The economics of predation: What drives pricing when there is learning-by-doing?*

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Abstract

Predatory pricing—a deliberate strategy of pricing aggressively in order to eliminate competitors—is one of the more contentious areas of antitrust policy and its existence and efficacy are widely debated. The purpose of this paper is to formally characterizes predatory pricing in a modern industry dynamics framework. We endogenize competitive advantage and industry structure through learning-by-doing. We show that we can isolate and measure a firm's predatory incentives by decomposing the equilibrium pricing condition. Our decomposition maps into existing economic definitions of predation and provides us with a coherent and flexible way to develop alternative characterizations of a firm's predatory incentives. We ask three interrelated questions. First, when does predation-like behavior arise? Second, what drives pricing and, in particular, how can we separate predatory incentives for pricing aggressively from efficiency-enhancing incentives for pricing aggressively in order to move further down the learning curve? Third, what is the impact of predatory incentives on industry structure, conduct, and performance? We find that predation-like behavior arises for wide range of parameterizations, and our decomposition-based definitions are succesful in isolating predatory incentives in the sense that eliminating them leads to improvemtns in long-term measures of market structure, conduct and performance. It also appears that consumers might be valuing short-term benefits of low predatory price more than the cost of future monopolization.

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1 Introduction

Predatory pricing—a deliberate strategy of pricing aggressively in order to eliminate competitors—is one of the more contentious areas of antitrust policy. Scholars such as Edlin (2010) argue that predatory pricing can, under certain circumstances, be an effective and profitable business strategy. Others—commonly associated with the Chicago School—suggest that predatory pricing is rarely rational and thus unlikely to be practiced or, as Baker (1994) puts it, somewhere between a white tiger and a unicorn—a rarity and a myth.

At the core of predatory pricing is a trade-off between lower profit in the short run due to aggressive pricing and higher profit in the long run due to reduced competition. But as the debate over the efficacy—and even the existence—of predatory pricing suggests, it is not necessarily straightforward to translate this intuitive understanding into a more precise characterization of what predatory pricing actually is.[1]

Characterizing predatory pricing is especially complicated because aggressive pricing with subsequent recoupment can also arise when firms face other intertemporal trade-offs such as learning-by-doing, network effects, or switching costs. The empirical literature provides ample evidence that the marginal cost of production decreases with cumulative experience in a variety of industrial settings.[2] The resulting tension between predatory pricing and mere competition for efficiency on a learning curve was a key issue in the policy debate about the "semiconductor wars" between the U.S. and Japan during the 1970s and 1980s (Flamm 1993, Flamm 1996). The European Commission case against Intel in 2009 over the use of loyalty reward payments to computer manufacturers (that lead to a record-breaking fine of $1.5 billion) likewise revolved around whether Intel's behavior was exclusionary or efficiency enhancing (Willig, Orszag & Levin 2009), with Intel CEO Paul Otellini vigorously arguing that "[w]e have ... consistently invested in innovation, in manufacturing and in developing leadership technology. The result is that we can discount our products to compete in a highly competitive marketplace, passing along to consumers everywhere the efficiencies of being the world's leading volume manufacturer of microprocessors."[3] More generally, contractual arrangements such as nonlinear pricing and exclusive dealing that can be exclusionary are often also efficiency enhancing (Jacobson & Sher 2006, Melamed 2006).

While predatory pricing is difficult to disentangle from pricing aggressively to pursue

[1] Edlin (2002) provides a comprehensive overview of the current law on predatory pricing. Bolton, Brodley & Riordan (2000) and Edlin (2010) provide excellent reviews of the theoretical and empirical literature.

[2] See Wright (1936), Hirsch (1952), DeJong (1957), Alchian (1963), Levy (1965), Kilbridge (1962), Hirschmann (1964), Preston & Keachie (1964), Baloff (1971), Dudley (1972), Zimmerman (1982), Lieberman (1984), Argote, Beckman & Epple (1990), Gruber (1992), Irwin & Klenow (1994), Jarmin (1994), Pisano (1994), Bohn (1995), Darr, Argote & Epple (1995), Hatch & Mowery (1998), Benkard (2000), Shafer, Nembhard & Uzumeri (2001), Thompson (2001), Thornton & Thompson (2001), and Thompson (2003).

[3] See http://www.zdnet.com/blog/btl/ec-intel-abused-dominant-position-vs-amd-fined-record-145-billion-in-antitrust-case/17884 (accessed on June 7, 2011).

efficiency, being able to do so is obviously important in legal cases involving alleged predation. Moreover, if one entertains the possibility that predatory pricing is a viable business strategy, then a characterization of predatory pricing is required to allow economists, legal scholars, and antitrust practitioners to detect its presence and measure its extent.

The purpose of this paper is therefore to formally characterize predatory pricing in a modern industry dynamics framework along the lines of Ericson & Pakes (1995). Unlike much of the previous literature, we do not attempt to deliver an ironclad definition of predatory pricing. Instead, our contribution is to show that we can usefully isolate and measure a firm's predatory incentives by decomposing the equilibrium pricing condition. We ask three interrelated questions. First, when does predation-like behavior arise in a dynamic pricing model with endogenous competitive advantage and industry structure? Second, what drives pricing and, in particular, how can we separate predatory incentives for pricing aggressively from efficiency-enhancing incentives? Third, what is the impact of predatory incentives on industry structure, conduct, and performance? We discuss these questions—and our answers to them—in turn.

When does predation-like behavior arise? We develop a dynamic pricing model with endogenous competitive advantage and industry structure similar to the models of learning-by-doing in Cabral & Riordan (1994) and Besanko, Doraszelski, Kryukov & Satterthwaite (2010). While there is a sizeable literature that attempts to rationalize predatory pricing as an equilibrium phenomenon by means of reputation effects (Kreps, Milgrom, Roberts & Wilson 1982), informational asymmetries (Fudenberg & Tirole 1986), or financial constraints (Bolton & Sharfstein 1990), our model forgoes these features and thus "stacks the deck" against predatory pricing. Our numerical analysis nevertheless reveals the widespread existence of Markov perfect equilibria involving behavior that resembles conventional notions of predatory pricing in the sense that possibility of rival's exit is associated with aggressive pricing. The fact that predation-like behavior arises routinely and without requiring extreme or unusual parameterizations calls into question the idea that economic theory provides *prima facie* evidence that predatory pricing is a rare phenomenon.

Our paper relates to earlier work by Cabral & Riordan (1994), who establish analytically the possibility that predation-like behavior can arise in a model of learning-by-doing, and Snider (2008), who uses the Ericson & Pakes (1995) framework to explore whether American Airlines engaged in predatory capacity expansion in the Dallas-Fort Worth to Wichita market in the late 1990s. Our paper goes beyond establishing possibility by way of an example or a case study by showing just how common predation-like behavior is.

Our paper moreover reinforces and formalizes a point made by Edlin (2010) that predatory pricing is common "if business folks think so." Equilibria involving predation-like behavior typically coexist in our model with equilibria involving much less aggressive pricing. Multiple equilibria arise in our model if, for given demand and cost fundamentals, there is more than one set of firms' expectations regarding the value of continued play that is consistent with rational expectations about equilibrium behavior and industry dynamics.[4] Which of these equilibria is realized therefore depends on firms' expectations. Loosely speaking, if firms anticipate that predatory pricing may work, then they have an incentive to choose the extremely aggressive prices that, in turn, ensure that predatory pricing does work.

What drives pricing? We isolate a firm's predatory pricing incentives by analytically decomposing the equilibrium pricing condition. Our decomposition is reminiscent of that of Ordover & Saloner (1989), but it extends to the complex strategic interactions that arise in the equilibrium of a dynamic stochastic game. The cornerstone of our decomposition is the insight that the price that a firm sets reflects two goals besides short-run profit. First, by pricing aggressively the firm may move further down its learning curve and improve its competitive position in the future, giving rise to what we call the *advantage-building motive* in pricing. Second, by pricing aggressively the firm may prevent its rival from moving further down its learning curve and becoming a more formidable competitor, giving rise to the *advantage-denying motive* in pricing.

Decomposing the equilibrium pricing condition with even more granularity reveals that the probability that the rival exits the industry—the linchpin of any notion of predatory pricing—affects both motives. For example, one component of the advantage-building motive is the *advantage-building/exit motive*. This is the incremental benefit from an increase in the probability of rival exit that results if the firm moves further down its learning curve. Similarly, the *advantage-denying/exit motive* is the incremental benefit from preventing a decrease in the probability of rival exit that results if the rival moves further down its learning curve. Other terms in the decomposed equilibrium pricing condition capture the impact of the firm's pricing decision on its competitive position, its rival's competitive position, and so on. In this way our decomposition corresponds to the common practice of antitrust authorities to question the intent behind a business strategy.

Certain terms of our decomposition map into the existing economic definitions of predation including those due to Ordover & Willig (1981) and Cabral & Riordan (1997). For example, we show that if the advantage-building/exit motive and the advantage-denying/exit motive are positive, then the equilibrium price is predatory according to the Cabral & Riordan (1997) definition. Our decomposition therefore allows us to clarify the relationship between the existing economic definitions of predation.

[4]Multiple equilibria can potentially also arise in our model if the best replies of the one-shot game that is being played given continuation values intersect more than once. This cannot happen in the model in Besanko et al. (2010).

Most important, however, our decomposition provides us with a coherent and flexible way to develop alternative characterizations of a firm's predatory pricing incentives, some of which are motivated by the existing literature while others are novel. To detect the presence of predatory pricing antitrust authorities routinely ask whether a firm sacrifices current profit in exchange for the expectation of higher future profit following the exit of its rival. One way to test for sacrifice is to determine whether the derivative of a profit function that "incorporate[s] everything except effects on competition" is positive at the price the firm has chosen (Edlin & Farrell 2004, p. 510). Our alternative characterizations of predatory incentives correspond to different operationalizations of the everything-except-effects-on-competition profit function and identify various terms in our decomposition as the firm's predatory incentives.

What is the impact of predatory incentives? While much of the previous literature has argued for (or against) the merits of particular definitions of predatory pricing on conceptual grounds, we instead directly measure the impact of predatory incentives on industry structure, conduct, and performance. To this end, we consider what happens if firms ignore the predatory incentives in setting their prices. We construct counterfactuals by "switching off" the terms in the decomposed equilibrium pricing condition that our various definitions identified as predatory incentives. We then compare counterfactuals to equilibria over a wide range of parameterizations.

Our alternative definitions of predatory incentives that follow from our decomposition correspond to conduct restrictions of different severity. As previously pointed out by Cabral & Riordan (1997), predation-like behavior may actually benefit consumer and welfare. Our numerical analysis echoes this point to the extent that conduct restrictions decrease competition for the market without increasing competition in the market.

Importantly, we find that the less severe conduct restrictions, including those inspired by Ordover & Willig (1981) and Cabral & Riordan (1997), have, on average, a small impact on industry structure, conduct, and performance. Hidden behind these averages is the fact that their impact is large for a small subset of parameterizations. In contrast, the more severe conduct restrictions have a large impact on industry structure, conduct, and performance. This large impact stems from the fact that they eliminate equilibria with predation-like behavior. In contrast, even the more severe conduct restrictions cause little change in equilibria involving less aggressive pricing.

Overall, our numerical analysis shows that there may be ways of disentangling predatory incentives for pricing aggressively from efficiency-enhancing incentives for pricing aggressively in order to move further down the learning curve. In particular, a conduct restriction in the spirit of a dynamic competitive vacuum appears to do this well and has the potential to help welfare in the long run without substantially harming consumers in the short run.

2 Model

Because predatory pricing is an inherently dynamic phenomenon with the potential to shape the evolution of an industry, we consider a discrete-time, infinite-horizon dynamic stochastic game between two firms that compete in an industry characterized by learning-by-doing. At any point in time, firm $n \in \{1, 2\}$ is described by its state $e_n \in \{0, 1, \ldots, M\}$. A firm can be either an incumbent firm that actively produces or a potential entrant. State $e_n = 0$ indicates a potential entrant. States $e_n \in \{1, \ldots, M\}$ indicate the cumulative experience or stock of know-how of an incumbent firm. By making a sale in the current period, an incumbent firm can add to its stock of know-how and, through learning-by-doing, lower its production cost in the subsequent period. Thus, competitive advantage is determined endogenously in our model. At any point in time, the industry is characterized by a vector of firms' states $\mathbf{e} = (e_1, e_2) \in \{0, 1, \ldots, M\}^2$. We refer to $\mathbf{e}$ as the state of the industry.

In each period, firms' decision making proceeds as a price-setting phase followed by an exit-entry phase as illustrated in Figure 1. During the price-setting phase, the state of the industry changes from $\mathbf{e}$ to $\mathbf{e}'$ depending on the outcome of pricing game between the incumbent firms. During the exit-entry phase, the state then changes from $\mathbf{e}'$ to $\mathbf{e}''$ depending on the exit decisions of the incumbent firm(s) and the entry decisions of the potential entrant(s). The state at the end of the current period ($\mathbf{e}''$) finally becomes the state at the beginning of the subsequent period. As shown in Figure 1, we model entry as a transition from state $e'_n = 0$ to state $e''_n = 1$ and exit as a transition from state $e'_n \geq 1$ to state $e''_n = 0$ so that the exit of an incumbent firm creates an opportunity for a potential entrant to enter the industry.

Before analyzing firms' decisions and the equilibrium of our dynamic stochastic game, we describe the remaining primitives.

Demand. The industry draws its customers from a large pool of potential buyers. In each period, one buyer enters the market and purchases one unit of either one of the "inside goods" that are offered by the incumbent firms at prices $\mathbf{p} = (p_1, p_2)$ or an "outside good" at an exogenously given price p_0.[5] The probability that firm n makes the sale is given by

[5]This assumption captures the sentiment of Intel CEO Paul Otellini that " [t]he natural result of a competitive market with only two major suppliers is that when one company wins sales, the other does not." See http://www.zdnet.com/blog/btl/ec-intel-abused-dominant-position-vs-amd-fined-record-145-billion-in-antitrust-case/17884 (accessed on June 7, 2011).

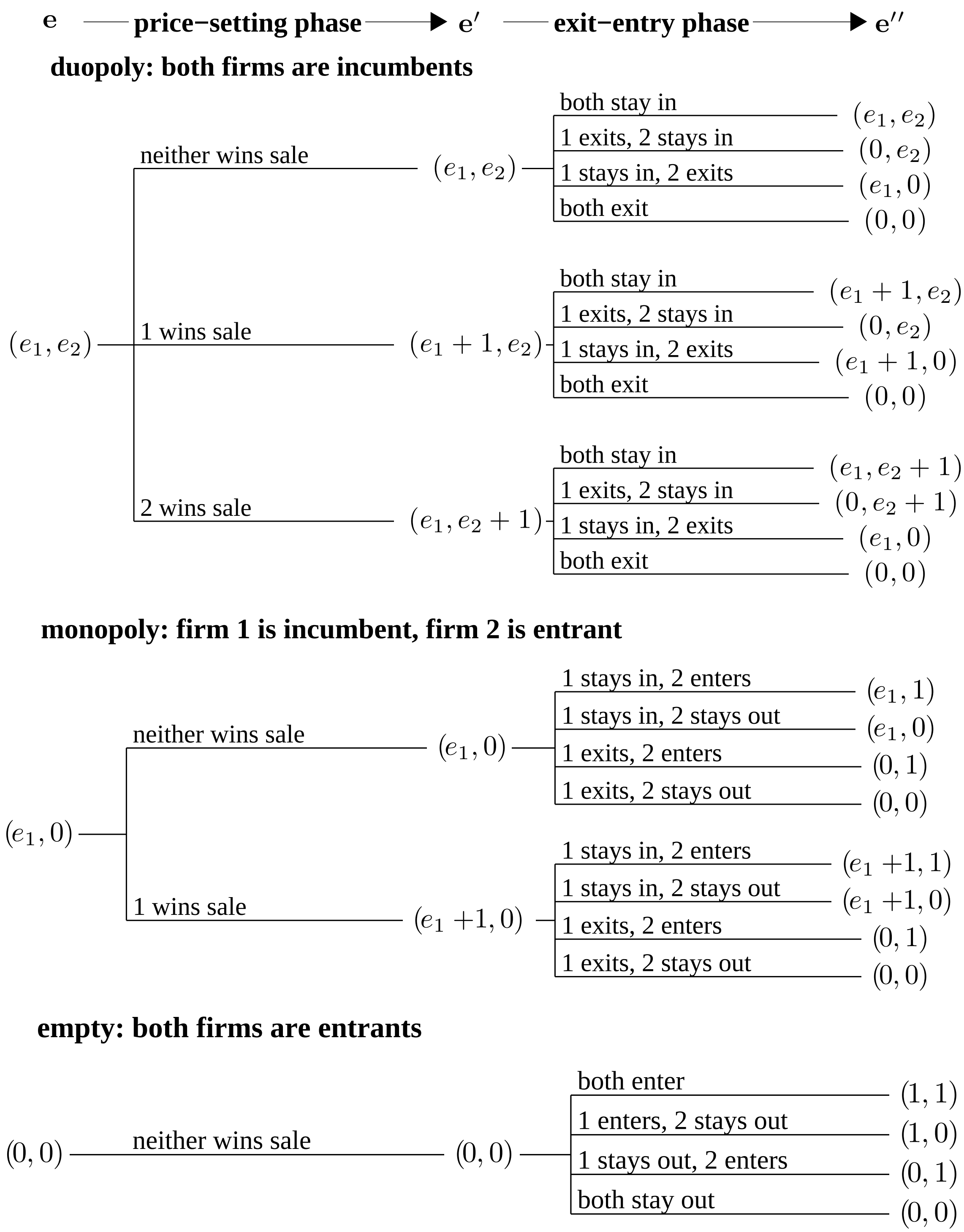

Figure 1: Possible state-to-state transitions.

the logit specification

$$D_n(\mathbf{p}) = \frac{\exp(\frac{-p_n}{\sigma})}{\sum_{k=0}^{2} \exp(\frac{-p_k}{\sigma})},$$

where $\sigma > 0$ is a scale parameter that governs the degree of product differentiation. As $\sigma \to 0$, goods become homogeneous. If firm n is a potential entrant, then we set its price to infinity so that $D_n(\mathbf{p}) = 0$.

Learning-by-doing and production cost. Incumbent firm n's marginal cost of production $c(e_n)$ depends on its stock of know-how through a learning curve with a progress ratio $\rho \in [0, 1]$:

$$c(e_n) = \begin{cases} \kappa\rho^{\log_2 e_n} & \text{if} \quad 1 \leq e_n < m, \\ \kappa\rho^{\log_2 m} & \text{if} \quad m \leq e_n \leq M. \end{cases}$$

Marginal cost decreases by $100(1 - \rho)\%$ as the stock of know-how doubles, so that a lower progress ratio implies a steeper learning curve. The marginal cost for a firm without prior experience, $c(1)$, is $\kappa > 0$. The firm can add to its stock of know-how by making a sale.[6] Once the firm reaches state m, the learning curve "bottoms out" and there are no further experienced-based cost reductions. Following Cabral & Riordan (1994), we refer to an incumbent firm in state $e_n \geq m$ as a *mature firm* and an industry in state $\mathbf{e} \geq (m, m)$ as a *mature duopoly*. In the same spirit, we refer to an incumbent firm in state $e_n = 1$ as an *emerging firm* and an industry in state $(1, 1)$ as an *emerging duopoly*.

Scrap value and setup cost. If incumbent firm n exits the industry, it receives a scrap value X_n drawn from a continuous distribution $F_X(\cdot)$ with compact support. If potential entrant n enters the industry, it incurs a setup cost S_n drawn from a continuous distribution $F_S(\cdot)$ with compact support. Scrap values and setup costs are independently and identically distributed across firms and periods, and their realization is observed by the firm but not its rival. We assume that scrap values are drawn from a symmetric triangular distribution with support $[\overline{X} - \Delta_X, \overline{X} + \Delta_X]$, where $E_X(X_n) = \overline{X}$ and $\Delta_X > 0$ is a scale parameter, and setup costs are drawn from a symmetric triangular distribution with support $[\overline{S} - \Delta_S, \overline{S} + \Delta_S]$, where $E_S(S_n) = \overline{S}$ and $\Delta_S > 0$ is a scale parameter.

2.1 Firms' decisions

To analyze the pricing decision $p_n(\mathbf{e})$ of incumbent firm n, the exit decision $\phi_n(\mathbf{e}', X_n) \in \{0, 1\}$ of incumbent firm n with scrap value X_n, and the entry decision $\phi_n(\mathbf{e}', S_n) \in \{0, 1\}$ of potential entrant n with setup cost S_n, we work backwards from the exit-entry phase

[6] We obviously have to ensure $e_n \leq M$. To simplify the exposition we abstract from boundary issues in what follows.

to the price-setting phase. Because scrap values and setup costs are private to a firm, its rival remains uncertain about the firm's decision. Combining exit and entry decisions, we let $\phi_n(\mathbf{e}')$ denote the probability, as viewed from the perspective of its rival, that firm n decides *not* to operate in state $\mathbf{e}'$: If $e_n \neq 0$ so that firm n is an incumbent, then $\phi_n(\mathbf{e}') = E_X[\phi_n(\mathbf{e}', X_n)]$ is the probability of exiting; if $e'_n = 0$ so that firm n is an entrant, then $\phi_n(\mathbf{e}') = E_S[\phi_n(\mathbf{e}', S_n)]$ is the probability of not entering.

