Chapter 10

STRATEGIC MODELS OF ENTRY DETERRENCE

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Contents

1. Introduction 306
2. Preemption 307
3. Signaling 313
   3.1. Attrition 313
   3.2. Limit pricing 315
4. Predation 318
5. Concluding remarks 323
Bibliography 324

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1. Introduction

In the 1980s the literature of economics and law concerning industry structure bloomed with articles on strategic aspects of entry deterrence and competition for market shares. These articles criticized and amended theories that incompletely or inconsistently accounted for strategic behavior. The aftermath is that game-theoretic models and methods are standard tools of the subject – although not always to the satisfaction of those concerned with empirical and policy issues; cf. Fisher (1989) for a critique and Shapiro (1989) for a rebuttal.

This chapter reviews briefly the popular formulations of the era and some interesting results, but without substantive discussion of economic and legal issues. The standard examination of the issues is Scherer (1980) and game-theoretic texts are Tirole (1988) and Fudenberg and Tirole (1991); see also Salop (1981). Issue-oriented expositions are the chapters by Gilbert (1989a) and Ordover and Saloner (1989) in *The Handbook of Industrial Organization*. Others emphasizing game-theoretic aspects are Wilson (1985, 1989a, 1989b), Fudenberg and Tirole (1986c), Milgrom (1987), Milgrom and Roberts (1987, 1990), Roberts (1987), Gilbert (1989b) and Fudenberg (1990). The combined length of these surveys matches the original articles, so this chapter collects many models into a few categories and focuses on the insights offered by game-theoretic approaches.

The motives for these studies are the presumptions, first, that for an incumbent (unregulated) firm one path to profits is to acquire or maintain monopoly power, which requires exclusion of entrants and expulsion, absorption, intimidation, or cartelization of competitors; and second, that monopoly power has adverse effects on efficiency and distribution, possibly justifying government intervention via antitrust and other legal measures. We examine here only the possibilities to exclude or expel entrants.

A single issue motivates most game-theoretic studies: when could an incumbent profitably deter entry or survival in a market via a strategy that is credible – in the sense that it is part of an equilibrium satisfying selection criteria that exclude incredible threats of dire consequences? This issue arises because non-equilibrium theories often presume implicitly that deterrence is easy or impossible. To address the matter of credibility, all studies assume some form of perfection as the equilibrium selection criterion: subgame perfection, sequential equilibrium, etc. in increasing selectivity. The models fall into three categories.

- *Preemption*. These models explain how a firm claims and preserves a monopoly position. The incumbent obtains a dominant position by arriving first in a natural monopoly; or more generally, by early investments in research and

product design, or durable equipment and other cost reduction. The hallmark is commitment, in the form of (usually costly) actions that irreversibly strengthen the incumbent's options to exclude competitors.

- *Signaling*. These models explain how an incumbent firm reliably conveys information that discourages unprofitable entry or survival of competitors. They indicate that an incumbent's behavior can be affected by private information about costs or demand either prior to entry (limit pricing) or afterwards (attrition). The hallmark is credible communication, in the form of others' inferences from observations of costly actions.
- *Predation*. These models explain how an incumbent firm profits from battling a current entrant to deter subsequent potential entrants. In these models, a "predatory" price war advertises that later entrants might also meet aggressive responses; its cost is an investment whose payoff is intimidation of subsequent entrants. The hallmark is reputation: the incumbent battles to maintain other's perception of its readiness to fight entry.

Most models of preemption do not involve private information; they focus exclusively on means of commitment. Signaling and predation models usually require private information, but the effects are opposite. Signaling models typically produce "separating" equilibria in which observations of the incumbent's actions allow immediate inferences by entrants; in contrast, predation models produce "pooling" equilibria (or separating equilibria that unravel slowly) in which inferences by entrants are prevented or delayed.[1]

These three categories are described in the following sections. We avoid mathematical exposition of the preemption models but specify some signaling and predation models. As mentioned, all models assume some form of perfection.

2. Preemption

A standard example of preemption studied by Eaton and Lipsey (1977), Schmalansee (1978) and Bonanno (1987), is an incumbent's strategy of offering a large product line positioned to leave no profitable niche for an entrant. A critique by Judd (1985) observes, however, that if the incumbent can withdraw products cheaply, then an entrant is motivated to introduce a product by anticipating the incumbent's incentive to withdraw close substitutes in order to avoid depressed prices for its other products.

[1]The distinction between signaling models and those predation models based on reputational effects is admittedly tenuous, as for example in the cases that a signaling model has a pooling equilibrium or an attrition model unravels slowly.

A second example invokes switching costs incurred by customers, which if large might deter entry. Klemperer (1987a, 1987b) uses a two-period model, and in Klemperer (1989) a four-period model, to study price wars to capture customers: monopoly power over customers provides later profits that can be substantially dissipated in the initial competition to acquire them – possibly with the motive of excluding opportunities for a later entrant. Farrell and Shapiro (1988) consider an infinite-horizon example with overlapping generations of myopic customers who live two periods; two firms alternate roles in naming prices sequentially. The net result is that the firms rotate: each captures periodically all the customers and then profits from them in the interim until they expire and it re-enters the market to capture another cohort. However, these conclusions are altered substantially by Beggs and Klemperer (1992) in an infinite-horizon model with continual arrival of new (non-myopic) customers having diverse tastes, continual attrition of old customers, and two firms with differentiated products. For a class of Markovian strategies, price wars occur initially when both firms have few captive customers, but when the population is stationary (as in an established market) the competitive process converges monotonically over time to a stationary configuration of prices and market shares. In particular, an incumbent's monopoly can be invaded by an entrant who eventually achieves a large share. This model casts doubt on interpreting switching costs as barriers to entry in stable markets: switching costs induce an incumbent to price high to exploit its captive market, enabling an entrant to capture new arrivals at lower but still profitable prices.

