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Hunting Unicorns? Experimental Evidence on Predatory Pricing

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Hunting Unicorns? Experimental Evidence on Predatory Pricing Policies

Preliminary and Incomplete

March 1, 2016

Abstract

[The paper provides an experimental analysis of above-cost predatory pricing in a multi-period interaction between a monopolistic incumbent and a potential entrant. It shows that, without policy interventions, the threat of post-entry price cuts discourages entry without forcing incumbents to abstain from monopoly pricing. A policy suggested by Edlin that curtails such price cuts encourages entry and reduces the prices set by monopolistic incumbents. An alternative policy suggested by Baumol that prohibits post-exit price increases does less to encourage entry, and it does not prevent high pre-entry prices. However, as expected, it keeps post-exit prices low.]

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1 Introduction

Should price cutting by a monopoly in response to entry be regulated, and if so how? Theorists have debated the point. In this paper we consider when, if ever, price cutting by a monopoly is undesirable either because it drives entrants from the market or because its prospect discourages entry in the first place. Our experimental approach suggests that there may be consumer or competition gains from regulating price cutting, at least when a monopoly incumbent has cost advantages.

Skeptical commentators have variously compared predatory pricing to unicorns, dragons, and basketball players scoring sixty four points in a game. Their point is that price cutting is generally good for consumers and they contend that it is bad only in fairy tales told by theorists or in extremely rare circumstances in practice. This argument supports a laissez faire policy to predatory pricing and has been used by the U.S. Supreme Court to justify a test for legality that bans only price cuts that leave prices below marginal or variable cost (Brooke Group, 1992).

A competing narrative promoted by Edlin (2002) points out that incumbent monopolies often have cost or other advantages (why else do they hold a monopoly?) and when they do that above-cost price cuts are the real threat. In particular, he argues that it is entirely credible that an incumbent monopoly will react to entry by pricing below an entrant's cost though above its own cost. Such pricing will drive the entrant from the market and so Edlin terms it "above-cost predatory pricing".¹

A typical view of the tradeoff in predatory pricing policy is that condemning these low prices sacrifices a beneficial price war (a bird in hand) in the speculative hope of promoting lower prices in the future (a bird in the bush). Edlin argues, however, that the beneficial price war is equally speculative and will only happen if there is entry. And lack of entry is the big problem in a monopoly market. If a high-cost entrant fears above-cost predatory pricing, he will not challenge a low-cost incumbent even if the latter charges high prices. The consequence can be persistent high pricing without entry. To remedy this, Edlin proposes that an

¹In a famous predatory pricing case, *Barry Wright*, Judge Breyer (as a district court judge before he joined the Supreme Court) acknowledged that above-cost price cuts could be undesirable but worried that problematic price cutting could not be distinguished from desirable limit pricing that discouraged entry but provided persistent low prices to consumers.

incumbent should not be allowed to lower its prices if it is substantially undercut by an entrant. The idea is to encourage low pricing by the incumbent prior to entry and to encourage entry if the incumbent charges high prices. Edlin's predatory pricing policy is in the class of dynamic predatory pricing policies.

Baumol (1979) likewise proposed a dynamic policy to combat predatory pricing. The Baumol policy would prevent an incumbent from raising prices if it fought off an entrant with price cuts. This policy might have better properties than Edlin conditional upon entry because then price competition is not restricted, but Baumol's policy doesn't appear to offer entrants as much protection and could in theory still allow persistent high prices if it doesn't manage to facilitate entry.

Empirical research has not to date found a satisfactory answer to the question of how often price cutting is undesirable or is aimed at driving rivals from a market. It is fundamentally difficult to learn much without policy variation. We cannot reliably know what would happen in a world where price cutting was regulated differently. Would there be more entry? Would consumers enjoy low prices more often or less often? We do not know how many would-be entrants, willing to price much lower than a monopoly's price, do not enter for fear of being wiped out in a subsequent price war. The post-entry performance of markets after entry tells us little of what would happen under alternative regimes. For instance, if we find that predatory pricing is as rare as a unicorn in practice, could this be because it is illegal, and that it would be prevalent in a *laissez faire* world?

