An Equilibrium Selection Theory of Monopolization*

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Abstract

We develop a duopoly model in which firms compete for the market (e.g., investing in process innovation or product development) as well as in the market (e.g., setting quantities or prices). Competition for the market generates multiple equilibria that differ in the firms' investment levels, relative size, and profitability. We show that monopolization that affects competition in the market can act as an equilibrium selection device in competition for the market. In particular, it eliminates equilibria that are undesirable for the monopolizing firm, while not generating new equilibria. This result complicates the task of determining whether a firm's dominance in a given market is the result of fair competition or unlawful monopolization. We discuss a number of implications for antitrust policy and litigation, and illustrate these by means of two well-known antitrust cases.

Keywords: Monopolization; antitrust; multiple equilibria; indeterminacy; firm behavior.

JEL codes: D4, L4, K2.

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> Every person who shall monopolize, or attempt to monopolize, or combine or conspire with any other person or persons, to monopolize any part of the trade or commerce among the several States, or with foreign nations, shall be deemed guilty of a felony. (*Sherman Act*, Section 2.)

1. Introduction

Section 2 of the Sherman Act makes it illegal to "monopolize" any part of the trade or commerce in the United States. In *United States v. Grinnell*, the U.S. Supreme Court specified two criteria for unlawful monopolization: "(1) the possession of monopoly power in the relevant market; and (2) the willful acquisition or maintenance of that power as distinguished from growth or development as a consequence of a superior product, business acumen, or historical accident" (384 US 563, 1966).

In practice, assessing the first criterion can be difficult. The conventional approach relies on a firm's large market share as an indicator, even though large market share *ex post* does not necessarily indicate the possession of monopoly power *ex ante*. Assessing the second criterion can pose an even greater challenge, because it requires courts to determine the cause of a firm's dominance. That is, it requires courts to construct a counterfactual scenario of what would have happened *but for* the hypothesized cause. Even if the alleged conduct of a firm—be it bundling discounts, loyalty rebates, exclusive dealing, etc.—is not in dispute, the effect of such conduct on rivals' ability to compete is often contested.[1] Plaintiffs in monopolization cases usually argue that the conduct illegally forecloses (part of) the market and thereby limits competition based on merits; defendants tend to counter that their conduct represents lawful business practices that benefit consumers, and that their dominant position is a result of vigorous competition. In many cases, both sides point to the same market data as evidence supporting their claims.

In this paper, we examine whether commonly observed market data can provide evidence of monopolization in an oligopolistic industry when there are multiple equilibria. To do so, we build a two-stage game between two firms that produce identical or differentiated varieties of a good. At the first stage, the firms decide whether to invest in innovation that leads to a lower marginal production cost for a given product (or, equivalently, to a better product for a given marginal cost). At the second stage, the

[1] For example, in *United States v. Microsoft Corp.* (253 F.3d 34, 58 (D.C. Cir. 2001)), the D.C. Circuit Court of Appeals articulated several principles that apply to distinguishing competitive and exclusionary conduct, including that "to be condemned as exclusionary, a monopolist's act must have an 'anticompetitive effect.' "

firms compete in a duopoly market, taking the first-stage choices as given. We compare this "fair game" to a "rigged game" in which a part of the market has been foreclosed by one of the firms to the other. We do not explicitly model a particular monopolizing conduct, but instead focus on the intended effect of monopolization, which is to exclude competitors from part of the market. In our model, this foreclosure effect takes the form of an (unlawful) quantity constraint on a firm's marketable output. The constraint directly affects the second-stage production or pricing decisions. More importantly, it indirectly feeds back to the firms' first-stage investment decisions. We solve for the equilibria of both games, and then ask the question: Having observed the firms' investments, prices, sales, and profits, is it possible to determine which of these two games—fair or rigged—generated these data?

We show that, for a range of quantity constraints, the answer to this question may be negative. The reason is the following. For certain parameter values, the fair game has multiple asymmetric equilibria. In these equilibria, one firm invests and becomes dominant while the other does not invest and becomes a fringe firm. Under monopolization, some equilibria of the fair game disappear, but others remain unchanged. In particular, the asymmetric equilibrium in which the monopolizing firm is dominant may become the unique equilibrium (and this equilibrium is inefficient if the monopolizing firm has higher investment costs than its rival). In other words, the role of monopolization is not to "alter" any equilibrium outcome, but to "select" a desirable outcome from the set of all possible equilibria of the fair game. Now, if an asymmetric market outcome is observed in some industry, is it because the dominant firm monopolized the market, or is it because the two firms happened to coordinate on this particular asymmetric equilibrium in the course of fair competition? We argue that neither theory is falsifiable by the observed market data. While monopolization is, in principle, detectable if sales quantities, prices, or investments are not consistent with any equilibrium that occurs in the absence of monopolization, it will be undetectable if it only eliminates equilibria without affecting the remaining one(s).

This result has several implications for the use of market data as circumstantial evidence for monopolization. First, establishing that a firm's conduct has anticompetitive effects is difficult if it eliminates possible market outcomes without affecting the remaining equilibria. Conversely, there exist multiple counterfactual scenarios of what the market equilibrium would look like but for the defendant's conduct. These indeterminacies complicate the prosecution of monopolization cases, where a well established requirement is that plaintiffs prove "harm to competition." We show that common legal tests for exclusionary or predatory conduct have little discriminatory power in our framework.

Second, the fact that the constraint imposed by unlawful monopolization is not binding in equilibrium can make it costly for firms to generate evidence *for* monopolization, and we argue that these costs may well be prohibitive. In particular, this is true when the industry exhibits large economies of scale and lumpy investments. In this case, the recoupment of the first-stage investment depends on the expectation of producing and selling a large quantity at the second stage, and even a relatively small foreclosure level may make the competitor's investment uneconomical (and thus achieve the intended equilibrium selection effect). Yet, such levels may still pass conventional "safe harbor" tests, such as those typically employed in exclusive dealing cases. This observation suggests that, instead of a "one-size-fits-all" safe harbor threshold, relatively more stringent thresholds could be reasonable in industries characterized by large, lumpy investments.

Third, a firm that *believes* that it faces constraints from monopolization may interpret the observed equilibrium as fully consistent with this belief, even if the true game is fair. By the same logic, a firm that is believed to have monopolized a part of the market may benefit from the equilibrium selection effect, even if its conduct did not harm its rivals.[2] In either case, firms can "agree to disagree" about the nature of competition they are engaged in, as neither firm observes evidence that could falsify its belief. They may thus arrive at mutually optimistic estimates of their success probability in a monopolization trial and fail to resolve the case out of court (or fail to resolve the case quickly). This result sheds new light on an old question in the theory of legal settlements—what is the source of irreconcilable differences in beliefs that prevent, or complicate, dispute settlement?

The remainder of the paper is structured as follows. In Section 2 we introduce our two-stage game of investment and Cournot competition, and characterize its equilibria assuming competition between the two firms is fair. In Section 3 we introduce monopolization to the model and characterize its equilibria when part of the market is foreclosed to one of the firms. In particular, we show that monopolization can serve as an equilibrium selection device. In Section 4 we discuss several implications of our results for antitrust policy, antitrust enforcement, and firm strategy, along the lines discussed above. In Section 5 we show that our results are robust under Bertrand competition or when firms can choose among more than two investment levels. Finally, in Section 6 we illustrate our findings by means of two actual monopolization cases, *United States v. Dentsply* and *AMD v. Intel*. The related literature will be discussed in the relevant sections as we go along. An Appendix contains all formal proofs.

[2]This observation suggests that large firms can maintain their dominance by adopting a posture of strategic ambiguity when using potentially anticompetitive instruments. The benefit of ambiguous conduct is discussed in more detail in Section 4.3.

2. A Two-Stage Model of Investment and Competition

2.1 The industry

We consider a market for a homogenous good supplied by two firms that compete as Cournot duopolists. The demand function is

$$p \;=\; 1 - q_i - q_{-i},$$

where p is the price, q_i is firm i's quantity, and q_{-i} is the competitor's quantity. Both firms are endowed with a technology that allows production of the good at marginal cost $h \in (0, 1/2)$.[3] The firms interact in two stages. At stage one, each firm can make an investment to reduce its marginal cost from h to 0. We denote by $\gamma_i > 0$ the investment required for firm i to adopt the low marginal cost technology. Investment choices are made simultaneously. At the second stage, the firms observe each others' realized marginal costs and compete by simultaneously setting their outputs q_1 and q_2. Firm i's goal is to maximize its profit,

$$\pi_i \;=\; q_i(p - c_i) - F_i \;=\; q_i(1 - q_i - q_{-i} - c_i) - F_i,$$

where $F_i \in \{0, \gamma_i\}$ is firm i's investment and $c_i \in \{0, h\}$ is i's marginal cost. In the absence of any additional constraints, the game described above reflects lawful competition between the two firms and is called the *fair game*.

The first-stage investment decisions should be interpreted broadly, to reflect a range of activities a firm may undertake in order to improve its competitiveness. In our model as it is stated above, the investment yields a "process innovation" that reduces a firm's variable production costs. This could include upgrading of existing manufacturing plants to a more efficient production technology, the construction of new plants, or the training of sales staff to reduce per-unit retailing costs.[4] A different interpretation, which is formally equivalent, is that the investment yields a "product innovation" that increases consumers' willingness to pay for the firm's product. This could include development efforts to enhance the good's quality, but also promotion and advertising to increase consumers' perceived value of the good. In such cases, the investment would not lower

[3]The requirement $h < 1/2$ ensures that all relevant equilibrium quantities are interior.

[4]We emphasize, however, that ours is not a model of entry deterrence, where one firm can use large capacity investments as a commitment of "being tough" (as developed by Spence 1977, Dixit 1979, Fudenberg and Tirole 1983, and others). In our model, both firms are active in the relevant market and both make simultaneous investment decisions. In particular, there is no *a priori* difference between an incumbent and an entrant, or between a dominant firm and a fringe firm.

production costs but increase the intercept of the firm's demand function.[5] We selected the case of process innovation without loss of generality, and our results could be restated to apply to the case of product innovation.

The assumptions that firms compete as Cournot duopolists, and can only choose between two investment levels, are made because they yield the most straightforward exposition of our framework and results. We extend the model to differentiated product Bertrand competition and to more than two investment choices in Section 5, where we demonstrate that our main results do not depend on these assumptions. What is important for our model is that investments are lumpy; that is, they require discrete outlays of money and yield discrete cost reductions or product innovations. This is a realistic assumption in many industries, including heavy manufacturing, pharmaceuticals, medical products, and certain high-tech sectors (e.g., microprocessor fabrication).