This is an instance of the general effect that [in the colorful terminology of Fudenberg and Tirole (1986c)] a "fat cat" incumbent with a large stock of "goodwill" with customers (due to switching costs or perhaps advertising) prefers to exploit its existing stock rather than countering an entrant. The incumbent may choose its prior investment in goodwill to take this effect into account, either investing in goodwill and conceding entry, or not investing and deterring entry.

Farrell and Saloner (1986) illustrate that switching costs can have appreciable effects in situations with growing demand affected by network externalities; that is, each customer's valuation of a product grows with the number of others adopting the product. In this case an incumbent can profit from aggressive pricing to prevent entry, because the losses are recouped later as profits from more numerous captive customers, especially if the prevention of entry encourages standardization on the incumbent's product and thereby lessens subsequent risks of entry.

On the supply side, Bernheim (1984) studies a model in which incumbents expend resources (e.g., advertising) to raise an entrant's sunk costs of entry; cf. Salop and Scheffman (1983, 1987) and Krattenmaker and Salop (1986, 1987) for an elaboration of the basic concept of "raising rivals' costs" as a competi-

strategy in other contexts than entry deterrence.[2] From each initial configuration, entry proceeds to the next larger equilibrium number of firms. He notes that official measures designed to facilitate entry can have ambiguous effects because intermediate entrants may be deterred by prospects of numerous arrivals later. Waldman (1987) re-analyzes this model allowing for uncertainty about the magnitude of the sunk cost incurred by entrants; in this case, entry deterrence is muted by each incumbent's incentive to "free ride" on others' entry-deterring actions. This result is not general: he shows also that an analogous variant of a model in Gilbert and Vives (1986) retains the opposite property that there is no free-rider effect.

Another example, studied by Ordover, Saloner and Salop (1990), refers to "vertical foreclosure". In the simplest case, one of two competing firms integrates vertically with one of two suppliers of inputs, enabling the remaining supplier to raise prices to the integrated firm's downstream competitor, thereby imposing a disadvantage in the market for final products. The authors examine a four-stage game, including an initial stage at which the two downstream firms bid to acquire one upstream supplier, and a later opportunity for the losing bidder to acquire the other supplier. Particular assumptions are used but the main conclusion is that foreclosure occurs if the residual supplier's gain exceeds the loss suffered by the unintegrated downstream firm. This circumstance precludes a successful offer from the latter to merge and thereby counter its competitor's vertical integration. Strategic complements [Bulow, Geanakoplos and Klemperer (1985a)], in the form of Bertrand price competition at both levels, implies this condition and therefore also implies that foreclosure occurs; but it is false in the case of strategic substitutes. As usually modeled, Cournot quantity competition implies strategic substitutes, but foreclosure can still occur in a duopoly. The particular forms of pricing and contracting (including commitment to exclusive dealing by the integrated firm) assumed in this model are relaxed in the more elaborate analysis by Hart and Tirole (1990) allowing arbitrary contractual arrangements.

Vertical integration is a particular instance of long-term contracting between a seller and a buyer, which has been studied by Aghion and Bolton (1987) and Rasmusen, Ramseyer and Wiley (1991) in the context of entry deterrence. They observe that an incumbent seller and buyer can use an exclusive-dealing contract to exercise their joint monopoly power over an entrant: penalties payable by the buyer to the seller if the buyer deals with the entrant are in effect an entry fee that extracts the profit the entrant might otherwise obtain.

[2]Entry costs are sunk if they cannot be recovered by exit; e.g., investments in equipment are not sunk if there is a resale market, but they are sunk to the degree the equipment's usefulness is specific to the firm or the product. Coate and Kleit (1990) argue from an analysis of two cases that the requirements of the theory of "raising rivals' costs" are rarely met in practice. See also Kleit and Coate (1991).

In particular, contractually created entry fees can prevent or delay (until expiration of the contract) entry by firms more efficient than the incumbent seller.

In a natural monopoly the first firm to install ample (durable) capacity obtains incumbency and deters entrants on a similar scale, provided all economies of scale are captured. Several critiques and extensions of this view have been developed. Learning effects (i.e., production costs decline as cumulative output increases) can engender a race among initial rivals. An incumbent can benefit from raising its own opportunity cost of exit: the standard example is a railroad whose immovable durable tracks ensure that it would remain a formidable competitor against truck, barge, or air carriers whose capacity can be moved to other routes. Eaton and Lipsey (1980) note that if capacity has a finite lifetime, then the incumbent must renew it prematurely to avoid preemptive investment by an entrant that would eliminate the incumbent's incentive to continue.

Gelman and Salop (1983) observe that entry on a small scale can still be profitable: there exists a scale and price small enough that the incumbent prefers to sell the residual demand at the monopoly price rather than match the entrant's price. They observe further that the entrant can extort the incumbent's profit by selling discount coupons that the incumbent has an incentive to honor if the discounted price exceeds its marginal cost. In the United States, the airlines' coupon war of the early 1980s is an evident example.