We use $V_n(\mathbf{e})$ to denote the expected net present value of future cash flows to firm n in state $\mathbf{e}$ at the beginning of the period and $U_n(\mathbf{e}')$ to denote the expected net present value of future cash flows to firm n in state $\mathbf{e}'$ *after* pricing decisions but *before* exit and entry decisions are made. The price-setting phase determines the value function $V_n(\mathbf{e})$ along with the policy function $p_n(\mathbf{e})$; the exit-entry phase determines the value function $U_n(\mathbf{e}')$ along with the policy function $\phi_n(\mathbf{e}')$.

Exit decision of incumbent firm. To simplify the exposition we focus on firm 1; the derivations for firm 2 are analogous. If incumbent firm 1 exits the industry, it receives the scrap value X_1 in the current period and perishes. If it does not exit and remains a going concern in the subsequent period, its expected net present value is

$$\widehat{X}_1(\mathbf{e}') = \beta \left[V_1(\mathbf{e}')(1 - \phi_2(\mathbf{e}')) + V_1(e'_1, 0)\phi_2(\mathbf{e}')\right],$$

where $\beta \in [0, 1)$ is the discount factor. The first bracketed term represents the contingency that firm 2 decides to operate in the subsequent period and the second term that firm 2 decides not to operate. Incumbent firm 1's decision to exit the industry in state $\mathbf{e}'$ is thus $\phi_1(\mathbf{e}', X_1) = 1\left[X_1 \geq \widehat{X}_1(\mathbf{e}')\right]$, where $1[\cdot]$ is the indicator function and $\widehat{X}_1(\mathbf{e}')$ serves as the critical level of the scrap value above which exit occurs. The probability of incumbent firm 1 exiting is $\phi_1(\mathbf{e}') = 1 - F_X(\widehat{X}_1(\mathbf{e}'))$. It follows that *before* incumbent firm 1 observes a particular draw of the scrap value, its expected net present value is given by the Bellman equation

$$\begin{aligned} U_1(\mathbf{e}') &= E_X\left[\max\left\{\widehat{X}_1(\mathbf{e}'), X_1\right\}\right] \\ &= (1 - \phi_1(\mathbf{e}'))\beta\left[V_1(\mathbf{e}')(1 - \phi_2(\mathbf{e}')) + V_1(e'_1, 0)\phi_2(\mathbf{e}')\right] \\ &\quad + \phi_1(\mathbf{e}')E_X\left[X_1 | X_1 \geq \widehat{X}_1(\mathbf{e}')\right], \end{aligned} \tag{1}$$

where $E_X\left[X_1 | X_1 \geq \widehat{X}_1(\mathbf{e}')\right]$ is the expectation of the scrap value conditional on exiting the industry.

Entry decision of potential entrant. If potential entrant 1 does not enter the industry, it perishes. If it enters and becomes an incumbent firm (without prior experience) in the subsequent period, its expected net present value is

$$\widehat{S}_1(\mathbf{e}') = \beta\left[V_1(1, e_2')(1-\phi_2(\mathbf{e}')) + V_1(1,0)\phi_2(\mathbf{e}')\right].$$

In addition, it incurs the setup cost S_1 in the current period. Potential entrant 1's decision to not enter the industry in state $\mathbf{e}'$ is thus $\phi_1(\mathbf{e}', S_1) = 1\left[S_1 \geq \widehat{S}_1(\mathbf{e}')\right]$, where $\widehat{S}_1(\mathbf{e}')$ is the critical level of the setup cost. The probability of potential entrant 1 not entering is $\phi_1(\mathbf{e}') = 1 - F_S(\widehat{S}_1(\mathbf{e}'))$ and *before* potential entrant 1 observes a particular draw of the setup cost, its expected net present value is given by the Bellman equation

$$\begin{aligned} U_1(\mathbf{e}') &= E_S\left[\max\left\{\widehat{S}_1(\mathbf{e}') - S_1, 0\right\}\right] \\ &= (1-\phi_1(\mathbf{e}'))\Big\{\beta[V_1(1,e_2')(1-\phi_2(\mathbf{e}')) + V_1(1,0)\phi_2(\mathbf{e}')] \\ &\quad - E_S\left[S_1 | S_1 \leq \widehat{S}_1(\mathbf{e}')\right]\Big\}, \end{aligned} \tag{2}$$

where $E_S\left[S_1 | S_1 \leq \widehat{S}_1(\mathbf{e}')\right]$ is the expectation of the setup cost conditional on entering the industry.[7]

Pricing decision of incumbent firm. In the price-setting phase the expected net present value of incumbent firm 1 is

$$\begin{aligned} V_1(\mathbf{e}) &= \max_{p_1}\,(p_1 - c(e_1))D_1(p_1, p_2(\mathbf{e})) + D_0(p_1, p_2(\mathbf{e}))U_1(\mathbf{e}) \\ &\quad + D_1(p_1, p_2(\mathbf{e}))U_1(e_1+1, e_2) + D_2(p_1, p_2(\mathbf{e}))U_1(e_1, e_2+1), \end{aligned} \tag{3}$$

where $U_1(\mathbf{e})$, $U_1(e_1+1, e_2)$, and $U_1(e_1, e_2+1)$ are determined in the exit-entry phase from equations (1) and (2).

Because $D_0(\mathbf{p}) = 1 - D_1(\mathbf{p}) - D_2(\mathbf{p})$, we can equivalently formulate the maximization problem on the right-hand side of the Bellman equation (3) as

$$\max_{p_1} \Pi_1(p_1, p_2(\mathbf{e}), \mathbf{e}),$$

[7] See Appendix A.1 for closed-form expressions for $E_X\left[X_1 | X_1 \geq \widehat{X}_1(\mathbf{e}')\right]$ in equation (1) and $E_S\left[S_1 | S_1 \leq \widehat{S}_1(\mathbf{e}')\right]$ in equation (2).

where

$$\Pi_1(p_1, p_2(\mathbf{e}), \mathbf{e}) = (p_1 - c(e_1))D_1(p_1, p_2(\mathbf{e})) + U_1(\mathbf{e})$$
$$+D_1(p_1, p_2(\mathbf{e}))\left[U_1(e_1+1, e_2) - U_1(\mathbf{e})\right] - D_2(p_1, p_2(\mathbf{e}))\left[U_1(\mathbf{e}) - U_1(e_1, e_2+1)\right] \quad (4)$$

is the long-run profit of incumbent firm 1. Given $p_2(\mathbf{e})$ and $\mathbf{e}$, $\Pi_1(p_1, p_2(\mathbf{e}), \mathbf{e})$ is strictly quasiconcave in p_1, so that the pricing decision $p_1(\mathbf{e})$ is uniquely determined by the solution to the first-order condition

$$mr_1(p_1, p_2(\mathbf{e})) - c(e_1)$$
$$+\left[U_1(e_1+1, e_2) - U_1(\mathbf{e})\right] + \frac{D_2(p_1, p_2(\mathbf{e}))}{1 - D_1(p_1, p_2(\mathbf{e}))}\left[U_1(\mathbf{e}) - U_1(e_1, e_2+1)\right] = 0, \quad (5)$$

where

$$mr_1(p_1, p_2(\mathbf{e})) = p_1 - \frac{\sigma}{1 - D_1(p_1, p_2(\mathbf{e}))}$$

is the marginal revenue of incumbent firm 1.[8] We note that $mr_1(p_1, p_2(\mathbf{e}))$ is increasing in p_1 and a formal representation of the concept of "inclusive price" formulated by Edlin (2010).

Equations (4) and (5) show that, besides short-run profit $(p_1 - c(e_1))D_1(p_1, p_2(\mathbf{e}))$, the price that an incumbent firm sets reflects two goals. First, by winning a sale, the firm may move further down its learning curve and improve its competitive position in the future. The "reward" that the firm receives if it wins the sale is $[U_1(e_1+1, e_2) - U_1(\mathbf{e})]$. We call this the *advantage-building motive* in pricing. Second, the firm may prevent its rival from moving further down its learning curve and becoming a more formidable competitor. The "penalty" that the firm incurs if its rival wins the sale is $[U_1(\mathbf{e}) - U_1(e_1, e_2+1)]$. This penalty is deflated by the probability $\frac{D_2(p_1, p_2(\mathbf{e}))}{1 - D_1(p_1, p_2(\mathbf{e}))}$ that the rival wins the sale in the event that the firm does not win the sale. We call $[U_1(\mathbf{e}) - U_1(e_1, e_2+1)]$ the *advantage-denying motive* in pricing.

Because $mr_1(p_1, p_2(\mathbf{e}))$ is strictly increasing in p_1 and $\frac{D_2(p_1, p_2(\mathbf{e}))}{1 - D_1(p_1, p_2(\mathbf{e}))}$ is independent of p_1 (from the properties of logit demand), equation (5) implies that any increase in the advantage-building or advantage-denying motives makes the firm more aggressive in pricing. To the extent that achieving improvements in the firm's competitive position is valuable, i.e., $[U_1(e_1+1, e_2) - U_1(\mathbf{e})] > 0$, and that preventing improvements in the rival's competitive position is valuable, i.e., $[U_1(\mathbf{e}) - U_1(e_1, e_2+1)] > 0$, the firm charges a price below the static optimum.[9] If these motives are sufficiently large, they may even result in price below

[8] See Appendix A.2 for an explanation.

[9] The value function $U_1(\mathbf{e})$ is endogenously determined in equilibrium. For some parameterizations, the advantage-building and advantage-denying motives fail to be positive.

marginal cost.

In sum, the pricing decision of an incumbent firm reflects the interplay of the short-run profit maximization, the advantage-building motive, and the advantage-denying motive. In Section 4, we further decompose the latter two motives and use them to isolate predatory incentives.

2.2 Equilibrium

Because our demand and cost specification is symmetric, we restrict ourselves to symmetric Markov perfect equilibria. The focus on symmetric equilibria does not imply that the industry inevitably evolves towards a symmetric structure. Depending on how successful a firm is in moving down its learning curve, it may have a cost and charge a price different from that of its rival.

Existence of a symmetric Markov perfect equilibrium in pure strategies follows from the arguments in Doraszelski & Satterthwaite (2010). In a symmetric equilibrium, the decisions taken by firm 2 in state $\mathbf{e} = (e_1, e_2)$ are identical to the decisions taken by firm 1 in state $\mathbf{e}^{[2]} = (e_2, e_1)$, where $\mathbf{e}^{[2]}$ is constructed from $\mathbf{e}$ by interchanging the stocks of know-how of firms 1 and 2. It therefore suffices to determine the value and policy functions of firm 1.

3 Equilibrium behavior and industry dynamics

We use the homotopy method in Besanko et al. (2010) to compute the Markov perfect equilibria of our dynamic stochastic game. [10] Although it cannot be guaranteed to find all equilibria, the advantage of this method is its ability to search for multiple equilibria in a systematic fashion.

Let $(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1)$ denote the vector of values and policies that are determined by the model, $\boldsymbol{\Omega}$ the vector of parameters of the model, and $\mathbf{H}(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1; \boldsymbol{\Omega}) = \mathbf{0}$ the system of equations (Bellman equations and optimality conditions) that defines an equilibrium. The equilibrium correspondence mapping parameters into values and policies is

$$\mathbf{H}^{-1}(\boldsymbol{\Omega}) = \{(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1) | \mathbf{H}(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1; \boldsymbol{\Omega}) = \mathbf{0}\}.$$

The equilibrium correspondence is a potentially complicated set of multidimensional surfaces. To explore the equilibrium correspondence, we compute slices of it by varying one parameter of the model, such as the progress ratio ρ. A slice of the equilibrium correspondence along ρ, denoted as $\mathbf{H}^{-1}(\rho)$ in what follows, consists of a finite number of differen-

[10] Our codes are available upon request. A detailed description of our application of natural-parameter homotopy is provided by Borkovsky, Doraszelski & Kryukov (2010).

tiable paths through $(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1, \rho)$ space. The homotopy algorithm traces out a path by numerically solving the differential equation that describes it.

Baseline parameterization. To compute slice of the equilibrium correspondence we hold all but one parameter fixed at the values in Table 1. While the baseline parameterization is not intended to be representative of any particular industry, it is neither entirely unrepresentative nor extreme. The discount factor is consistent with discount rates and product life cycle lengths in high-tech industries where learning-by-doing may be particularly important.[11] The baseline value for the progress ratio lies well within the range of empirical estimates Dutton & Thomas (1984). Setup costs are about three times scrap values and therefore largely sunk. Scrap values and setup costs are reasonably variable.[12]

The picture that the baseline parameterization paints is that of an industry where an emerging firm has a reasonable shot at gaining traction and a mature firm enjoys a modest degree of market power. In an emerging duopoly the own-price elasticity of demand is -9.15 at static Nash equilibrium prices and -2.63 in a mature duopoly; the corresponding cross-price elasticities are 2.08 and 2.61, respectively. Profit opportunities are reasonably good: if the industry instantly became a mature duopoly, then at static Nash equilibrium prices the annual rate of return on setup costs is about 22%.

3.1 Predation-like behavior

To illustrate the types of behavior that can emerge in our model, we examine the equilibria that arise for the baseline parameterization in Table 1. For two of these three equilibria Figure 2 shows the pricing decision of firm 1, the non-operating probability of firm 2, and the time path of the probability distribution over industry structures (empty, monopoly, and duopoly).[13]

The upper panels of Figure 2 exemplify what we call a *trenchy equilibrium*.[14] The pricing decision in the upper left panel exhibits a deep well in state (1,1) with $p_1(1,1) = -34.78$.

[11] The discount factor can be thought of as $\beta = \frac{\zeta}{1+r}$, where $r > 0$ is the per-period discount rate and $\zeta \in (0,1]$ is the exogenous probability that the industry survives from one period to the next. Consequently, our baseline value of β corresponds to a variety of scenarios that differ in the length of a period. For example, it corresponds to a period length of one year, a yearly discount rate of 5.26%, and certain survival. But it also corresponds to a period length of one month, a monthly discount rate of 1% (corresponding to a yearly discount rate of 12.7%), and a monthly survival probability of about 0.96. To put this in perspective, technology companies such as IBM and Microsoft had costs of capital in the range of 11 to 15% per annum in the late 1990s. Further, an industry with a monthly survival probability of 0.96 has an expected lifetime of 26.25 months. This scenario is therefore consistent with a pace of innovative activity that is expected to make an industry's current generation of products obsolete within two to three years.

[12] Any predatory incentives vanish as $\Delta_X \to \infty$ because the probability that the rival exits the industry approaches 0.5 irrespective of the behavior of the firm.

[13] The third equilibrium is essentially intermediate between the two shown in Figure 2.

[14] Our terminology is similar, but not identical, to that of Besanko et al. (2010).

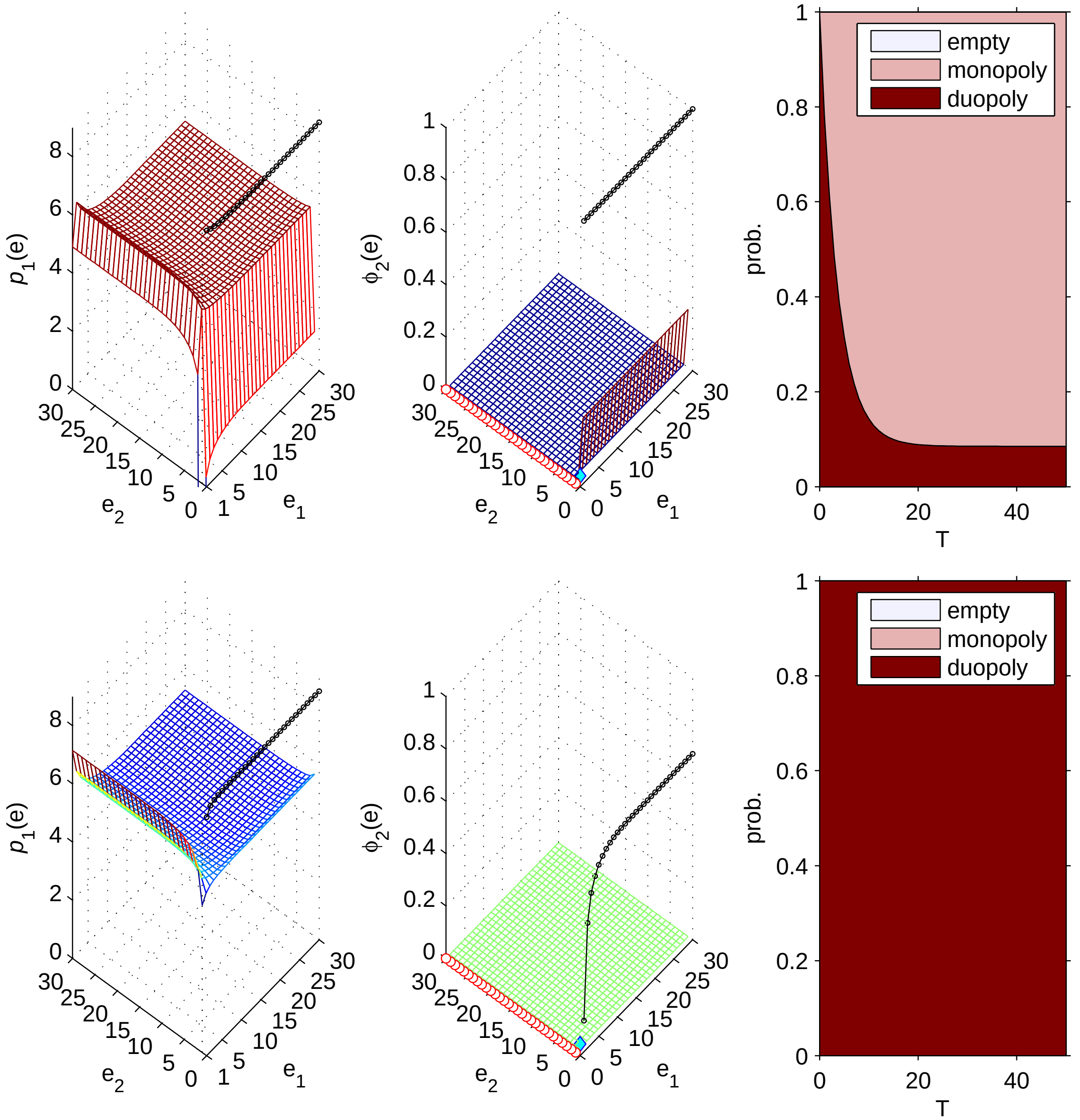

Figure 2: Pricing decision of firm 1 (left), non-operating probability of firm 2 (middle), and time path of probability distribution over industry structures, starting from $\mathbf{e} = (1, 1)$ at $T = 0$ (right). Trenchy (upper) and flat (lower) equilibria.

parameter	value
maximum stock of know-how M	30
price of outside good p_0	10
product differentiation σ	1
cost at top of learning curve κ	10
bottom of learning curve m	15
progress ratio ρ	0.75
scrap value $\overline{X}$, Δ_X	1.5, 1.5
setup cost $\overline{S}$, Δ_S	4.5, 1.5
discount factor β	0.95

Table 1: Baseline parameterization.

A *well* is a preemption battle where firms vie to be the first to move down from the top of their learning curves in order to gain a competitive advantage. The pricing decision further exhibits a deep trench along the e_1 axis with $p_1(e_1, 1)$ ranging from 0.08 to 1.24 for $e_1 \in \{2, \ldots, 30\}$.[15] A *trench* is a price war that the leader (firm 1) wages against the follower (firm 2). One can think of a trench as an endogenously arising mobility barrier in the sense of Caves & Porter (1977). In the trench the follower exits the industry with a positive probability of $\phi_2(1, e_2) = 0.22$ for $e_2 \in \{2, \ldots, 30\}$ as the upper middle panel shows. The follower remains in in this exit zone as long as it does not win the sale. Once the follower exits, the leader raises its price and the industry becomes an entrenched monopoly.[16] This sequence of events resembles conventional notions of predatory pricing. The industry may also evolve into a mature duopoly if the follower manages to crash through the mobility barrier by winning the sale but, as the upper right panel of Figure 2 shows, this is far less likely than an entrenched monopoly.

The lower panels of Figure 2 are typical for a *flat equilibrium*. There is a shallow well in state $(1, 1)$ with $p_1(1, 1) = 5.05$ as the lower left panel shows. Absent mobility barriers in the form of trenches, however, any competitive advantage is temporary and the industry evolves into a mature duopoly as the lower right panel shows.