2.2 Equilibrium of the fair game

Our solution concept is subgame perfect equilibrium. We first solve for the output decisions at stage two, and then for the investment decisions at stage one.

At stage two, the firms' marginal costs c_1, c_2 are known and the interior Cournot equilibrium outputs are

$$q_1(c_1,c_2) = \frac{1}{3} - \frac{2}{3}c_1 + \frac{1}{3}c_2 \quad \text{and} \quad q_2(c_1,c_2) = \frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1. \tag{1}$$

Our assumption that $h < 1/2$ ensures that equilibrium quantities are positive for any marginal cost combination. The equilibrium price is

$$p(c_1,c_2) = \frac{1}{3} + \frac{1}{3}c_1 + \frac{1}{3}c_2, \tag{2}$$

and the firms' profits are

$$\pi_1(c_1,c_2) = \left(\frac{1}{3} - \frac{2}{3}c_1 + \frac{1}{3}c_2\right)^2 - F_1 \quad \text{and} \quad \pi_2(c_1,c_2) = \left(\frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1\right)^2 - F_2. \tag{3}$$

At stage one, firm i anticipates this Cournot equilibrium and maximizes (3) by choice of $(c_i, F_i) \in \{(h,0),(0,\gamma_i)\}$. Thus, a subgame perfect equilibrium in pure strategies is a pair of investments that are mutual best responses in the first-stage game, together with the second-stage strategies in (1). To save on notation, we identify this equilibrium by its marginal cost pair (c_1, c_2) only.

[5] In such a model, we would assume that both firms have the same production costs, and that each firm can make a costly investment γ_i in product innovation. This innovation increases the price firm i receives for its own product from $p_i = 1 - q_i - q_{-i}$ to $p_i = 1 + b - q_i - q_{-i}$, where $b > 0$.

We now identify a subset of parameter values for which two asymmetric equilibria exist. In these equilibria, exactly one of the two firms invests in the low marginal cost technology. This firm becomes the dominant firm in the market, while the other becomes a fringe firm. To do so, we define two cutoff values for the investment cost associated with the low marginal cost technology:

$$\underline{\gamma} \equiv \frac{4}{9}h(1-h) < \frac{4}{9}h \equiv \overline{\gamma}.$$

We then have the following result:

Proposition 1. *If $\underline{\gamma} < \gamma_i < \overline{\gamma}$ for $i = 1, 2$, the fair game has two strict pure strategy equilibria, $(0, h)$ and $(h, 0)$. That is, one firm invests and adopts the low marginal cost technology, while the other firm does not invest and retains the high marginal cost technology.*[6]

The formal proof of Proposition 1 is in the Appendix; however, the intuition is straightforward: If γ_i was very low firm i would always want to invest, regardless of whether the other firm does so or not. Likewise, if γ_i was very high firm i would never want to invest, regardless of whether the other firm invests or not. Thus, to obtain two asymmetric equilibria, the firms' investment costs must be in an intermediate range, which is the interval identified in Proposition 1. For costs outside of this interval, there is generally only one equilibrium (which may be symmetric or asymmetric). Because our theory of monopolization as an equilibrium selection device, which we develop in Section 3, requires the fair game to possess multiple asymmetric equilibria, in the remainder of the paper we focus only on the case $\underline{\gamma} < \gamma_i < \overline{\gamma}$ $(i = 1, 2)$.

The asymmetric equilibrium where firm 1 invests is characterized by the cost pair $(c_1, c_2) = (0, h)$. In this equilibrium, we have

$$q_1(0, h) = \frac{1}{3}(1 + h) > \frac{1}{3}(1 - 2h) = q_2(0, h). \tag{4}$$

The reverse inequality holds if firm 2 invests. Thus, the investing firm becomes the dominant firm in the market. Furthermore, each firm earns a greater overall profit in the equilibrium in which it invests, compared to the equilibrium in which it does not invest. To see this, note that

$$\pi_1(0, h) > \pi_1(h, h) > \pi_1(h, 0). \tag{5}$$

[6] In addition to these two pure strategy equilibria there is also a mixed-strategy equilibrium, in which each firm chooses the low marginal cost technology with some probability and the high marginal cost technology with the remaining probability. We ignore this possibility here.

The first inequality follows from $(0, h)$ being a strict equilibrium, and the second inequality follows from the fact that π_1 is strictly increasing in c_2 (see (3)). These rankings are reversed if the firms switch roles. Thus, every firm prefers the equilibrium in which it is the dominant firm to the equilibrium in which it is the fringe firm.

2.3 Ranking the equilibria of the fair game

The multiple equilibria of this model can be ranked both normatively and positively. Note that, as we move from one asymmetric equilibrium to the other, the quantities, prices, and variable costs simply switch across firms, which means that consumer and producer surplus are the same in the two equilibria. Social welfare, therefore, depends only on the fixed cost the investing firm incurs. Specifically, welfare is higher in the equilibrium in which the dominant firm is the firm for which adopting the low marginal cost technology is less costly (i.e., the firm with the lower γ_i).

The equilibrium in which the low γ_i firm invests also survives the selection criterion of *risk dominance* (Harsanyi and Selten 1988; Harsanyi 1995). In general, consider a game with two equilibria, say A and B. Equilibrium A risk-dominates equilibrium B if the set of mixed strategy profiles under which the A-strategies are best responses is larger than the set of mixed strategy profiles under which the B-strategies are best responses. For our model, we obtain the following result:

Proposition 2. *Assume $\underline{\gamma} < \gamma_1 \neq \gamma_2 < \overline{\gamma}$. Then the equilibrium in which the low γ_i firm invests and the high-γ_i firm does not invest is the risk-dominant equilibrium of the fair game.*

One may think of a risk-dominant equilibrium as the equilibrium with the largest "basin of attraction," which is thus most likely to emerge as the long-run outcome in a dynamic adjustment process (see, e.g., Sandholm 2010). This criterion is appealing in games where equilibrium multiplicity arises from a coordination problem, as is the case here.

3. Monopolization

We now introduce a "rigged" version of our model, in which one firm has monopolized part of the market, and then examine how monopolization changes the equilibrium set.

3.1 Modeling unlawful monopolization

To distinguish unlawful monopolization from the mere possession of market power, we make the following observation: In a two-player Cournot duopoly, we can always regard each firm as a "monopolist" over its residual demand curve (i.e., given the other firm's output). The residual market of each firm is contestable, however: If a firm sells to, say, half of its residual market, its competitor could sell to the "unserved half" of that market if it wanted. In equilibrium, each firm sells just enough to not want to compete over the residual demand it leaves to its competitor. If, on the other hand, a firm's quantity is artificially restricted, so that it cannot exceed some upper limit $\hat{q}$, then the other firm is *guaranteed* a monopoly over a market of size $\alpha = 1 - \hat{q}$. This guaranteed monopoly is not contestable. Conversely, if a firm manages to monopolize the market for α units, it implicitly limits the quantity its competitor can sell to $\hat{q} = (1 - \alpha)$ units. Thus, unlawful monopolization by one firm can be represented by a quantity cap $\hat{q}$ imposed on the other firm.[7]

Like the investment at stage one, this quantity cap should be interpreted broadly. In practice, market foreclosure can be achieved through either vertical or horizontal exclusion, or a combination of both. Vertical exclusion involves a firm leveraging market power in vertically related markets, that is, in upstream or downstream markets, as discussed in Aghion and Bolton (1987), Rasmussen *et al.* (1991), Segal and Whinston (2000), and Whinston (2006, ch. 4), for example. Horizontal exclusion involves a firm leveraging market power in a horizontally related (i.e., parallel) market; see Dansby and Conrad (1984), Whinston (1990), Greenlee *et al.* (2008), and Elhauge (2009) among others. We do not model the specific conduct that leads to monopolization. Instead, we simply assume that, if a firm monopolizes by engaging in some anticompetitive activity, then this conduct manifests itself as an upper bound on the quantity the other firm can sell.

Without loss of generality, let firm 1 be the firm that monopolizes.[8] We call the resulting game the *rigged game*. The rigged game differs from the fair game only at the production and sales stage, where firm 2's marketable quantity cannot exceed some cap $\hat{q}$. That is, in the Cournot framework, monopolization changes firm 2's strategy set at the production stage from $[0, \infty)$ to $[0, \hat{q}]$. The investment stage is not directly affected by

[7]This interpretation reflects the intuition presented in Salop *et al.* (2014) in a discussion of the consumer harm from exclusive dealing: "[T]he foreclosure could restrict the entrants' ability to expand and gain market share, whether or not it raises the entrants' costs of producing low output levels. If competitors' outputs are capped by costs of expansion, the monopolist can maintain its supra-competitive pricing while ceding a limited market share to the entrants" (p. 18). The authors also note that "over time, exclusive dealing may harm consumers and the competitive process by reducing the ability or incentive of rivals to invest in superior technologies and better products, perhaps relegating them to niche positions where they provide less of a competitive constraint on a dominant firm or monopolist" (p. 7).

[8]We assume that only one firm has the opportunity to rig the game, and do not model differences across the firms that would allow one firm to rig the game but not the other. Firm 1 may be in position to rig the game due to dominance in other markets; we assume that such an advantage does not affect the model in the current market.

monopolization. However, it can (and will) be affected *indirectly*, because the constraint on strategies at the second stage changes the profitability of the firms' investments at the first stage.

3.2 Equilibrium of the rigged game

As before, we look for subgame perfect equilibria of the two-stage game.