Even in an oligopoly, incumbent firms have incentives to install more capacity (or alter the positioning of their product designs) when entry is possible; cf. Spence (1977, 1979), Dixit (1979, 1980), Eaton and Lipsey (1981), Ware (1984) and, for models with sequential entry, Prescott and Visscher (1977)[3], and Eaton and Ware (1987). Profitable entry is prevented by capacities (and product designs) that prevent an additional firm from recovering its sunk costs of entry and fixed costs of operation. Conceivably, extra unused capacity might be held in reserve for price wars against entrants, and indeed Bulow, Geanakoplos and Klemperer (1985b) provide an example in the case of strategic complements. However, in the case of strategic substitutes (the usual case when considering capacities as strategic variables) capacity is fully used for production, as demonstrated in the model of Eaton and Ware (1987). The Stackleberg model of Basu and Singh (1990), however, allows a role for an incumbent to use inventories strategically.

The thrust of these models is to develop the proposition [e.g., Spence (1979) and Dixit (1980)] that incumbency provides an inherent advantage to move first to commit to irreversible investments in durable capacity that restrict the

[3]An additional feature is added by Spence (1984): investments in capacity are fully appropriable by the firm but other cost-reducing investments in process and product design are not fully appropriable; moreover, if these spillover effects strengthen competitors, then each firm's incentive to make such investments is inhibited.

opportunities available to entrants. Ware (1984), and Arvan (1986) for models with incomplete information, show that this advantage is preserved even when the entrant has a subsequent opportunity to make a comparable commitment. Bagwell and Ramey (1990) examine this proposition in more detail in a model in which the incumbent has the option to avoid its fixed cost by shutting down when sharing the market is unprofitable; also see Maskin and Tirole (1988). They observe that the entrant can install capacity large enough to induce exit by the incumbent; indeed, to avoid this the incumbent restricts its capacity to curtail its fixed cost and thereby to sustain its profitability in a shared market. This argument invokes the logic of forward induction: in a subgame-perfect equilibrium that survives elimination of weakly dominated strategies, the incumbent either restricts its capacity to maintain viability after large-scale entry, or if fixed costs are too high, cedes the market to the entrant. This strategy is akin to the one in Gelman and Salop (1983), but applied to the incumbent rather than the entrant.

When capacity can be incremented smoothly and firms have competing opportunities, an incumbent's profits might be dissipated in too-early preemptive investments to deter entrants. Gilbert and Harris (1984) study a game of competition over the timing of increments, and identify a subgame-perfect equilibrium in which all profits are eliminated.[4] Similar conclusions are derived by Fudenberg and Tirole (1985) for the case of timing of adoptions of a cost-reducing innovation in a symmetric duopoly,[5] and this is extended to the asymmetric case of an incumbent and an entrant by Fudenberg and Tirole (1986c): if Bertrand competition prevails in the product market, then the incumbent adopts just before the entrant would, and thereby maintains its advantage at the cost of some dissipation of potential profit. This result is similar to the role of preemptive patenting in maintaining a monopolist's advantage, as analyzed by Gilbert and Newbery (1982).

Examining an issue raised by Spence (1979), Fudenberg and Tirole (1983) suppose that firms build capacity smoothly at bounded rates over time, which allows multiple equilibria. In one equilibrium the firms accumulate capacity to reach the Cournot equilibrium (or perhaps a Stackleberg equilibrium if one has a head start) but in other equilibria they stop with smaller final capacities: each firm expands farther only if another does. Indeed, they can stop at the monopoly total capacity and split the profits. In this view, an incumbent may be interested less in exploiting its head start by racing to build capacity, than in an accommodation with an entrant to ensure that both refrain from large capacities. Continual arrival of new entrants may therefore be necessary to ensure socially efficient capacities.

[4]Mills (1988) notes, however, that sufficiently lumpy capacity increments allow an incumbent with a first-mover advantage a substantial portion of the monopoly profit.

[5]Three or more firms yields different results.

Another example is a market without durable capacity but with high fixed costs; e.g., capacity is rented. Each period each active firm incurs a fixed cost so high that the market is a natural monopoly. Maskin and Tirole (1988) assume that an active firm is committed to its output level for two periods and two firms have alternating opportunities to choose whether to be active or not. In the symmetric equilibrium with Markovian strategies, the first firm (if the other is not active) chooses an output level large enough to deter entry by the other next period, and this continues indefinitely. In particular, suppose the profit of firm 1 in a period with outputs (q_1, q_2) is $\pi(q_1, q_2)$ and symmetrically for firm 2; also, the maximum monopoly profit $(q_2 = 0)$ covers the fixed cost c of one firm but not two. Then the optimal entry-deterring output is the minimum value of q for which

$$\pi(q, q) - c + \frac{\delta}{1-\delta}[\pi(q, 0) - c] \leq 0,$$

if the discount factor δ is not too small. That is, if q is the optimal output and next period the other firm were to incur the fixed cost c enabling it to choose a positive output, then it too would choose q; therefore, this output must be sufficiently large to ensure that the present value of successful expulsion of the incumbent is not positive. If the period length is short $(\delta \approx 1)$, however, then such a market is easily "contestable" since the commitment period is negligible; in particular, the entry-deterring output grows and the incumbent's profit shrinks as the period length is shortened.

There can also be asymmetric Markovian equilibria if the fixed cost and the discount factor are large enough; e.g., the first firm merely uses its two-period reaction function and then the second never enters. And via the Folk Theorem, there are many symmetric subgame-perfect equilibria that are not Markovian and that yield higher profits.