3.2 Industry structure, conduct, and performance

As looking at policy functions plots for large number of equilibria is not practical, we succinctly describe an equilibrium by the industry structure, conduct, and performance that it implies. First, we use the policy functions $\mathbf{p}$ and $\boldsymbol{\phi}$ to construct the matrix of state-to-

[15]Because prices are strategic complements, there is also a shallow trench along the e_2 axis with $p_1(1, e_2)$ ranging from 3.63 to 4.90 for $e_2 \in \{2, \ldots, 30\}$.

[16]In this particular equilibrium, $\phi_2(e_1, 0) = 1.00$ for $e_1 \in \{2, \ldots, 30\}$, so that a potential entrant does not enter if the incumbent firm has moved down from the top of its learning curve.

state transition probabilities that characterizes the Markov process of industry dynamics. From this, we compute the transient distribution over states in period T, $\boldsymbol{\mu}^T$, starting from state $(1,1)$ in period 0. This tells us how likely each possible industry structure is in period T given that the game began as an emerging duopoly. Depending on T, the transient distributions can capture short-run or long-run (steady-state) dynamics. We think of period 1000 as the long run and, with a slight abuse of notation, denote $\boldsymbol{\mu}^{1000}$ by $\boldsymbol{\mu}^{\infty}$. Finally, we use the transient distributions to compute six metrics of industry structure, conduct, and performance.

Structure. *Expected long-run Herfindahl index:*

$$HHI^{\infty} = \sum_{\mathbf{e} \geq (0,0)} \frac{\mu^{\infty}(\mathbf{e})}{1 - \mu^{\infty}(0,0)} HHI(\mathbf{e}),$$

where

$$HHI(\mathbf{e}) = \sum_{n=1}^{2} \left[\frac{D_n(\mathbf{e})}{D_1(\mathbf{e}) + D_2(\mathbf{e})} \right]^2$$

is the Herfindahl index in state $\mathbf{e}$ and $D_k(\mathbf{e}) = D_k(p_1(\mathbf{e}), p_2(\mathbf{e}))$ is the probability that the buyer purchases good $k \in \{0, 1, 2\}$ in state $\mathbf{e}$. The expected long-run Herfindahl index is a summary measure of industry concentration. If $HHI^{\infty} > 0.5$, then an asymmetric industry structure arises and persists.

Conduct. *Expected long-run average price:*

$$\overline{p}^{\infty} = \sum_{\mathbf{e} \geq (0,0)} \frac{\mu^{\infty}(\mathbf{e})}{1 - \mu^{\infty}(0,0)} \overline{p}(\mathbf{e}),$$

where

$$\overline{p}(\mathbf{e}) = \sum_{n=1}^{2} \frac{D_n(\mathbf{e})}{D_1(\mathbf{e}) + D_2(\mathbf{e})} p_n(\mathbf{e})$$

is the (share-weighted) average price in state $\mathbf{e}$.

Performance. *Expected long-run consumer surplus:*

$$CS^{\infty} = \sum_{\mathbf{e}} \mu^{\infty}(\mathbf{e})\, CS(\mathbf{e}),$$

where

$$CS(\mathbf{e}) = \sigma \log \left\{ \exp\left(\frac{-p_0}{\sigma} \right) + \sum\nolimits_{n=1}^{2} \exp\left(\frac{-p_n(\mathbf{e})}{\sigma} \right) \right\}$$

is consumer surplus in state $\mathbf{e}$.

Expected long-run total surplus:

$$TS^{\infty} = \sum_{\mathbf{e}} \mu^{\infty}(\mathbf{e}) \left\{ CS(\mathbf{e}) + \sum_{n=1}^{2} PS_n(\mathbf{e}) \right\},$$

where $PS_n(\mathbf{e})$ is the producer surplus of firm n in state $\mathbf{e}$.[17]

Expected discounted consumer surplus:

$$CS^{NPV} = \sum_{T=0}^{\infty} \beta^T \sum_{\mathbf{e}} \mu^T(\mathbf{e})\, CS(\mathbf{e}).$$

Expected discounted total surplus:

$$TS^{NPV} = \sum_{T=0}^{\infty} \beta^T \sum_{\mathbf{e}} \mu^T(\mathbf{e}) \left\{ CS(\mathbf{e}) + \sum_{n=1}^{2} PS_n(\mathbf{e}) \right\}.$$

By focusing on the states that arise in the long run (as given by $\boldsymbol{\mu}^{\infty}$), CS^{∞} and TS^{∞} summarize the long-run implications of equilibrium behavior for industry performance. In contrast, CS^{NPV} and TS^{NPV} summarize the short-run and the long-run implications that arise along entire time paths of states (as given by $\boldsymbol{\mu}^0$, $\boldsymbol{\mu}^1$, ...). Hence, CS^{NPV} and TS^{NPV} reflect any short run *competition for the market* as well as any long-run *competition in the market.*

Table 2 illustrates industry structure, conduct, and performance for the equilibria in Section 3.1. The Herfindahl index reflects that the industry is substantially more likely to be monopolized under the trenchy equilibrium than under the flat equilibrium. In the entrenched monopoly prices are higher. Finally, consumer and total surplus are lower under the trenchy equilibrium than under the flat equilibrium. The difference between the equilibria is smaller for CS^{NPV} than for CS^{∞} because the former metric accounts for the competition for the market in the short run that manifests itself in the deep well and trench of the trenchy equilibrium and mitigates the lack of competition in the market in the long run.

Progress ratio. The upper panel of Figure 3 illustrates the equilibrium correspondence by plotting HHI^{∞} against ρ.[18] If $\rho = 1$ there is no learning-by-doing, while if $\rho = 0$ the learning economies become infinitely strong in the sense that the marginal cost of production jumps from κ for the first unit to 0 for any further unit. The progress ratio ρ therefore

[17] See Appendix A.3 for a derivation.

[18] See the Online Appendix for the remaining metrics.

metric	trenchy equilibrium	flat equilibrium
HHI^{∞}	0.96	0.50
$\overline{p}^{\infty}$	8.26	5.24
CS^{∞}	1.99	5.46
TS^{∞}	6.09	7.44
CS^{NPV}	104.17	109.07
TS^{NPV}	110.33	121.14

Table 2: Industry structure, conduct, and performance. Trenchy and flat equilibria.

determines the possible extent of efficiency gains from pricing aggressively in order to move down the learning curve.

There are multiple equilibria for ρ from 0 to 0.80. $\mathbf{H}^{-1}(\rho)$ involves a main path (labeled MP) with one equilibrium for ρ from 0 to 1, a semi-loop (SL) with two equilibria for ρ from 0 to 0.80, and two loops (L_1 and L_2) with two equilibria for ρ from 0.25 to 0.70 and, respectively, from 0.35 to 0.65.

The equilibria on MP are flat. The industry evolves into a mature duopoly with $HHI^{\infty} = 0.5$ as in the flat equilibrium in Section 3.1. The equilibria on the lower fold of SL similarly involve an almost symmetric industry structure. The equilibria on the upper fold of SL as well as those on L_1 and L_2 are trenchy. As in the trenchy equilibrium in Section 3.1, the industry evolves into an entrenched monopoly with $HHI^{\infty} \approx 1.0$.

Product differentiation. The middle panel of Figure 3 plots HHI^{∞} against σ, which influences how desirable it is for a firm to induce its rival to exit the industry. As $\sigma \to 0$ the goods become homogenous. As competition intensifies, profits fall. $\sigma = 0.3$ already entails very weak product differentiation: In an emerging duopoly the own- and cross-price elasticities of demand are -28.17 and 6.38, respectively, at static Nash equilibrium prices and -6.42 and 6.42 in a mature duopoly.[19] As $\sigma \to \infty$, firms operate in independent markets. $\sigma = 3$ already entails very strong product differentiation: The own- and cross-price elasticities are -3.72 and 0.84, respectively, in an emerging duopoly and -1.66 and 1.07 in a mature duopoly.

There are multiple equilibria for σ below 1.10. While $\mathbf{H}^{-1}(\sigma)$ involves just a main path (labeled MP), multiple equilibria arise as this path bends back on itself. The equilibria on the lower fold of MP are flat and the industry evolves into a mature duopoly. The equilibria on the upper fold of MP are trenchy and the industry evolves into an entrenched monopoly.

[19] Our algorithm fails for σ below 0.3.

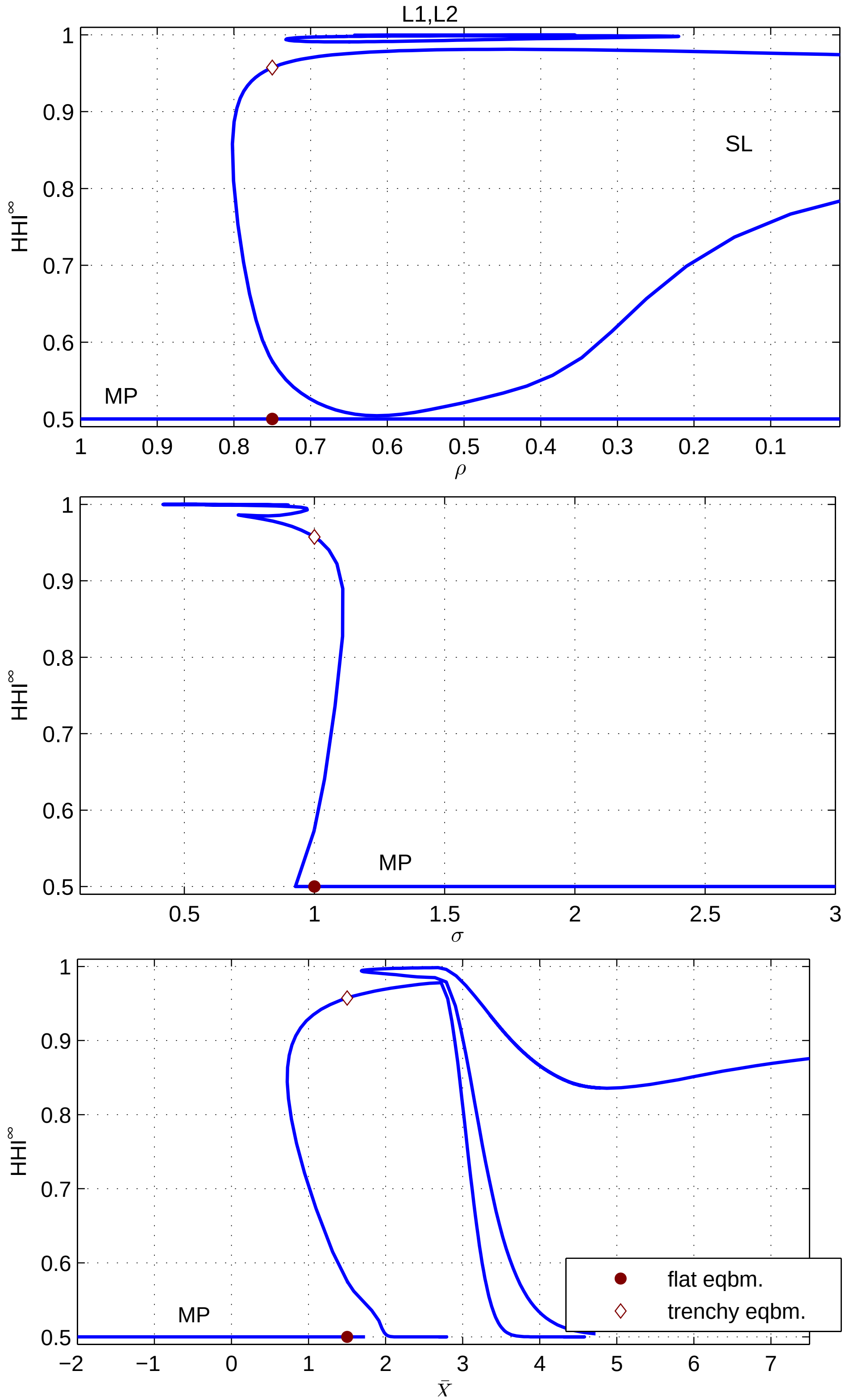

Figure 3: Expected long-run Herfindahl index. Equilibrium correspondence: slice along $\rho \in [0, 1]$ (upper panel), $\sigma \in [0.3, 3]$ (middle panel), and $\overline{X} \in [-1.5, 7.5]$ (lower panel).

Scrap value. The lower panel of Figure 3 plots HHI^{∞} against $\overline{X}$. $\overline{X}$ determines how easy it is for a firm to induce its rival to exit the industry. Because a firm can always guarantee itself a nonnegative short-run profit, exit is impossible if $\overline{X} + \Delta_X < 0 \Leftrightarrow \overline{X} < 1.5$. As $\overline{X} \to \infty$, exit becomes inevitable. At the same time, however, exit is immediately followed by entry. In particular, if $\overline{X} - \Delta_X > \overline{S} + \Delta_S \Leftrightarrow \overline{X} > 7.5$, then a potential entrant has an incentive to incur the setup cost for the exclusive purpose of receiving the scrap value.[20]

There are multiple equilibria for $\overline{X}$ from 0.7 to 5. $\mathbf{H}^{-1}(\overline{X})$ involves a main path (labeled MP) that bends back on itself. The equilibria on the lower fold of MP are flat and the industry evolves into a mature duopoly. The equilibria on the upper fold of MP are trenchy and the industry evolves into an entrenched monopoly.

Overall, many equilibria are trenchy. In these equilibria predation-like behavior arises. Multiplicity of equilibria is the norm rather than the exception, and trenchy equilibria typically coexist with flat equilibria.

4 Isolating predatory incentives

To isolate a firm's predatory pricing incentives, we decompose the advantage-building and advantage-denying motives in the equilibrium pricing condition (5). Straightforward, albeit tedious, algebra shows that in a symmetric Markov perfect equilibrium the first-order condition (5) for the equilibrium price $p_1(\mathbf{e})$ charged by incumbent firm 1 can be written as

$$mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) - c(e_1) + \left[\sum_{k=1}^{5} \Gamma_1^k(\mathbf{e})\right] + \frac{D_2(\mathbf{e})}{1 - D_1(\mathbf{e})} \left[\sum_{k=1}^{4} \Theta_1^k(\mathbf{e})\right] = 0. \tag{6}$$

The terms $\Gamma_1^k(\mathbf{e})$ decompose the advantage-building motive $[U_1(e_1+1, e_2) - U_1(\mathbf{e})]$ and the terms $\Theta_1^k(\mathbf{e})$ decompose the advantage-denying motive $[U_1(\mathbf{e}) - U_1(e_1, e_2+1)]$. Throughout we use equation (1) to express $U_1(\mathbf{e})$ in terms of $V_1(\mathbf{e})$. Below we describe each term in the decomposition in turn.[21]

Advantage building. The decomposed advantage-building motives summarized in Table 3 are the various sources of incremental benefit to the firm from winning the sale and moving further down its learning curve.

[20] Our model cannot capture perfect contestability which requires $\Delta_X = \Delta_S = 0$ in addition to $\overline{X} = \overline{S}$.

[21] The decomposition applies to an industry with two incumbent firms in state $\mathbf{e} \geq (1,1)$. Because the terms $\Gamma_1^k(\mathbf{e})$ and $\Theta_1^k(\mathbf{e})$ are typically positive, we refer to them as incremental benefits. To streamline the exposition, we further presume monotonicity of the value and policy functions. For some parameterizations these assumptions fail.

advantage-building motives	if the firm wins the sale and moves further down its learning curve, then the firm...
$\Gamma_1^1(\mathbf{e})$ baseline	... improves its competitive position within the duopoly
$\Gamma_1^2(\mathbf{e})$ exit	... increases its rival's exit probability
$\Gamma_1^3(\mathbf{e})$ survival	... decreases its exit probability
$\Gamma_1^4(\mathbf{e})$ scrap value	... increases its expected scrap value
$\Gamma_1^5(\mathbf{e})$ market structure	... gains from an improved competitive position as a monopolist versus as a duopolist

Table 3: Decomposed advantage-building motives.

Baseline advantage-building motive:

$$\Gamma_1^1(\mathbf{e}) = (1-\phi_1(\mathbf{e}))\beta \left[V_1(e_1+1,e_2) - V_1(\mathbf{e})\right].$$

The baseline advantage-building motive is the incremental benefit to the firm from an improvement in its competitive position, assuming that its rival does not exit in the current period. The increase in the firm's expected net present value $V_1(e_1+1,e_2)-V_1(\mathbf{e})$ is deflated by the probability $(1-\phi_1(\mathbf{e}))$ that the firm remains in the industry in the current period because otherwise the incremental benefit is nil. The baseline advantage-building motive captures both the lower marginal cost and any future advantages (winning the sale, exit of rival, etc.) that stem from this lower cost.

Advantage-building/exit motive:

$$\Gamma_1^2(\mathbf{e}) = (1-\phi_1(\mathbf{e}))\left[\phi_2(e_1+1,e_2) - \phi_2(\mathbf{e})\right]\beta[V_1(e_1+1,0) - V_1(e_1+1,e_2)].$$

The advantage-building/exit motive is the incremental benefit to the firm from increasing its rival's exit probability from $\phi_2(\mathbf{e})$ to $\phi_2(e_1+1,e_2)$. The increase in the firm's expected net present value if the rival exits $V_1(e_1+1,0) - V_1(e_1+1,e_2)$ is again deflated by the probability $(1-\phi_1(\mathbf{e}))$ that the firm remains in the industry.

Advantage-building/survival motive:

$$\Gamma_1^3(\mathbf{e}) = \left[\phi_1(\mathbf{e}) - \phi_1(e_1+1,e_2)\right]\beta\left[\phi_2(e_1+1,e_2)V_1(e_1+1,0) + (1-\phi_2(e_1+1,e_2))V_1(e_1+1,e_2)\right].$$

The advantage-building/survival motive is the incremental benefit to the firm from decreasing its exit probability from $\phi_1(\mathbf{e})$ to $\phi_1(e_1+1,e_2)$; if the firm remains a going concern, its expected net present value is $[\phi_2(e_1+1,e_2)V_1(e_1+1,0) + (1-\phi_2(e_1+1,e_2))V_1(e_1+1,e_2)]$.

advantage-denying motives	if the firm wins the sale and prevents its rival from moving further down its learning curve, then the firm ...
$\Theta_1^1(\mathbf{e})$ baseline	... prevents its rival from improving its competitive position within the duopoly
$\Theta_1^2(\mathbf{e})$ exit	... prevents its rival's exit probability from decreasing
$\Theta_1^3(\mathbf{e})$ survival	... prevents its exit probability from increasing
$\Theta_1^4(\mathbf{e})$ scrap value	... prevents its expected scrap value from decreasing

Table 4: Decomposed advantage-denying motives.

Advantage-building/scrap value motive:

$$\Gamma_1^4(\mathbf{e}) = \phi_1(e_1+1,e_2)E_X\left[X_1|X_1 \geq \widehat{X}_1(e_1+1,e_2)\right] - \phi_1(\mathbf{e})E_X\left[X_1|X_1 \geq \widehat{X}_1(\mathbf{e})\right].$$

The advantage-building/scrap value motive is incremental benefit to the firm from increasing its scrap value in expectation from $\phi_1(\mathbf{e})E_X\left[X_1|X_1 \geq \widehat{X}_1(\mathbf{e})\right]$ to $\phi_1(e_1+1,e_2)E_X\left[X_1|X_1 \geq \widehat{X}_1(e_1+1,e_2)\right]$.
Advantage-building/market structure motive:

$$\Gamma_1^5(\mathbf{e}) = (1-\phi_1(\mathbf{e}))\phi_2(\mathbf{e})\beta\left\{[V_1(e_1+1,0) - V_1(e_1,0)] - [V_1(e_1+1,e_2) - V_1(\mathbf{e})]\right\}.$$

The advantage-building/market structure motive is the incremental benefit to the firm from a lower marginal cost and any future advantages that stem from this lower cost as a monopolist, $[V_1(e_1+1,0) - V_1(e_1,0)]$, versus as a duopolist, $[V_1(e_1+1,e_2) - V_1(\mathbf{e})]$.

Advantage denying. The decomposed advantage-denying motives summarized in Table 3 are the various sources of incremental benefit to the firm from winning the sale and, in so doing, preventing its rival from moving further down its learning curve.
Baseline advantage-denying motive:

$$\Theta_1^1(\mathbf{e}) = (1-\phi_1(\mathbf{e}))(1-\phi_2(e_1,e_2+1))\beta\left[V_1(\mathbf{e}) - V_1(e_1,e_2+1)\right].$$

The baseline advantage-denying motive is the incremental benefit to the firm from preventing an improvement in its rival's competitive position, assuming its rival does not exit in the current period. The increase in the firm's expected net present value $V_1(\mathbf{e})-V_1(e_1,e_2+1)$ is deflated by the probability $(1-\phi_1(\mathbf{e}))$ that the firm remains in the industry in the current period and by the probability $(1-\phi_2(e_1,e_2+1))$ that the rival does so because otherwise the incremental benefit is nil.