Consider stage two first. If the quantity produced by firm 2 in the Cournot equilibrium of the fair game is weakly below $\hat{q}$, then $\hat{q}$ is not binding for the given pair of marginal costs:

$$\frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1 \;\leq\; \hat{q}. \tag{NB}$$

In this case, the firms' quantities, prices, and profits are the same as in the fair game. On the other hand, if the constraint on firm 2's marketable output is binding, that is, if

$$\frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1 \;>\; \hat{q}, \tag{B}$$

firm 2 produces $\hat{q}$ units and firm 1 plays a best response to $\hat{q}$. Combining these two cases, we can derive the following second-stage equilibrium quantities, prices, and profits:

$$q_1(c_1, c_2|\hat{q}) \;=\; \begin{cases} \frac{1}{3} - \frac{2}{3}c_1 + \frac{1}{3}c_2 & \text{if (NB)}, \\ \frac{1}{2} - \frac{1}{2}\hat{q} - \frac{1}{2}c_1 & \text{if (B)}, \end{cases} \tag{6}$$

$$q_2(c_1, c_2|\hat{q}) \;=\; \begin{cases} \frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1 & \text{if (NB)}, \\ \hat{q} & \text{if (B)}, \end{cases} \tag{7}$$

$$p(c_1, c_2|\hat{q}) \;=\; \begin{cases} \frac{1}{3} - \frac{1}{3}c_1 + \frac{1}{3}c_2 & \text{if (NB)}, \\ \frac{1}{2} - \frac{1}{2}\hat{q} + \frac{1}{2}c_1 & \text{if (B)}, \end{cases} \tag{8}$$

$$\pi_1(c_1, c_2|\hat{q}) \;=\; \begin{cases} \left(\frac{1}{3} - \frac{2}{3}c_1 + \frac{1}{3}c_2\right)^2 - F_1 & \text{if (NB)}, \\ \left(\frac{1}{2} - \frac{1}{2}\hat{q} - \frac{1}{2}c_1\right)^2 - F_1 & \text{if (B)}, \end{cases} \tag{9}$$

$$\pi_2(c_1, c_2|\hat{q}) \;=\; \begin{cases} \left(\frac{1}{3} - \frac{2}{3}c_2 + \frac{1}{3}c_1\right)^2 - F_2 & \text{if (NB)}, \\ \left(\frac{1}{2} - \frac{1}{2}\hat{q} - c_2 + \frac{1}{2}c_1\right)\hat{q} - F_2 & \text{if (B)}. \end{cases} \tag{10}$$

At the first stage, firms maximize the profits (9) and (10) through their technology investments. These investment decisions are characterized in the following result.

Proposition 3. *Suppose that $\underline{\gamma} < \gamma_i < \overline{\gamma}$ (so that the fair game has two asymmetric pure strategy equilibria). There exists B, with $q_2(h,h) < B < q_2(h,0)$, such that the following holds if and only if $\hat{q} \in \big(q_2(0,h), B\big)$:*

(a) The rigged game with quantity cap $\hat{q}$ has a unique equilibrium, $(c_1, c_2) = (0, h)$.

(b) In this equilibrium, all outputs, prices, and profits are the same as they are in the equilibrium of the fair game where $(c_1, c_2) = (0, h)$, and the quantity constraint imposed on firm 2 is not binding (that is, $q_2(0, h|\hat{q}) < \hat{q}$).

Furthermore, B increases in γ_2.

The equilibrium effect of unlawful monopolization identified in Proposition 3 is subtle. By imposing an appropriately chosen quantity constraint on its competitor, a firm can guarantee itself the status of the dominant firm in the industry. However, the quantity cap $\hat{q}$ does not enhance or otherwise alter a firm's dominant market position—it merely eliminates equilibria in which the firm is not dominant. Thus, from a purely observational perspective monopolization is an equilibrium selection device in our model. This is illustrated in the following example.

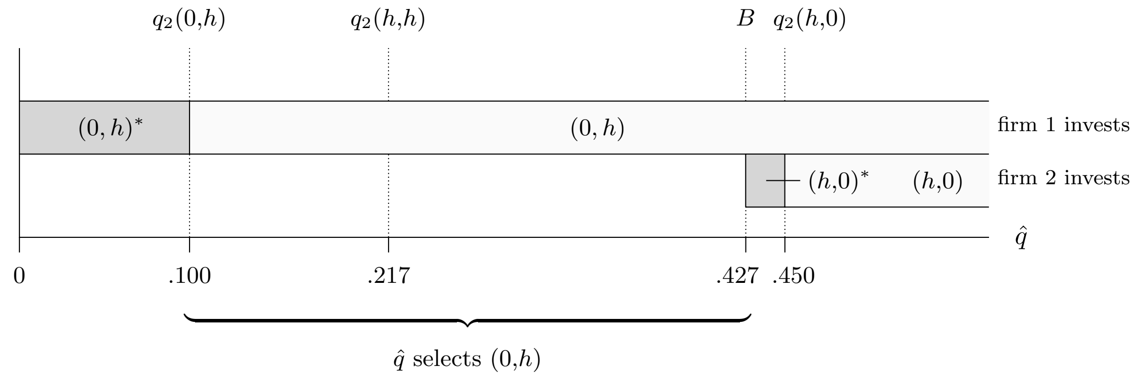
Example 1. Suppose $h = .35$ and $\gamma_1 = \gamma_2 = .15$. These values satisfy the condition in Proposition 1, so the fair game has two asymmetric equilibria. The quantities and profits in these equilibria are:

$$\begin{aligned} q_1(0,h) &= .450 = q_2(h,0), & \pi_1(0,h) &= .053 = \pi_2(h,0), \\ q_1(h,0) &= .100 = q_2(0,h), & \pi_1(h,0) &= .010 = \pi_2(0,h). \end{aligned}$$

When a quantity cap $\hat{q}$ is imposed on firm 2's output, the game becomes rigged. Its equilibria depend on the value of $\hat{q}$ and are depicted in Figure 1. (An asterisk indicates that the quantity constraint on firm 2 is binding in the equilibrium.)

In this example, we get $B = .427$. For quantity caps $\hat{q} \geq .427$ the rigged game has two asymmetric equilibria, while for $\hat{q} < .427$ it has a unique equilibrium in which firm 1 invests and firm 2 does not. Note that some quantity caps generate new equilibria that do not exist in the fair game: If $\hat{q} \in [.427, .450)$, an equilibrium exists in which $(c_1, c_2) = (h, 0)$. While this cost pair is also an equilibrium in the fair game, the firms' outputs and profits are different. This is because a cap in the given range places a binding constraint on firm 2's production decision, but is not stringent enough to deter firm 2 from investing. Similarly, if $\hat{q} < .100$, the equilibrium in the rigged game has $(c_1, c_2) = (0, h)$ but quantities and profits are not the same as in the $(0, h)$-equilibrium of the fair game. Such caps are, in principle, detectable.

Figure 1: Equilibria of the rigged game in Example 1.



Equilibrium selection, as described in Proposition 3, occurs for quantity caps $.100 < \hat{q} < .427$. In this case, the rigged game has a unique equilibrium in which firm 1 invests and firm 2 does not. Moreover, because the quantity cap does not bind in the resulting market outcome where firm 2 is a fringe firm, the firms' quantities and profits are the same as in in $(0, h)$-equilibrium of the fair game.

From a social welfare perspective, even if a quantity constraint does not bind on firm 2 in an equilibrium, there are still reasons to be concerned with its role in selecting the equilibrium to begin with. If $\gamma_1 > \gamma_2$, the unique equilibrium selected in the rigged game is inefficient relative to the outcome in which firm 2 is the dominant firm. This alternative outcome is an equilibrium of the fair game. Of course, there is no guarantee that the more efficient equilibrium would be played if the game was fair, but it is at least possible and, as Proposition 2 suggests, more likely to arise. If, on the other hand, firm 1 has the lower investment cost, monopolization actually selects the efficient outcome. However, this efficiency is static and monopolization may still create dynamic losses. For example, we may imagine that firms perform R&D activities with the aim of lowering their investment cost γ_i. Monopolization would reduce the incentive for firm 2 to engage in such innovative efforts, as it would be unable to benefit from its discoveries; this, in turn, may weaken firm 1's incentive to innovate. An industry in which one firm's dominance remains unchallenged because it imposes constraints on its competitors' market access may, therefore, be less likely to operate efficiently in the long run, even if the dominant firm is the more efficient competitor in the short run.

4. Implications

We now discuss the implications of our results for antitrust policy, antitrust enforcement, and firm behavior. We make the following arguments in order:

First, even with perfect information about market outcomes, courts and antitrust authorities may be unable to determine whether or not a firm's conduct has harmful effects on competition. This complicates the task of "protecting competition but not competitors," as well as the application of legal tests to identify harm to competition. Second, the fact that, under monopolization, the victim firm appears unconstrained in equilibrium affects a firm's ability to generate evidence for monopolization. Despite these negative implications, we show that Proposition 3 has some useful implications for the design of antitrust laws, and in particular for the choice of safe harbor thresholds. Third, firms engaged in competition may "agree to disagree" over whether competition is fair or rigged. Thus, our model provides a rational explanation for differences in beliefs that can generate protracted legal battles and settlement delays in the context of monopolization cases.

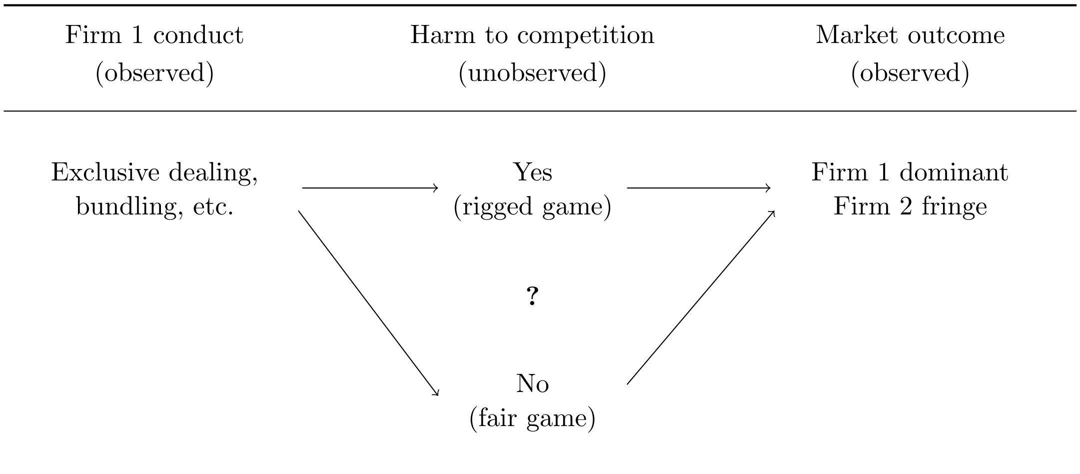
4.1 Observational equivalence, equilibrium indeterminacy, and detecting harm to competition

Proposition 1 and Proposition 3 show that the unique subgame perfect equilibrium of the rigged game with a quantity cap $\hat{q} \in \big(q_2(0,h), B\big)$ is also an equilibrium of the fair game. Thus, when an asymmetric market outcome prevails, it is possible that the firms are playing the fair game and happen to coordinate on this particular asymmetric equilibrium; but it is also possible that the firms are playing a rigged game in which the dominant firm imposed a quantity cap on the small firm and whose equilibrium is the observed asymmetric outcome. Regardless of the true nature of the game, the small firm can always allege that the true game is rigged and that it is the victim of monopolization by the dominant firm. On the other hand, the dominant firm can always maintain that the true game is fair and that its success is the result of lawful business practices.