In general, ease of entry need not ensure low prices, due to the Folk Theorem. For instance, using a model of a market for a durable good, Ausubel and Deneckere (1987) observe that an incumbent monopolist can persist in charging nearly the monopoly price without incurring entry. The entrant is deterred from entering by the prospect of marginal-cost pricing thereafter, and the incumbent is deterred from offering lower prices by the prospect of entry and even lower prices thereafter that are still high enough to justify entry. The feature enabling this result is the Coase property of durable good pricing:[6] if the period length is short and marginal cost is constant, then in any subgame-perfect equilibrium with stationary strategies for the customers, the price of a

[6]The Coase property is stated here for the case of a continuous demand function intersecting the seller's supply function; cf. Gül, Sonnenschein and Wilson (1986) for other technical assumptions.

monopolist (not threatened with entry) is close to marginal cost. As shown also by Gül (1987) in greater generality, this relatively unprofitable prospect can be used as a punishment to construct subgame-perfect equilibria of duopolies that sustain the incumbent's punishments required above.

The overall theme of preemption models is that costly irreversible investments that enhance incumbents' competitive strength (or burden entrants) provide genuine commitment that can deter entry. The models in the next sections, in contrast, suppose that incumbents cannot make commitments.

3. Signaling

Signaling models examine costly credible "communication" that selects the firms to enter or survive in a market. Typically some aspect of each firm's profitability is private information, such as its marginal or fixed cost. Moreover, the only credible signal of a firm's competitive strength is the demonstration itself, via endurance of lower profits longer than it would tolerate if its cost were higher. We mention two prominant examples. Among firms currently active in a market, the battle for survival is modeled as a war of attrition. In the case of incumbents threatened with entry, their current prices signal costs or demand and thereby affect the potential entrant's decision about proceeding with entry.

3.1. Attrition

Attrition models study markets with excess numbers and examine the process that selects survivors. The formulation of Fudenberg and Tirole (1986a, 1986c) is representative. Consider a symmetric market in which at each time $t \geqslant 0$ each of N firms $i = 1, \ldots, N$ initially active in the market obtains net profit at the rate $\pi_n(t) - c_i$ if it is one of n firms remaining active, and zero if it has irrevocably exited earlier. For instance, if i is the solve survivor when its last remaining competitor exits at time t, then its present value of continuation is, using $n = 1$,

$$V_n(t, c_i) = \int_t^\infty [\pi_n(s) - c_i]\, \mathrm{e}^{-r[s-t]}\, \mathrm{d}s$$

when the interest rate is r. Suppose the profit functions π_n are monotone and continuous as functions of time, and uniformly decreasing in the number of active firms. Furthermore, the firms' fixed operating costs c_i are privately

known, each drawn independently according to the differentiable distribution function F having an interval support including both extreme possibilities: the cost might be so high that the firm is unprofitable as a monopolist, or so low that it could forever profit as one of N firms.[7]

In the end-game between two firms ($n=2$), firm i prefers at time t to continue in the duopoly if

$$\pi_2(t) - c_i + h(t)V_1(t, c_i) \geqslant 0\,,$$

where $h(t)$ is the hazard rate at which the other firm exits, leaving i with a perpetual monopoly. Representing each firm's strategy in a symmetric equilibrium as the lowest cost $C(t)$ inducing it to exit at time t if the other has not exited previously, this hazard rate is

$$h(t) = [1 - F(C(t))]'/F(C(t))\,,$$

based on the inference that the other's cost is less than $C(t)$ if it has not exited previously. An equilibrium requires, therefore, that the inequality above is actually an equality at $c_i = C(t)$. This condition yields a differential equation characterizing the equilibrium strategy; moreover, its boundary condition is given by the initial condition $V_1(0, C(0)) = 0$ indicating that a firm unable to profit as a monopolist exits immediately. If profits increase with time, then $C(t)$ and $\pi_2(t)$ may intersect at some time after which a duopoly is viable; hence, the actual strategy is to continue as long as one's cost is less than the greater of $C(t)$ and $\pi_2(t)$. If each firm is initially viable as a monopolist, then the net result is that the higher-cost firm eventually exits; or if both have sufficiently low costs, then a duopoly persists foreover.

The basic theory of attrition games is developed by Nalebuff and Riley (1985) and Riley (1980). Milgrom and Weber (1985) study the symmetric equilibria of symmetric attrition games in which, as above, each party has a privately known cost of delay that increases linearly with time. They provide an analysis in terms of distributional strategies; the hazard rate of exit is shown to decline with time; and mixed strategy equilibria are characterized.[8] Additional applications to markets with declining demand are discussed by Ghemawat and Nalebuff (1985, 1990) using models with complete information, and by Fishman (1990) who includes an initial entry phase. One model supposes identical cost structures but firms differ in their capacities, which impose fixed costs in

[7]As described by Fudenberg and Tirole (1986a), this support assumption ensures a unique equilibrium in the example below.

[8]Section 4 describes an alternative version of attrition, called "chicken", derived from models of reputational effects, in which the hazard rate increases. See Ordover and Rubinstein (1986) for a related model in a different context.

proportion to capacity: the subgame-perfect equilibrium has larger firms exiting earlier. The second allows firms to shrink their capacities: again, larger firms contract earlier.

3.2. Limit pricing

Studies of limit pricing examine the incentives of incumbent firms to signal their private information about costs or demands to deter misguided entry. The motive is clearest in the case of an incumbent monopolist with a privately known marginal cost who anticipates that a potential entrant will enter if it perceives that its profits would exceed its privately known sunk cost of entering. Suppose that profits are lower for the entrant (and higher for the incumbent) if the incumbent's cost is lower, and lower for the incumbent after entry. Moreover, prior to entry the entrant can observe the price chosen by the incumbent but not its marginal cost. Suppose first that the incumbent anticipates naive inferences by the entrant; for instance, the entrant infers that the marginal cost is the one for which the price is the myopically optimal monopoly price. Then the incumbent prefers to cut its price somewhat to reduce the entrant's assessment of its cost, and therefore to reduce the chance of entry. In reverse, suppose the incumbent anticipates sophisticated inferences by the entrant; then the incumbent cannot charge the higher myopically optimal monopoly price without inducing false hopes in the entrant and thereby encouraging entry. Thus, one anticipates an equilibrium in which the incumbent shaves its price before entry: this provides an accurate signal to the entrant, who then enters only if the (correctly) anticipated profit exceeds its sunk cost.

