

## THE LEARNING CURVE, PREDATION, ANTITRUST, AND WELFARE\*

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An economic definition of predation is applied to a dynamic model of duopoly competition with learning curves. It is shown that rational predation occurs in equilibrium, although below-cost pricing is neither a necessary nor a sufficient indicator of predation. A conceptual framework for antitrust analysis of predation shows that a prohibition of predation might help or harm consumer welfare depending on details of market structure, although the informational requirements of fashioning an effective legal rule against harmful predation are formidable.

“Predatory pricing schemes are rarely tried, and even more rarely successful.”—The Supreme Court in *Matsushita Electric Industrial Co. v. Zenith Radio Corp.*<sup>1</sup>

### I. INTRODUCTION

RECENTLY, in *Brooke Group Ltd. v. Brown. & Williamson Tobacco Corp.*,<sup>2</sup> the US Supreme Court clarified two elements of illegal predatory pricing. The first element is a finding that a price is below some appropriate measure of cost.<sup>3</sup> The second element is a finding that the alleged predator is sufficiently likely to recoup its losses from below-cost pricing.<sup>4</sup> The Court reasoned that without recoupment there is no consumer injury.

The recoupment test appears to require a plausible theory of the rationality of below-cost pricing intended to achieve monopoly power. Indeed, the Court established that it is insufficient for a plaintiff merely to prove that the alleged predator intended to injure rivals and expected to recoup its losses. The plaintiff must also prove that the alleged predator’s expectation of recoupment was rational. Moreover, in reaching its

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<sup>1</sup> 106 S. Ct. 1348 [1986].

<sup>2</sup> 113 S. Ct. 2578 [1993].

<sup>3</sup> The Supreme Court declined to say what is the appropriate measure of cost, and the circuit courts are divided on this issue (ABA Antitrust Section, 1992, 227–234).

<sup>4</sup> For Sherman Act cases the standard is a “dangerous probability” of recoupment, while for Robinson–Patman cases it is a “reasonable prospect” of recoupment.

decision, the Court reaffirmed a general skepticism about the plausibility of predation theories that it had expressed previously in *Matsushita*.<sup>5</sup>

This article develops a theory of predation in a formal model of duopoly competition. The critical feature of the model is that firms have learning curves; i.e., there is complementarity between production and process improvement, so that the unit cost of a firm decreases with its cumulative production. The learning curve provides a motive and an opportunity for a firm to produce more and lower its price in order to induce a rival to exit the market. We call such exit-inducing behavior predation.<sup>6</sup>

The welfare effects of “learning curve predation” are mixed. In our model, an exit-inducing strategy succeeds because the surviving firm becomes relatively more efficient by moving down its learning curve faster. But even though successful predation creates monopoly, this does not necessarily harm consumers because of the cost reduction that results from a movement down the learning curve. A monopolist with a lower marginal cost charges a lower price, so it is plausible that consumers might benefit in the end. This, among other reasons, makes it difficult to identify exit-inducing expansions of output that necessarily harm consumers.<sup>7</sup>

Nevertheless, our analysis shows that, when firms have learning curves, there are plausible circumstances in which rational predation harms consumers on balance. Several aspects of this conclusion are worth emphasizing. First, consumers do not necessarily benefit from predation even in the short run, because the more aggressive behavior of the predator may be offset by an opposite reaction of the prey. In our quantity-setting duopoly model, the larger output of the predator may be offset by a smaller output of the prey, with a neutral short-run effect on price. Second, consumers may not benefit even when attempted predation fails, because, while the unlucky predator is more efficient by virtue of having moved down its learning curve faster, the surviving prey is less efficient by fault of having moved down its learning curve slower. Finally, even though a predator is a more efficient monopolist when its rival exits, this may be a small consolation to consumers who prefer duopoly, especially if the probability of monopoly is small in the absence of predation. Under these conditions, the main effect of predation is a harmful one—a greater likelihood of monopoly.

<sup>5</sup> *Matsushita* and *Brooke Group* both involved theories of recoupment by an oligopoly that the Court found to be particularly implausible because of coordination and free-rider problems. The *Matsushita* case is discussed in DeSanti and Kovacic [1991] and Elzinga [1994]. The *Brooke Group* case is discussed in the symposium “Predatory Pricing after *Brooke Group*” in the Spring 1994 issue of the *Antitrust Law Journal* and Burnett [1994].