It is then up to a third party, such as a court or antitrust authority, to determine the true game. Suppose that this third party observes the *potentially* monopolizing conduct of firm 1 (e.g., an exclusive dealing arrangement, product bundling, etc.) and all outcome variables of the game (i.e., investments, costs, prices, outputs, profits), but not whether firm 1's conduct harms competition. As illustrated in Figure 2, both hypotheses—harm and no harm—are consistent with a causal chain from conduct to market outcomes.[9]

[9] Our model assumes that monopolization is costless for firm 1, which implies that whether the firm has engaged in monopolization can not be inferred from its costs. This is reasonable if, as assumed earlier, the issue before an antitrust authority is not whether the conduct (such as an exclusive dealing clause)

Figure 2: Observational equivalence of the fair and rigged game.

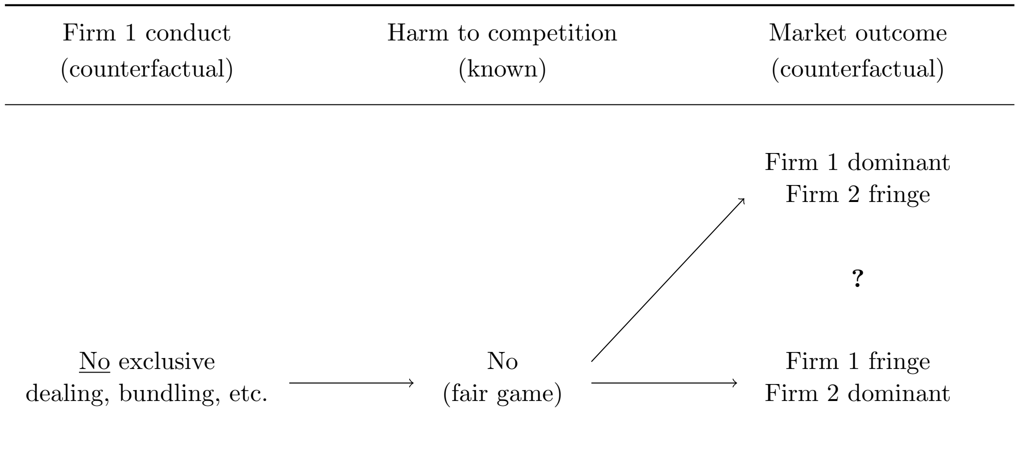


A similar difficulty arises when we look at counterfactuals. To determine whether an alleged conduct harms competition, courts typically perform a "but for" analysis: Hypothesize the absence of the conduct, in which case the game is unambiguously fair, and predict (by means of economic and statistical analysis) the counterfactual market outcome that would obtain in this scenario. A counterfactual prediction different from the actual outcome can then be seen as evidence for monopolization. However, in our model, monopolization does not create new equilibria, and only selects among the multiple equilibria of the fair game. Thus, the counterfactual market outcome is indeterminate, and includes the outcome under monopolization. This is illustrated in Figure 3.

These results are important for the following reason. Antitrust laws distinguish between the *protection of competition* and the *protection of competitors*. In the course of competition, it is almost inevitable that winners and losers are created—indeed, the very fact that winning firms are rewarded with larger market shares and higher profits is what provides firms with incentives to cut costs and improve products. While antitrust laws are aimed at protecting fair competition, their goal is never to protect the competitors themselves, and in particular not those competitors that lose in the course of fair competition. Thus, when a competition authority or a court needs to determine whether a particular market outcome is the result of monopolization, a type-1 error (a fair game being erroneously ruled a rigged game) protects losing competitors, while a type-2 error (a rigged game being erroneously ruled a fair game) fails to protect competition.

took place, but rather whether the conduct imposed a quantity cap on firm 2. The cost of the exclusive dealing clause would be incurred regardless of the competitive effect of the clause.

Figure 3: Counterfactual equilibrium indeterminacy.



Our analysis suggests that, in industries where firms compete both for the market and in the market, both types of errors are inherent.

This finding contributes to the existing literature concerned with the identification of unlawful conduct from market outcomes. An extreme instance of an industry to which our framework applies is a natural monopoly, where competition is entirely for the market. Evans and Schmalensee (2002) suggest that "if a defendant can establish that the relevant market is characterized by winner-take-all competition then they have provided a complete defense against a charge of predatory behavior . . . " and conclude that "there is no nonexclusion standard of comparison that makes logical sense in a winner-take all setting . . . under winner take-all competition we not only lack useful tools for detecting predatory behavior, we do not have a good definition of such behavior" (p. 26).[10] Our analysis shows that the undetectability of anticompetitive conduct extends from predatory behavior to general monopolizing conduct, and from winner-take-all competition to more general settings where competition is both for the market *and* in the market. We show that it is *precisely* in markets characterized by winner-take-all (or winner-take-most) competition where harm to competition may be impossible to either prove *or* disprove. The negative conclusions offered by Evans and Schmalensee (2002) can thus be interpreted as a statement about the relative cost of type-1 and type-2 errors—namely, the social cost of a type-1 error outweighs the social cost of a type-2 error.

Phlips (1995, 1996) argues that in the absence of detailed information on firm costs and market demand, defendants have an incentive to misreport market parameters and

[10]See also Farrell and Katz (2005), Encaoua and Hollander (2002) and Rubinfeld (1998) for further discussion of anticompetitive conduct in the presence of innovation and network effects.

thereby make anticompetitive behavior indistinguishable from lawful conduct. In our model, *even with full information* it may remain impossible to infer unlawful conduct from market data, owing to the multiplicity of equilibria. Of course, courts and antitrust authorities can, and do, utilize other evidence to determine harm to competition. However, in virtually all antitrust disputes, evidence based on the analysis of market data is central to the arguments of both sides, and several legal tests for whether a given business practice has anticompetitive effects specifically involve variables such as prices, quantities, costs, and profits, or measures of consumer welfare derived from these variables (see Hovenkamp 2008 for an overview of these tests). In light of our results, the problem with such tests is less the fact that the data are noisy or incomplete—if this was the problem, then better data or more data would eventually enable courts to get to the truth. Instead, our analysis reveals a deeper problem: In some industries, market data is indeterminate.

For such industries, our analysis calls into question, in particular, the usefulness of the "no economic sense" test that has been advocated by the U.S. Department of Justice.[11] Werden (2006) describes the premise of this test as follows: "[C]onduct is not exclusionary or predatory unless it would make no economic sense for the defendant but for the tendency to eliminate or lessen competition" (p. 413).[12] He cautions—correctly, in our view—that "[t]he no economic sense test can be applied only when there is a single, well-defined 'but for' scenario" (p. 422). But this is precisely the condition that is violated in our model. Figure 3 shows that there is no "single, well-defined 'but for' scenario" that would arise in the absence of the conduct in question.

4.2 Safe harbor thresholds and the limits of experimentation

While the fair and rigged games are observationally equivalent in equilibrium, they lead to different outcomes off the equilibrium. Therefore, by deviating from its equilibrium strategy in a rigged game, a firm will be able to generate evidence that it is indeed playing the rigged game. In particular, a firm that produces more than $\hat{q}$ units of output but only sells $\hat{q}$ units could use this fact to support the claim that it is the victim of monopolization. If this increases the likelihood of winning judgment against its rival, a firm may be willing to experiment with off-equilibrium strategies.

[11] For example, the Department of Justice applied the "no economic sense' test in *United States v. Dentsply*, which Werden (2006) describes as "an easy case" (p. 415). We examine this case in more detail in Section 6.1 and arrive at a different conclusion.

[12] An analogous approach is often followed in the price-fixing context, where collusive conduct and "conscious parallelism" lead to similar market outcomes. There, it has motivated the use of *plus factors* as additional circumstantial evidence of a price-fixing agreement (Kovacic *et al.* 2011, Marshall and Marx 2012). A plus factor is either a market condition that facilitates collusion or increases the gains from collusion, or conduct that is against a firm's self interest but for the existence of a price-fixing agreement (e.g., a firm sharing business information with rivals, or a firm selling to rivals at non-market prices).

However, such experimentation is costly. Recall from Proposition 3 that the quantity cap $\hat{q}$ that eliminates equilibria from the fair game is non-binding in equilibrium of the rigged game. Thus, the fringe firm would have to increase its output by more than a marginal amount if it wanted to create a situation in which the cap becomes binding. The resulting loss in profits for the fringe firm can be severe. Consider, once again, the case in Example 1 and suppose the equilibrium in which firm 1 is dominant is selected through a quantity cap $\hat{q} = 0.4$ on firm 2's output. To prove that it is playing a rigged game, firm 2 would have to quadruple its quantity from $q_2 = 0.1$ to $\hat{q} = 0.4$. This would decrease firm 2's profit from 0.01 in the equilibrium to -0.08 in the experiment, a reduction of 900%. Alternatively, firm 2 could deviate at the investment stage and pay γ_2 in order to reduce its marginal cost to zero. This would make the second stage experiment less costly, but 2's overall profit would still be reduced by 533% relative to the original equilibrium. In addition, firm 2 would have to finance the upfront investment, which again becomes a very costly proposition in industries characterized by lumpy investments.[13]

In addition to the costs of generating evidence, firms need to consider the benefit, which is the (expected) value of prevailing in an antitrust case. One hurdle that plaintiffs must overcome in such cases is a *safe harbor test*, which courts employ in order to reduce type-1 errors, limit frivolous lawsuits, and offer firms more certainty regarding the legality of their business practices. The safe harbor test typically specifies a percentage of the market foreclosed below which a firm's conduct is deemed unlikely to have anticompetitive effects. Paschal (2011), for example, notes that "although no uniform test exists to determine whether an [exclusive dealing] agreement is illegal, all courts evaluate the percentage of distribution channels foreclosed to rivals of an established competitor" (p. 253). While there is no fixed rule as to what a reasonable safe harbor cutoff should be, some courts have concluded that exclusive dealing contracts resulting in foreclosure levels of less than 30 to 40 percent are unlikely to warrant antitrust concerns in cases brought under Section 2 of the Sherman Act.[14] In Example 1, given the equilibrium market quantity

[13]For example, in the case of *AMD v. Intel*, which we review in Section 6.2, Intel stated: "Fabrication plants for the production of silicon based microprocessors routinely cost in excess of $2 billion to construct. Typically, the time to bring a [fabrication plant] from construction to full production is three to four years." (Civil Action No. 05-441 (D. Del. 2005), Answer at 3.) Making capacity investments of this scale for the sake of generating evidence in an antitrust case is not a financially viable option for most firms. (The final settlement negotiated between AMD and Intel was worth $1.25 billion—about 60% of the cost of building a single microprocessor plant.)