This logic is formalized in a model developed by Milgrom and Roberts (1982a). Knowing its marginal cost c, the incumbent chooses its pre-entry price p to maximize the expected present value of its pre-entry profit $\pi(p, c)$ and post-entry profit $\pi_n(c)$ with $n = 1$ or 2 firms:

$$\pi_1(p, c) + \delta\{\pi_1(c) - h(p)[\pi_1(c) - \pi_2(c)]\} ,$$

where $h(p)$ is the probability of entry. If $P(c)$ is this optimal price, and supposing P is invertible (i.e., the equilibrium is separating, so the signal is "accurate"), then entry occurs if the entrant's sunk cost is less than its anticipated profit $\pi_2^e(\hat{c})$ based on the inferred cost $\hat{c} = P^{-1}(p)$. Thus, if the entrant's sunk cost is drawn independently according to the distribution function F, then from the incumbent's perspective:

$$h(p) = F(\pi_2^e(P^{-1}(p))) .$$

Combining this equilibrium condition with the previous one yields a differential equation that determines the incumbent's strategy. If there is an upper bound on the incumbent's cost, then the boundary condition is simply the requirement that for this highest cost the price is the myopically optimal price: this reflects the usual property of separating signaling equilibria that (in this model) the highest cost incumbent has no fear of being mistaken as having a higher cost.

Milgrom and Roberts actually assume that the entrant's private information consists of its own marginal cost, which is distributed independently of the incumbent's marginal cost, but the analysis is similar. Regularity conditions that ensure the existence of a separating equilibrium are provided by Milgrom and Roberts. In some cases a unique separating equilibria is obtained by eliminating weakly dominated strategies, but usually partial pooling and full pooling equilibria exist too. Mailath (1987) establishes general results about signaling games that, in the context of the Milgrom–Roberts model, imply (subject to a parameter restriction) existence and uniqueness of a separating equilibrium. Ramey (1987) demonstrates that a pooling equilibrium is necessary if the gain from entry deterrence is sufficiently large. In particular, if costs are independent, then the incumbent's gain from reducing the likelihood of entry can be so great that no amount of price reduction can credibly signal low costs; in such cases there are no separating equilibria. More generally, Cho (1990a, 1990b) establishes that for a large (and relevant) domain of parameters the stable equilibria must be partially pooling; thus, the incumbent's action leaves the entrant with some residual uncertainty.

Matthews and Mirman (1983) extend the model to the case that the entrant's observation of the price is affected by noise, which in some cases assures a unique equilibrium. Saloner (1982) studies a multiperiod model in which an entrant has repeated opportunities to enter; in this case, one effect of noisy signaling is that there can be more (i.e., mistaken) entry than with complete information. Bagwell and Ramey (1988) adapt the model to the case that the incumbent uses both its price and another expenditure (such as advertising) to signal.[9] Elimination of weakly dominated strategies yields a unique separating equilibrium in which the incumbent acts as it would if the entrant were informed and its cost were lower than it is; analogous results are obtained for cases with pooling equilibria if an additional "intuitive" equilibrium selection criterion due to Cho and Kreps (1987) is used. Presumably the effects of these selection criteria apply also to the Milgrom–Roberts model.

A variety of other specifications of the incumbent's private information have been suggested. Roberts (1985) supposes that in an initial phase *after* entry the incumbent has superior information about demand (and its ouput is not

[9]Matthews and Fertig (1990) analyze an alternative motive for advertising by the incumbent, based on counteracting false advertising by the entrant.

observable by the entrant). Thus, as in the predation models reviewed in Section 4, the incumbent drives the price down to influence the entrant's decision to exit. As in other signaling models, however, the entrant makes the correct inferences (in equilibrium) so the exit decision is not actually biased, but entry is discouraged by the entrant's anticipation that this behavior by the incumbent reduces expected profits in the initial phase. As in limit pricing, moreover, the incumbent is forced to lower prices in the initial phase lest he encourage the entrant to stay when it is unprofitable. Fudenberg and Tirole (1986b) note that the incumbent's superior demand information is unnecessary for this result: if both firms are uncertain about demand conditions, then the incumbent prefers to encourage exit by lowering the price observed by the entrant – again, provided the entrant cannot observe the incumbent's action.

A variant of limit pricing is studied by Saloner (1987) in the context that two incumbents negotiate a merger. If the firms have private information about their costs, then the bargaining process encourages each to expand output or cut prices to signal to the other that it will be a formidable competitor if the merger fails. This motive is strengthened if there is also a threat of entry, especially if deterring entry is vital to the success of the merger. Thus, limit pricing could deter new entry and simultaneously facilitate the incumbent's merger.