Despite the lack of empirical evidence on the relative efficacy of different predatory pricing rules, we are motivated by anecdotal evidence such as that from the American Airlines case in the U.S. In that case, several entrants were driven from the Dallas-Fort Worth market by American. American priced high before entry and high afterward. The entrants brought significant value to consumers in the form of lower prices, but only for short periods when they were in the market. The Department of Justice (DOJ) introduced evidence showing that American priced low to drive entrants out, but could not win their case because American did not price below its variable cost.

These various observations lead us to take an experimental approach. We study a setting where an incumbent monopoly has low marginal costs but where its monopoly price exceeds an entrant's higher cost. If the monopoly prices high,

the other firm may be tempted to enter, but an unregulated monopoly can drive the entrant from the market while still earning money at least in the short term. Our basic question is whether entry results and how does this depend upon predatory pricing policy?

We consider a setting of Bertrand-style price competition repeated over four periods. An incumbent monopoly has a cost advantage over a potential entrant. We consider four policy treatments: 1. *laissez faire*; 2. a ban on below-cost pricing a la Brooke Group 1992); 3. a ban on certain post-entry price cuts a la Edlin (2002); and 4. permanence of post-entry price cuts a la Baumol (1979). These policies affect entry; pre- and post-entry pricing; post-entry exit; and thereby consumer and total welfare.

In theory, the equilibrium in this game involves monopoly pricing for four periods with no entry under policies 1, 2, and 4. The benefits of the Baumol proposal are not enjoyed here for two reasons. The first potential benefit is that entry might be encouraged if the incumbent is unlikely to drive the entrant from the market. The second benefit of Baumol is that conditional upon entry the benefits of any post-entry price war will persist even if the entrant exits. However, these benefits do not materialize if there is no entry. And, although the Baumol rule makes a post-entry price cut less attractive to the incumbent than in the Brooke Group or *Laissez Faire* regimes, it may well be in the incumbent's interest to drive the entrant from the market by pricing below the entrant's cost given that the incumbent continues to earn a short run profit due to its own low costs. As a result, the potential entrant stays on the side lines under the Baumol rule, just as under *Laissez Faire* or Brooke Group.

Under Edlin's proposal, there is likewise no entry, but to ensure this, the monopoly must price low until the final period, when it charges the monopoly price due to end-game effects. Thus, in theory, Edlin's proposal has advantages because it makes the market contestable. Under Edlin, since price cannot be cut post entry, the only way to prevent entry is to price low in the first place prior to entry. Though there is no entry along the equilibrium path, there is an important difference between Edlin and the remaining games. In the latter, entry does not arise in any subgame equilibrium, whereas for Edlin it always does for high prices. This suggests that entry is more likely under Edlin than in the other games.

In our experiment, we find that Laissez Faire and Brooke Group policies are largely indistinguishable. Both frequently involve monopoly pricing pre-entry, often no entry (consistent with a fear of post-entry predation), and exit when there is entry off of the equilibrium path. Entry is usually a mistake under these two policies, as nothing stops the incumbent from driving the entrant from the market. As a result, the entrant ends up losing its sunk cost of entry. It turns out that the incumbent never prices below its own cost (that kind of predation is a unicorn) but it typically responds to entry with prices below the entrant's break-even level.

Edlin's policy has the expected effect of lowering the monopoly's pre-entry price and increasing the frequency of entry when the monopoly prices above the entry-detering price. When the incumbent monopoly prices high pre-entry under Edlin, entry is typically profitable because the monopoly cannot immediately respond with low prices. Once players understand the game, consumers enjoy the lowest prices overall under Edlin, but overall welfare is low because of the wasted replication of fixed costs from entry.

Baumol's policy generally suffers from monopoly pricing pre-entry as Edlin predicted, just as Brooke and Laissez Faire do. On the other hand, Baumol leads to higher consumer welfare than Laissez Faire and Brooke due to low prices when there is entry. When compared to Edlin, Baumol has higher consumer welfare for inexperienced players, but substantially lower for experienced players. Entry under Baumol is on average a mistake for the entrant because the monopoly typically responds by driving the entrant from the market as theory predicts. Overall welfare under Baumol is comparable to Laissez Faire and Brooke, because while there is a replication of fixed costs in the case of entry, there is a gain from the low post-exit prices Baumol's permanence rule.