<sup>6</sup> In Cabral and Riordan [1994] we developed a related theory of predation in a price-setting model. In the present article we develop a more refined definition of predation, apply it to a quantity-setting model, and focus on consumer welfare.

<sup>7</sup> Schwartz [1989] analyzes predatory investment and shows that welfare effects are ambiguous without substantial information on market structure and conduct.

Ordover and Saloner [1989] surveyed recent economic models of equilibrium predation based on strategic considerations arising from credit market imperfections, reputation-building, or signaling, all of which can be understood to derive from some form of asymmetric information. These theories demonstrate the rationality of predation in strategic contexts and show that below-cost pricing is not a prerequisite for predation. At the same time, the theories suggest that asymmetric information is a prerequisite (Klevorick [1993]). We show that this is not true. Our model of rational predation is based on the dynamics of strategic advantage that come from learning curves, and does not assume asymmetric information.<sup>8</sup>

In Section II we present a general framework to define predatory behavior and to characterize and evaluate equilibrium predation. This “economic definition” of predation is in the spirit of Ordover and Willig’s [1991], in that it tries to capture the intuitive idea that a predator intends to drive a rival from the market. We propose a methodology for the antitrust analysis of predation by comparing our predatory equilibrium with the equilibrium of an alternative model in which predation is prohibited by the antitrust authorities.

In Section III, we specialize our framework to a two-period model of duopoly competition with learning curves. This model builds on Spence [1981] and Fudenberg and Tirole [1983], but allows one of the firms to avoid a fixed cost by exiting at the end of the first period. We illustrate why the consumer welfare consequences of a prohibition against predation are ambiguous *a priori*. This leads us to the search for particular conditions under which the effects of a prohibition against predation are unambiguous. We prove conditions under which the prohibition reduces consumer welfare, and alternative conditions under which the prohibition benefits consumers. These various cases illustrate that below-cost pricing is neither a necessary nor a sufficient indicator of predation.

Section IV concludes with some discussion of policy issues and emphasizes that the information requirements of effective legal rules against harmful predation are formidable.

## II. GENERAL FRAMEWORK

In this section, we present a general two-period model of duopoly competition. The model illustrates both our positive ideas about predation and our approach to antitrust policy. In the next section, we specialize the model by considering the particular case of a learning curve.

<sup>8</sup>In a related paper, Bagwell, Ramey, and Spulber [1994] consider a model in which firms make cost-reducing investments and a “shakeout” takes place, whereby uninformed consumers coordinate on purchasing from the firm with the lowest price and only this firm remains active in the market. Petrakis, Rasmusen, and Roy [1995] show how learning curves can cause shakeouts in a competitive industry.

Consider a market with two firms,  $i = A, B$ . Given demands and costs, the profit of firm  $i$  is a function,  $\mu_i(x_i, x_j)$ , of its own and its rival's strategy.  $x_i$  can be related to quantity, price, or some other strategic variable, although we will interpret a higher  $x_i$  as a more aggressive strategy. A best-response function (or reaction curve) satisfies

$$\tilde{r}_i(x_j) \in \arg \max_{x \geq 0} \mu_i(x, x_j),$$

and a (pure strategy) Nash equilibrium is determined by an intersection of reaction curves.

Now suppose that future payoffs depend on today's strategies.<sup>9</sup> Specifically, the future payoff of firm  $i$  is a function  $v_i(x_i, x_j)$  and is discounted by a factor  $\delta \geq 0$ . This can be interpreted as a reduced-form profit function that solves for equilibrium behavior after period 1. In this dynamic model, a reaction curve in first period strategies satisfies

$$\hat{r}_i(x_j) \in \arg \max_{x \geq 0} \mu_i(x, x_j) + \delta v_i(x, x_j).$$

Assume  $\frac{\partial v_i}{\partial x_i} > 0$  and  $\frac{\partial v_i}{\partial x_j} < 0$ .