Advantage-denying/exit motive:

$$\Theta_1^2(\mathbf{e}) = (1-\phi_1(\mathbf{e}))[\phi_2(\mathbf{e}) - \phi_2(e_1, e_2+1)]\beta[V_1(e_1,0) - V_1(\mathbf{e})]. \tag{7}$$

The advantage-denying/exit motive is the incremental benefit to the firm from preventing its rival's exit probability from decreasing from $\phi_2(\mathbf{e})$ to $\phi_2(e_1, e_2+1)$. The increase in the firm's expected net present value $V_1(\mathbf{e})$ to $V_1(e_1, 0)$ if the rival exits is again deflated by the probability $(1-\phi_1(\mathbf{e}))$ that the firm remains in the industry.
Advantage-denying/survival motive:

$$\Theta_1^3(\mathbf{e}) = [\phi_1(e_1, e_2+1) - \phi_1(\mathbf{e})]\,\beta\,[\phi_2(e_1, e_2+1)V_1(e_1,0) + (1-\phi_2(e_1, e_2+1))V_1(e_1, e_2+1)]\,.$$

The advantage-denying/survival motive is the incremental benefit to the firm from preventing its exit probability from increasing from $\phi_1(\mathbf{e})$ to $\phi_1(e_1, e_2+1)$; if the firm remains a going concern, its expected net present value is $[\phi_2(e_1, e_2+1)V_1(e_1,0) + (1-\phi_2(e_1, e_2+1))V_1(e_1, e_2+1)]$.
Advantage-denying/scrap value motive:

$$\Theta_1^4(\mathbf{e}) = \phi_1(\mathbf{e})E_X\left[X_1|X_1 \geq \widehat{X}_1(\mathbf{e})\right] - \phi_1(e_1, e_2+1)E_X\left[X_1|X_1 \geq \widehat{X}_1(e_1, e_2+1)\right].$$

The advantage-denying/scrap value motive is the incremental benefit to the firm from preventing its scrap value from decreasing in expectation from $\phi_1(\mathbf{e})E_X\left[X_1|X_1 \geq \widehat{X}_1(\mathbf{e})\right]$ to $\phi_1(e_1, e_2+1)E_X\left[X_1|X_1 \geq \widehat{X}_1(e_1, e_2+1)\right]$.

The upper left and middle panels of Table 5 illustrate the decomposition (6) for the trenchy equilibrium in Section 3.1 for a set of states where firm 2 is emerging. The competition for the market in the well is driven mostly by the baseline advantage-building motive $\Gamma_1^1(1,1)$ and the advantage-building/exit motive $\Gamma_2^1(1,1)$. In contrast, the competition for the market in the trench is driven mostly by the baseline advantage-denying motive $\Theta_1^1(e_1, 1)$ and the advantage-denying/exit motive $\Theta_2^1(e_1, 1)$ for $e_1 \in \{2, \ldots, 30\}$. The predation-like behavior in the trench arises not because by becoming more efficient the leader increases the probability that the follower exits the industry but because by preventing the follower from becoming more efficient the leader keeps the follower in the trench and thus prone to exit. Another way to put this is that the leader makes the cost to the follower of attempting to move down its learning curve comparable to the benefit to the follower of doing so, so that exit is in the follower's interest. Viewed this way, the aggressive pricing in the trench can be viewed as raising the rival's cost of remaining in the industry.

As can be seen in lower left and middle panels of Table 5 for a set of states where firm 2 has already gained some traction neither the advantage-building nor the advantage-denying motives are very large. To the extent that the price is below the static optimum this is due mostly to the baseline advantage-building motive $\Gamma_1^1(e_1, 4)$ for $e_1 \in \{1, \ldots, 30\}$.

4.1 Definitions of predatory pricing in the literature

To serve as a point of departure for defining predatory incentives, we relate our decomposition (6) to economic definitions of predatory pricing formulated in the existing literature.

Cabral & Riordan (1997). Cabral & Riordan (1997) call "an action predatory if (1) a different action would increase the probability that rivals remain viable and (2) the different action would be more profitable under the counterfactual hypothesis that the rival's viability were unaffected" (p. 160). In the context of predatory pricing, it is natural to interpret "a different action" as a higher price. To port the Cabral & Riordan definition from their two-period model to our infinite-horizon dynamic stochastic game, we take the "rival's viability" to refer to the probability that the rival exits the industry in the current period. Finally, we interpret "the different action would be more profitable" in the spirit of Markov perfection to mean that by a setting a higher price in the current period but returning to equilibrium play from the subsequent period onward, the firm can affect the evolution of the state to increase its expected net present value.

With these interpretations, Proposition 1 tells us that the Cabral & Riordan definition of predatory pricing boils down to the signs of the advantage-building/exit and advantage-denying/exit motives.

Proposition 1 *Consider an industry with two incumbent firms in state* $\mathbf{e} \geq (1, 1)$*. Assume* $\phi_1(\mathbf{e}) < 1$*,* $V_1(e_1, 0) > V_1(\mathbf{e})$*, and* $V_1(e_1 + 1, 0) > V_1(e_1 + 1, e_2)$*, i.e., exit is less than certain and the expected net present value of a monopolist exceeds that of a duopolist. (a) If* $\Gamma_1^2(\mathbf{e}) \geq 0$ *and* $\Theta_1^2(\mathbf{e}) \geq 0$*, with at least one of these inequalities being strict, then the equilibrium price* $p_1(\mathbf{e})$ *in state* $\mathbf{e}$ *is predatory according to the Cabral & Riordan (1997) definition; (b) if* $p(\mathbf{e})$ *is predatory according to the Cabral & Riordan definition, then* $\Gamma_1^2(\mathbf{e}) > 0$ *or* $\Theta_1^2(\mathbf{e}) > 0$*.*

Proof. See Appendix B. ■

Ordover & Willig (1981). According to Ordover & Willig (1981), "[p]redatory behavior is 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" (pp. 9–10). As Cabral & Riordan (1997) observe,

			advantage building					advantage denying				alternative characterizations					
$\mathbf{e}$	$p_1(\mathbf{e})$	$c(e_1)$	$\Gamma_1^1(\mathbf{e})$	$\Gamma_1^2(\mathbf{e})$	$\Gamma_1^3(\mathbf{e})$	$\Gamma_1^4(\mathbf{e})$	$\Gamma_1^5(\mathbf{e})$	$\Theta_1^1(\mathbf{e})$	$\Theta_1^2(\mathbf{e})$	$\Theta_1^3(\mathbf{e})$	$\Theta_1^4(\mathbf{e})$	1	2	3	4	5	6
(1,1)	-34.78	10.00	39.45	6.44	0.02	0.00	-0.01	0.93	0.03	0.44	-0.51	√√	√√	√√	√√	√	√√
(2,1)	0.08	7.50	4.27	0.02	0.00	0.00	-0.20	32.93	6.45	0.00	0.00	√√	√√	√√	√√	√√	√
(3,1)	0.56	6.34	2.94	0.01	0.00	0.00	-0.12	33.96	6.27	0.00	0.00	√√	√√	√√	√√	√√	√
(4,1)	0.80	5.63	2.20	0.01	0.00	0.00	-0.08	34.54	6.17	0.00	0.00	√√	√√	√√	√√	√√	√
(5,1)	0.95	5.13	1.71	0.01	0.00	0.00	-0.05	34.91	6.10	0.00	0.00	√√	√√	√√	√√	√√	√
(6,1)	1.05	4.75	1.36	0.00	0.00	0.00	-0.04	35.17	6.06	0.00	0.00	√√	√√	√√	√√	√√	
(7,1)	1.11	4.46	1.09	0.00	0.00	0.00	-0.03	35.35	6.02	0.00	0.00	√√	√√	√√	√√	√√	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
(14,1)	1.24	3.34	0.09	0.00	0.00	0.00	0.00	35.71	5.96	0.00	0.00	√√	√√	√√	√√	√√	
(15,1)	1.24	3.25	0.00	0.00	0.00	0.00	0.00	35.71	5.96	0.00	0.00	√√	√√	√√	√√	√√	
(16,1)	1.24	3.25	0.00	0.00	0.00	0.00	0.00	35.71	5.96	0.00	0.00	√√	√√	√√	√√	√√	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
(30,1)	1.24	3.25	0.00	0.00	0.00	0.00	0.00	35.71	5.96	0.00	0.00	√√	√√	√√	√√	√√	
(1,4)	4.41	10.00	5.21	0.00	1.92	-0.52	0.00	0.00	0.00	0.00	0.00	√√	√				
(2,4)	6.06	7.50	2.87	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.00	√√	√				
(3,4)	5.79	6.34	2.12	0.00	0.00	0.00	0.00	0.24	0.00	0.00	0.00	√√	√				
(4,4)	5.65	5.63	1.66	0.00	0.00	0.00	0.00	0.31	0.00	0.00	0.00	√√	√				
(5,4)	5.56	5.13	1.34	0.00	0.00	0.00	0.00	0.35	0.00	0.00	0.00	√√	√				
(6,4)	5.49	4.75	1.10	0.00	0.00	0.00	0.00	0.39	0.00	0.00	0.00	√√	√				
(7,4)	5.45	4.46	0.90	0.00	0.00	0.00	0.00	0.41	0.00	0.00	0.00	√√	√				
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
(14,4)	5.32	3.34	0.09	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	√√	√				
(15,4)	5.32	3.25	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	√	√				
(16,4)	5.32	3.25	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	√	√				
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
(30,4)	5.32	3.25	0.00	0.00	0.00	0.00	0.00	0.47	0.00	0.00	0.00	√	√				

Table 5: Decomposed advantage-building and advantage-denying motives and alternative characterizations of predatory incentives, Trenchy equilibrium. √√ means that the weighted sum of the predatory pricing incentives is larger than 0.5, √ that the weighted sum is between 0 and 0.5, and a blank that the weighted sum smaller or equal to 0.

the premise in the Ordover & Willig definition is that the rival is viable with certainty.[22] Proposition 2 establishes a formal relationship between the Ordover & Willig definition of predation and our decomposition.

Proposition 2 *Consider an industry with two incumbent firms in state* $\mathbf{e} \geq (1,1)$*. Assume* $\phi_1(\mathbf{e}) < 1$*,* $V_1(e_1, 0) > V_1(\mathbf{e})$*, and* $V_1(e_1+1, 0) > V_1(e_1+1, e_2)$*, i.e., exit is less than certain and the expected net present value of a monopolist exceeds that of a duopolist. (a) If* $\Gamma_1^2(\mathbf{e}) \geq 0$*,* $\Theta_1^2(\mathbf{e}) \geq 0$*,* $\Gamma_1^5(\mathbf{e}) \geq 0$*,* $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right] \geq 0$*,* $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right] \geq 0$*, and* $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right] \geq 0$*, with strict inequality for either* $\Gamma_1^2(\mathbf{e})$ *or* $\Theta_1^2(\mathbf{e})$*, then the equilibrium price* $p_1(\mathbf{e})$ *in state* $\mathbf{e}$ *is predatory according to the Ordover & Willig (1981) definition;*[23] *(b) if* $p_1(\mathbf{e})$ *is predatory according to the Ordover & Willig definition, then* $\Gamma_1^2(\mathbf{e}) > 0$*,* $\Theta_1^2(\mathbf{e}) > 0$*,* $\Gamma_1^5(\mathbf{e}) > 0$*,* $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right] > 0$*,* $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right] > 0$*, or* $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right] > 0$*.*

Proof. See Appendix B. ■

4.2 Alternative definitions of predatory incentives

To detect the presence of predatory pricing antitrust authorities routinely ask whether a firm sacrifices current profit in exchange for the expectation of higher future profit following the exit of its rival. This sacrifice test thus views predation as an "investment in monopoly profit" (Bork 1978). As Edlin & Farrell (2004) point out, one way to test for sacrifice is to determine whether the derivative of a suitably defined profit function is positive at the price the firm has chosen, which indicates that the chosen price is less than the price that maximizes profit. Moreover, "[i]n principle this profit function should incorporate *everything except effects on competition*" (p. 510, our italics). [24]

To formalize the sacrifice test, decompose the profit function of incumbent firm 1 $\Pi_1(p_1)$ into an everything-except-effects-on-competition profit function $\Pi_1^{EEEC}(p_1)$ and the remainder $\Omega(p_1)$:

$$\Pi_1(p_1) = \Pi_1^{EEEC}(p_1) + \Omega_1(p_1), \tag{8}$$

[22]This observation indeed motivates Cabral & Riordan (1997) to propose their own definition: "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 [the scrap value]) hardly means that firm A intends to drive firm B from the market" (p. 160).

[23]The notation $\cdot|_{\phi_2=0}$ signifies that we are evaluating the relevant term under the assumption that the rival remains viable with certainty.

[24]The sacrifice test is closely related to the 'no economic sense' test that holds that "conduct is not exclusionary or predatory unless it would make no economic sense for the defendant but for the tendency to eliminate or lessen competition" (Werden 2006, p. 417). Both tests have been criticized for "not generally [being] a reliable indicator of the impact of allegedly exclusionary conduct on consumer welfare—the primary focus of antitrust laws" (Salop 2006, p. 313).

where with a slight abuse of notation we suppress $p_2(\mathbf{e})$ and $\mathbf{e}$ as arguments. By construction $\Omega(p_1)$ reflects the effects on competition of the chosen price and therefore the predatory incentives of incumbent firm 1. It follows from equation (8) that in equilibrium

$$\frac{\partial \Pi_1^{EEEC}(p_1(\mathbf{e}))}{\partial p_1} > 0 \Leftrightarrow -\frac{\partial \Omega_1(p_1(\mathbf{e}))}{\partial p_1} > 0. \tag{9}$$

If $-\frac{\partial \Omega(p_1(\mathbf{e}))}{\partial p_1} > 0$, then the marginal return to pricing more aggressively in order to improve the competitive environment to the firm's advantage is positive so that the "investment in monopoly profit" is worthwhile. Our definitions of predatory incentives correspond to different operationalizations of the everything-except-effects-on-competition profit function.

Expanding the above quote from Edlin & Farrell (2004) "[i]n principle this profit function should incorporate everything except effects on competition, *but in practice sacrifice tests often use short-run data*, and we will often follow the conventional shorthand of calling it short-run profit" (p. 510, our italics). Letting $\Pi^{EEEC}(p_1) = (p_1 - c_1(e_1))D_1(p_1, p_2(\mathbf{e}))$ be the short-run profit of incumbent firm 1, it follows from equation (9) that $-\frac{\partial \Omega(p_1(\mathbf{e}))}{\partial p_1} > 0$ if and only if $\left[\sum_{k=1}^{5} \Gamma_1^k(\mathbf{e})\right] + \frac{D_2(\mathbf{e})}{1-D_1(\mathbf{e})}\left[\sum_{k=1}^{4} \Theta_1^k(\mathbf{e})\right] > 0$. Our first definition of predatory incentives is thus:

Definition 1 (short-run profit) *The predatory pricing incentives of incumbent firm 1 are all the advantage-building motives $\Gamma_1^k(\mathbf{e})$, where $k = 1, 2, 3, 4, 5$, and all the advantage-denying motives $\Theta_1^k(\mathbf{e})$, where $k = 1, 2, 3, 4$.*

Because $mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) \to p_1(\mathbf{e})$ as $\sigma \to 0$, in an industry with very weak product differentiation Definition 1 is nearly equivalent to the classic Areeda & Turner (1975) test that equates predatory pricing with below-cost pricing.[25] Otherwise Definition 1 allows for the possibility of above-cost predatory pricing.

Definition 1 may be too severe as it denies the efficiency gains from pricing aggressively in order to move down the learning curve. Instead, the firm should behave as if it were operating in a "dynamic competitive vacuum" in the sense that the firm takes as given the competitive position of its rival in the current period but ignores that its current price can affect the evolution of the competitive position of its rival beyond the current period. Hence, $\Pi^{EEEC}(p_1) = (p_1 - c(e_1))D_1(p_1, p_2(\mathbf{e})) + U_1(\mathbf{e}) + D_1(p_1, p_2(\mathbf{e}))\left[U_1(e_1+1, e_2) - U_1(\mathbf{e})\right]$, where we assume that from the subsequent period onward play returns to equilibrium. To us, this best captures the idea that the firm is sacrificing something now in exchange for a later improvement in the competitive environment. It follows from equation (9) that $-\frac{\partial \Omega(p_1(\mathbf{e}))}{\partial p_1} > 0$ if and only if $\sum_{k=1}^{4} \Theta_1^k(\mathbf{e}) > 0$. Our second definition of predatory incentives is thus:

[25] Below-cost pricing underpins the current *Brooke Group* standard for predatory pricing in the U.S.

Definition 2 (dynamic competitive vacuum) *The predatory pricing incentives of incumbent firm 1 are all the advantage-denying motives $\Theta_1^k(\mathbf{e})$, where $k = 1, 2, 3, 4$.*

Definition 2 is akin to a sacrifice test that compares the inclusive price $mr_1(p_1(\mathbf{e}), p_2(\mathbf{e}))$ to the long-run marginal cost $c(e_1) - \left[\sum_{k=1}^5 \Gamma_1^k(\mathbf{e})\right]$ that reduces out-of-pocket cost by the incremental benefit to the firm from winning the sale and moving further down its learning curve. Note that lower bound on long-run marginal cost $c(e_1) - \left[\sum_{k=1}^5 \Gamma_1^k(\mathbf{e})\right]$ is out-of-pocket cost at the bottom of the learning curve $c(m)$ (see Spence 1981). Hence, if $mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) < c(m)$, then $mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) < c(e_1) - \left[\sum_{k=1}^5 \Gamma_1^k(\mathbf{e})\right]$. This provides a one-way test for sacrifice that can be operationalized given some basic knowledge of demand and cost.

Definitions 1 and 2 may be criticized for not focusing more narrowly on the probability that the rival exits the industry that is at the heart of the economic definitions of predation in Section 4.1. Using the fact these definitions can be mapped into our decomposition (4), our next two definitions of predatory incentives are:

Definition 3 (Ordover & Willig (1981)) *The predatory pricing incentives of incumbent firm 1 are the advantage-building/exit motive $\Gamma_1^2(\mathbf{e})$, the advantage-denying/exit motive $\Theta_1^2(\mathbf{e})$, the advantage-building/market structure motive $\Gamma_1^5(\mathbf{e})$, the difference in the advantage-building/scrap value motives $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$, the difference in the baseline advantage-denying motives $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right]$, and the difference in the advantage-denying/scrap value motives $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$.*

Definition 4 (Cabral & Riordan (1997)) *The predatory pricing incentives of incumbent firm 1 are the advantage-building/exit motive $\Gamma_1^2(\mathbf{e})$ and the advantage-denying/exit motive $\Theta_1^2(\mathbf{e})$.*

Both definitions can be construed as sacrifice tests. The Cabral & Riordan definition of predation, for example, is akin to a sacrifice test based on an everything-except-effects-on-competition profit function that excludes the advantage-building/exit motive and the advantage-denying/exit motive.

Our fifth definition partitions the predatory incentives in Definition 4 more finely by maintaining that the truly exclusionary effect on competition is the one aimed at inducing exit by preventing the rival from winning the sale and moving further down its learning curve:

Definition 5 (modified Cabral & Riordan (1997)) *The predatory pricing incentive of incumbent firm 1 is the advantage-denying/exit motive $\Theta_1^2(\mathbf{e})$.*

	the firm assumes that its price does not affect...	predatory incentives
1. short-run profit	...its and its rival's competitive positions	$\Gamma_1^k(\mathbf{e})$, $k = 1,\ldots,5$, $\Theta_1^k(\mathbf{e})$, $k = 1,\ldots,4$
2. dynamic competitive vacuum	...its rival's competitive position	$\Theta_1^k(\mathbf{e})$, $k = 1,\ldots,4$
3. Ordover & Willig (1981)	...the probability of rival exit, which is zero	$\Gamma_1^2(\mathbf{e})$, $\Theta^2(\mathbf{e})$, $\Gamma_1^5(\mathbf{e})$, $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big\vert_{\phi_2=0}\right]$, $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big\vert_{\phi_2=0}\right]$, $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big\vert_{\phi_2=0}\right]$
4. Cabral & Riordan (1997)	...the probability of rival exit	$\Gamma_1^2(\mathbf{e})$, $\Theta_1^2(\mathbf{e})$
5. modified Cabral & Riordan (1997)	...the probability of rival exit through preventing an improvement in its rival's competitive position	$\Theta_1^2(\mathbf{e})$
6. Snider (2008)	...the probability of rival exit through an improvement in its competitive position	$\Gamma_1^2(\mathbf{e})$

Table 6: Alternative definitions of predatory incentives.

The other partition of the predatory incentives leads to our sixth definition:

Definition 6 (Snider (2008)) *The predatory pricing incentive of incumbent firm 1 is the advantage-building/exit motive* $\Gamma_1^2(\mathbf{e})$.