As described above, the threat of entry lowers prices. Harrington (1986) notes that the effect is reversed if the entrant's marginal cost is highly correlated with the incumbent's. The reason is that entry is deterred differently: in the case of independent costs, by a low cost for the incumbent; but in the case of similar costs, by a *high* cost for the incumbent, because that indicates low profits for the entrant too. With highly correlated costs, therefore, the incumbent's limit price generally *exceeds* the myopically optimal monopoly price. The case that the entrant's information is strictly inferior to the incumbent's produces a "pooling" equilibrium: for all costs of the incumbent in a middle range the incumbent charges the same price, which is below or above the monopoly price as the correlation between their costs is low or high. This price is the same as the myopically optimal price for the least cost of the incumbent that, if known to the entrant, would make entry unprofitable (in expectation). Harrington (1987) extends this analysis to the case of multiple incumbents having the same cost of producing products that are perfect substitutes. He retains the key assumption that the entrant has inferior information and observes only a single signal, say the price on the presumption that the incumbents' separate outputs are unobservable. In this case the equilibrium is again pooling except for costs so low that deterrence cannot be avoided and costs so high that the entrant is deterred surely: in the middle range the price is constant at the price for the least cost in the high range of entry-deterring costs. Neither of these models is developed for the case that the

entrant's information is not inferior (e.g., the entrant's sunk cost is privately known), which might alter or eliminate the pooling equilibrium, as in Milgrom and Robert's model where the probability $h(p)$ of entry varies smoothly.

Bagwell and Ramey (1991) find a dramatically different equilibrium when the incumbents' products are differentiated and the entrant observes their individual pre-entry prices. In this case there are equilibria in which the incumbents charge their myopic pre-entry prices; i.e., the equilibrium prices for the associated Bertrand game without threat of entry. Each incumbent anticipates that entry is unaffected by its own price because the entrant can still infer the cost parameter from others' prices. Moreover, equilibrium refinements derived from stability arguments suffice to eliminate all other equilibria.

In sum, signaling models interpret battles for survival among incumbent firms, as well as incumbents' limit pricing to deter new entrants, as communication motivated by implicit bargaining over who shall retain or acquire market shares. The language is restricted to choices of prices, outputs, and other significant decisions that, because they are costly, credibly convey information by averting speculative inferences that survival or entry might be more profitable than it actually is. In some limit-pricing models the net effect is to induce entry when and only when it is profitable for the entrant. Cho's application of stability criteria, and Harrington's analysis of oligopolistic incumbents with a common cost and a single price signal, are sufficient however to indicate that communication can be imperfect (even in the absence of noise) due to pooling equilibria that prevent exact inferences by an entrant. Attrition and limit prices below the myopically optimal prices confer benefits on customers, but in the case of common costs, higher limit prices injure customers until entry occurs.

The next section examines a complementary hypothesis about the effects of an incumbent's private information.

4. Predation

Predation models aim to explain why an incumbent might willingly incur losses battling an entrant, as in a price war. The hypothesized motive is that the cost of the battle is an investment that pays off later, either by expelling the entrant or by deterring later entrants. To introduce this hypothesis, we mention two examples indicating that private information might be an important ingredient; however, we do not repeat here the analyses of basic issues in the references cited in the introduction.

A prominent view of predation is that it is irrational; e.g., the incumbent could obtain the same result at less cost by buying the entrant; cf. McGee (1958). This poses a bargaining problem and, as described in Section 3, Saloner

(1987) assumes the incumbent has private information: it prices aggressively in the product market to signal its competitive strength were the entrant to refuse the terms offered for purchase. Burns (1986) provides some empirical data.

An opposing rationalist view sees predation as the punishment phase of a subgame-perfect equilibrium of a repeated game between the incumbent and the entrant; cf. Milgrom and Roberts (1982b, appendix A). Like other Folk Theorem arguments, this one is usually deemed inadequate because it presumes an equilibrium selection in favor of the incumbent. An alternative view examines asymmetries favoring the incumbent, such as capital-market imperfections and related features that prevent competition on equal terms; cf. Telser (1966) and Poitevin (1989). Benoit (1984) shows that moderate asymmetries can produce severely asymmetric outcomes. Suppose the entrant has limited financial resources, in the sense that the entrant can survive at most n periods battling the incumbent before it is forced to exit. Assume also that for the incumbent, battling to expel the entrant is profitable if $n \leqslant m$, where $m \geqslant 1$. Then an induction argument implies that the incumbent is willing to battle for any value of n: when $n \leqslant m + 1$, battling for *one* period reduces the entrant's remaining resources, allowing continuation for at most m periods, whereupon the entrant knows that it will lose the ensuing battle and therefore prefers to exit immediately with its remaining resources intact. Anticipating this, the incumbent is willing to battle for the one period required to reach this situation; and anticipating this, the entrant prefers to forgo entry or to exit immediately when $n \leqslant m + 1$.

However, this view of predation encounters an argument examined by Selten (1978) and Rosenthal (1981). Suppose the market terminates after a finite number of periods and the entrant can enter (without sunk costs) in any period; actually, Selten assumes a series of different entrants, but this is immaterial. Then a costly battle in the past period is useless, and by backwards induction the incumbent is unwilling to battle in any period. Thus, if the duration of the market is finite, then in effect one must suppose that $m = 0$ in Benoit's construction, and therefore his induction argument fails.[10]

Several models rely on private information to resurrect predatory battles to expel entrants. Benoit's analysis considers a version in which the entrant's financial resources are privately known. To explain inequalities in the parties' resources, Poiteven (1989) examines a model in which the two firms' financial obligations differ because the entrant must obtain capital via debt that credibly signals to lenders its private information about profitability. Sharfstein and Bolton (1990) study the optimal design of a contract between the entrant and its financiers, noting that a contract that naively terminates funding if profits

[10]The tone of Selten's and Rosenthal's expositions is actually to argue against the plausibility of results that depend on long chains of backward induction from a known fixed finite terminus.

are low encourages the incumbent to meet entry with aggressive pricing. Judd and Peterson (1986) apply analogous ideas to limit-pricing contexts.