Next, suppose that firm  $A$  is committed to the market in the second period, but firm  $B$  is not. Specifically, assume that firm  $B$  must incur a fixed cost,  $K$ , to remain active in period 2. We treat  $K$  as a random variable with a cumulative distribution function  $\Phi(K)$  and a density function  $\phi(K)$ . The realisation of  $K$  becomes known at the end of period 1. Therefore, firm  $B$  remains active only if  $v_B(x_B, x_A)$  exceeds  $K$ , and exits with probability  $1 - \Phi(v_B(x_B, x_A))$ . If firm  $B$  exits, then firm  $A$  becomes a monopolist in the second period and earns a profit  $\xi_A(x_A)$  that is a function of its first-period strategy. It is assumed that  $\xi_A(x_A) > v_A(x_A, x_B)$  when  $x_B > 0$ : monopoly profits are higher than duopoly profits. In this model, reaction curves are defined by

$$r_A(x_B) \in \arg \max_{x \geq 0} \mu_A(x, x_B) + \delta [\Phi(v_B(x_B, x))v_A(x, x_B) + (1 - \Phi(v_B(x_B, x)))\xi_A(x)]$$

and

$$r_B(x_A) \in \arg \max_{x \geq 0} \mu_B(x, x_A) + \delta \left[ \Phi(v_B(x, x_A))v_B(x, x_A) - \int_{-\infty}^{v_B(x, x_A)} K\phi(K)dK \right].$$

A Nash equilibrium corresponds to the intersection of reaction curves and is assumed to exist uniquely.<sup>10</sup> Uniqueness of equilibrium amounts to assuming that reaction curves intersect from below; i.e., the absolute value of the slope of  $r_A$  is less than the absolute value of the slope of

<sup>9</sup>A learning curve, considered in the following sections, constitutes a particular instance of this dynamic strategic effect, but many of our points have more general implications.

<sup>10</sup>Our analysis implicitly studies subgame perfect Nash equilibrium because we are working with equilibrium reduced-form profit functions.

the inverse of  $r_B$  (as is true in the linear Cournot model discussed later).<sup>11</sup>

The assumption that firm  $A$  is committed to the market, but firm  $B$  is not, can be justified by supposing that the two firms have different technologies. Firm  $A$ 's technology requires all fixed costs to be sunk at the beginning of period 1, while firm  $B$ 's technology involves an avoidable fixed cost in period 2. In other words, firm  $A$ 's technology may require assets that are more specific, and firm  $B$  may be better able to redeploy its assets. For example, firm  $A$  may produce with a patented technology that requires highly specialized plant and equipment, and firm  $B$  may produce with a standard technology that uses more general purpose plant and equipment.

At an interior solution,<sup>12</sup> the first-order conditions for the first-period values of  $x_i$  are

$$(1) \quad \frac{\partial \mu_A}{\partial x_A} + \delta \left( \Phi(v_B) \frac{\partial v_A}{\partial x_A} + (1 - \Phi(v_B)) \frac{\partial \xi_A}{\partial x_A} \right) + \delta \phi(v_B) \frac{\partial v_B}{\partial x_A} (v_A - \xi_A) = 0$$

$$(2) \quad \frac{\partial \mu_B}{\partial x_B} + \delta \Phi(v_B) \frac{\partial v_B}{\partial x_B} = 0.$$

The equilibrium first-order condition for firm  $A$  sums three components. The first two components reflect first- and second-period marginal profits taking the probability of firm  $B$ 's second period participation decision as a fixed function of  $K$ . The third term accounts for how firm  $A$ 's first-period quantity influences firm  $B$ 's participation decision, and is positive under our assumptions. Firm  $A$  internalizes the facts that a higher  $x_A$  increases the probability that firm  $B$  exits, and that firm  $B$ 's exit yields firm  $A$  a "prize" equal to the difference between monopoly and duopoly profit.

The condition for firm  $B$  is easy to understand. The firm chooses its first-period quantity taking into account the benefit of a higher quantity in terms of second-period profits, but understands that it gets this benefit only if it remains active.

■ **Predation.** Intuitively, a predatory action is intended to drive rivals from the market. Ordover and Willig [1981] capture this idea by defining

<sup>11</sup>When reaction curves intersect from above, an equilibrium thus determined would not be "stable." This notion of "stability" is based on the assumption that reaction curves describe behaviour that relates a firm's current output to its rival's previous output. Such dynamics make no sense in the model at hand. In fact, static equilibrium concepts fail to reject "unstable" equilibria over "stable" ones. However, the stability condition implies that the Nash equilibrium is the unique rationalizable outcome; cf. Condition (a) of Proposition 5.2 in Bernheim [1984]. Moreover, "unstable" equilibria imply counter-intuitive comparative statics, as we show in Cabral and Riordan [1995].