Definition 6 is identical to the definition used by Snider (2008) to explore whether American Airlines engaged in predatory capacity expansion in the Dallas-Fort Worth to Wichita market in the late 1990s.[26]

Table 6 summarizes our alternative definitions of predatory incentives in what intuitively seems to be decreasing order of severity. The right panels of Table 5 illustrate this point at the example of the trenchy equilibrium in Section 3.1. A sacrifice test based on a later definition has indeed a greater tendency to identify a price as predatory.

5 Economic significance of predatory incentives

The ultimate goal of studying predatory pricing is to determine whether it is detrimental to consumers and society at large and, if so, to devise policy interventions that change

[26]Snider invokes the Cabral & Riordan definition of predation to motivate his analysis. As we have seen from Proposition 1, however, their definition is closely linked to both $\Gamma_1^2(\mathbf{e})$ and $\Theta_1^2(\mathbf{e})$.

industry conduct for the better. As a step toward this goal, we implement the ideal conduct restriction that completely eliminates the predatory incentives (according to the various definitions in Section 4.2). We imagine an omniscient regulator that can instantly flag an illegitimate profit sacrifice and prevent a firm from pricing to effectuate that sacrifice by forcing it to ignore the predatory incentives. This implicitly restricts the range of the firm's price. Definition 1, for example, rules out that marginal revenue—and thus *a fortiori* price—is less than marginal cost. The conduct restriction associated with Definition 2 allows marginal revenue to be less than marginal cost but not by "too much."

We formalize a conduct restriction as a constraint $\Xi(p_1, p_2(\mathbf{e}), \mathbf{e}) = 0$ on the maximization problem on the right-hand side of the Bellman equation (3). We construct the constraint by expanding our decomposition (6) as

$$mr_1(p_1, p_2(\mathbf{e})) - c(e_1)$$
$$+ \left[\sum_{k=1}^{5} \Gamma_1^k(\mathbf{e}) \pm \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right] + \frac{D_2(p_1, p_2(\mathbf{e}))}{1 - D_1(p_1, p_2(\mathbf{e}))}\left[\sum_{k=1}^{4} \Theta_1^k(\mathbf{e}) \pm \Theta_1^1(\mathbf{e})\big|_{\phi_2=0} \pm \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right] = 0, \tag{10}$$

where $\pm$ means adding and subtracting the subsequent term. We then "switching off" the predatory incentives. For example, for Definition 3 we set the terms $\Gamma_1^2(\mathbf{e})$, $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$, $\Gamma_1^5(\mathbf{e})$, $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right]$, $\Theta_1^2(\mathbf{e})$, and $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$ to zero to obtain the constraint. For Definition 4 we set the terms $\Gamma_1^2(\mathbf{e})$ and $\Theta_1^2(\mathbf{e})$ to zero. We proceed similarly for the remaining definitions. Note that the conduct restrictions amount to altering the $U(\mathbf{e}) - U(\overline{\mathbf{e}})$ terms in (5), but not the way firm's own price p_1 enters it, so pricing decision $p_1(\mathbf{e})$ is uniquely determined by the solution to the constrained optimality condition.

We measure the economic significance of the predatory incentives by analyzing the impact of the conduct restriction on the equilibrium correspondence and industry structure, conduct, and performance. We use the homotopy method on the modified system of equations to compute a counterfactual correspondence for the various definitions of predatory incentives in Section 4.2. Because firms retain rational expectations about the evolution of the industry, a counterfactual can be viewed as an equilibrium of a game with a conduct restriction in place that eliminates the predatory incentives. Comparing counterfactuals and equilibria tells us how much bite the predatory incentives have.

Figures 4 and 5 illustrate the counterfactual correspondence for Definitions 1–6 by plotting HHI^∞ against ρ. [27] We superimpose the equilibrium correspondence $\mathbf{H}^{-1}(\rho)$ from Figure 3.

[27] Here and below we limit discussion to slice along ρ. See the Appendix C for slices along other variables.

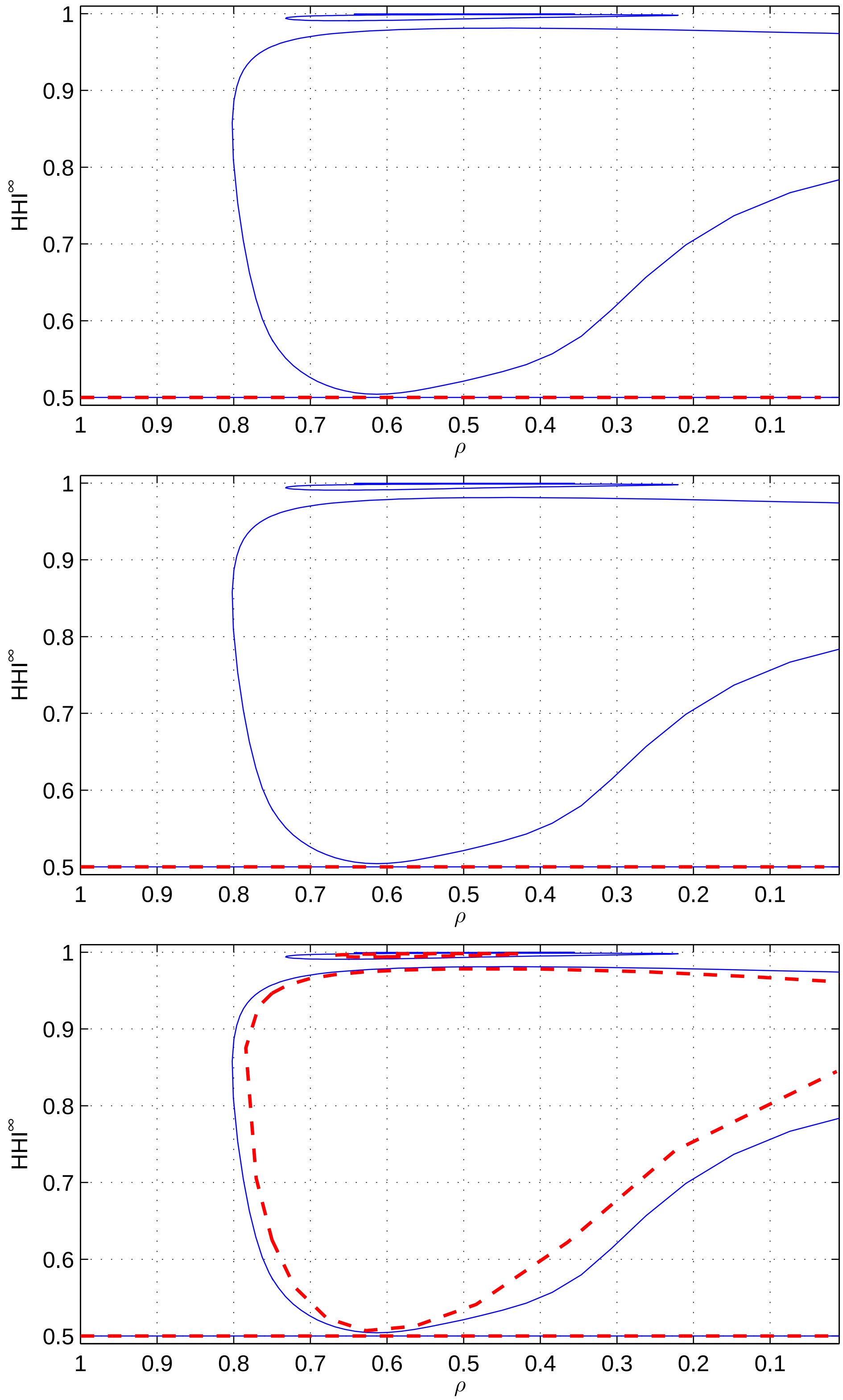

Figure 4: Counterfactual correspondence for Definitions 1–3 (upper, middle, and lower panel). Equilibrium correspondence (Expected long-run Herfindahl index), slice along $\rho \in [0, 1]$.

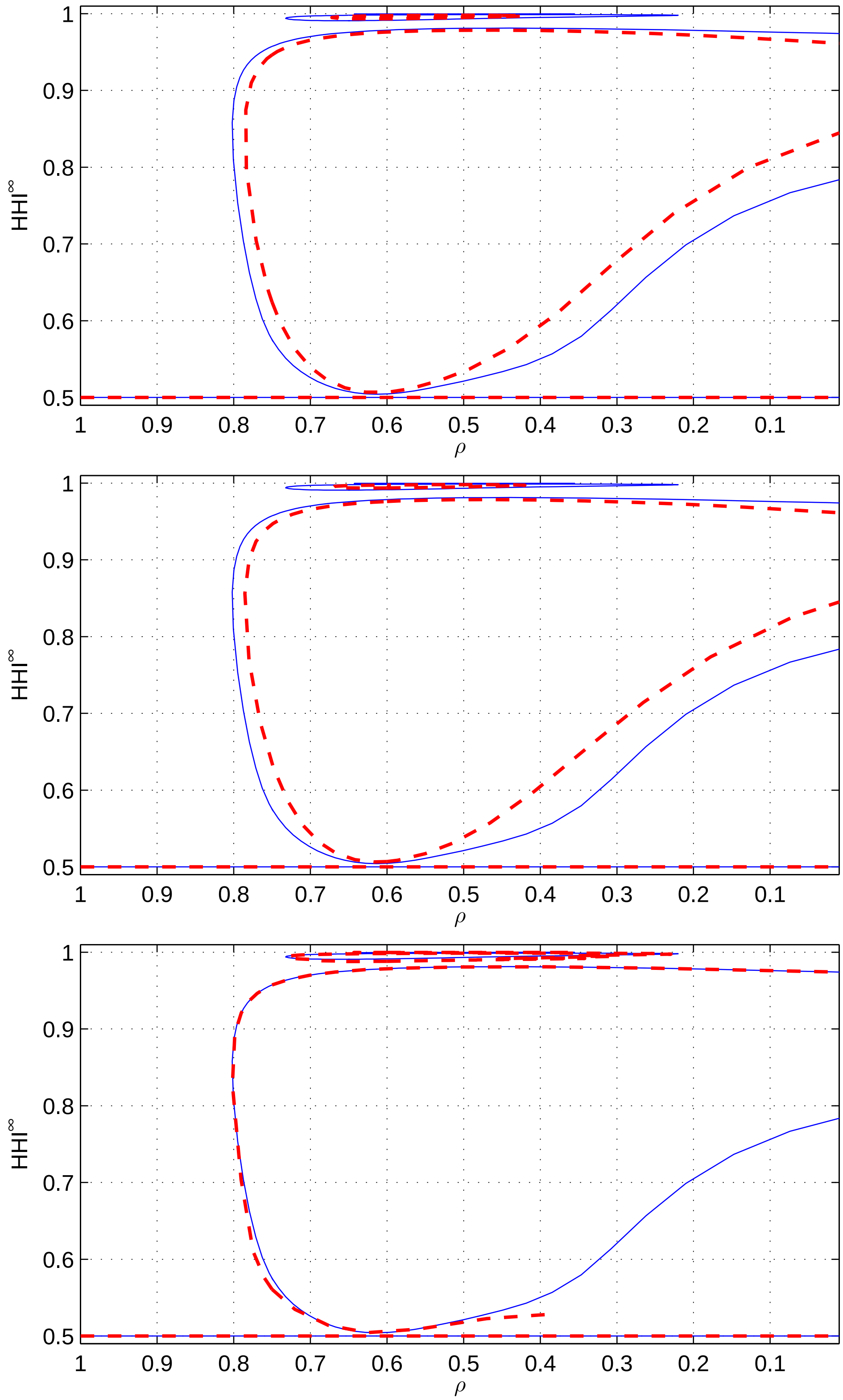

Figure 5: Counterfactual correspondence for Definitions 4–6 (upper, middle, and lower panel). Equilibrium correspondence (Expected long-run Herfindahl index), slice along $\rho \in [0, 1]$.

The counterfactual correspondence for Definitions 3–6 resembles the equilibrium correspondence and consists of a main path, a semi-loop, and one (Definitions 3–5) or two (Definition 6) loops. The counterfactuals span the same range of industry structures as the equilibria. The counterfactuals appear to be counterparts of the equilibria in that most, but not all, equilibria have a counterfactual nearby.

In contrast, the counterfactual correspondence for Definitions 1 and 2 consists only of the main path. The industry evolves into a mature duopoly with $HHI^{\infty} = 0.5$. Further inspection reveals that the counterfactuals are flat. While the flat equilibria on MP and the lower fold of SL have a counterfactual nearby, the trenchy equilibria on the upper of SL as well as those on L_1 and L_2 do not.

A similar picture emerges from plotting HHI^{∞} against σ and $\overline{X}$: For Definitions 3–6, counterfactual correspondence retains features similar to the equilibrium one. For Definitions 1 and 2 the counterfactuals are unique and flat, so the industry evolves into a mature duopoly with $HHI^{\infty} = 0.5$ except for σ below 0.5 where the counterfactuals are trenchy and the industry evolves into an entrenched monopoly with $HHI^{\infty} \approx 1.0$.

5.1 Eliminated and surviving equilibria

Figures 4 and 5 quite intuitively suggest that some equilibria are eliminated by a particular conduct restriction while other equilibria survive it. To make this intuition about eliminated and surviving equilibria more precise, we use the homotopy to relate equilibria and counterfactuals. Instead of abruptly switching off the predatory incentives in equation (10), we aim to gradually drive them to zero. For Definition 4, for example, we put the weight *lambda* on the terms $\Gamma_1^2(\mathbf{e})$ and $\Theta_1^2(\mathbf{e})$ and then allow the homotopy method to vary λ (along with the vector of values and policies $(\mathbf{V}_1, \mathbf{U}_1, \mathbf{p}_1, \boldsymbol{\phi}_1)$. At $\lambda = 1$ we have an equilibrium and at $\lambda = 0$ a counterfactual. If starting from an equilibrium such artificial homotopy reaches the counterfactual correspondence, we say that the equilibrium survives the conduct restriction in the sense that the equilibrium can be smoothly deformed into a counterfactual. Otherwise, if the homotopy algorithm returns to the equilibrium correspondence, we say that the equilibrium is eliminated by the conduct restriction. [28]

Figure 6 distinguishes between eliminated and surviving equilibria. Definition 2 (which has similar effects to Definition 1) eliminates the trechny equilibria that are associated with higher expected long-run Herfindahl indices whereas the flatter equilibria that are associated with lower expected long-run Herfindahl indices survive the conduct restriction. In contrast, Definition 4 (which is broadly representative of Definitions 3–6) allows some of the trenchier equilibria survive, along with all of the flat ones. Still, with exception of Definition 6, at

[28] For an example of such return, see Fig.1, case B in Borkovsky et al. (2010). In the unlikely case of homotopy crashing, we deduce surival or elimination from adjacent equilibria along the solution path.

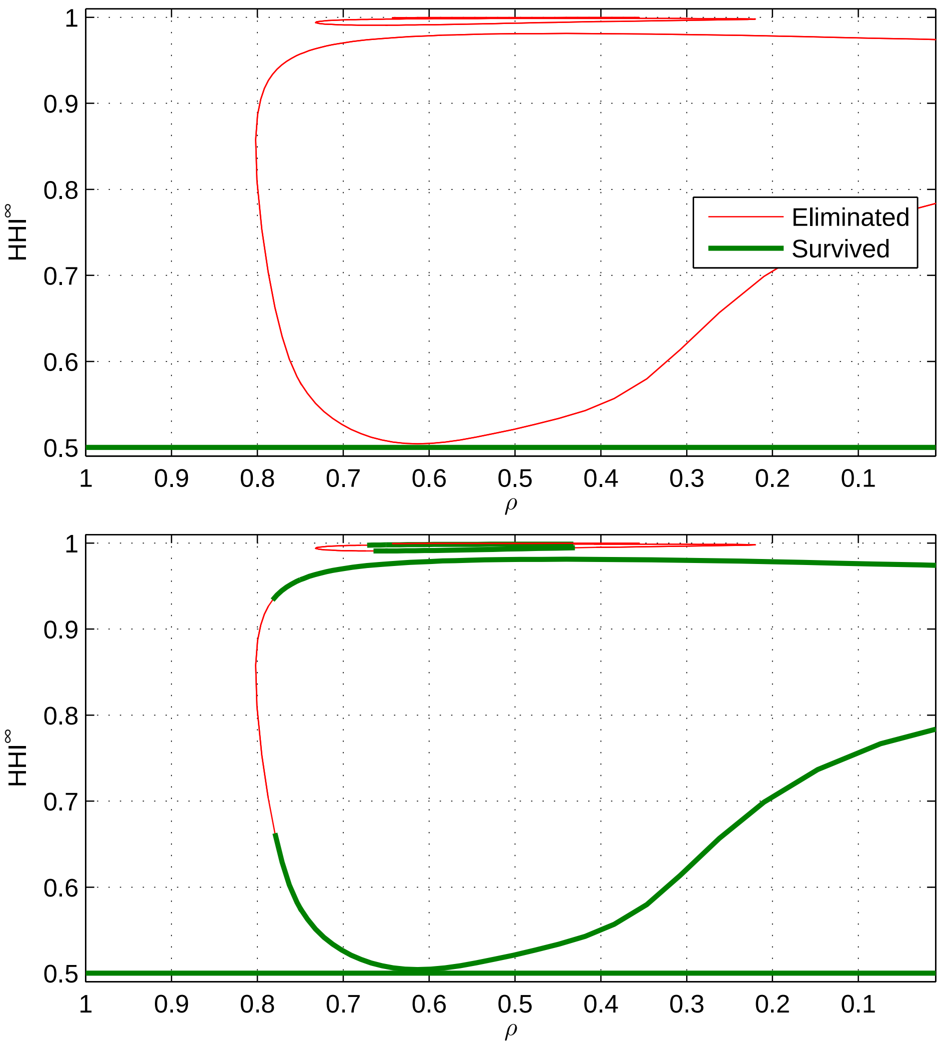

Figure 6: Eliminated and surviving equilibria for Definitions 2 (upper panel) and 4 (lower panel). Equilibrium correspondence (Expected long-run Herfindahl index), slice along $\rho \in [0, 1]$.

		definitions					
metric		1	2	3	4	5	6
	surv.	22%	22%	74%	74%	76%	84%
	elim.	78%	78%	24%	24%	24%	0%
HHI^{∞}	surv.	0.50	0.50	0.74	0.74	0.74	0.77
	elim.	0.88	0.88	0.98	0.98	0.98	NaN
EP^{∞}	surv.	2.99	2.99	5.45	5.45	5.50	5.88
	elim.	7.00	7.00	8.11	8.11	8.11	NaN
CS^{∞}	surv.	7.71	7.71	4.98	4.98	4.93	4.51
	elim.	3.28	3.28	2.07	2.07	2.07	NaN
TS^{∞}	surv.	9.70	9.70	9.07	9.07	9.05	8.76
	elim.	8.57	8.57	8.08	8.08	8.08	NaN
CS^{NPV}	surv.	158.28	158.28	158.96	158.96	158.64	152.96
	elim.	155.65	155.65	148.69	148.69	148.69	NaN
TS^{NPV}	surv.	172.48	172.48	167.86	167.86	167.49	161.54
	elim.	162.18	162.18	154.83	154.83	154.83	NaN

Table 7: Industry structure, conduct, and performance for eliminated and surviving equilibria for various definitions of predatory incentives. Slice along $\rho \in [0.05, 0.8]$, uniformly spaced grid limited to the multiplicity area.

least some of trenchy equilibria are eliminated.

Table 7 compares surviving and eliminated equilibria. Top row shows that stronger conduct restriction based on Definitions 1 and 2 eliminate many more equilibria than the weaker conduct restriction based on Definitions 3–6. Other rows of Table 7 contrast average measures of industry structure, conduct, and performance for eliminated and surviving equilibria. We see that surviving equilibria tend to be less concentrated and lead to substantially higher long-term welfare than eliminated ones. The comparison for discounted welfare measures is less dramatic, and in fact reverses for slices along σ and $\overline{X}$, indicating that both consumers and overall economy receive some benefit from lower prices and faster learning that result from predation.