Milgrom and Roberts (1982b, appendix B) suggest an elegant version in which absence of common knowledge about the incumbent's information eliminates Selten's backward induction. Consider a finite sequence of different entrants, all of whom know that battling any entrant is unprofitable for the incumbent; however, the incumbent is unsure whether they know this, ascribing positive probability to the event that some (at least those late in the sequence) are unsure whether a battle is costly or profitable – and sufficiently unsure to be unwilling to take the risk. In this case the incumbent battles early entrants (who would therefore be reckless to enter) in the mistaken belief that this might deter later entrants by preserving their uncertainty. The incumbent thinks that failure to battle any entrant might reveal that battles are unprofitable and induce a flood of subsequent entrants. Even if the early entrants are well informed, they are deterred by the incumbent's readiness to battle and so the incumbent's mistaken beliefs are not challenged until later.

Kreps and Wilson (1982) and Milgrom and Roberts (1982b) study other versions of this "demonstration effect" derived from the entrant's uncertainty about the incumbent's payoffs or feasible actions. The former studies an N-period market with an incumbent facing a single entrant (or a sequence of entrants). In each period the entrant enters or not, and if it enters the incumbent concedes or fights. The incumbent knows privately that it is permanently weak or strong, determined initially with probabilities $1-p$ and p; and similarly the entrant is weak or strong with probabilities $1-q$ and q. Normalized per-period payoffs are shown in Table 1: assume $a>0$ and $0<b<1<B$ so that fighting is unprofitable for weak types but not for strong types. Assume that each party's payoff is the sum of its per-period payoffs, although similar results are valid for any discount factor close to 1.

If both parties are surely weak, then Selten's (subgame-perfect) equilibrium applies: the entrant always enters and the incumbent always concedes. A similar sequential equilibrium applies if only the incumbent is surely weak. Now suppose the entrant is surely weak but the incumbent might be strong:

Table 1
Per-period payoffs

Actions		Payoffs			
Entrant	Incumbent	Entrant		Incumbent	
		Weak	Strong	Weak	Strong
No entry		0	0	a	a
Entry	Concedes	b	B	0	-1
	Fights	$b-1$	$B-1$	-1	0

$q = 0$ but $p > 0$. In this case there is a sequential equilibrium described as follows. With n periods remaining and a current belief that the incumbent is strong with probability $\hat{p}$, the entrant enters if $\hat{p} < b^n$, enters with probability $1/a$ if $\hat{p} = b^n$, and stays out otherwise. Following entry, the strong incumbent surely fights, and the weak incumbent fights if $\hat{p} \geqslant b^{n-1}$ and otherwise fights with a probability such that the entrant's belief next period is b^{n-1} using Bayes' Rule. If the incumbent ever concedes, then the entrant believes thereafter that it is surely weak.

The analogous model adopted by Milgrom and Roberts (1982b) amends the formulation as follows. First, each period's entrant has a privately known type affecting its payoff from forgoing entry; similarly, the incumbent has a privately known type (fixed for the entire game) affecting its per-period payoff from fighting entry. These type parameters have independent non-atomic distributions. Second, the incumbent has private information about whether it is forced always to concede or always to fight, or it can choose each period. The second ensures that the sequential equilibrium is unique, and the first allows pure strategies.[11] Easley, Masson and Reynolds (1985) use an alternative specification in which the incumbent's private information is knowledge of demand in multiple markets: demand is high in all markets or so low that entry is unprofitable. In the analogous equilibrium, the incumbent responds to early entrants with secret price cutting that mimics the effect of low demand.

In all these formulations the equilibrium produces the intended result. In the model above, if the duration N of the market is so long that $p > b^N$, then even the weak incumbent initially fights entry, and anticipating this behavior the entrant stays out. The entrant's belief remains fixed at p until the last few periods (independent of N) when it first ventures to enter. This equilibrium illustrates the weak incumbent's incentive to maintain a reputation for possibly being strong: maintenance of the reputation (preserving $\hat{p} = p$ early in the game) is expensive when the entrant recklessly challenges the incumbent too early, but the incumbent perceives benefits from deferral of further entry. The notion that reputational effects could motivate predatory responses to entry was proposed by Yamey (1972).

This equilibrium extends to the case that each party has private information about whether it is weak or strong. To illustrate the close connection with attrition models, consider the version obtained in the limit as the period length shrinks, although preserving the assumption that the market has a finite duration T. Of course a strong entrant enters and a strong incumbent fights at every time, so failure to enter reveals a weak entrant and failure to fight reveals a weak incumbent. Using the limit of the above equilibrium, a

[11]In the Kreps–Wilson model, other sequential equilibria can be ruled out by stability arguments; cf. Cho and Kreps (1987).