<sup>12</sup>This means that both firms produce positive quantities in period 1 and firm  $B$  participates in period 2 with a probability between zero and one.

predation as “a response to a rival that sacrifices part of the profit that could be earned under competitive circumstances, were the rival to remain viable, in order to induce exit and gain consequent additional monopoly profit.” A problem with applying this definition to our model is that it does not account very well for the possibility that a rival’s viability is uncertain, depending on the realization of the avoidable fixed cost for period 2. Is the appropriate counterfactual hypothesis that firm *B* remain viable with probability one? We don’t think so. Taking into account that firm *B* exits for exogenous reasons (i.e. a high realization of *K*) hardly means that firm *A* intends to drive firm *B* from the market.

To deal with this issue of uncertain viability, we propose a new definition of predation that is similar in spirit to Ordover and Willig’s. We call an action predatory if (1) a different action would increase the likelihood that rivals remain viable, and (2) the different action would be more profitable under the counterfactual hypothesis that the rival’s viability were unaffected.<sup>13</sup> In other words, a predatory action is unprofitable but for its effect on a rival’s exit decision.

In our model with exit, firm *A*’s period 1 value of  $x_A$  is predatory according to this definition if a lower  $x_A$  would be more profitable under the counterfactual hypothesis that the probability that firm *B* exits were fixed at its equilibrium level. To be more concrete,  $x_A$  is predatory if

$$(3) \quad \frac{\partial \mu_A}{\partial x_A} + \delta \left( \Phi(v_B) \frac{\partial v_A}{\partial x_A} + (1 - \Phi(v_B)) \frac{\partial \zeta_A}{\partial x_A} \right) < 0.$$

This condition means that at equilibrium firm *A* would choose a lower  $x_A$  if it took the probability of firm *B*’s participation to be independent of its own strategy. Thus, firm *A* predated when it takes into account that a higher  $x_A$  increases the probability of monopoly. Our assumption that  $\frac{\partial v_B}{\partial x_A} < 0$  implies that, in the equilibrium corresponding to (1)–(2), firm *A* is indeed a predator.<sup>14</sup>

■ **Antitrust analysis.** Many economic analyses of predation have proceeded along the steps of (i) deriving exit as the equilibrium of a model; (ii) analyzing the welfare properties of the equilibrium; and (iii) inquiring whether a restriction on the “predator’s” behavior would improve social welfare (Ordover and Saloner [1989]). It is not very useful to consider (ii) and (iii) separately. Indeed, evaluating the welfare effects of predation is only meaningful by comparison with a different equilibrium in which the

<sup>13</sup>The appendix of Cabral and Riordan [1995] has an example showing that our definition and Ordover and Willig’s [1981] are not equivalent.

<sup>14</sup>Our theory of predatory conduct has much in common with the theory of entry deterrence. The important difference is that the victim is able to defend itself against predation with its period one strategy, whereas the victim does not have a first period action in the standard entry deterrence model. For a discussion, see Cabral and Riordan [1995].

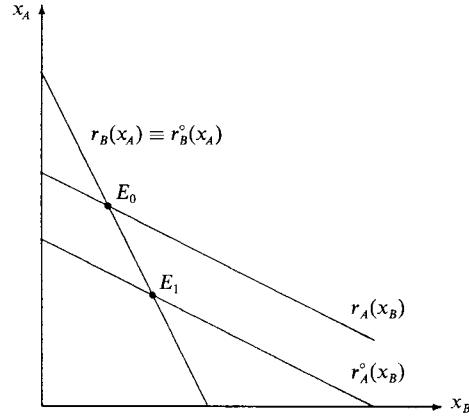


Figure 1

A prohibition against predation shifts down firm  $A$ 's reaction curve.

predator is prevented from implementing such an exit-inducing strategy.

What does it mean to prohibit predation? Again, we appeal to our definition of predatory pricing, as displayed in inequality (3): the choice of  $x_A$  is predatory if, ignoring its effect on firm  $B$ 's viability, the first-order condition would call for a lower value of  $x_A$ . Rigorously speaking, then, a prohibition against predation would consist of restricting firm  $A$  to behave as if the probability of firm  $B$ 's being viable were set constant at its equilibrium value.<sup>15</sup> Enforcing this restriction causes firm  $A$  to change its behavior, resulting in a new (interior) first-order condition,

$$(4) \quad \frac{\partial \mu_A}{\partial x_A} + \delta \left( \Phi(v_B) \frac{\partial v_A}{\partial x_A} + (1 - \Phi(v_B)) \frac{\partial \xi_A}{\partial x_A} \right) = 0.$$

Firm  $B$ 's first-order condition is unaffected by the prohibition, because firm  $A$  is committed to the market by assumption. Therefore, a non-predatory equilibrium is defined by conditions (4) and (2).