5.2 Impact of conduct restriction

While the counterfactual correspondence (at a fixed parameterization) delineates what can happen if a particular conduct restriction is implemented, it does not directly speak to what is likely to happen. Without knowing how agents behave out of equilibrium, it is difficult to say how they adjust to a shock to the system, especially if the game with the conduct restriction in place has multiple equilibria. In what follows below, we assume that any equilibrium can be transformed by the conduct restriction into any of the counterfactuals

		Definitions					
Measure		1	2	3	4	5	6
$\overline{p}^{\infty}$	Up	-	-	30%	30%	30%	-
	Down	80%	80%	45%	45%	45%	55%
Avg=	Same	20%	20%	25%	25%	25%	45%
6.6371	Change	-2.4154	-2.4154	-0.4224	-0.4239	-0.3904	-0.5156
HHI^{∞}	Up	-	-	-	-	-	-
	Down	80%	80%	45%	45%	45%	50%
Avg=	Same	20%	20%	55%	55%	55%	50%
0.72932	Change	-0.2293	-0.2293	-0.0456	-0.0457	-0.0424	-0.0435
CS^{∞}	Up	80%	80%	45%	45%	45%	55%
	Down	-	-	30%	30%	30%	-
Avg=	Same	20%	20%	25%	25%	25%	45%
3.8812	Change	+2.6640	+2.6640	+0.4701	+0.4716	+0.4346	+0.5641
TS^{∞}	Up	80%	80%	45%	45%	45%	50%
	Down	-	-	-	-	5%	-
Avg=	Same	20%	20%	55%	55%	50%	50%
7.6903	Change	+0.7062	+0.7062	+0.1382	+0.1386	+0.1284	+0.1354
CS^{NPV}	Up	-	-	-	-	40%	5%
	Down	95%	90%	65%	65%	-	70%
Avg=	Same	5%	10%	35%	35%	60%	25%
132.46	Change	-63.0230	-3.1223	-2.9357	-2.9285	+0.5679	-1.6791
TS^{NPV}	Up	-	80%	45%	45%	45%	40%
	Down	95%	-	-	-	-	-
Avg=	Same	5%	20%	55%	55%	55%	60%
142.33	Change	-9.9866	+5.6425	+1.1772	+1.1773	+1.1032	+1.2761

Table 8: Impact of conduct restriction for $\rho \in (0, 1)$.

with equal probability.

Table 8 summarizes the economic impact of each of the six definitions of predatory incentives. To construct the data in Table 8, we perform the following steps. First, for a uniformly spaced grid of parameterizations. for $\rho \in (0, 1)$, we compute the average of a given metric over the equilibria that arise for that parameterization (this is reported in the first column of Table 8). Next, for each definition of predatory incentives, we compute an analogous average metric for the counterfactuals for that parameterization, and compute the difference between the counterfactual and equilibrium averages. We then average these differences over all parameterizations in the grid. By comparing this average difference (which is reported at the bottom of each cell in Table 8) to the average value of a metric for the equilibria, we can gauge the extent to which, on average, the shutdown of predatory incentives affects equilibrium outcomes across $\rho \in (0, 1)$. In addition, Table 8 reports the percentage of parameterizations where the average value of the metric for the counterfactuals is greater than (less than) (the same as) the average value of the metric for the equilibria. This tells us the extent to which the predatory incentives tend to improve the structure, conduct, and welfare metrics or make them worse. Specifically, if conduct restriction is improving the outcome, then predatory incentives must have been making it worse.

Generally speaking, the predatory incentives under Definitions 3-6 have a relatively small impact on the industry structure, price, and welfare metrics as we vary ρ between 0 and 1. For example, switching off the Definition 4 predatory incentives reduces p^{∞} on average by about 6.4%, increases CS^{∞} by about 12%, increases TS^{∞} by about 1.8%, decreases CS^{NPV} by about 2.2%, and increases TS^{NPV} by about 0.8 percent. Moreover, the Definition 3-6 predatory incentives are sometimes benign for consumers. For example, in 30% of the parameterizations, switching off the Definition 4 predatory incentives increases p^{∞} and decreases CS^{∞}, and in 65 percent of the parameterizations, switching off these incentives decreases CS^{NPV}.

By contrast, the predatory incentives under Definitions 1 and 2 have relatively large adverse effects on the long-run price and the per-period flows of consumer and total surplus and mixed effects on discounted consumer and total surplus. For example, switching off the Definition 2 predatory incentives reduces p^{∞} on average by about 36.4%, increases CS^{∞} by about 68.6%, and increases TS^{∞} by about 9.2%. The Definition 2 incentives had modest effects, though, on CS^{NPV} and TS^{NPV}: switching them off reduces CS^{NPV} by about 2.3% and increases TS^{NPV} by about 3.9%. The Definition 1 predatory incentives affect the long-run price and per-period flows of consumer and total surplus in a similar manner as the Definition 2 incentives do, but they have a much stronger impact on discounted consumer surplus: switching them off decreases CS^{NPV} by almost 50% and decreases TS^{NPV} by about 10%.

The decreases in CS^{NPV} are naturally attributable to increased prices in early predation stage of industry development. [29] The decrease in TS^{NPV} is likely due to slower learning in the industry as a whole.

The generally large impact of the Definition 1 or Definition 2 incentives on long-run outcomes arises because they are, in effect, necessary for the trenchy equilibria. As noted above, switching off either set of incentives preserves the flat equilibria along MP but eliminates the trenchy equilibria that arise (to varying extent) for ρ less than about 0.8. Therefore, for many parameterizations—especially values of ρ between 0.35 and 0.65 where there may be as many as five trenchy equilibria—we eliminate equilibria that involve, in the long run, a high probability of monopolization, and in the short run, competition for the

[29] The increase in CS^{NPV} for Definition 5 is unique to the equilibrium correspondence along ρ, and does not occur for other parameters.

market in an emerging duopoly and intense trench warfare between a leader and an emerging rival. Since the competition for the market is especially intense in the trenchy equilibria, and because such competition is mainly driven by advantage-building motives and not the advantage-denying motives (recall Table 5), the Definition 1 predatory incentives (which include the advantage-building motives) tend to cause more "good things" for consumers in the short run than the Definition 2 predatory incentives. For this reason, along $\mathbf{H}_{\rho}^{-1}$, the Definition 2 predatory incentives are generally more harmful than the Definition 1 predatory incentives.

Product differentiation and scrap value. We also performed the counterfactual analysis for variations in the product differentiation parameter σ and the average scrap value $\overline{X}$, with figures and tables presented in Appendix C

This analysis provides the same broad insights that we get when we vary ρ (but with a nuance that we discuss presently). The predatory incentives for Definitions 3-6 generally have a modest impact across the range of values of σ and $\overline{X}$ we considered, while the Definition 1 and 2 incentives tend, on average, to have a more substantial impact. The basic reason is that for both parameters, shutting down the Definitions 1 and 2 of predation tends to widen the ranges of parameter values for which there is a unique flat equilibrium, whereas switching off the Definitions 3-6 will not necessarily eliminate all the trenchy equilibria that can lead to long-run monopolies.

There is, however, an important qualification to this point. If σ is sufficiently small (roughly less than about 0.5), then switching off the Definition 1 or 2 predatory incentives has relatively limited impact on the long-run Herfindahl index, the long-run per-period consumer surplus, and the discounted consumer surplus. The reason is that as product differentiation weakens, flat equilibria cease to exist, and while forcing firms to ignore the predatory motives does make the counterfactual flat for intermediate levels of σ, this effect vanishes for sufficiently weak differentiation.

Switching off the Definition 1 predatory incentives again has a substantial and negative effect on discounted measures of both consumer and total surplus, regardless of the strength of differentiation. This suggests that advantage-building motives have a positive impact on consumers, and a direct application of Areeda-Turner rule might do more harm than good.

Summary For the parameterizations we have explored, we can summarize our findings as follows:

1. For parameter values that give rise to multiple equilibria, switching off predatory incentives under any of our six definitions eliminates some equilibria. The equilibria that are eliminated are typically the "trenchiest."

2. For parameter values that give rise to multiple equilibria, switching off the predatory incentives under Definitions 3-6 does not eliminate all the trenchy equilibria; that is, with these incentives switched off, we may continue to have trenchy equilibria.

3. Switching off the predatory incentives under Definitions 1 and 2 typically eliminates all the trenchy equilibria. The notable exception to this is when product differentiation is extremely weak (σ less than about 0.5).

4. On average, switching off the predatory incentives under any of our six definitions tends to reduce the long-run Herfindahl index, the long-run price, and tends to increase the long-run per-period consumer and toal surplus. However, these effects tend to be very small for Definitions 3-6. They are much more pronounced for Definitions 1 and 2. Thus, on average over our parameterizations, predatory incentives under any of our definitions tend to be responsible for worsening long-run industry outcomes, but these effects are large only for Definitions 1 and 2.

5. On average, switching off the predatory incentives under Definitions 3-6 tends to have a small negative impact on discounted consumer surplus and a small positive impact on discounted total surplus. Switching off the predatory incentives under Definition 1 tends to have a large negative impact on discounted consumer surplus and a modest negative impact on total surplus. Thus, predatory incentives under any of our definitions tend to be responsible for improvements in discounted consumer surplus, but these effects are slight except for Definition 1.

6 Conclusions

Our analysis shows how predatory pricing can be analyzed in a modern industry dynamics framework. We have analyzed and computed equilibria for a dynamic stochastic game with learning-by-doing, and by decomposing the equilibrium pricing condition, we proposed a variety of ways to describe a firm's predatory pricing incentives. Some of these definitions map into definitions of predation that have been offered in the economics literature. Moreover, these definitions correspond to alternative implementations of sacrifice standards to test for the presence of predatory pricing. Based on computations of equilibria using a baseline set of parameterizations, we show the economic impact of these incentives on long-run and transitory industry dynamics for (virtually) full ranges of values of the progress ratio of the learning curve, the degree of product differentiation, and the scrap value.

Because our results are based on computations and not formal proofs, they are, of course, necessarily tentative. We nevertheless believe that our results are suggestive and can enrich policy discussions of predatory pricing. Here, we emphasize three implications.

First, our analysis confirms the analytical finding of Cabral & Riordan (1994) that behavior that resembles conventional notions of predatory pricing can arise as a Markov perfect equilibrium in a dynamic pricing game with learning-by-doing. This equilibrium behavior is rooted in the fundamentals of demand and cost, rather than asymmetric information or capital market imperfections. And going beyond the "possibility" result in Cabral & Riordan (1994), we show that the equilibria that spawn predatory behavior are not special cases or the results of extreme parameterizations. Rather, they arise for empirically plausible parameter values and occur over rather wide ranges of certain parameter values. For example, the trenchy equilibria that give rise to predation-like behavior arise for all progress ratios less than about 0.80. Overall, our analysis, at the very least, calls into question the claim that economic theory implies that predatory pricing is a myth and need not taken seriously by antitrust authorities.

Second, the multiplicity of equilibria in our model confirms an important point about predatory pricing made by Edlin (2010) who writes: "Whether predation is a successful strategy depends very much on whether predator and prey believe it is successful strategy." Multiple equilibria arise in our model if, for given demand and cost fundamentals, there is more than one set of firms' expectations regarding the value of continued play that is consistent with rational expectations about equilibrium behavior and industry dynamics. As we have shown, for certain definitions of predatory incentives, forcing firms to ignore these incentives can actually short-circuit some of these expectations and eliminate the trenchy equilibria that spawn predation-like behavior.

Third, our analysis has implications for defining predatory pricing incentives in situations in which a firm's aggressive pricing may reflect both efficiency and predatory considerations, and this in turn can provide insight into how a sacrifice test might be framed under such circumstances. We find that definitions of predatory pricing incentives based on counterfactuals that emphasize the direct impact of pricing on rival exit—in particular Definitions 3–6—seem, on average to have a relatively modest impact on long-run equilibrium outcomes. By contrast, when predatory incentives are defined by Definition 1—a definition that equates any departure from short-run profit maximization with predation—the predatory incentives have a significant impact on long-run outcomes. This is because removing these incentives tends to eliminate all the trenchy equilibria which give rise to long-run monopolization of the industry. But as firms move toward the long run, these incentives also tend to lead to lower prices. In particular, the advantage-building motives that are included within them, are responsible for intense competition "for the market" in an emerging duopoly. Our analysis suggests that in markets with learning curves, equating predation with Definition 1 incentives may involve giving up considerable consumer surplus (and modest amounts of total surplus) as the industry transitions to an eventual state of maturity. An advantage of sacrifice standards based on the “less strict” definitions of predation-like Definitions 3-6 is that they could achieve *some* improvements in long-run outcomes, without the large costs to consumers in the short run that would come from a standard based on Definition 1. Put another way, if one believes that a good policy is one that bends over backwards to avoid labeling aggressive pricing as predatory in situations where firms are competing for efficiency-based advantages, then one might prefer standards based on Definitions 3–6.

Still, our analysis suggests that perhaps the notion of predatory incentives that achieves the best balance of long run/short run effects resides within Definition 2. Like the Definition 1 incentives, for the parameterizations we studied, these incentives have an economically significant impact on long-run outcomes; by switching them off, we eliminate the trenchy equilibrium and attain significant improvements in long-run per period consumer and total surplus. However, in contrast to the Definition 1 incentives, switching off the Definition 2 incentives has only a modestly negative impact on discounted consumer surplus over the time the industry evolves toward maturity (and a modestly positive impact on discounted total welfare). This is because the advantage-denying motives that form the basis of the Definition 2 incentives are mainly responsible for the aggressive pricing behavior that resembles conventional notions of predation but not the intense competition between firms as they battle for advantage in an emerging industry.

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A Appendix: Omitted expressions

A.1 Expectations and probabilities

Given the assumed distribution for scrap values, the probability of incumbent firm 1 exiting the industry in state $\mathbf{e}'$ is

$$\begin{aligned}\phi_1(\mathbf{e}') &= E_X\left[\phi_1(\mathbf{e}', X_1)\right] \\ &= \int \phi_1(\mathbf{e}', X_1) dF_X(X_1) = 1 - F_X(\widehat{X}_1(\mathbf{e}')) \\ &= \begin{cases} 1 & \text{if} \quad \widehat{X}_1(\mathbf{e}') < \overline{X} - \Delta_X, \\ \frac{1}{2} - \frac{\left[\widehat{X}_1(\mathbf{e}') - \overline{X}\right]}{2\Delta_X} & \text{if} \quad \widehat{X}_1(\mathbf{e}') \in [\overline{X} - \Delta_X, \overline{X} + \Delta_X], \\ 0 & \text{if} \quad \widehat{X}_1(\mathbf{e}') > \overline{X} + \Delta_X. \end{cases}\end{aligned}$$

and the expectation of the scrap value conditional on exiting the industry is

$$\begin{aligned}E_X\left[X_1 | X_1 \geq \widehat{X}_1(\mathbf{e}')\right] &= \frac{\int_{F_X^{-1}(1-\phi_1(\mathbf{e}'))}^{\overline{X}+\Delta_X} X_1 dF_X(X_1)}{\phi_1(\mathbf{e}')} \\ &= \frac{1}{\phi_1(\mathbf{e}')}\left[Z_X(0) - Z_X\left(1 - \phi_1(\mathbf{e}')\right)\right],\end{aligned}$$

where

$$Z_X(1-\phi) = \frac{1}{\Delta_X^2}\begin{cases} -\frac{1}{6}\left(\overline{X} - \Delta_X\right)^3 & \text{if} \quad 1 - \phi \leq 0, \\ \frac{1}{2}\left(\Delta_X - \overline{X}\right)\left(F_X^{-1}(1-\phi)\right)^2 + \frac{1}{3}\left(F_X^{-1}(1-\phi)\right)^3 & \text{if} \quad 1 - \phi \in \left[0, \frac{1}{2}\right], \\ \frac{1}{2}\left(\Delta_X + \overline{X}\right)\left(F_X^{-1}(1-\phi)\right)^2 - \frac{1}{3}\left(F_X^{-1}(1-\phi)\right)^3 - \frac{1}{3}\overline{X}^3 & \text{if} \quad 1 - \phi \in \left[\frac{1}{2}, 1\right], \\ \frac{1}{6}\left(\overline{X} + \Delta_X\right)^3 - \frac{1}{3}\overline{X}^3 & \text{if} \quad 1 - \phi \geq 1 \end{cases}$$

and

$$F_X^{-1}(1-\phi) = \overline{X} + \Delta_X\begin{cases} -1 & \text{if} \quad 1 - \phi \leq 0, \\ -1 + \sqrt{2(1-\phi)} & \text{if} \quad 1 - \phi \in \left[0, \frac{1}{2}\right], \\ 1 - \sqrt{2\phi} & \text{if} \quad 1 - \phi \in \left[\frac{1}{2}, 1\right], \\ 1 & \text{if} \quad 1 - \phi \geq 1. \end{cases}$$

Given the assumed distribution for setup costs, the probability of potential entrant 1 not entering the industry in state $\mathbf{e}'$ is

$$\begin{aligned}\phi_1(\mathbf{e}') &= E_S\left[\phi_1(\mathbf{e}', S_1)\right] \\ &= \int \phi_1(\mathbf{e}', S_1) dF_S(S_1) = 1 - F_S(\widehat{S}_1(\mathbf{e}')) \\ &= \begin{cases} 1 & \text{if} \quad \widehat{S}_1(\mathbf{e}') < \overline{S} - \Delta_S, \\ \frac{1}{2} - \frac{\left[\widehat{S}_1(\mathbf{e}') - \overline{S}\right]}{2\Delta_S} & \text{if} \quad \widehat{S}_1(\mathbf{e}') \in [\overline{S} - \Delta_S, \overline{S} + \Delta_S], \\ 0 & \text{if} \quad \widehat{S}_1(\mathbf{e}') > \overline{S} + \Delta_S \end{cases}\end{aligned}$$

and the expectation of the setup cost conditional on entering the industry is

$$\begin{aligned}
E_S\left[S_1|S_1 \leq \widehat{S}_1(\mathbf{e}')\right] &= \frac{\int_{\overline{S}-\Delta_S}^{F_S^{-1}(1-\phi_1(\mathbf{e}'))} S_1 dF_S(S_1)}{(1-\phi_1(\mathbf{e}'))} \\
&= \frac{1}{\phi_1(\mathbf{e}')}\left[Z_S\left(1-\phi_1(\mathbf{e}')\right) - Z_S\left(1\right)\right],
\end{aligned}$$

where

$$Z_S\left(1-\phi\right) = \frac{1}{\Delta_S^2}\begin{cases}
-\frac{1}{6}\left(\overline{S}-\Delta_S\right)^3 & \text{if} \quad 1-\phi \leq 0, \\
\frac{1}{2}\left(\Delta_S-\overline{S}\right)\left(F_S^{-1}(1-\phi)\right)^2 + \frac{1}{3}\left(F_S^{-1}(1-\phi)\right)^3 & \text{if} \quad 1-\phi \in \left[0,\frac{1}{2}\right], \\
\frac{1}{2}\left(\Delta_S+\overline{S}\right)\left(F_S^{-1}(1-\phi)\right)^2 - \frac{1}{3}\left(F_S^{-1}(1-\phi)\right)^3 - \frac{1}{3}\overline{S}^3 & \text{if} \quad 1-\phi \in \left[\frac{1}{2},1\right], \\
\frac{1}{6}\left(\overline{S}+\Delta_S\right)^3 - \frac{1}{3}\overline{S}^3 & \text{if} \quad 1-\phi \geq 1
\end{cases}$$

and

$$F_S^{-1}(1-\phi) = \overline{S} + \Delta_S\begin{cases}
-1 & \text{if} \quad 1-\phi \leq 0, \\
-1+\sqrt{2\left(1-\phi\right)} & \text{if} \quad 1-\phi \in \left[0,\frac{1}{2}\right], \\
1-\sqrt{2\phi} & \text{if} \quad 1-\phi \in \left[\frac{1}{2},1\right], \\
1 & \text{if} \quad 1-\phi \geq 1.
\end{cases}$$

A.2 Marginal revenue

Let $q_1 = D_1(p_1, p_2(\mathbf{e}))$ be demand and $p_1 = P_1(q_1, p_2(\mathbf{e}))$ inverse demand as implicitly defined by $q_1 = D_1(P_1(q_1, p_2(\mathbf{e})), p_2(\mathbf{e}))$. The marginal revenue of incumbent firm 1 is

$$MR_1(q_1, p_2(\mathbf{e})) = \frac{\partial\left[q_1 P_1(q_1, p_2(\mathbf{e}))\right]}{\partial q_1} = q_1\frac{\partial P_1(q_1, p_2(\mathbf{e}))}{\partial q_1} + P_1(q_1, p_2(\mathbf{e})). \tag{11}$$

Define $mr_1(p_1, p_2(\mathbf{e})) = MR_1(D_1(p_1, p_2(\mathbf{e})), p_2(\mathbf{e}))$ to be the marginal revenue of incumbent firm 1 evaluated at the quantity q_1 corresponding to price p_1. Then we have

$$\frac{\partial P_1(D_1(p_1, p_2(\mathbf{e})), p_2(\mathbf{e}))}{\partial q_1} = \left[\frac{\partial D_1(p_1, p_2(\mathbf{e}))}{\partial p_1}\right]^{-1} = -\frac{\sigma}{\left[1-D_1(p_1, p_2(\mathbf{e}))\right] D_1(p_1, p_2(\mathbf{e}))}. \tag{12}$$

Substituting equation (12) into equation (11), it follows that $mr_1(p_1, p_2(\mathbf{e})) = p_1 - \frac{\sigma}{1-D_1(p_1, p_2(\mathbf{e}))}$.