[14]See *Stop & Shop Supermarket Co. v. Blue Cross & Blue Shield of R.I.* (373 F.3d 57, 68 (1st Cir. 2004)) and *Minnesota Mining & Manufacturing Co. v. Appleton Papers Inc.* (63 35 F. Supp. 2d 1138, 1143 (D. Minn. 1999)). Likewise, in its 2008 report on single firm conduct (retracted in 2009), the U.S. Department of Justice (2008) recommends that "exclusive-dealing arrangements that foreclose less than thirty percent of existing customers or effective distribution should not be illegal" (p. 141). For arguments in favor of a foreclosure safe harbor and a discussion of the more recent use of safe harbors, see Wright(2009) and Paschal (2011).

$q_1 + q_2 = 0.55$, a quantity cap of $\hat{q} = 0.4$ still allows firm 2 to freely contest 72.7% of the market, while 27.3% of the market is foreclosed. This foreclosure level is, therefore, within conventional safe harbor thresholds used in the U.S. Even if firm 2 were to successfully demonstrate the existence of the quantity cap, this may not suffice as proof that firm 1's conduct is anticompetitive.

Furthermore, Proposition 3 shows that the least restrictive quantity cap that selects the equilibrium in which firm 1 is dominant (i.e., B) increases in γ_2. This implies that foreclosure levels that guarantee dominance by firm 1 can be even lower, and the costs of experimentation even larger, in industries with higher investment costs. More stringent safe harbor thresholds may therefore be desirable in industries characterized by strong economies of scale and, hence, large lumpy investments.

4.3 Agreeing to disagree and the benefits of ambiguity

We have so far assumed that the rules of the game were common knowledge among the two firms, but not known to outside observers such as courts or antitrust authorities. It is possible to extend our observational equivalence argument to inside observers—that is, to the firms themselves—by using the concept of a *rational perceptions equilibrium* developed in Klumpp and Su (2013). This solution applies to games whose payoff functions are *not* common knowledge among the players. It posits that (i) each player uses a best responses to the strategies of the opponents in the game that player believes to be playing, and (ii) the observable data generated by the strategy profile does not contradict any player's perception of the game, where a perception is a possible version (i.e., payoff function) of the game.

We will not formalize this extended equilibrium definition here—the details can be found in Klumpp and Su (2013)—but simply present the following argument. Consider an asymmetric market outcome in which firm 1 invests and grows large, and firm 2 does not invest and stays small. This is an equilibrium of the fair game, and also of the rigged game provided $\hat{q}$ is in the range identified in Proposition 3. Because the firms' investments and quantities are best responses to one another in each game, the same strategy profile is also a pair of best responses in a situation in which firm 1 believes it is playing the fair game and firm 2 believes it is playing the rigged game. And because all investments, costs, prices, and quantities that arise under this strategy profile are consistent with both theories, neither firm will, in the course of competition, learn any information that might induce it to revise its theory. (Furthermore, as we demonstrated in Section 4.2, it may not be practically feasible for firm 2 to experiment with off-equilibrium investments or quantities that permit falsification of its belief.) Thus, two firms can be stuck in a situation in which the fringe firm believes it is the victim of monopolization and the dominant firm believes it has done nothing unlawful. Such differences in belief are more than legal posturing in a monopolization case: Each firm's opinion is an honest perception of the nature of competition they are engaged in, creating a situation in which the firms can rationally "agree to disagree."

This observation provides an rational explanation for why some antitrust disputes are not settled immediately out-of-court, as would be optimal when there are costs of going to trial and when the parties hold a common belief regarding the likelihood of trial outcomes (Landes 1971). Irreconcilable differences in beliefs are sometimes pointed to as the reason why out-of-court settlements are not reached immediately, and why some disputes are ultimately decided by courts (e.g., Shavell 1982). However, no theory has been proposed as to why parties should have irreconcilable differences in beliefs and the later law and economics literature largely abandoned theories that rely on inconsistent priors to generate trials.[15] In our model, on the other hand, it is possible that firms hold inconsistent beliefs about whether competition is fair or not, and thus arrive at different estimates of their success probability in a monopolization case.

The same "agreeing to disagree" effect also suggests that large firms can maintain their dominance by adopting a posture of strategic ambiguity when using potentially anticompetitive instruments. This is because a firm that is believed (by competitors) to have rigged the game benefits from the the equilibrium selection effect identified in this paper. Such ambiguity can be achieved through deliberate adoption of business practices that are lawful under some circumstances but not others—as is the case for most practices commonly examined in antitrust cases. Even if these practices do not curtail fair competition, and even if they have no direct cost-saving effects, they can benefit a firm by manipulating the perceptions held by rivals. Of course, no firm will make an outright claim that the purpose of its conduct is to foreclose the market. However, in order to limit competition from rivals, the conduct only needs to be believed to impose constraints on competitors' market access. As long as such beliefs can be instilled in competitors (without making explicit public statements to that effect), the firm will benefit from the rivals' response. To our knowledge, this subtle consequence of ambiguous firm conduct has not been examined in an antitrust case, even though it could be a potentially important factor when determining the effects of a firm's conduct on market outcomes.

[15] See, for instance, Daughety and Reinganum (2005) for a survey. A few recent papers have, once again, relied on differences in beliefs to generate trials (Prescott et al. (2014), Prescott and Spier (2016)), but also they do not explain how such differences might arise from the observations of common evidence.

5. Robustness and Extensions

In our original model, we used a homogeneous good Cournot competition model at stage 2, and gave firms a binary choice to invest or not at stage 1. In this section, we demonstrate that the implications we derived in this model prevail if firms compete as differentiated goods Bertrand duopolists, or have more than two investment choices. In particular, a quantity constraint imposed on one of the firms can act as an (undetectable) equilibrium selection device in our game. However, a number of subtle effects arise in these extensions that were not present in our simple original model.

5.1 Bertrand competition

We formulated our main model as a Cournot competition model for the following reason. When firms compete by setting outputs, a quantity cap could be introduced as a direct constraint on the strategy set of one of the firms. Thus, studying the effects of monopolization is easiest in the Cournot context. We now demonstrate that the main result from our Cournot model—namely, that monopolization can serve as an equilibrium selection device—carries over to a differentiated goods Bertrand model, in which firms choose prices instead of quantities.

Suppose the firms produce differentiated varieties of a product and compete by setting prices $p_1 > 0$ and $p_2 > 0$. The quantity firm i sells is given by the demand function

$$q_i \;=\; 1 - p_i + \beta p_{-i}, \tag{11}$$

where $0 < \beta \leq 1$. Firms i's marginal cost is $c_i = h \in (0,1)$ and be reduced to $c_i = 0$ if firm i invests $\gamma_i > 0$.

At the second stage of the fair game, equilibrium prices, quantities, and profits are straightforward to compute and are as follows:

$$p_1(c_1,c_2) = \frac{2(1+c_1)+\beta(1+c_2)}{4-\beta^2}, \quad p_2(c_1,c_2) = \frac{2(1+c_2)+\beta(1+c_1)}{4-\beta^2}, \tag{12}$$

$$q_1(c_1,c_2) = \frac{2(1-c_1)+\beta(1+c_2+\beta c_1)}{4-\beta^2}, \quad q_2(c_1,c_2) = \frac{2(1-c_2)+\beta(1+c_1+\beta c_2)}{4-\beta^2}, \tag{13}$$

$$\pi_1(c_1,c_2) = \frac{\big(2(1-c_1)+\beta(1+c_2+\beta c_1)\big)^2}{\big(4-\beta^2\big)^2} - F_1,$$
$$\pi_2(c_1,c_2) = \frac{\big(2(1-c_2)+\beta(1+c_1+\beta c_2)\big)^2}{\big(4-\beta^2\big)^2} - F_2. \tag{14}$$

Anticipating this outcome, firms choose their costs c_i and associated investments F_i at stage 1. Similar to our Cournot model, it can be shown that if the firms' investment costs are in an intermediate range the fair game has two asymmetric pure strategy equilibria. This range is $\underline{\gamma} < \gamma_i < \overline{\gamma}$ $(i = 1, 2)$, with

$$\underline{\gamma} \equiv h\frac{(2-\beta^2)}{\left(4-\beta^2\right)^2}\Big[2(2-h) + \beta(2+\beta h)\Big] \;<\; h\frac{(2-\beta^2)}{\left(4-\beta^2\right)^2}\Big[2(2-h) + \beta(2+\beta h+2h)\Big] \equiv \overline{\gamma} \quad (15)$$

(derived along the same lines as in the proof of Proposition 1). In each asymmetric equilibrium, exactly one firm invests in the low-c_i technology. Inspecting (12)–(14) reveals that the investing firm charges a lower price and sells a larger quantity than its rival. Furthermore, inequality (5) still holds in the Bertrand case, so each firm strictly prefers the equilibrium in which it is the dominant firm to the equilibrium in which its rival is dominant.

In the rigged game with quantity cap $\hat{q}$, firm 2's demand function is no longer that in (11), but becomes

$$q_2 \;=\; \min\big\{1 - p_2 + \beta p_1,\; \hat{q}\big\}. \quad (16)$$

Note that, given firm 1's price p_1, firm 2 will not set its own price lower than $p_2 = 1-\hat{q}+\beta p_1$, as doing so would not increase firm 2's sales quantity, but only lower its revenue per unit sold. Thus, like in the Cournot setup, the quantity cap $\hat{q}$ effectively constrains firm 2's strategy set. Unlike in our Cournot model, however, the constraint is implicit and depends on the rival's strategy p_1 (which firm 2 holds correct expectations about in equilibrium).

A more fundamental difference between the two models is that Cournot competition is competition in strategic substitutes, while Bertrand competition is competition in strategic complements.[16] In the latter case, it is possible for a firm to *benefit* from a rival's exclusionary conduct. The reason is the following: A quantity cap in a Bertrand model limits the constrained firm's ability to compete aggressively by lowering its price. This raises its rival's price, which raises the constrained firm's price, which further raises its rival's price, and so on. These mutual price increases may more than offset the accompanying demand reductions and thereby increase both firms' profits.

