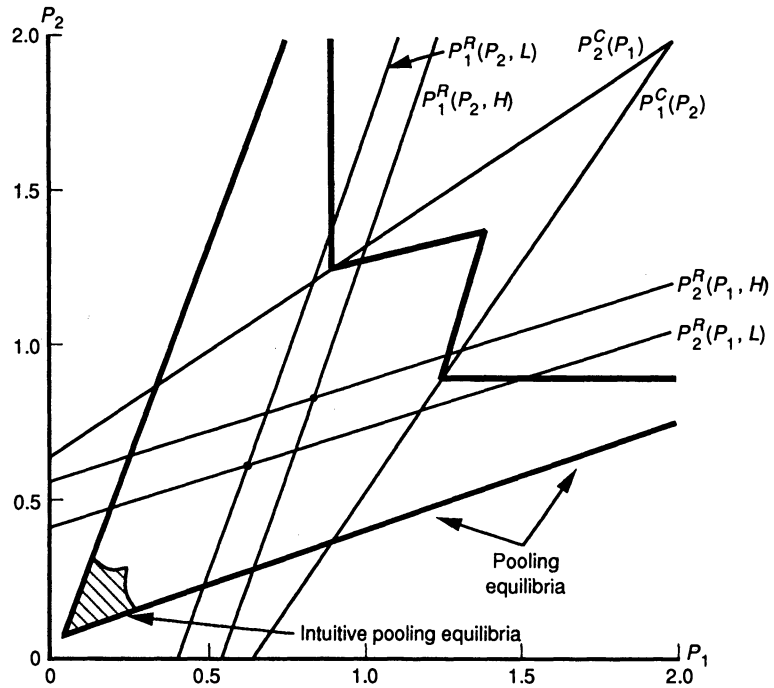
FIGURE 4



Parameterization:  
 $\alpha_1 = 10, \alpha_2 = 20, \beta = 5, \gamma = 5$   
 $H = 0.5, L = 0.2, \rho = 0.5$

$$f(K) = \begin{cases} 0.15, & 0 \leq K \leq 3.4 \\ 2.15, & 3.4 < K < 3.6 \\ 0.15, & 3.6 \leq K \leq 4 \end{cases}$$

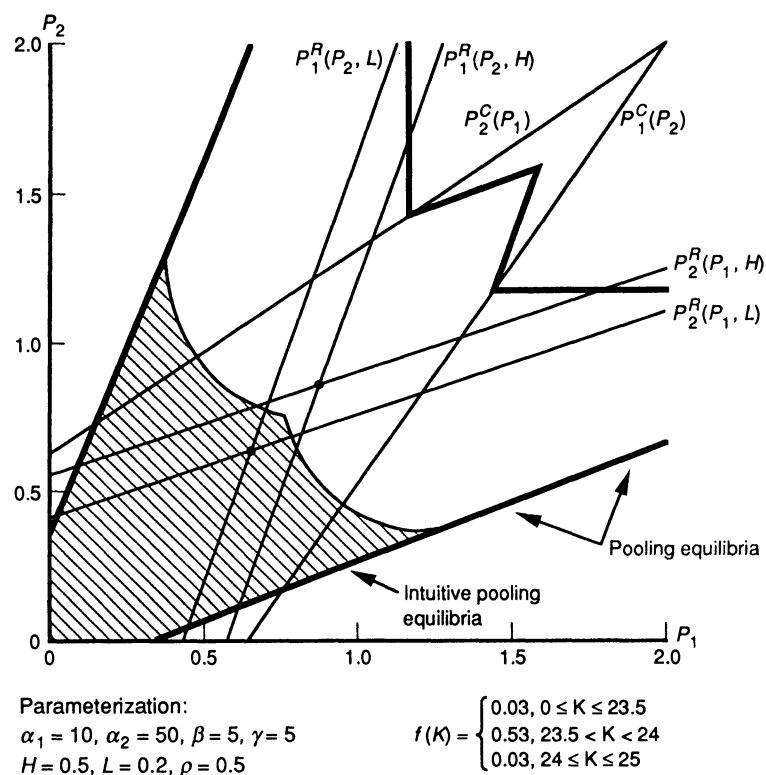
FIGURE 5



Parameterization:  
 $\alpha_1 = 10, \alpha_2 = 30, \beta = 5, \gamma = 5$   
 $H = 0.5, L = 0.2, \rho = 0.5$

$$f(K) = \begin{cases} 0.07, & 0 \leq K \leq 8.2 \\ 1.3033, & 8.2 < K < 8.5 \\ 0.07, & 8.5 \leq K \leq 9 \end{cases}$$

FIGURE 6



associated with low prices, as illustrated in the examples. The key factor is that when one incumbent chooses a low price, the variability of the other incumbent's preentry profits is reduced: any price increase by the latter causes only a small change in preentry profits relative to the large possible change in postentry profits. There is then no price increase that decreases preentry profits sufficiently to be equilibrium dominated for the low-cost incumbent. This gives a limit pricing theory for growing markets, in which pooling behavior leads to price reductions, and equilibria are intuitive due to the rent dissipation associated with low prices.