A.3 Producer surplus

The producer surplus of firm 1 in state $\mathbf{e}$ is

$$
\begin{aligned}
PS_1(\mathbf{e}) = 1\left[e_1 > 0\right] \Bigg\{ & D_0(\mathbf{e})\phi_1(\mathbf{e}) E_X \left[X_1 | X_1 \geq \widehat{X}_1(\mathbf{e})\right] \\
& + D_1(\mathbf{e}) \left\{ p_1(\mathbf{e}) - c(e_1) + \phi_1(e_1+1, e_2) E_X \left[X_1 | X_1 \geq \widehat{X}_1(e_1+1, e_2)\right] \right\} \\
& + D_2(\mathbf{e})\phi_1(e_1, e_2+1) E_X \left[X_1 | X_1 \geq \widehat{X}_1(e_1, e_2+1)\right] \Bigg\} \\
- 1\left[e_1 = 0\right] \Bigg\{ & D_0(\mathbf{e}) \left(1 - \phi_1(\mathbf{e})\right) E_S \left[S_1 | S_1 \leq \widehat{S}_1(\mathbf{e})\right] \\
& + D_1(\mathbf{e}) \left(1 - \phi_1(e_1+1, e_2)\right) E_S \left[S_1 | S_1 \leq \widehat{S}_1(e_1+1, e_2)\right] \\
& + D_2(\mathbf{e}) \left(1 - \phi_1(e_1, e_2+1)\right) E_S \left[S_1 | S_1 \leq \widehat{S}_1(e_1, e_2+1)\right] \Bigg\}.
\end{aligned}
$$

The first set of terms represents the contingency that firm 1 is an incumbent that participates in the product market and receives a scrap value upon exit; the second set the contingency that firm 1 is an entrant that incurs a setup cost upon entry.

B Appendix: Proofs

Proof of Proposition 1. *Part (a):* Define $\widetilde{p}_1(\mathbf{e})$ as the solution to the first-order condition

$$
mr_1(\widetilde{p}_1(\mathbf{e}), p_2(\mathbf{e})) - c(e_1) + \left[\Gamma_1^1(\mathbf{e}) + \sum_{k=3}^{5} \Gamma_1^k(\mathbf{e})\right] + \frac{D_2(\mathbf{e})}{1 - D_1(\mathbf{e})} \left[\Theta_1^1(\mathbf{e}) + \sum_{k=3}^{4} \Theta_1^k(\mathbf{e})\right] = 0. \tag{13}
$$

Subtracting equation (13) from equation (6), we have

$$
mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) - mr_1(\widetilde{p}_1(\mathbf{e}), p_2(\mathbf{e})) = \Gamma_1^2(\mathbf{e}) + \frac{D_2(\mathbf{e})}{1 - D_1(\mathbf{e})} \Theta_1^2(\mathbf{e}) > 0.
$$

Hence, $\widetilde{p}_1(\mathbf{e}) > p_1(\mathbf{e})$.

Because $\phi_1(\mathbf{e}) < 1$, $V_1(e_1, 0) > V_1(\mathbf{e})$, and $V_1(e_1+1, 0) > V_1(e_1+1, e_2)$ by assumption, the expressions for $\Gamma_1^2(\mathbf{e})$ and $\Theta_1^2(\mathbf{e})$ imply $\phi_2(e_1+1, e_2) - \phi_2(\mathbf{e}) \geq 0$ and $\phi_2(\mathbf{e}) - \phi_2(e_1, e_2+1) \geq 0$, with strict inequality for at least one. Given a price p_1, the probability of rival exit is

$$
\begin{aligned}
& D_0(p_1, p_2(\mathbf{e}))\phi_2(\mathbf{e}) + D_1(p_1, p_2(\mathbf{e}))\phi_2(e_1+1, e_2) + D_2(p_1, p_2(\mathbf{e}))\phi_2(e_1, e_2+1) \\
= {} & \phi_2(\mathbf{e}) + D_1(p_1, p_2(\mathbf{e})) \left[\phi_2(e_1+1, e_2) - \phi_2(\mathbf{e})\right] - D_2(p_1, p_2(\mathbf{e}))[\phi_2(\mathbf{e}) - \phi_2(e_1, e_2+1)].
\end{aligned} \tag{14}
$$

The probability of rival exit decreases in p_1 because $D_1(\cdot)$ decreases in p_1, $D_2(\cdot)$ increases in p_1, $\phi_2(e_1+1,e_2)-\phi_2(\mathbf{e}) \geq 0$, and $\phi_2(\mathbf{e})-\phi_2(e_1,e_2+1) \geq 0$, with strict inequality for at least one. Hence, the higher price $\widetilde{p}_1(\mathbf{e})$ increases the viability of the rival relative to the equilibrium price $p_1(\mathbf{e})$. Thus, condition (1) of the Cabral & Riordan definition is met.

If counterfactually the rival's viability is unaffected by the pricing decision of the firm, then $\phi_2(e_1+1,e_2)-\phi_2(\mathbf{e})=0$ and $\phi_2(\mathbf{e})-\phi_2(e_1,e_2+1)=0$. By construction, then $\widetilde{p}_1(\mathbf{e})$ rather than $p_1(\mathbf{e})$ satisfies the first-order condition (13). Since the first-order condition (13) is sufficient for maximizing the expected net present value of the firm, the higher price $\widetilde{p}_1(\mathbf{e})$ is more profitable than $p_1(\mathbf{e})$ under the premise of the counterfactual. Thus, condition (2) of the Cabral & Riordan definition is met. It follows that the equilibrium price $p_1(\mathbf{e})$ is predatory according to the Cabral & Riordan definition.

Part (b): Suppose the equilibrium price $p_1(\mathbf{e})$ is predatory according to the Cabral & Riordan definition. Then there exists a higher price $\widetilde{p}_1(\mathbf{e})$ that is more profitable under the premise that $\phi_2(e_1+1,e_2)-\phi_2(\mathbf{e})=0$ and $\phi_2(\mathbf{e})-\phi_2(e_1,e_2+1)=0$. Given the expression for the probability of rival exit in equation (14) this implies that

$$\begin{aligned}&[D_1(p_1(\mathbf{e}),p_2(\mathbf{e}))-D_1(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e})]\,[\phi_2(e_1+1,e_2)-\phi_2(\mathbf{e})]\\&-[D_2(p_1(\mathbf{e}),p_2(\mathbf{e}))-D_2(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e}))]\,[\phi_2(\mathbf{e})-\phi_2(e_1,e_2+1)]>0.\end{aligned}$$

Because $D_1(\cdot)$ decreases in p_1, $D_2(\cdot)$ increases in p_1, and $\widetilde{p}_1(\mathbf{e}) > p_1(\mathbf{e})$, it follows that $[D_1(p_1(\mathbf{e}),p_2(\mathbf{e}))-D_1(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e})] > 0$ and $-[D_2(p_1(\mathbf{e}),p_2(\mathbf{e}))-D_2(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e}))] > 0$. This, in turn, implies that $\phi_2(e_1+1,e_2)-\phi_2(\mathbf{e})>0$ or $\phi_2(\mathbf{e})-\phi_2(e_1,e_2+1)>0$ or both. Because $\phi_1(\mathbf{e})<1$, $V_1(e_1,0)>V_1(\mathbf{e})$, and $V_1(e_1+1,0)>V_1(e_1+1,e_2)$ by assumption, this is equivalent to $\Gamma_1^2(\mathbf{e})>0$ or $\Theta_1^2(\mathbf{e})>0$. ■

Proof of Proposition 2. *Part (a):* Define $\widetilde{p}_1(\mathbf{e})$ as the solution to the first-order condition

$$\begin{aligned}&mr_1(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e}))-c(e_1)+\left[\Gamma_1^1(\mathbf{e})+\Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}+\Gamma_1^4(\mathbf{e})\right]\\&+\frac{D_2(\mathbf{e})}{1-D_1(\mathbf{e})}\left[\Theta_1^1(\mathbf{e})\big|_{\phi_2=0}+\Theta_1^3(\mathbf{e})\big|_{\phi_2=0}+\Theta_1^4(\mathbf{e})\right]=0.\end{aligned}\tag{15}$$

Subtracting equation (15) from equation (6), we have

$$\begin{aligned}&mr_1(p_1(\mathbf{e}),p_2(\mathbf{e}))-mr_1(\widetilde{p}_1(\mathbf{e}),p_2(\mathbf{e}))=\left[\Gamma^2(\mathbf{e})+\Gamma^5(\mathbf{e})+\left[\Gamma^3(\mathbf{e})-\Gamma^3(\mathbf{e})\big|_{\phi_2=0}\right]\right]\\&+\frac{D_2(\mathbf{e})}{1-D_1(\mathbf{e})}\left[\Theta^2(\mathbf{e})+\left[\Theta^1(\mathbf{e})-\Theta^1(\mathbf{e})\big|_{\phi_2=0}\right]+\left[\Theta^3(\mathbf{e})-\Theta^3(\mathbf{e})\big|_{\phi_2=0}\right]\right]>0.\end{aligned}$$

Hence, $\widetilde{p}_1(\mathbf{e})>p_1(\mathbf{e})$.

Proceeding as in the proof of Proposition 1, the higher price $\widetilde{p}_1(\mathbf{e})$ increases the viability of the rival relative to the equilibrium price $p_1(\mathbf{e})$. Thus, condition (1) of the Ordover & Willig definition is met.

If counterfactually the rival's viability is certain, then $\phi_2(e_1+1,e_2)=\phi_2(\mathbf{e})=\phi_2(e_1,e_2+1)=0$. By construction, then, $\widetilde{p}_1(\mathbf{e})$ rather than $p_1(\mathbf{e})$ satisfies the first-order condition (15). Since the first-order condition (15) is sufficient for maximizing the expected net present value of the firm, the higher price $\widetilde{p}_1(\mathbf{e})$ is more profitable than $p_1(\mathbf{e})$ under the premise of the counterfactual. Thus, condition (2) of the Ordover & Willig definition is met. It follows that the equilibrium price $p_1(\mathbf{e})$ is predatory according to the Ordover & Willig definition.

Part (b): Suppose the equilibrium price $p_1(\mathbf{e})$ is predatory according to the Ordover & Willig definition. Then there exists a higher price $\widetilde{p}_1(\mathbf{e}) > p_1(\mathbf{e})$ that is more profitable under the premise that $\phi_2(\mathbf{e}) = \phi_2(e_1+1, e_2) = \phi_2(e_1, e_2+1) = 0$. This implies that

$$\begin{aligned} & mr_1(p_1(\mathbf{e}), p_2(\mathbf{e})) - c(e_1) + \left[\Gamma_1^1(\mathbf{e}) + \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0} + \Gamma_1^4(\mathbf{e})\right] \\ & + \frac{D_2(\mathbf{e})}{1 - D_1(\mathbf{e})}\left[\Theta_1^1(\mathbf{e})\big|_{\phi_2=0} + \Theta_1^3(\mathbf{e})\big|_{\phi_2=0} + \Theta_1^4(\mathbf{e})\right] < 0. \end{aligned}$$

This, in turn, implies that

$$\begin{aligned} & \left[\Gamma_1^2(\mathbf{e}) + \Gamma_1^3(\mathbf{e}) + \Gamma_1^5(\mathbf{e}) + \frac{D_2(\mathbf{e})}{1 - D_2(\mathbf{e})}\left[\Theta_1^1(\mathbf{e}) + \Theta_1^2(\mathbf{e}) + \Theta_1^3(\mathbf{e})\right]\right] \\ & > \left[\Gamma_1^3(\mathbf{e})\big|_{\phi_2=0} + \frac{D_2(\mathbf{e})}{1 - D_2(\mathbf{e})}\left[\Theta_1^1(\mathbf{e})\big|_{\phi_2=0} + \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right]\right] \end{aligned}$$

or equivalently

$$\begin{aligned} & \Gamma_1^2(\mathbf{e}) + \Gamma_1^5(\mathbf{e}) + \left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right] \\ & + \frac{D_2(\mathbf{e})}{1 - D_1(\mathbf{e})}\left[\Theta_1^2(\mathbf{e}) + \left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right] + \left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right]\right] > 0. \end{aligned}$$

For this to hold one or more of the terms $\Gamma_1^2(\mathbf{e})$, $\Theta_1^2(\mathbf{e})$, $\Gamma_1^5(\mathbf{e})$, $\left[\Gamma_1^3(\mathbf{e}) - \Gamma_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$, $\left[\Theta_1^1(\mathbf{e}) - \Theta_1^1(\mathbf{e})\big|_{\phi_2=0}\right]$, $\left[\Theta_1^3(\mathbf{e}) - \Theta_1^3(\mathbf{e})\big|_{\phi_2=0}\right]$ must be positive. ■

C Appendix: Additional figures and tables

C.1 Slice along σ

Figures 7-8 present the counterfactual correspondence. Figure 9 and Table 9 present the surviving and eliminated equilibria, while Table 10 presents the impact of conduct restrictions.

C.2 Slice along $\overline{X}$

Figures 10-11 present the counterfactual correspondence, Figure 12 and Table 11 present the surviving and eliminated equilibria, while Table 12 presents the impact of conduct restrictions.

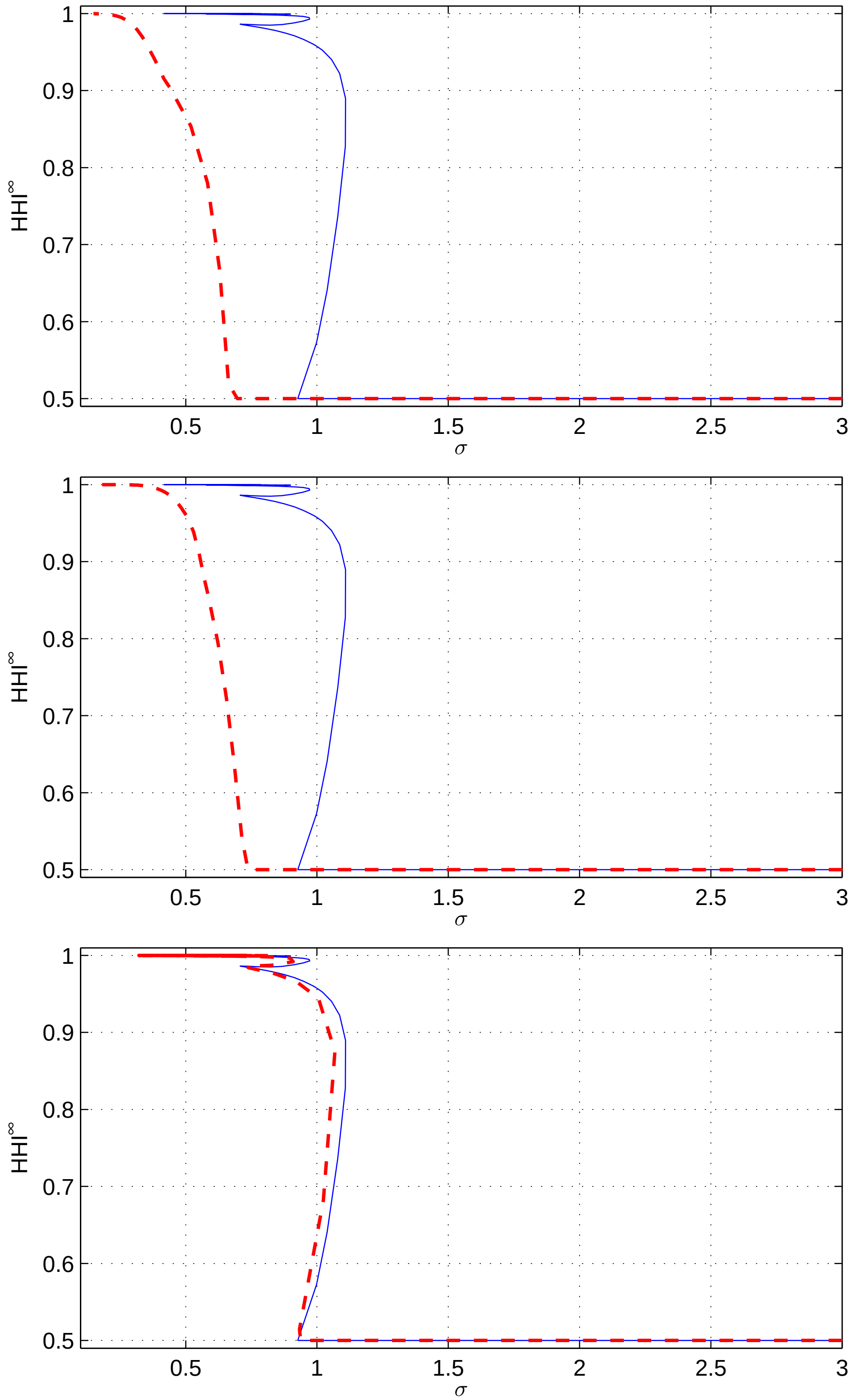

Figure 7: Counterfactual correspondence for Definitions 1–3 (upper, middle, and lower panel). Equilibrium correspondence (expected long-run Herfindahl index), slice along $\sigma \in [0, 3]$.

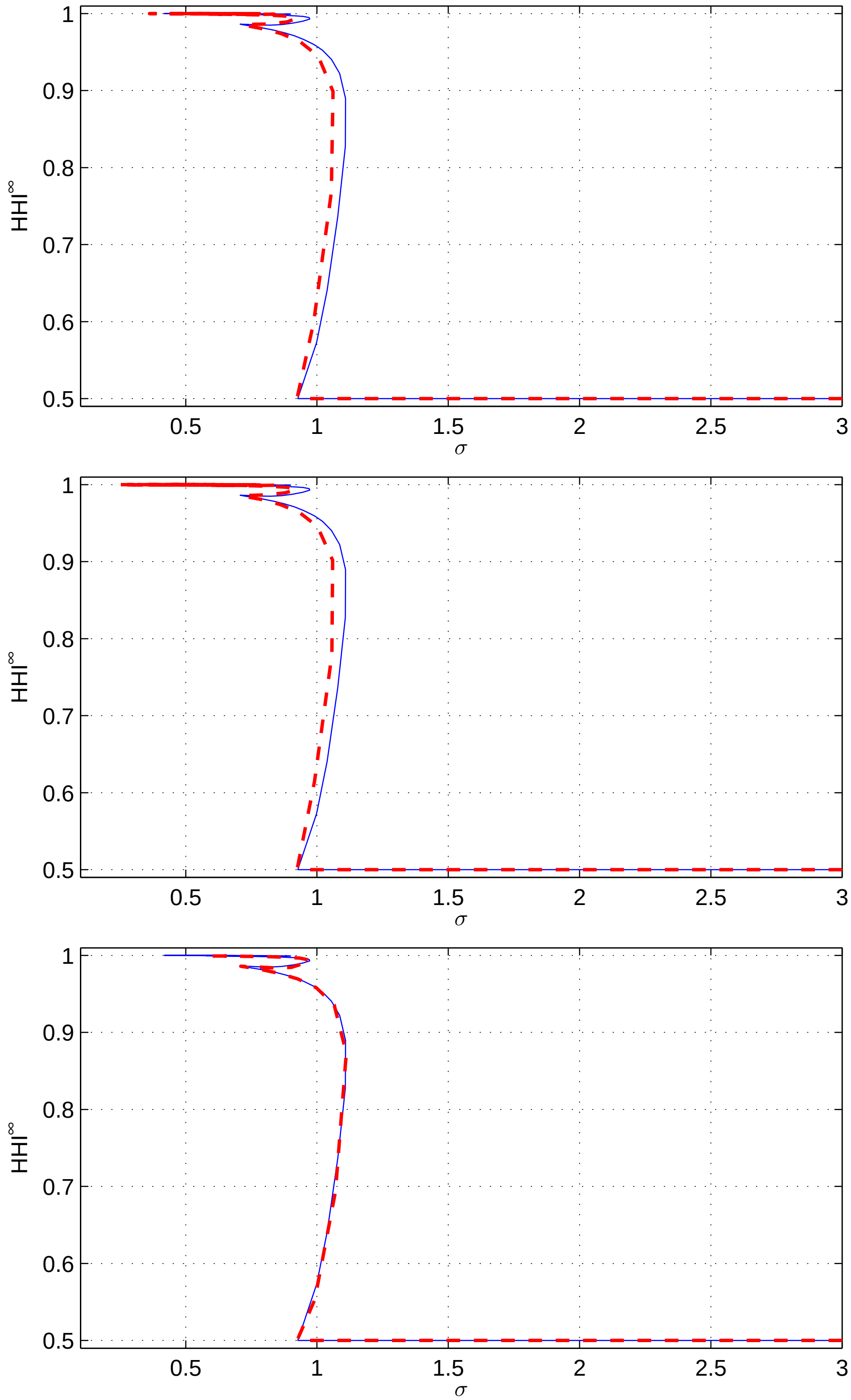

Figure 8: Counterfactual correspondence for Definitions 4–6 (upper, middle, and lower panel). Equilibrium correspondence (expected long-run Herfindahl index), slice along $\sigma \in [0, 3]$.