The equilibria of the rigged game can be found by incorporating firm 2's constrained demand function in the second-stage solutions, and then re-solving for the firms' first-stage

[16]Competition is in strategic substitutes if the following holds: When one firm plays a more aggressive strategy (e.g., an output increase) the other's best response is to play a less aggressive strategy (e.g., an output decrease). Competition is in strategic complements if the opposite holds: When one firm plays a more aggressive strategy (e.g., a price cut) the other's best response is to play a more aggressive strategy as well (e.g., it matches the price cut). For a general introduction to strategic substitutes and complements, see Bulow *et al.* (1985).

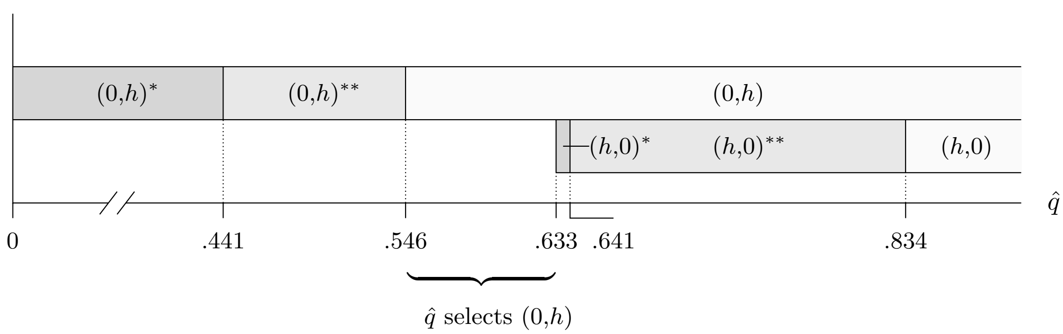
investments. We omit the somewhat tedious calculations here, and instead demonstrate the effects of a quantity cap on the equilibria of the rigged game in an example.

Example 2. Suppose that $h = .4$, $\gamma_1 = \gamma_2 = .25$, and $\beta = 0.62$. Plugging these values into the expressions in (15) confirms that two pure asymmetric pure strategy equilibria exist in the fair game. The prices, quantities, and profits in these equilibria are:

$$p_1(0,h) = .793 = p_2(h,0), \qquad q_1(0,h) = .834 = q_2(h,0), \qquad \pi_1(0,h) = .379 = \pi_2(h,0),$$
$$p_1(h,0) = .946 = p_2(0,h), \qquad q_1(h,0) = .546 = q_2(0,h), \qquad \pi_1(h,0) = .298 = \pi_2(0,h).$$

For the rigged game, Figure 4 depicts the equilibrium investments for various values of $\hat{q}$. An asterisk indicates that the quantity constraint on firm 2 is binding in the equilibrium, so that the second stage variables differ from those in the corresponding equilibrium of the fair game, making the constraint detectable in principle. A second asterisk indicates that *both* firms' profits are higher than in the corresponding unconstrained equilibrium (due to the strategic complementarity effect we discussed above).

Figure 4: Equilibria of the rigged Bertrand game (Example 2).



For large enough $\hat{q}$, the fair and rigged game have the same two asymmetric equilibria, $(0, h)$ and $(h, 0)$. Equilibrium selection occurs when $\hat{q} \in (.546, .633)$. There is now a unique equilibrium, in which firm 1 invests and is dominant, while firm 2 is the fringe firm. In this equilibrium $\hat{q}$ does not bind—the case described in Proposition 3 for the Cournot model.

Therefore, the main implication from our original model is maintained under Bertrand competition. Interestingly, however, the example also shows that a new possibility emerges that did not exist in the Cournot case—namely, firm 2 may benefit from the existence of a quantity cap. For example, if $\hat{q} \in (.441, .546)$, there exists a unique equilibrium in which only firm 1 invests. In this case, $\hat{q}$ binds and the market quantities and prices in this equilibrium are different from those associated with the $(0, h)$-equilibrium of the fair game, making the existence of the cap $\hat{q}$ in principle detectable. However, both firm 1's profit and firm 2's profit are larger than they are if $\hat{q} \in (.546, .633)$. In such cases, monopolization is not so much an equilibrium selection device as it is a "collusive device" that facilitates a higher overall price level in the market. When this happens, the constrained firm may not want to challenge its rival's conduct because it, too, benefits from its anticompetitive effects.

5.2 More than two investment levels

In our original model, each firm chooses between two technologies. We made this assumption for tractability, but our results hold more generally. What matters is that technology investments are lumpy and yield discrete reductions in marginal costs. This feature ensures that, when a firm faces a sufficiently stringent quantity cap on its output, it reduces its investment to the next discrete level (instead of reducing it continuously). This, in turn, is important for the non-detectability of the quantity cap which we discussed in Section 4. There can, however, be more than two investment levels—as long as they are discrete, the "all-or-nothing" flavor of investments in our model is maintained locally, allowing monopolization to serve as an equilibrium selection device.

To demonstrate this, suppose that two Cournot firms choose their marginal production costs from the set $\{l, m, h\}$, with $l < m < h$ and associated investments $\gamma^l > \gamma^m > \gamma^h$ (which, for simplicity, we assume to be symmetric across firms). In the fair game, the second-stage solutions are still described by (1)–(3) in Section 2, and the equilibria in first-stage investment choices can be found by comparing these expressions for various (c_1, c_2)-combinations. Extending our result in Proposition 1, we can identify a set of parameter values for which the fair game has *three* pure strategy equilibria: (l, h), (m, m), and (h, l). This set is characterized by the following chain of inequalities (calculations are omitted):

$$\begin{aligned} \frac{4}{9}\big(1+l-m-h\big) \;\leq\; \frac{\gamma^m-\gamma^h}{h-m} \;\leq\; \frac{4}{9}\big(1-h\big) \;\leq\; \frac{\gamma^l-\gamma^h}{h-l} \\ \leq\; \frac{4}{9}\big(1-l\big) \;\leq\; \frac{\gamma^l-\gamma^m}{m-l} \;\leq\; \frac{4}{9}\big(1-l-m+h\big). \qquad (17) \end{aligned}$$

If the game is rigged with quantity cap $\hat{q}$, the set of equilibria may be a strict subset of that in the fair game. That is, Proposition 3 continues to hold qualitatively. This is illustrated in the following example.

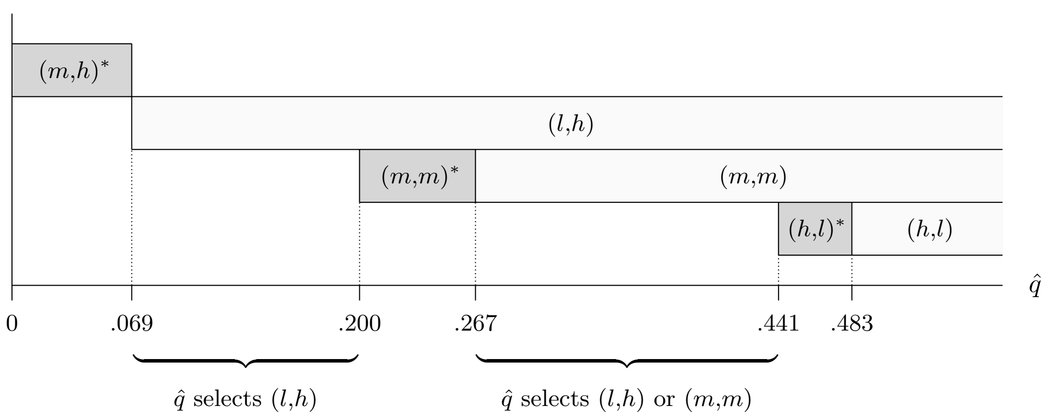
Example 3. Suppose that marginal and fixed costs are given by $\{l, m, h\} = \{0, .2, .45\}$ and $\{\gamma^l, \gamma^m, \gamma^h\} = \{.15, .05, 0\}$. Plugging these values into (17) confirms that three equilibria exist in the fair game. The quantities and profits in these equilibria are:

$$\begin{aligned} q_1(l,h) &= .483 = q_2(h,l), & \pi_1(l,h) &= .084 = \pi_2(h,l), \\ q_1(m,m) &= .267 = q_2(m,m), & \pi_1(m,m) &= .021 = \pi_2(m,m), \\ q_1(h,l) &= .033 = q_2(l,h), & \pi_1(h,l) &= .001 = \pi_2(l,h). \end{aligned}$$

Similar to our original model, each firm strictly prefers being the dominant firm, over being in the symmetric equilibrium, over being the fringe firm.

Turning now to the rigged game, Figure 5 depicts the equilibria of this game for a range of values of $\hat{q}$. (An asterisk indicates that the quantity constraint on firm 2 is binding in the equilibrium.)

Figure 5: The rigged Cournot game with three investment levels (Example 3).



Firm 2 ceases to invest in the low marginal cost technology if $\hat{q} < .441$, and ceases to invest in the medium marginal cost technology if $\hat{q} < .200$. For quantity caps in the range $.069 < \hat{q} < .200$, the most desirable equilibrium for firm 1 (i.e., (l, h)) is uniquely selected.[17] If firm 1 could not impose such a tight cap, a less stringent cap $.267 < \hat{q} < .441$ would ensure that the least desirable equilibrium for firm 1 (i.e., (h, l)) is eliminated from the game.

[17] Note that the lower end of this range is above firm 2's quantity in the (l, h)-equilibrium: $.069 > q_2(l, h) = .033$. A cap of $\hat{q} = .069$ is therefore non-binding on firm 2. Why, then, does the (l, h)-equilibrium disappear when $\hat{q} < .069$? The reason is that, for $\hat{q} < .069$, firm 1 would change its first-stage choice from l to m. While this diminishes firm 1's cost advantage, firm 2 would be unable to fully exploit this in the resulting stage-2 subgame, because $\hat{q}$ would be binding now. In fact, a monopolist in this example would choose $c = m$, and this is what firm 1 does for low enough $\hat{q}$.

The region $\hat{q} \in (.267, .441)$ in Example 3 is particularly interesting. If firm 1 were impose a quantity cap on the right side of this region, say, $\hat{q} = .44$, the equilibrium in which firm 1 is the fringe firm would be eliminated from the game, and firm 1 would be guaranteed at least the symmetric profit $\pi_1(m, m)$. Depending on which of the two remaining equilibria is played, such a cap would imply a foreclosure level of 15 or 18 percent. Note that total output is lower, and the price higher, in the two asymmetric equilibria than it is in the symmetric equilibrium. Thus, if the likelihood of the symmetric equilibrium increases as a result of foreclosure, consumers would benefit on expectation.