Edlin and Baumol both lead to more entry than Laissez Faire or Brooke Group policies overall, though the difference is larger for Edlin and statistically significant. In particular, Edlin has 21 percent more entry than LaissezFaire and Baumol has 9 percent more entry than Laissez Faire. The difference for Edlin becomes particularly large for experienced players, so that by the last round entry is roughly 47 percent higher under Edlin than LaissezFaire.

The remainder of this paper is organized as follows. Section 2 introduces the model and the experimental design, and it deerives theoretical predictions. Section

3 presents the results. Section 4 concludes.

2 Theory and Experimental Design

2.1 The game

In the following, we describe the assumptions of the games underlying our experiment and derive some predictions. We confine ourselves to the specific parameterization that we use in the experiment, even though some results hold much more generally.

Two firms, a low-cost incumbent L and a high-cost potential entrant H , can produce an identical good. Each firm that produces needs to set the price for the good. In stage 1, only firm L is present and chooses its price. In stages 2 – 4, each firm can decide whether to participate in the market or to stay out. Only if the firm is present in the market, it is able to produce the good and to set a price. If, however, it stays outside the market it earns a fixed amount from an outside option. If both firms are active in the market, they compete in a homogenous Bertrand fashion. If only one firm is active in the market, it enjoys a monopoly position. Once a firm decides to exit, it cannot anymore enter the market during this round.

Suppose only one of the firms is active in the market in a given stage. The firm $i = L, H$ faces the linear demand

$$D_i(p_i) = 80 - p_i$$

where p_i is the price it sets in this stage.

Suppose now both firms are active in the market in a given stage. They simultaneously and independently choose a price p_i for the production of the homogeneous good. Their action sets are integers in the interval $[\underline{p}, \bar{p}]$. The bounds of the interval, \underline{p} and \bar{p} are treatment specific. Consumers buy at the lowest price. Hence,

each firm faces the following demand:

$$D_i(p_i, p_j) = \begin{cases} 80 - p_i & \text{if } p_i < p_j, \\ \frac{1}{2}(80 - p_i) & \text{if } p_i = p_j, \\ 0 & \text{if } p_i > p_j, \end{cases}$$

A firm is considered *dominant* in a given stage t if it produced and served the entire market in the prior stage $t - 1$.

Firm i 's profit in a given stage is

$$\pi_i = (p - c_i)D_i(p_i, p_j)p_i - F$$

where c_i is the marginal cost and F the fixed cost. The incumbent has a technological advantage over the entrant and thus produces the good at a lower marginal cost. Marginal costs are $c_I = 20$ for the incumbent and $c_E = 30$ for the entrant. Fixed costs are $F = 300$ for both firms.²

The treatments differ with respect to the interval $[p, \bar{p}]$ in which the dominant firm can choose its price. The firm which is not dominant can always choose its price in the entire interval of $[0, 80]$. The LAISSEZFAIRE treatment is our benchmark treatment. The dominant firm can choose, on an equal footing with the entrant, its price in the entire interval of $[0, 80]$. In the BROOKE treatment, when there is a dominant firm in a duopoly in stage t , this firm cannot choose a price below its own marginal cost in that stage, that is, it is restricted to choosing $p_i^t \in [c_i, 80]$. In EDLIN, the firm which is considered dominant in stage t faces a price floor such that it cannot choose a price below 80% of its price in $t - 1$, that is, $p_i^t \in [0.8 \cdot p_i^{t-1}, 80]$. This restriction is what we call the Edlin price freeze, and it applies only if the market in t is a duopoly. If the dominant firm is a monopolist in t , it can choose its price in the entire interval $[0, 80]$. In BAUMOL, the firm which is considered dominant in a duopoly in stage t faces a price cap such that it cannot choose a price above the price level in $t - 1$ in stage t and all subsequent stages until the period ends. This price cap only applies, however, if the other firm has left the market in t . Hence, $p_i^{t+k} \in [0, p_i^{t-1}]$ for $k = 0, 1, \dots$. If the other firm

²Here we think of the fixed cost as the sum of the cost of operating in the market (250) plus the opportunity cost (50)

has not left the market in t , the dominant firm can choose its price in the entire interval $[0, 80]$.