The prohibition causes a downward shift in firm  $A$ 's curve and leaves firm  $B$ 's reaction curve the same. If firm  $A$ 's reaction curve crosses firm  $B$ 's from below, then the prohibition results in a lower  $x_A$  and a higher  $x_B$ , as illustrated in Figure 1. In this figure,  $r_i(x_j)$  denotes firm  $i$ 's reaction curve in the initial situation and  $r_i^o(x_j)$  the reaction curves under the prohibition. Since  $v_B$  is increasing in  $x_B$  and decreasing in  $x_A$ , the restriction on firm  $A$ 's conduct also implies an increase in firm  $B$ 's probability of being viable.

<sup>15</sup> While this may seem complex from the perspective of actual antitrust policy, we do not think a prohibition of this sort is entirely unrealistic. For example, as the result of a suit by ECS against AKZO (a British and a Dutch chemical company, respectively), AKZO agreed with the European Commission that it would not reduce its normal selling prices in the market from which it was allegedly inducing ECS to exit. See Philips and Moras [1993].

This comparative statics exercise illustrates a basic problem for the antitrust analysis of predation: Predatory behavior is likely to produce an anticompetitive effect in the future, namely a higher probability of monopoly. However, predatory behavior may also be pro-competitive in the present. In fact, imposing a restriction against predatory behavior implies a lower  $x_A$ , which, recalling the interpretation of this variable as an indicator of aggressive competition, should imply a reduced consumer welfare, although, as we have seen, the decrease in  $x_A$  is at least partly compensated by an increase in  $x_B$ . Which effects dominate?

In the next section, we specialize our general framework to the particular case of a learning curve model. Our purpose is to demonstrate conditions under which a prohibition against predation is unequivocally welfare increasing or welfare decreasing.

### III. A LEARNING CURVE MODEL WITH PREDATION

We now turn to a particular case of the framework presented in the previous section. The one-shot profit function derives from a symmetric linear Cournot model and the linkage between periods is provided by a learning curve.<sup>16</sup> More specifically, a (normalized) inverse demand curve  $P = \alpha - Q$  and a constant average cost  $\beta$  imply  $\mu_i(q_i, q_j) = (\alpha - \beta - q_i - q_j)q_i$ . Each firm's cost in period 2 is a linear decreasing function of first period quantity,

$$c_{i2} = \beta - \gamma q_i.$$

If we ignore non-negativity constraints on second-period quantities,<sup>17</sup> second-period equilibrium profits if both firms remain active are given by

$$v_i(q_i, q_j) = \left( \frac{\alpha - \beta + 2\gamma q_i - \gamma q_j}{3} \right)^2.$$

Notice that this future payoff is a convex function of firm  $i$ 's first-period output. Consequently, the second-order condition for discounted profit maximization requires  $\delta\gamma^2 < \frac{2}{3}$ ; i.e., the future cannot be too important. This restriction implies that reaction curves in first-period quantities have a

<sup>16</sup>In Cabral and Riordan [1994, 1995] we also consider cases of price competition with product differentiation.

<sup>17</sup>Second period quantities are non-negative if  $\alpha - \beta + \gamma(2q_i - q_j) \geq 0$  for both firms, where  $q_i$  and  $q_j$  are the first period quantities of firm  $i$  and its rival.



negative slope. The slope is less than unity if and only if  $\delta\gamma^2 < \frac{3}{4}$ , which is obviously stronger than the second-order condition.<sup>18</sup> Thus, in contrast to the linear Cournot model, the slope of the reaction curve in our model (which parallels that of Fudenberg and Tirole [1983]) can be less than, equal to, or greater than unity.