## 7. Extensions

■ The model developed above is quite stylized. This section briefly considers some possible extensions.

A first observation is that our analysis extends directly to the possibility of an  $N$ -firm oligopoly. Our arguments are in fact even more persuasive for large  $N$ , since the coordination of deception is then more difficult and the temptation to free-ride more acute.

The model may also be extended to examine the strategic costs associated with collusive behavior. The essential point is that if the incumbents are able to collude (coordinate price deviations), then prices must be distorted in a separating equilibrium when costs are high. An oligopoly thus faces a tradeoff: noncooperative but undistorted prices are possible without coordination, while collusive but distorted prices are available with coordination. Similarly, if we think of a parent firm controlling Incumbents 1 and 2, the delegation of price control to the respective branch incumbents may provoke noncooperative pricing but does avoid pricing distortions.

Interesting possibilities emerge when the model is amended to allow that the incumbents interact in a Leader-Follower setting, where Incumbent 2 selects its price after observing

Incumbent 1's price. Since incumbents share a purpose in deterring entry, there is scope for coordination in this framework. If high-cost prices are not distorted, the low-cost Incumbent 1 can instigate deception by mimicking its high-cost price. Seeing this, the low-cost Incumbent 2 will do the same and thereby fool the entrant, reducing the probability of entry. Some distortion in incumbent pricing is thus necessary; future work might investigate whether the Leader or Follower bears the burden.<sup>16</sup>

Finally, it is important to examine alternative technology and informational assumptions. Let us now follow Milgrom and Roberts, supposing that firms' costs are independently determined to be, say, low or high, and that existing firms know one another's cost levels. The entrant then allows that both incumbents may have low or high costs, or that the incumbents' costs may differ. Entry is more attractive the more incumbents that are believed to have high costs. While these assumptions alter our model significantly, it is in fact straightforward to show that there again exist NDE in which each incumbent ignores the entry threat.<sup>17</sup> We conclude that the key assumption is that incumbents know one another's costs.<sup>18</sup>

Pricing distortions clearly will reappear if each incumbent has a (persistent) idiosyncratic cost component whose value is unknown to the rival incumbent. Useful future work might search for a general relation between the degree of idiosyncratic information and the size of the pricing distortion. One difficulty we foresee is that an incumbent will desire to signal high industry-specific costs but low incumbent-specific costs. The latter cannot be accomplished under the single-crossing condition employed above.

## 8. Conclusion

■ We have examined the extension of the information-based approach to limit pricing to the important possibility of multiple, uncoordinated incumbents. Assuming that the incumbents share private information, we find that the inability of incumbents to coordinate deception results in separating equilibria in which no distortion occurs. Moreover, the incentive that incumbents have to free-ride on the signalling of others precludes the existence of other signalling equilibria in which both incumbents separate. Plausible pooling equilibria fail to exist or involve downward price distortions. In general, the lack of coordination among incumbents results in a very focal equilibrium in which incumbents simply ignore the threat of entry and choose their complete-information, Nash prices.

The assumption that incumbents have common, private information seems quite plausible. One can imagine that an entrant is often interested in rather coarse information, such as whether input prices will profitably support entry or not, and incumbents will generally agree about this information. For such settings, the informational theory of limit pricing is correct in predicting that entry will occur exactly when it is profitable, but incorrect in associating this process with distortions in preentry pricing.

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<sup>16</sup> We thank Greg Shaffer for suggesting the Leader-Follower extension. Matthews and Fertig (1989) also consider a sequential signalling model, but in their model the senders have opposite preferences about the desired inference (see also note 11). There, if a large distortion is undertaken, it is done by the Follower. The small distortions that they discuss do not separate when preferences are congruent.

<sup>17</sup> To see this, consider Figure 1. The reaction curves intersect at four points, and each of these points corresponds to an undistorted price equilibrium for one possible configuration of incumbents' costs. Generically, no one of these points lies directly below or directly to the right of any other. Thus, no unilateral deviation will enable an incumbent to mimic the pricing that would occur in some alternative cost state.

<sup>18</sup> By contrast, as Harrington (1986) discusses, single-incumbent models are sensitive to the degree of cost correlation. Similar reasoning indicates that NDE are not sensitive to whether incumbents choose observable prices or quantities or have common private information about costs or demand.

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