2.2 Predictions

We now describe the subgame perfect equilibria of the four games underlying our treatments. For simplicity, we carry out the analysis for continuous price sets. We first introduce some self-explanatory terminology.

1. The *break-even price* p_θ^B for $\theta \in \{L, H\}$ is given by $(p_\theta^B - c_\theta) D(p_\theta^B) = F$.
2. The *entry-deterring price* p^* of L in the Edlin Game is defined by $0.8p^* = p_H^B$.

Figure 1 gives an overview of the relevant prices.

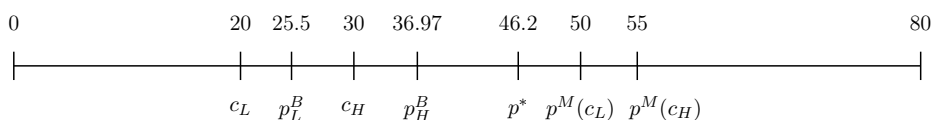


Figure 1: Overview of Prices

Most aspects of the ordering depicted in this figure hold for all conceivable parameterizations, not just for those chosen for the experiment. However, two comparisons are specific to our parameterization: First, the break-even price p_L^B of firm L is below the marginal cost c_H of firm H . Second, the entry-deterring price p^* is below the monopoly price of the low-cost firm ($p^m(c_L)$). These two properties will play a role in some of the arguments below.

We formulate the results in an informal way. We confine ourselves to describing the equilibrium outcome and the most important features of the equilibrium strategies. Apart from the proofs, the online appendix contains precise formal statements of equilibrium strategies and tie-breaking rules.

2.2.1 Laissez Faire and Brooke Game

We treat the Laissez Faire and Brooke Games together, as the analysis is essentially the same.

Proposition 1. *The Laissez Faire and Brooke Game both have a subgame-perfect equilibrium (SPE) in pure strategies. The SPE outcome is that there is no entry and firm L charges its monopoly price. The equilibrium strategies in each period are such that pricing in any period is independent of previous prices. Moreover, the entrant will exit from duopoly immediately after any off-equilibrium entry. Finally, any SPE has these properties.*

The intuition is straightforward. In both games, both firms are essentially free to set arbitrary prices.³ Pricing in any given period therefore has no effect on future behavior. Thus, in each period, firms set prices that are optimal in the short term. In particular, in any duopoly situation the incumbent undercuts the entrant in equilibrium. Anticipating this, the H-firm will not enter.

The intuition immediately implies that Proposition 1 does not depend on the details of our parameterization: The only thing that matters is that pricing in any given period does not affect pricing in any future period.

2.2.2 Edlin Game

The equilibrium prediction of the Edlin Game and the off-equilibrium behavior differ from the two previous cases.

Proposition 2. *The Edlin Game has an SPE without entry, in which firm L sets the entry-detering price p^* except in period 4 where it charges the monopoly price. The equilibrium strategies involve hit-and-run entry after incumbent prices above p^* : The entrant prices just below the incumbent's Edlin restriction and exits in the next period. Any equilibrium has these properties.*

Though the SPE does not involve entry, the Edlin rule has a desirable effect on prices. The incumbent understands that high prices will attract entry. To avoid this, it sets prices that are so low that, in spite of the Edlin restriction, it can limit price the high-cost firm in the next period. Anticipating this, the high-cost firm does not enter. Importantly, however, the result also suggests that after high prices of the incumbent, the high-cost firm will enter. This differs from the previous games where entry does not occur in any subgame.

³In the Brooke game, prices below own costs are not allowed, but the incumbent does not want to choose such prices anyway.