Our model extends Fudenberg and Tirole's to allow for the possibility of exit. If firm *B* decides to leave the market, which happens when *K* exceeds  $v_B$ , then firm *A* receives a second period monopoly profit equal to

$$\xi_A(q_A) = \left( \frac{\alpha - \beta + \gamma q_A}{2} \right)^2.$$

Some results below refer to the slope of firm *B*'s reaction curve. Firm *B*'s reaction curve is linear if  $\Phi(K) = C - \frac{D}{\sqrt{K}}$ , where *C* and *D* are positive parameters, and its slope is greater (less) than unity in absolute value if *C* is greater (less) than  $\frac{3}{4\delta\gamma^2}$ . Firm *B*'s reaction curve slopes down by assumption, but in general this slope can be greater than or less than unity. Part of the welfare analysis below focuses on the case where the slope of firm *B*'s reaction curve is approximately unity, which neutralizes the first-period welfare effects of predation. There is nothing particularly unusual about this benchmark case.

■ **Consumer welfare.** Our goal is to evaluate the effect on consumer welfare of a prohibition against predation. Our measure of consumer welfare is the expected present value of aggregate consumer surplus. Consumer surplus in the first period is given by  $\chi(q_A + q_B) = \frac{1}{2}(q_A + q_B)^2$ . Second-period consumer surplus in the case of a duopoly can be expressed as a reduced form function of first period quantities:  $\Psi(q_A, q_B) = \frac{1}{2}[2(\alpha - \beta) + \gamma(q_A + q_B)]^2$ .<sup>19</sup> If firm *A* is a monopolist in period 2, then the expression for consumer welfare is  $\Omega(q_A) = \frac{1}{2}(\alpha - \beta + \gamma q_A)^2$ . Notice that  $\Psi(q_A, q_B) > \Omega(q_A)$ ; i.e., consumers are better off with the duopoly. When we pull these elements together, equilibrium consumer welfare as a function of first-period quantities is measured by

$$W(q_A, q_B) = \chi(q_A + q_B) + \delta[\Phi(v_B(q_B, q_A))\Psi(q_A, q_B) + (1 - \Phi(v_B(q_B, q_A)))\Omega(q_A)].$$

As before, firm *B*'s second-period profit determines the probability of a second-period duopoly versus a monopoly, reflecting that firm *B* exits if its

<sup>18</sup> These technical conditions are independent of the units in which quantity is measured. Our normalization of the slope of the demand curve implies a normalization of monetary or quantity units and a corresponding normalization of  $\gamma$ . The reason why absolute numbers appear on the right hand side of these expressions is that the number of firms is set equal to two.

<sup>19</sup> In this linear model, second-period price and consumer welfare depend only on the sum of first-period quantities. This property would fail if, for example, the learning curves were non-linear.

avoidable fixed cost exceeds its second-period profit from market participation.

It is apparent that a restriction on predation has mixed effects on consumer welfare. In the case of Figure 1 (interpreting  $x_i = q_i$ ), a prohibition against predation lowers  $q_A$  and raises  $q_B$ . Because firm  $B$ 's reaction curve has a slope of less than unity in this case, first-period price rises, to the detriment of consumers. As a second-period monopolist, firm  $A$  will have higher costs, also to the detriment of consumers, because it has moved less distance down its learning curve. The consequences of first-period output changes on a second period duopoly are unclear in general, but in the linear case that we consider second-period price goes up because aggregate first-period quantity is less, again to the detriment of consumers. Finally, the prohibition raises the second-period duopoly profit of firm  $B$ , reducing the probability of exit and monopoly, and thus benefiting consumers. In this case, the first three effects of the prohibition are negative for consumers, while the last effect is positive. Thus, the net effect on consumer welfare is ambiguous, depending on the strengths of these various effects. We next identify special cases in which the dominant effects are clear.

■ **Welfare improving predation.** We begin by showing that predation is beneficial when the future is not very important or when the marginal effect of predation on firm  $B$ 's exit probability is small. In these cases, the important effect of a prohibition against predation is to raise prices in period 1.

*Proposition 1* A prohibition against predation reduces consumer welfare if

1.  $\delta$  is small; or
- 2a. reaction curves slope less than unity; and
- 2b.  $\phi(v_B)$  is small in the equilibrium with predation.

*Proof:* Consider first the case when  $\delta$  is small. From (1), a prohibition against predation shifts down firm  $A$ 's reaction curve. Since  $\delta$  is small, reaction curves must slope less than 1. Therefore, the shift in firm  $A$ 's reaction curve implies a decrease in total quantity and a higher price in the first period, which harms consumers. Since  $\delta$  is small, any effect on second period consumer welfare is negligible.