6. Conclusion: Two Antitrust Cases

To conclude this paper, we relate our analytical framework to two antitrust cases, *United States v. Dentsply* and *AMD v. Intel*. The first case illustrates to our finding that, to outside observers such as courts, the same market data can be consistent with two views: One in which the dominant firm gained its position through unlawful monopolization, and one in which it did not. The second case illustrates our finding that "inside observers"—the firms in an industry themselves—may maintain opposing perceptions about whether or not one firm's dominance is due to monopolization or simply an asymmetric equilibrium of a fair game.

6.1 *United States v. Dentsply*

On January 5, 1999, the Department of Justice ("DOJ") filed a monopolization case against Dentsply International, Inc. ("Dentsply") with the U.S. District Court for the District of Delaware. Dentsply was the largest manufacturer of artificial teeth in the United States and sold its products to dental laboratories through a network of dealers with whom it had exclusive dealing agreements. DOJ alleged that this practice foreclosed part of the market for artificial teeth to competitors and hence violated Sections 1 and 2 of the Sherman Act and Section 3 of the Clayton Act. The District Court sided with the defendant on August 8, 2003.[18] DOJ appealed the ruling on Section 2 of the the Sherman Act before the U.S. Court of Appeals for the Third Circuit, which overturned the lower court's decision on February 24, 2005 and found Dentsply guilty of monopolization.[19]

Let us first look at the lower court's decision. After a bench trial, the District Court concluded that DOJ had failed to prove that Dentsply's dealer agreement was in violation of U.S. antitrust laws, as alleged in the complaint. This decision was based on the following arguments. First, Dentsply did not have long-term contractual agreements with

[18] 277 F. Supp. 2d 387 (D. Del. 2003).

[19] 399 F.3d 181 (3d Cir. 2005).

its authorized tooth dealers. Instead, Dentsply's exclusive dealing agreements operated on a purchase order basis. Authorized dealers were free to stop buying from Dentsply at any time without penalty, and if Dentsply's dealers decided to take on the teeth of a rival they could simply sell their Dentsply-brand inventory or send it back to Dentsply for full credit. Given the terminable-at-will nature of the agreements, "dealers are free to leave Dentsply whenever they choose."[20] Second, Dentsply's competitors could sell through other distribution channels, including direct sales to dental laboratories and selling to dealers not used by Dentsply. Given that these alternatives were available, "Dentsply does not have the power to exclude competitors from the ultimate consumer."[21]

Why, then, was Dentsply the dominant firm in the market for artificial teeth? The District Court had the following explanation for the observed market outcome: Dentsply's dominant position was the result of a long company history of innovating artificial tooth products, as well as an aggressive sales campaign that included efforts to promote its teeth in dental schools, a sales force dedicated exclusively to teeth, and various direct-to-patient marketing programs. In contrast, the teeth manufactured by Dentsply's main rivals were of lower quality, lacked features desired by U.S. consumers, and were marketed by sales teams that concentrated their efforts on other product lines. Given these differences in products and processes, Dentsply's rivals "failed to gain market share as a result of their own business decisions, not Dentsply's exclusionary practices."[22] In sum, the District Court determined that "DOJ has failed to prove that Dentsply has created a market with supra-competitive pricing."[23]

DOJ appealed the District Court's ruling on Section 2 of the Sherman Act. The Appeals Court concluded that Dentsply's dominant market share resulted not from competitive effort but from unlawful business practices, and reversed the judgment of the District Court. The court discounted the terminable-at-will nature of Dentsply's exclusive dealing agreements, stating that "[t]he fact that dealers have chosen not to drop Dentsply teeth in favor of a rival's brand demonstrates that they have acceded to heavy economic pressure."[24] The court further concluded that direct selling to the laboratories "is 'viable' only in the sense that it is 'possible,' not that it is practical or feasible in the market as it exists and functions."[25] Moreover, "[t]he reality is that over a period of years, because of Dentsply's domination of dealers, direct sales have not been a practical

[20] 277 F. Supp. 2d 387 (D. Del. 2003) at 450.

[21] *Id.* at 452.

[22] *Ibid.*

[23] *Id.* at 453.

[24] 399 F.3d 181 (3d Cir. 2005) at 196.

[25] *Id.* at 193.

alternative for most manufacturers."[26] Consequently, the Appeals Court also arrived at a very different conclusion as to why Dentsply's rivals had been unable to increase their market share: "It has not been so much the competitors' less than enthusiastic efforts at competition that produced paltry results, as it is the blocking of access to key dealers. This is the part of the real market that is denied to the rivals. The apparent lack of aggressiveness by competitors is not a matter of apathy but a reflection of the effectiveness of Dentsply's exclusionary policy."[27]

To use the language of our model, in the District Court's opinion Dentsply and its competitors were playing the fair game. In this game, the firms had coordinated on an asymmetric equilibrium, in which Dentsply was dominant because it had invested heavily in its products and processes. Dentsply's competitors, on the other hand, were fringe firms because they had chosen to not make similar investments. In the Appeals Court's opinion, Dentsply and its competitors were playing the rigged game. The equilibrium of this game was asymmetric, and Dentsply was dominant, because Dentsply had placed effective constraints on the quantities that could be sold by its competitors. The fact that competitors appeared to make only small investments was a rational response to the constraints placed on them by Dentsply's business practices.

It is, of course, not unusual for higher courts to overturn the decisions of lower courts, and it is also common that courts and the disputing parties in antitrust cases agree on the defendant's conduct, but disagree on the competitive effects of the conduct. What makes *United States v. Dentsply* interesting for us is that both courts also agreed that differences in the firms' investments—in development, production, and marketing of artificial teeth—could account for differences in their market shares, but disagreed on the following question: Were the competitors' low efforts simply their "own business decisions" for which Dentsply was not responsible (the District Court's opinion), or a "rational response" to constraints that Dentsply's exclusive dealing practices had created on its competitors' ability to sell their product (the Appeals Court's opinion)? Under the Sherman Act, a firm is guilty of monopolization only in the latter case but not in the former. Our theoretical results suggest that this is precisely the question that may remain unanswerable, given the data available to courts, even if all other aspects of a monopolization case are undisputed.

6.2 *AMD v. Intel*

On June 27, 2005, Advanced Micro Devices, Inc. ("AMD") filed a complaint against Intel Corporation ("Intel") in the U.S. District Court for the District of Delaware, alleging

[26] *Id.* at 189.

[27] *Ibid.*

monopolization. Intel and AMD were the two largest manufacturer of microprocessors that utilized the x86 instruction set on which the Windows and Linux PC operating systems run. x86 was developed by Intel in the 1970s and licensed to AMD during the 1980s and early 1990s, when AMD served primarily as "second source" of microprocessors for PC manufacturers. In 1995, AMD obtained a shared interest in the x86 technology as part of a settlement of a separate, earlier dispute with Intel. It subsequently began developing its own x86-based chip designs, but failed to reach a scale comparable to that of its larger rival. Between 1999 and 2004, Intel's share of the worldwide market for x86 processor units was approximately 82%, while AMD's was 16%.

In its complaint, AMD claimed that its failure to gain market share was the result of anticompetitive practices that Intel had engaged in to maintain its near-monopoly in microprocessors. It submitted a long list of allegations: "Among other things, Intel has forced major customers into exclusive or near-exclusive deals; it has conditional rebates, allowance and market development funding on customers' agreement to severely limit or forego entirely purchases from AMD; it has established a system of discriminatory, retroactive, first-dollar rebates triggered by purchases at such high levels as to have the practical and intended effect of denying customers the freedom to purchase any significant volume of processors from AMD; it has threatened retaliation against customers introducing AMD computer platforms, particularly in strategic market segments; it has established and enforced quotas among key retailers requiring them to stock overwhelmingly, if not exclusively, Intel-powered computers, thereby artificially limiting consumer choice; it has forced PC makers and technology partners to boycott AMD product launches and promotions; and it has abused its market power by forcing on the industry technical standards and products which have as their central purpose the handicapping of AMD in the marketplace."[28]

The effect of these practices, AMD claimed, was to limit the quantities it could sell on the market, and, hence, to curtail its ability to grow: "Intel's conduct has unfairly and artificially capped AMD's market share. ... With AMD's opportunity to compete thus constrained, the cycle continues, and Intel's monopoly profits continue to flow."[29] AMD also pointed to the fact that, while it had made large investments in product development, the constraints Intel had imposed on AMD's market access prevented AMD from making complementary investments in manufacturing capacity that would have been required to sell a larger number of chips to PC makers: "Tellingly, AMD's market share has not kept pace with its technical leadership. Intel's misconduct is the reason. Intel has ... systematically excluded AMD from any meaningful opportunity to compete

[28]Civil Action No. 05-441 (D. Del. 2005), Complaint at 2.

[29]*Id.* at 3.

for market share . . . by preventing AMD from achieving the minimum scale necessary to become a full-fledged, competitive alternative to Intel; and by erecting impediments to AMD's ability to increase its productive capacity for the next generation of AMD's state of the art microprocessors."[30]

In its answer to AMD's complaint, Intel characterized its business practices as lawful and desirable means of competition: "AMD is seeking to prevent Intel from using discounts and other incentives that have the effect of lowering prices paid by customers, even though vigorous competition on price and continual improvements in consumer value are the very practices that the antitrust laws are designed to protect."[31] Intel further claimed that its conduct did not restrict AMD's market access: "Intel also specifically denies the existence of any monopoly pricing or economic coercion within the semiconductor industry. . . . Customers are perfectly free to purchase products from Intel or from AMD based on each customer's own evaluation of the overall strengths and benefits of the products offered."[32]

To explain AMD's small market share, Intel pointed out that the two firms had made very different investments into their production capabilities: "Over the period covered by AMD's Complaint, Intel has made a series of multi-billion dollar investments to expand its manufacturing capacity and to fund research and development related to enhancing manufacturing production. . . . By contrast, AMD's investments in manufacturing capacity during this period was anemic."[33] AMD's under-investment was a strategic business decision its management had made: "AMD had embarked on a strategy to remedy its limited capacity through a partnership with chipmaker UMC and through what it hoped would be improvements in the design of its microprocessors, rather than through additional large investments in capacity. In the end, the partnership failed, and AMD never sold a single microprocessor produced through UMC. The designed-based strategy also failed . . . . AMD's current constraints thus are direct result of these business decisions and others made by the company's management."[34] The capacity constraints AMD had created for itself not only prevented it from gaining market share, but also created a reputation of being an unreliable supplier: "To the extent that AMD's statement [that its market share has not kept pace with its technical leadership] is accurate in any respect, Intel states that this is not the result of any misconduct by Intel, but rather of a

[30] *Id.* at 9.