revealed-weak entrant stays out thereafter (if the incumbent might be strong), and a revealed-weak incumbent encounters entry and concedes thereafter. Thus, after revelation of the weakness of the entrant the incumbent accrues profits at the rate a, or after revelation of the weakness of the incumbent the entrant accrues profits at the rate b if weak or B if strong. If neither is revealed, then their beliefs when a duration t remains are represented by a pair (p_t, q_t), where $(p_T, q_T) = (p, q)$. In the state space of these beliefs, the equilibrium assigns a special role to a locus along which the two weak parties have expected values of continuation that are each zero. Along this locus each weak party selects a stopping time at which it first reveals its weakness by not entering or by conceding. As long as neither reveals weakness their beliefs evolve along the locus, reaching $(1, 1)$ at a time (*before* expiration at $t = 0$) when each concludes the other is strong. In particular, letting $\alpha = b/[1 - b]$, this locus satisfies $p_t^{1/a} = q_t^{1/\alpha}$, or in a time parameterization, $p_t = k_1 t^{-1/\alpha}$ and $q_t = k_2 t^{-1/a}$, where the constants k_i depend on initial conditions. The behavioral strategies that in combination with Bayes' Rule generate this locus can be represented in terms of the weak parties' hazard rates of revealing actions: the weak incumbent's hazard rate of conceding is $[\alpha t(1 - p_t)]^{-1}$ and the weak entrant's hazard rate of not continuing entry is $[at(1 - q_t)]^{-1}$. At the first instant $t = T$, however, the beliefs are not on this locus, so depending on which side of the locus the beliefs lie, one or the other randomizes as to whether to adopt the revealing action, with probabilities such that application of Bayes' Rule yields a posterior on the locus if the revealing action is not taken. Consequently, k_1 and k_2 are determined by the two requirements that $(p_\tau, q_\tau) = (1, 1)$ for some remaining duration $\tau > 0$, and $p_T = p$ or $q_T = q$ depending on which initial belief is unchanged after the initial randomization.

Two-sided reputational equilibria of this sort are akin to attrition: each weak party continues the costly battle in the hope that the other will concede defeat first if it is also weak. Fudenberg and Kreps (1987) address cases in which the incumbent faces several entrants simultaneously or in succession, and depending on whether entrants who have exited can re-enter if the incumbent is revealed weak. Reputational effects persist but depend on the ability of entrants to re-enter. If they can re-enter, then the behavior with many entrants faced sequentially is similar to the behavior with many entrants faced simultaneously. That is, the reputation of the incumbent predominates. Fudenberg and Kreps also develop a point made in the Milgrom–Roberts model; namely, the incumbent, even if his reputation predominates, may prefer that each contest is played behind a veil, isolated from others. This happens when the incumbent has a very high prior probability of being strong, and also the entrants each have a high probability of being strong. The incumbent's reputation causes all weak entrants to concede immediately, but to defend those gains the incumbent must fight many strong entrants. If the contests were

isolated, the incumbent would do nearly as well against his weak opponents and better against the strong.

The structure of such games is a variation on the infinitely repeated games addressed by the Folk Theorem, but where only one of the parties in the stage game plays repeatedly. In such cases, results analogous to the Folk Theorem obtain although often they are interpreted in terms of reputation effects. Fudenberg and Levine (1989a, 1989c) present general analyses for the case that the long-lived player has private information about his type, including formulations in which his actions are imperfectly observed by others.[12] The key result, stated for simultaneous-move stage games, is that in any Nash equilibrium the long-run player's payoff is no less in the limit as the interest rate shrinks than what he would achieve from the pure strategy to which he would most like to commit himself – provided the prior probability is positive of being of a type that would optimally play this "Stackleberg" strategy were his type known. The lower bound derives from the fact that the short-run players adopt best responses to the Stackleberg strategy whenever they attach high probability to the long-run player using this strategy; consequently, if the long-run player uses the Stackleberg strategy consistently, then the short-run players eventually infer that this strategy is likely and respond optimally.[13]

This result establishes the essential principle that explains reputational effects. Moreover, the thrust of models based on reputational effects is, in effect, to select among the equilibria allowed by Folk Theorems: such arguments would not be compelling if the resulting equilibrium (in which the incumbent deters entry) were sensitive to the prior distribution of its possible types, but in fact Fudenberg and Levine's results include a robustness property – entry deterrence occurs for a wide class of prior distributions in both finite and infinite-horizon models.

5. Concluding remarks

Previous theories of entry deterrence and market structure sorely needed amendment to account for strategic features. The formulations and analytical methods of game theory helped clarify the issues and suggest revisions of

[12]This work is reviewed by Fudenberg (1990) and portions are included in Fudenberg and Tirole (1991). See also Fudenberg, Kreps and Maskin (1990) and Fudenberg and Levine (1989b) for related results in settings without private information, as well as Fudenberg and Maskin (1986) for the case that both players are long-lived.

[13]That is, for each $\epsilon > 0$ there exists a number K such that with probability $1 - \epsilon$ the short-run players play best responses to the Stackleberg strategy in all but K periods; moreover, there exists an upper bound on K that is independent of the interest rate and the equilibrium under consideration. See the appendix of Fudenberg and Levine (1989c) for a general statement of this lemma.

long-standing theoretical constructs. A principal contribution of the game-theoretic approach is the precise modeling it enables of timing and informational conditions. In addition, it provides a systematic means of excluding incredible threats by imposing perfection criteria; e.g., subgame-perfect, sequential, or stable equilibria. Applications of these tools provide "toy" models that illustrate features discussed in informal accounts of entry deterrence. The requirements of precise modeling can also be a limitation of game theory when general conclusions are sought. In particular, the difficulties of analyzing complex models render this approach more a means of criticism than a foundation for construction of general theories of market structure.

The plethora of predictions obtainable from various formulations indicate that empirical and experimental studies are needed to select among hypotheses. Many models present econometric difficulties that impede empirical work, but this is realistic: the models reveal that strategic behavior can depend crucially on private information inaccessible to outside observers. Estimation of structural models is likely to be difficult, therefore, but it may be possible to predict correlations in the data. Experimental studies may be more effective; cf. Isaac and Smith (1985), Camerer and Weigelt (1988), Jung et al. (1989), and Neral and Ochs (1989).

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