The proof for the second set of conditions is similar. From (1), a prohibition against predation shifts down firm  $A$ 's reaction curve by a value of order  $\epsilon \approx 0$  (by condition (2b) of the proposition). By condition (2a), this implies that the imposition of the prohibition implies a decrease in  $q_A$  and an increase in  $q_B$  by values of order  $\epsilon$  and that  $q_A + q_B$  decreases also by a value of order  $\epsilon$  (by condition (2a) of the proposition). In period

2, consumer surplus goes down both under duopoly and under monopoly, since both  $q_A + q_B$  and  $q_A$  in period 1 are lower under the prohibition. Finally, there is a decrease in the probability of second-period duopoly (the only anticompetitive effect) given by

$$d\Phi(v_B) = \phi(v_B) \frac{\partial v_B}{\partial q_A} dq_A,$$

which is of order  $\epsilon^2$ . ■

The explanation for this result is simple. A prohibition against predation causes a lower total quantity and a higher price in period 1. The conditions in the proposition imply that any effects on period 2 are less important than the effect on the first period quantity. A small  $\delta$  or a small  $\phi(v_B)$  can be interpreted to mean that predation is difficult, either because it takes a relatively long time for predation to succeed or because the predator's action has little effect on the prey's exit decision. However, even in these extreme cases some amount of predatory behavior is profitable—and beneficial for consumers.

■ **Predation that decreases consumer welfare.** We next turn to a case in which equilibrium predation is potentially substantial and harms consumers. An important element of the following proposition is that the effect of predation on duopoly prices is small, so the dominant effect of a prohibition is to decrease the probability of monopoly.

*Proposition 2* A prohibition against predation increases consumer welfare if

- a. the slope of firm  $B$ 's reaction curve is approximately unity;
- b. firm  $B$  is unlikely to exit absent predation.

*Proof:* The prohibition shifts down firm  $A$ 's reaction curve. Since reaction curves intersect from below, this causes  $q_A$  to fall and  $q_B$  to rise. So  $v_B$  increases, and firm  $B$  is less likely to exit. This by itself increases consumer welfare because  $\Psi(q_A, q_B) > \Omega(q_A)$ . Moreover, condition (a) implies that second-period duopoly price is not much affected by the conduct restriction, so consumers are about as well off when firm  $B$  stays in the market. It is possible that smaller  $q_A$  makes consumers worse off when firm  $B$  exits, but a monopoly rarely occurs by condition (b). Finally, the effect on first-period consumer surplus is negligible because condition (a) implies that first-period price is about the same. Therefore, on balance the prohibition benefits consumers by decreasing the probability of monopoly. ■

This proposition demonstrates plausible conditions for predatory behavior that harms consumers. The intuitive idea behind it is that a more

aggressive firm  $A$  is offset by a less aggressive firm  $B$ , with a neutral effect on the period 1 price. Correspondingly, a more efficient firm  $A$  due to predation is balanced by a less efficient firm  $B$ , with offsetting consequences for the period 2 duopoly price. Condition (a) holds if the distribution of firm  $B$ 's avoidable fixed costs has a shape similar to  $\Phi(K) = \frac{3}{4\delta\gamma^2} - \frac{D}{\sqrt{K}}$  for a positive parameter  $D$  over the relevant range.<sup>20</sup> There is nothing strange about the shape of the corresponding density function. The approximation can be valid, for example, if  $\phi(K)$  has the shape of a normal density function over the relevant range. Moreover, there is no contradiction between (a) and our implicit assumption that reaction curves intersect from below, since firm  $A$ 's reaction curve has additional terms with respect to firm  $B$ 's. Finally, condition (b) states that firm  $B$ 's exit can be blamed almost entirely on predation by firm  $A$ . Table I of Cabral and Riordan [1995] presents a plausible numerical example in which all of these conditions hold.

The conditions of the proposition isolate circumstances under which the dominant effect of predation is to increase the probability of monopoly. Any offsetting efficiencies are small in these circumstances. Moreover, some apparently plausible efficiency arguments are not necessarily valid at all. Consumers do not benefit during the period of predation if the prey contracts output to offset the predator's expansion. And a more efficient failed predator does not necessarily benefit consumers if the surviving prey is less efficient.