[31] Civil Action No. 05-441 (D. Del. 2005), Answer at 2.

[32] *Id.* at 8.

[33] *Id.* at 2–3.

[34] *Id.* at 3.

marketplace perception created by AMD's sustained record of poor product performance, manufacturing problems, and unreliability as a supplier over a period of many years."[35]

Four years after the original complaint was filed, AMD and Intel reached a settlement agreement in November of 2009. Without admitting liability or fault, Intel agreed to pay AMD 1.25 billion dollars in a deal to settle all outstanding legal disputes between the two companies.

As was the case in the previous example, *AMD v. Intel* can be translated into the language of our formal model. In Intel's opinion, the microprocessor industry was characterized by the fair game. In this game, the firms had coordinated on an asymmetric equilibrium, in which Intel was dominant because it had invested heavily in its production capacity, and AMD was a fringe firms because it had chosen to not make similar investments. In AMD's opinion, the firms were playing the rigged game. The equilibrium of this game was asymmetric, and Intel was dominant, because Intel had capped the number of chips AMD could sell to PC manufacturers. AMD did not have the capacity to increase production, but making large investments in manufacturing capacity would not have been optimal for AMD given the sales constraints imposed by Intel.

What makes *AMD v. Intel* interesting in our context is not the fact that AMD made allegations that Intel denied—this is to be expected of any two firms engaged in a legal dispute. The case is interesting because at the core of the firms' dispute lay precisely the observational ambiguity we found in our two-stage model: Both parties agreed that Intel had built a larger production capacity than AMD, and was in a better position to serve the market. The firms disagreed on the question of whether AMD' underinvestment in capacity was a business decision for which Intel was not responsible, or a rational response to constraints Intel's conduct had created on AMD's ability to sell its chips.

Appendix: Proofs

Proof of Proposition 1

Consider firm 1. $c_1 = h$ is a strict best response to $c_2 = 0$ if $\pi_1(h, 0) > \pi_1(0, 0)$. Using the profit function (3), this condition is

$$\left(\frac{1}{3} - \frac{2}{3}h\right)^2 > \left(\frac{1}{3}\right)^2 - \gamma_1 \quad \Leftrightarrow \quad \gamma_1 > \frac{4}{9}h(1-h) \equiv \underline{\gamma}.$$

[35] *Id.* at 17.

If the reverse inequality holds, then $c_1 = 0$ is a strict best response to $c_2 = 0$. Similarly, $c_1 = 0$ is a strict best response to $c_2 = h$ if $\pi_1(0, h) > \pi_1(h, h)$:

$$\left(\frac{1}{3} + \frac{1}{3}h\right)^2 - \gamma_1 \;>\; \left(\frac{1}{3} + \frac{1}{3}h\right)^2 \quad\Leftrightarrow\quad \gamma_1 \;<\; \frac{4}{9}h \;\equiv\; \overline{\gamma}.$$

If the reverse inequality holds, then $c_1 = h$ is a strict best response to $c_2 = h$. For firm 2, a best response function can be obtained in the same fashion, and combining the two firms' best responses establishes the result. □

Proof of Proposition 2

The technology adoption problem at the first stage of our model is a bimatrix game (each player has the choice to invest, or not to invest). In such games, one equilibrium risk dominates another equilibrium if and only if the product of deviation losses is larger in the first (Harsanyi 1995). Applied to our model, the equilibrium $(c_1 = h, c_2 = 0)$ risk dominates the equilibrium $(c_1 = 0, c_2 = h)$ if

$$\Big[\pi_1(h,0) - \pi_1(0,0)\Big] \cdot \Big[\pi_2(h,0) - \pi_2(h,h)\Big] \\ > \Big[\pi_1(0,h) - \pi_1(h,h)\Big] \cdot \Big[\pi_2(0,h) - \pi_2(0,0)\Big]. \quad (18)$$

Given a pair of marginal costs (c_i, c_{-i}), denote firm i's gross-of-investment profit by

$$\hat{\pi}(c_i, c_{-i}) \;\equiv\; \left(\frac{1}{3} - \frac{2}{3}c_i + \frac{1}{3}c_{-i}\right)^2 \quad (19)$$

(this is symmetric across firms). Inequality (18) can now be expressed as follows:

$$\Big[\hat{\pi}(h,0) - \hat{\pi}(0,0) + \gamma_1\Big] \cdot \Big[\hat{\pi}(0,h) - \hat{\pi}(h,h) - \gamma_2\Big] \\ > \Big[\hat{\pi}(0,h) - \hat{\pi}(h,h) - \gamma_1\Big] \cdot \Big[\hat{\pi}(h,0) - \hat{\pi}(0,0) + \gamma_2\Big]. \quad (20)$$

After eliminating common terms, (20) becomes

$$\gamma_2\Big[\hat{\pi}(0,0) - \hat{\pi}(h,0) + \hat{\pi}(h,h) - \hat{\pi}(0,h)\Big] \;>\; \gamma_1\Big[\hat{\pi}(0,0) - \hat{\pi}(h,0) + \hat{\pi}(h,h) - \hat{\pi}(0,h)\Big]. \quad (21)$$

Using (19), we can express the term in brackets as follows:

$$\hat{\pi}(0,0) - \hat{\pi}(h,0) + \hat{\pi}(h,h) - \hat{\pi}(0,h) \;=\; -\frac{4}{9}h^2 \;<\; 0.$$

Thus, (21) is equivalent to $\gamma_2 < \gamma_1$. It follows that the equilibrium in which firm 2 invests risk dominates the equilibrium in which firm 1 invests if firm 2's cost of investing is less than firm 1's cost of investing. Similarly, equilibrium $(0,h)$ risk dominates equilibrium $(h,0)$ is the reverse inequality holds (i.e., if $\gamma_2 > \gamma_1$). $\square$

Proof of Proposition 3

Note that firm 2's output quantity in the various stage-two subgames of the fair game is ordered as follows: $q_2(0,h) < q_2(h,h) < q_2(0,0) < q_2(h,0)$. A rigged game with $\hat{q} \geq q_2(h,0)$ is therefore equivalent (in terms of its equilibria) to the fair game. If $\hat{q}$ decreases, then the constraint on firm 2 will first become binding in the subgame where $(c_1,c_2) = (h,0)$, then for $(c_1,c_2) = (0,0)$, then for $(c_1,c_2) = (h,h)$, and finally for $(c_1,c_2) = (0,h)$.

We now show that there exists $B \in \big(q_2(h,h), q_2(h,0)\big)$ such that, in any rigged game with $\hat{q} \in \big(q_2(0,h), B\big)$, firm 2 has a strictly dominant strategy to not invest. For this, two conditions must hold:

1. Firm 2 strictly prefers to not invest if firm 1 invests (i.e., $\pi_2(0,0|\hat{q}) < \pi_2(0,h|\hat{q})$). This condition is straightforward to establish: Note that $\pi_2(0,0|\hat{q}) \leq \pi_2(0,0)$ (since, for a given cost pair, a quantity cap never strictly increases the profit of a Cournot duopolist); $\pi_2(0,0) < \pi_2(0,h)$ (since $(0,h)$ is a strict equilibrium of the fair game); and $\pi_2(0,h) = \pi_2(0,h|\hat{q})$ (since $\hat{q} > q_2(0,h)$, so $\hat{q}$ does not bind if $(c_1,c_2) = (0,h)$). Combining these inequalities, we get $\pi_2(0,0|\hat{q}) < \pi_2(0,h|\hat{q})$.

2. Firm 2 strictly prefers to not invest if firm 1 does not invest (i.e., $\pi_2(h,0|\hat{q}) < \pi_2(h,h|\hat{q})$). Using (10), this condition can be expressed as

$$\left(\frac{1}{2} - \frac{1}{2}\hat{q} + \frac{1}{2}h\right)\hat{q} - \gamma_2 \;<\; \left(\frac{1}{3} - \frac{1}{3}h\right)^2. \tag{22}$$

   Substitute $\hat{q} = q_2(h,h) = \frac{1}{3}(1-h)$ in (22) and simplify, to get $\gamma_2 > \frac{1}{3}h(1-h)$. Since we assume $\gamma_2 > \underline{\gamma} = \frac{4}{9}h(1-h)$, this is true. Thus, (22) holds for $\hat{q} = q_2(h,h)$. On the other hand, if $\hat{q} = q_2(h,0)$ the rigged game is equivalent to the fair game, in which firm 2 strictly prefers to invest if firm 1 does not invest. It follows that, by continuity of payoffs there exists B, with $q_2(h,h) < B < q_2(h,0)$, such that (22) holds for all $\hat{q} < B$ and becomes an equality at $\hat{q} = B$. This value is given by

$$B \;=\; \frac{1}{2}(1+h) - \sqrt{\frac{1}{4}(1+h)^2 - \frac{2}{9}(1-h)^2 - 2\gamma_2}. \tag{23}$$

(Note that the solution cannot be the right root, as this would imply $B > \frac{1}{2}(1+h) > \frac{1}{3}(1+h) = q_2(h,0)$.)

Combining the above conditions, we have established that in the rigged game with quantity cap $\hat{q} \in \big(q_2(0,h), B\big)$, firm 2's strictly dominant strategy is $c_2 = h$.

Now take a rigged game with such a $\hat{q}$. Firm 2 will play its dominant strategy $c_2 = h$ at the first stage, and since $\hat{q} > q_2(h,h) > q_2(0,h)$, the cap will be non-binding at the second stage regardless of c_1. Thus, $\pi_1(c_1, h|\hat{q}) = \pi_1(c_1, h)$ for all $c_1 \in \{0, h\}$, and since $(0, h)$ is a strict equilibrium of the fair game, $c_1 = 0$ is a strict best response to $c_2 = h$ in the rigged game. It now follows that, in the rigged game with cap $\hat{q}$, there is a unique equilibrium, characterized by the cost pair $(c_1, c_2) = (0, h)$ (property (a) in the result). Furthermore, because $\hat{q}$ is non-binding in this equilibrium, the firms' outputs, the equilibrium price, and the firms' profits must be the same as in the corresponding equilibrium of the fair game (property (b) in the result). Furthermore, $\hat{q} \in (q_2(0,h), B)$ is also necessary for (a) and (b): If $\hat{q} > B$ then firm 2 would at least weakly prefer to invest if firm 1 does not invest; and if $\hat{q} < q_2(0,h)$ then $\hat{q}$ would bind in the subgame where $(c_1, c_2) = (0, h)$.

Finally, inspection of (23) shows that B increases in γ_2, as stated in the result. $\square$

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