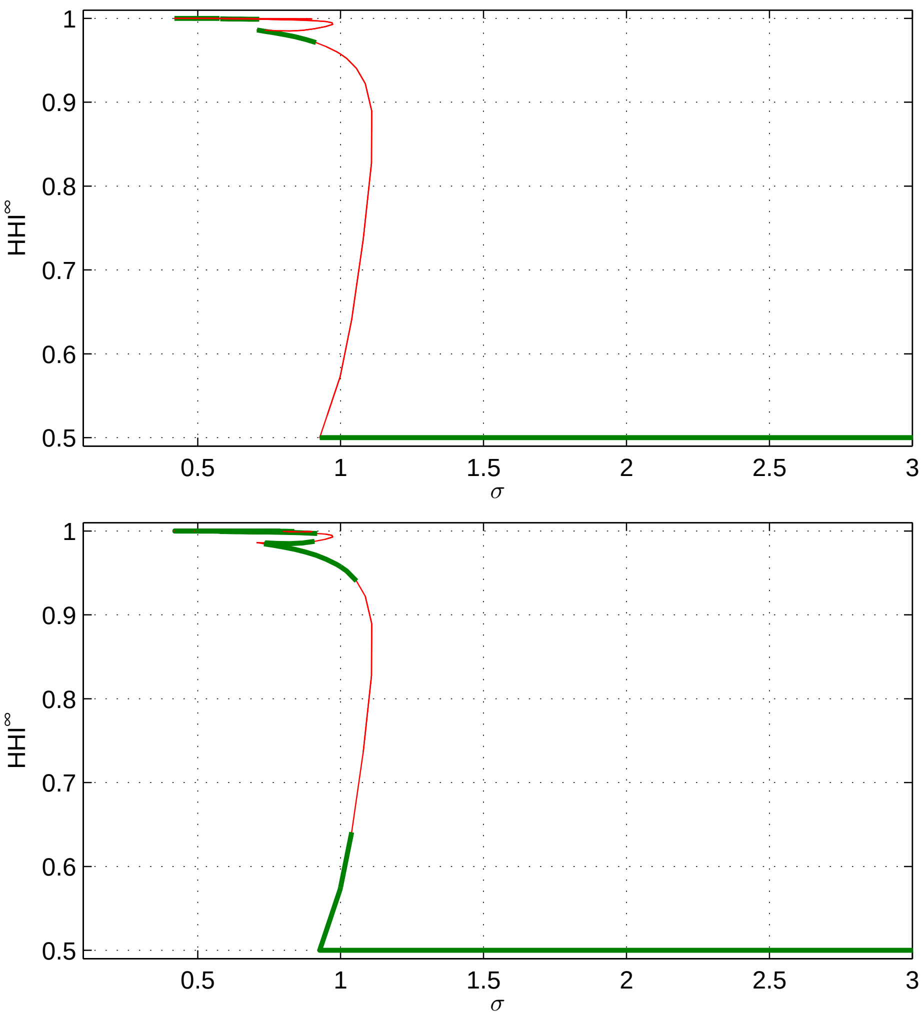

Figure 9: Eliminated and surviving equilibria for Definitions 2 (upper panel) and 4 (lower panel). Equilibrium correspondence (expected long-run Herfindahl index), slice along $\sigma \in [0, 3]$.

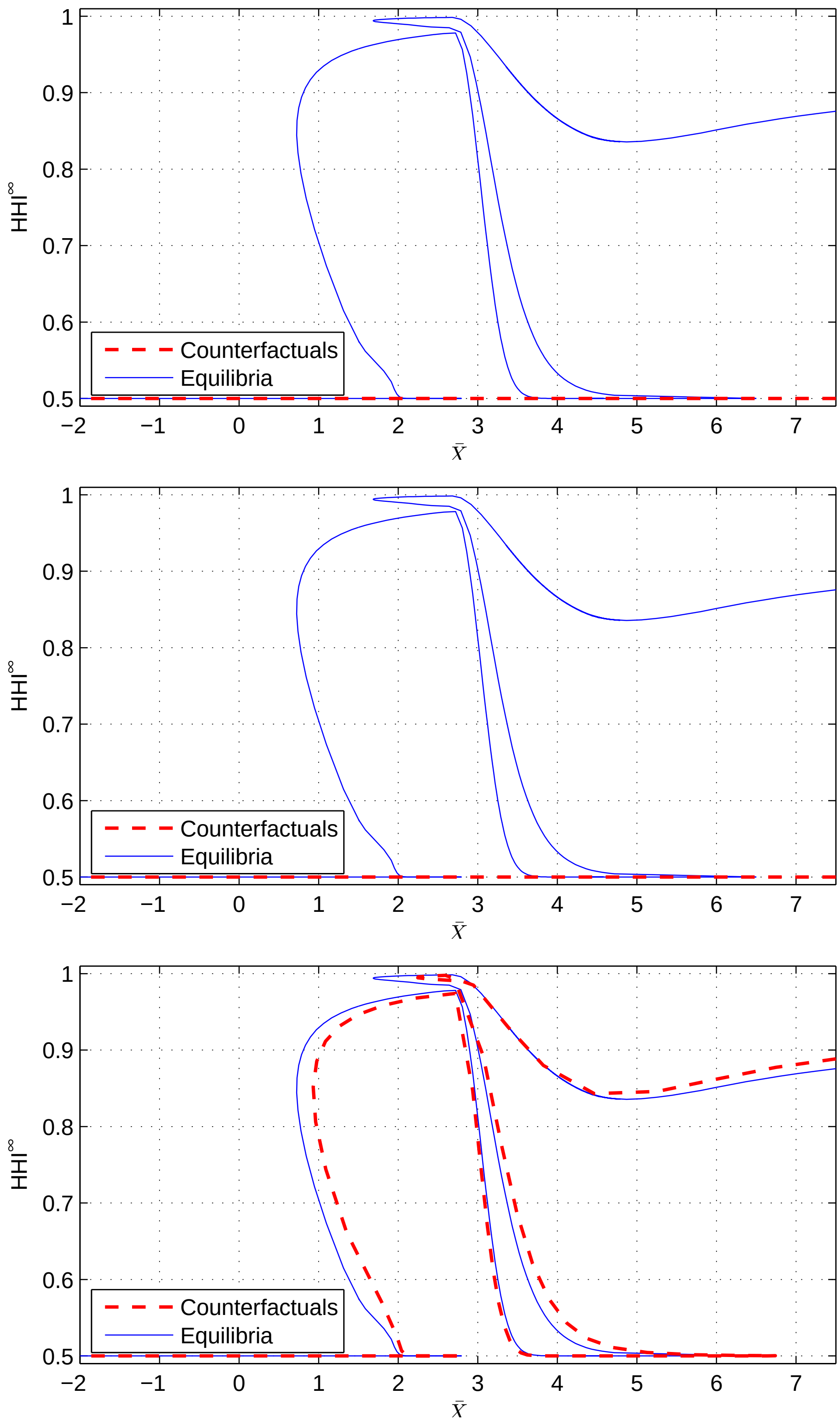

Figure 10: Counterfactual correspondence for Definitions 1–3 (upper, middle, and lower panel). Equilibrium correspondence (expected long-run Herfindahl index), slice along $\overline{X} \in [-1.5, 7.5]$.

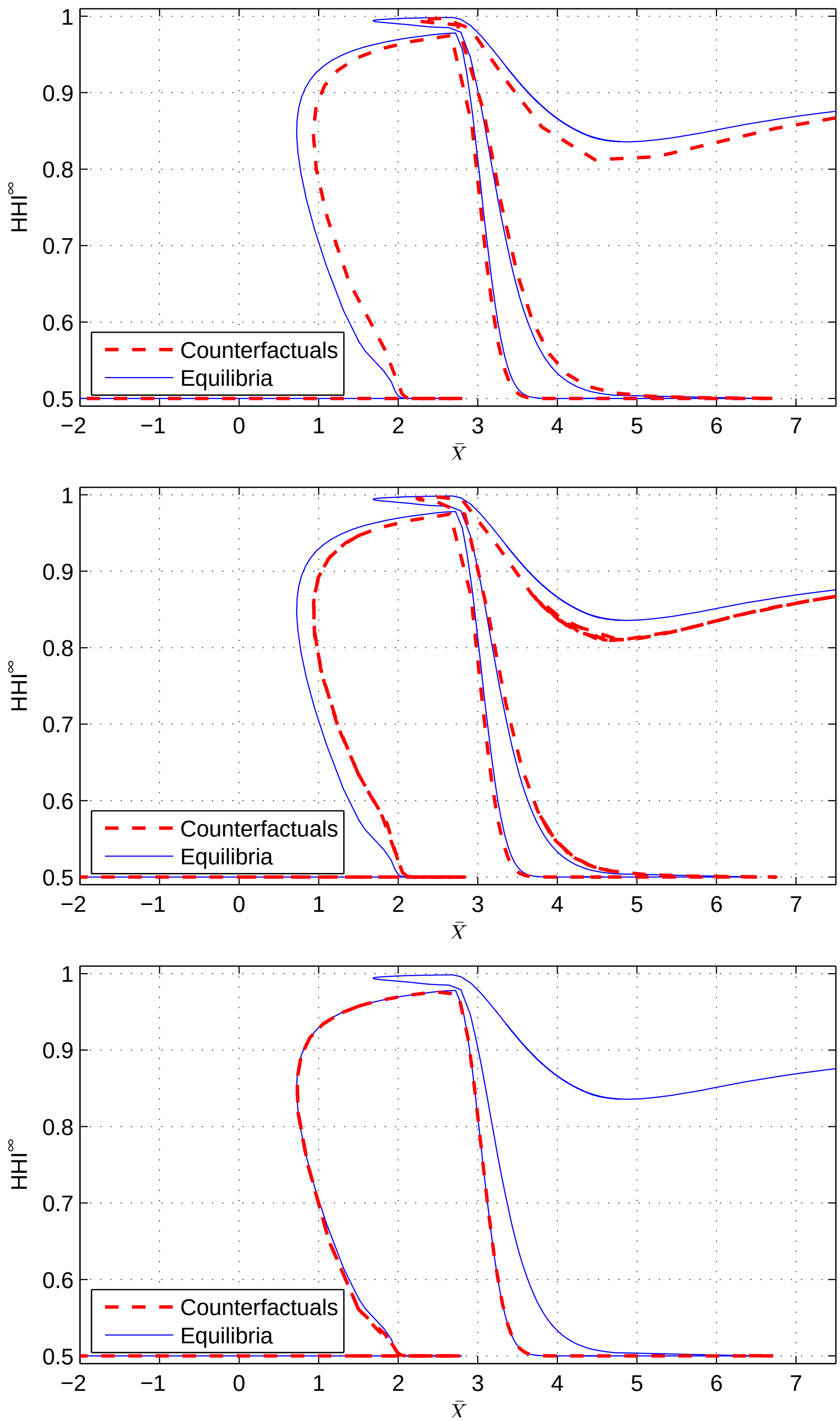

Figure 11: Counterfactual correspondence for Definitions 4–6 (upper, middle, and lower panel). Equilibrium correspondence (expected long-run Herfindahl index), slice along $\overline{X} \in [-1.5, 7.5]$.

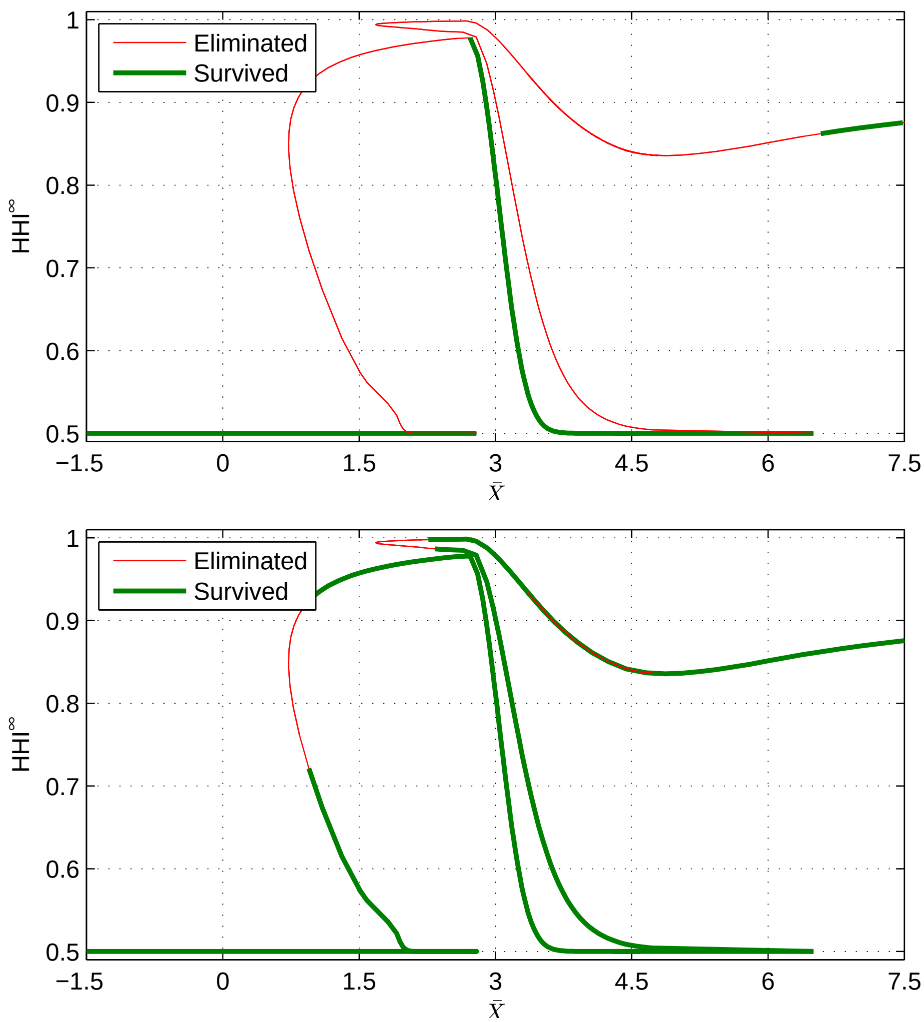

Figure 12: Eliminated and surviving equilibria for Definitions 2 (upper panel) and 4 (lower panel). Equilibrium correspondence (Expected long-run Herfindahl index), slice along $\overline{X} \in [-1.5, 7.5]$.

		definitions					
metric		1	2	3	4	5	6
	surv.	8%	8%	42%	39%	39%	94%
	elim.	91%	92%	58%	61%	61%	0%
HHI^{∞}	surv.	0.85	0.85	0.95	0.94	0.94	0.98
	elim.	0.99	0.99	1.00	1.00	1.00	NaN
EP^{∞}	surv.	7.68	7.68	8.36	8.32	8.32	8.56
	elim.	8.67	8.67	8.74	8.75	8.75	NaN
CS^{∞}	surv.	2.60	2.60	1.79	1.84	1.84	1.56
	elim.	1.43	1.43	1.34	1.33	1.33	NaN
TS^{∞}	surv.	6.55	6.55	6.31	6.31	6.31	6.26
	elim.	6.24	6.24	6.23	6.24	6.24	NaN
CS^{NPV}	surv.	107.40	107.40	107.37	107.13	107.13	107.49
	elim.	107.73	107.71	107.90	108.04	108.04	NaN
TS^{NPV}	surv.	114.71	114.71	113.26	113.09	113.09	113.08
	elim.	113.10	113.09	113.19	113.32	113.32	NaN

Table 9: Industry structure, conduct, and performance for eliminated and surviving equilibria for various definitions of predatory incentives. Slice along $\sigma \in [0.4, 1.1]$, uniformly spaced grid over multiplicity area.

		Definitions					
Measure		1	2	3	4	5	6
$\overline{p}^{\infty}$	Up	-	-	10%	10%	10%	-
	Down	62%	62%	10%	10%	10%	5%
Avg=	Same	38%	38%	81%	81%	81%	95%
7.2254	Avg.	-1.5700	-1.3614	-0.1047	-0.1054	-0.1033	-0.0059
HHI^{∞}	Up	-	-	5%	-	5%	-
	Down	62%	62%	10%	10%	10%	-
Avg=	Same	38%	38%	86%	90%	86%	100%
0.75624	Avg.	-0.2077	-0.1833	-0.0163	-0.0164	-0.0160	-0.0009
CS^{∞}	Up	62%	62%	10%	10%	10%	5%
	Down	-	-	10%	10%	10%	-
Avg=	Same	38%	38%	81%	81%	81%	95%
3.2744	Avg.	+1.7449	+1.5194	+0.1209	+0.1217	+0.1193	+0.0068
TS^{∞}	Up	62%	62%	10%	10%	10%	-
	Down	-	-	5%	5%	5%	-
Avg=	Same	38%	38%	86%	86%	86%	100%
6.8399	Avg.	+0.5062	+0.4597	+0.0496	+0.0499	+0.0490	+0.0028
CS^{NPV}	Up	-	14%	-	-	5%	-
	Down	100%	62%	48%	52%	-	62%
Avg=	Same	-	24%	52%	48%	95%	38%
104.57	Avg.	-48.1640	-3.0778	-0.9812	-0.9924	-0.0105	-1.2047
TS^{NPV}	Up	-	48%	10%	10%	10%	-
	Down	100%	-	-	-	-	-
Avg=	Same	-	52%	90%	90%	90%	100%
117.22	Avg.	-10.7580	+2.2789	+0.3677	+0.3559	+0.3440	+0.0199

Table 10: Impact of conduct restriction for $\sigma \in (0.3, 3)$.

		definitions					
metric		1	2	3	4	5	6
	surv.	14%	14%	82%	77%	91%	70%
	elim.	86%	82%	18%	23%	9%	11%
HHI^∞	surv.	0.55	0.55	0.71	0.73	0.71	0.78
	elim.	0.76	0.77	0.82	0.76	0.95	0.81
EP^∞	surv.	5.57	5.57	6.60	6.68	6.58	7.03
	elim.	6.91	6.94	7.26	6.86	8.16	7.17
CS^∞	surv.	5.07	5.07	3.88	3.79	3.91	3.39
	elim.	3.53	3.50	3.13	3.58	2.09	3.22
TS^∞	surv.	7.28	7.28	6.89	6.86	6.90	6.71
	elim.	6.76	6.75	6.56	6.73	6.14	6.62
CS^{NPV}	surv.	106.73	106.73	104.98	104.85	105.01	104.35
	elim.	104.44	104.39	103.71	104.42	102.14	103.24
TS^{NPV}	surv.	117.74	117.74	117.84	117.65	117.85	115.70
	elim.	117.12	117.07	114.32	115.67	110.70	114.84

Table 11: Industry structure, conduct, and performance for eliminated and surviving equilibria for various definitions of predatory incentives. Slice along $\overline{X} \in [1, 6.5]$, uniformly spaced grid over multiplicity area.

		Definitions					
Measure		1	2	3	4	5	6
$\overline{p}^{\infty}$	Up	-	-	15%	15%	10%	5%
	Down	57%	57%	40%	45%	45%	10%
Avg=	Same	43%	43%	45%	40%	45%	85%
6.4019	Avg.	-0.9956	-0.9956	-0.0982	-0.0906	-0.0874	-0.0334
HHI^{∞}	Up	-	-	5%	5%	-	5%
	Down	57%	57%	15%	15%	10%	10%
Avg=	Same	43%	43%	80%	80%	90%	85%
0.67904	Avg.	-0.1538	-0.1538	-0.0089	-0.0140	-0.0135	-0.0052
CS^{∞}	Up	57%	57%	25%	45%	50%	10%
	Down	-	-	15%	15%	10%	5%
Avg=	Same	43%	43%	60%	40%	40%	85%
4.1214	Avg.	+1.1452	+1.1452	+0.1023	+0.1041	+0.1005	+0.0385
TS^{∞}	Up	57%	57%	25%	15%	10%	10%
	Down	-	-	5%	5%	-	5%
Avg=	Same	43%	43%	70%	80%	90%	85%
7.0664	Avg.	+0.3007	+0.3007	+0.0488	+0.0359	+0.0337	+0.0154
CS^{NPV}	Up	-	14%	-	-	5%	-
	Down	100%	71%	55%	65%	-	70%
Avg=	Same	-	14%	45%	35%	95%	30%
105.35	Avg.	-46.3980	-3.9722	-1.2757	-1.6928	-0.0201	-1.8716
TS^{NPV}	Up	-	36%	20%	5%	5%	5%
	Down	100%	14%	-	5%	-	5%
Avg=	Same	-	50%	80%	90%	95%	90%
120.51	Avg.	-13.6140	+0.0110	+0.5811	+0.1540	+0.1151	+0.0728

Table 12: Impact of conduct restriction for $\overline{X} \in (-2, 7.5)$.