2.2.3 Baumol Game

In the Baumol game, the equilibrium outcome is as in the Laissez-Faire and Brooke games. The off-equilibrium behavior is more complex, however.

Proposition 3. *The Baumol Game has an SPE without entry in which firm L sets its monopoly price in all periods. In this SPE, in any subgame with a duopoly, the asymmetric Bertrand equilibrium where both firms charge the high cost c_H is played in periods 2-4. There are other SPE yielding the same outcome. These SPE differ only in period 2, when the price chosen by both firms is an arbitrary element of the interval $[30, 32.679]$.*

The equilibrium outcome is thus analogous to the Laissez Faire and Brooke Games. The difference exclusively concerns off-equilibrium behavior. After entry, the incumbent knows that, if he undercuts the entrant, his duopoly price is an upper bound for future prices if the entrant exits again. Given the parameter values of our model, he nevertheless always prices below the entrants marginal cost in periods 3 and 4: The short-term profit at a price just below c_H is sufficiently high to justify the resulting reduction in future profits. In period 2, however, the incumbent may prefer to let the entrant win for prices slightly above c_H : This way, he is not constrained in his future pricing behavior and can benefit from monopoly prices in two more periods.

2.2.4 Welfare

Figure 2 below compares welfare in the outcomes of our games with standard benchmarks.

At one extreme, we consider a completely unregulated low-cost monopoly, with low consumer surplus and total welfare, but high producer surplus. The unregulated low-cost monopolist corresponds to the outcome of the Laissez-Faire, Brooke and Baumol Games.

At the other extreme, we take a low-cost monopoly with marginal and average cost regulation. In these cases, consumer surplus and total welfare are high, whereas producer surplus is low (or even negative for marginal cost regulation).

As an intermediate welfare benchmark, we consider a Bertrand duopoly where both firms enter. This market structure generates inefficient duplication of fixed

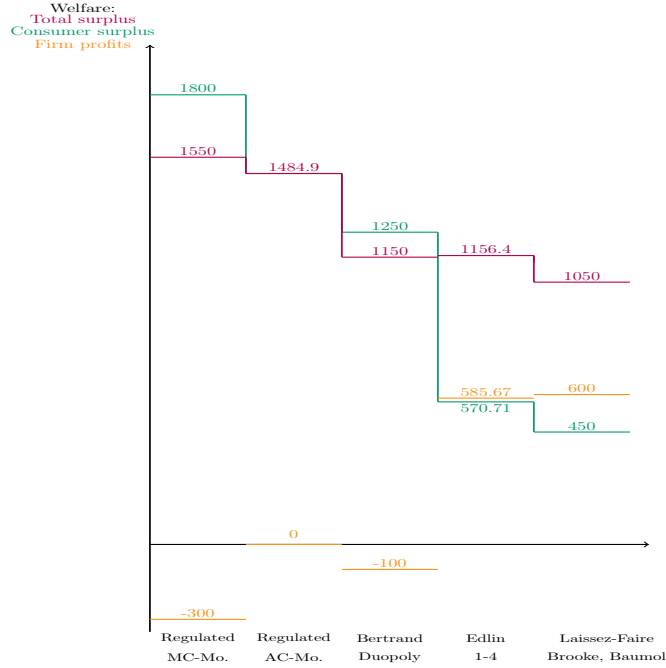


Figure 2: Welfare Benchmarks

costs, but it keeps prices at the marginal cost of the high-cost firm without regulation.⁴ Compared to the unregulated monopoly, the Bertrand duopoly yields higher consumer surplus, but a lower producer surplus.⁵ The Edlin Game (no entry and entry-detering prices) yields similar total welfare as the Bertrand duopoly. However, Edlin predicts lower consumer surplus because entry-detering prices p^* are higher than limit prices c_H , and it predicts higher producer surplus, because inefficient duplication of fixed costs is avoided.⁶

2.3 Experimental Design and Procedures

We consider four treatments: LAISSEZFAIRE, BROOKE, EDLIN, and BAUMOL. Each treatment consists of 7 rounds of the baseline game outlined above. In all treatments, the game is played in a stranger matching protocol such that in the beginning of each round, firms are newly paired and the roles of firm L and firm

⁴Like a regulated marginal cost monopoly, this structure is not viable without subsidies.