Notice that the conditions of the proposition do not refer to any relationship between price and cost. In fact, the numerical example referred to above features first-period duopoly prices above first-period cost ( $\beta$ ). In general, below-cost pricing is not a necessary condition for harmful predation. Likewise, it can be shown that, even without exit, first-period price may be less than marginal cost.<sup>21</sup> Therefore, below-cost pricing is neither a necessary nor sufficient indication of predatory behavior.

#### IV. CONCLUDING DISCUSSION

When learning curves are important, choosing a larger quantity with an intent to drive rivals from the market is an equilibrium phenomenon. A rational profit-maximizing firm takes into account how the additional quantity increases the probability of a rival's exit, and rationally expects to recoup any short-term losses with expected future monopoly profits.

<sup>20</sup>This is a Pareto distribution if  $\delta\gamma^2 = 3/4$ . It is a truncated Pareto distribution if  $\delta\gamma^2 < 3/4$ . The relevant range is the range of outputs in between the quantities that correspond to equilibrium with and without predation.

<sup>21</sup>See equation 15 in Fudenberg and Tirole [1983]. It suffices for  $\delta$  and  $\lambda$  to be sufficiently large.

This behavior satisfies the economic definition of predation that we propose and appears to go some way toward capturing the spirit of the Supreme Court's recoupment test.

Our model ignores new entry or the re-entry of firm *B*. However, it is noteworthy that a learning curve creates a barrier to entry. Firm *A* has an advantage over an entrant because it has already moved down its learning curve. A firm that exited would not re-enter unless it could somehow substantially lower its costs. Similarly, another firm would not enter unless it was substantially more efficient than the firm that exited. Therefore, a theory of predation based on a learning curve appears to address the Supreme Court's concern in *Matsushita* that "without barriers to entry it would presumably be impossible to maintain supracompetitive prices for an extended time."

The Supreme Court has so far declined to clarify what is the appropriate measure of cost below which a price is potentially predatory. The Circuit Courts have taken various positions, many accepting some variant of the Areeda and Turner's [1975] proposed average variable cost standard. However, in our model, pricing below average variable cost is neither a necessary nor a sufficient indicator of predation.

The Sherman Act permits a private plaintiff to collect treble damages. Suppose that the Sherman Act were interpreted to prohibit predation (as we define it), or, even more narrowly, to prohibit predation that harms consumers. A potential drawback of such a policy is that it might create a strategic incentive for firm *B* to change its behavior to cause firm *A* to violate the prohibition. For example, in our model firm *B* could underproduce relative to its equilibrium quantity, causing firm *A*'s behavior to satisfy our definition of predation, even if firm *A* chose its equilibrium quantity for the no-predation model. This suggests that firm *A* ought to be able to defend against a predation suit by proving that firm *B* did not choose a best response. Thus our definition of predation might be modified to require firm *B*'s action to be a best response. However, this also is potentially problematic because it might create a strategic incentive to firm *A* to cause firm *B*'s behavior not to be a best response. Thus, as a practical matter, perhaps firm *A* ought to be able to defend only by claiming that firm *B*'s behavior was not a best response to a reasonable anticipation of firm *A*'s action.

This discussion supports the idea that an attempt to enforce a prohibition against predation under the Sherman Act potentially creates rich opportunities for "nuisance suits" by private plaintiffs. Some commentators have argued that this is a good reason not to enforce any policy against predation, or to establish a high burden of proof for plaintiffs. (Indeed, this might be part of the Supreme Court's reason for framing the recoupment test.) We do not necessarily disagree with this point of view, but do think the issue deserves more rigorous attention.

Worrying about nuisance suits, however, is different from arguing that predation is irrational, which has been the first line of attack against predation suits. We have shown that predation can be both rational and harmful to consumers in a duopoly with learning curves. In these cases the “recoupment test” articulated by the Supreme Court may not be such a difficult burden of proof as some commentators and the Supreme Court imagine.

Nevertheless, it appears that the information requirements of fashioning an effective legal rule against harmful predation are formidable. Although Proposition 2 identifies harmful predation by firm *A*, it would be difficult to demonstrate the conditions of the proposition in a court of law. A crucial reason for this difficulty is that it is hard to distinguish predatory behavior by firm *A* from the alternative hypothesis that firm *A* is more efficient and produces more output because it has a lower cost.

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