⁵For our specific parameter values, the total producer surplus is zero.

⁶We distinguish between the equilibrium of the Edlin game as described above where firm L charges the monopoly price in the final period and a version where this end effect does not arise.

H are randomly reassigned within these groups. When a new round starts and the players are newly matched, neither player knows anything about the decisions of the other firm in prior rounds. Within a given round, the roles and the firms remain the same. At the end of each stage, the players are informed about the market price, the output sold, and the profits realized by each of the players in their group. Firms cannot communicate.

The sessions were run in the WiSo experimental research laboratory of the University of Hamburg in July 2015 and were programmed in z-Tree (Bock et al., 2014; Fischbacher, 2007). Subjects were randomly allocated to computer terminals in the laboratory so that they could not infer with whom they would interact. For the entire experiment, communication was not allowed. We provided written instructions which informed the subjects of all the features of the markets (see the Appendix). Similar to other studies on experimental oligopolies, we used an economic framing (see, for example, Huck et al. (2004)). We asked subjects to think of themselves as representing a firm which, with another firm, could sell goods in a market and that their job was to decide whether to be active in the market and which price to set. When answering the control questions and when choosing the quantity during the game, players had access to a profit calculator allowing them to calculate the payoff of hypothetical combinations of their quantity and the quantity produced by their competitor.

For the profits during the experiment, we used an experimental currency unit called points. At the beginning of the session subjects were endowed with 1500 points to cover potential losses. The payments to the subjects consisted of a 5 Euros show-up fee plus the sum of the profits over the course of the experiment. The sessions lasted for about 90 minutes, and the average earnings were €16.80. We conducted ten sessions with a total of 228 participants. The subjects were undergraduate students from the University of Hamburg.

3 Results

We start by looking at the LAISSEZFAIRE treatment and showing that predatory pricing occurs frequently, exit is common and entry less so. After that, we investigate the potential of the three policies to improve the situation. Throughout our

analysis, we will distinguish between three phases of the game: (i) *PreEntry*, the phase from period one until entry if there is entry;⁷ (ii) *Duopoly*, after the entrant has entered the market when the two firms compete; and (iii) *PostExit*, after one of the two firms—typically the entrant—has left the market.⁸

3.1 Predatory pricing: a unicorn? LaissezFaire

Is predatory pricing rare like a unicorn? That depends upon what you mean by the term. If predatory pricing means pricing below the incumbent’s marginal cost, then it is a unicorn in our experiment even when it is legal: No participant set a below-equilibrium price in the experiment. However, we define predatory pricing, following Edlin (2002) as exclusionary pricing, pricing at a level that prevents a rival from breaking even; such pricing “excludes” in the sense of providing rivals the incentive to exit a market or not to enter in the first place. By this definition when the incumbent charges 37 or below it is predatory pricing because the entrant cannot help but to lose money by being in the market.⁹ It cannot undercut the incumbent as $36 < p_H^B$; and the duopoly profits obtained when both firms charge 37 do not suffice to cover fixed costs.

Under our definition, far from being a unicorn, predatory pricing is the most common reaction to entry under LaissezFaire. Player experience makes predatory pricing only more prevalent. Readers who are committed to defining predatory pricing as below-cost pricing are invited to continue reading and replace the term with “exclusionary pricing”.

Prior to entry, during the *PreEntry* phase, the incumbent is a monopoly and prices as such. In 85 percent of the cases it chooses the monopoly price of 50. Its average price is likewise 50.

Entry lowers the average incumbent price substantially to 35, which is in our predatory range of 37 and below. The decrease is highly significant ($p = .008$,

⁷More precisely, we define the *PreEntry* phase as all periods in which the entrant did not yet enter, except period four. We exclude the final period, because the incumbent does not have to bother about market entry in this period.

⁸The phases are typically encountered in this specific order. In very few cases, we observe that the incumbent exits and the entrant enters at the same stage. In this case the group moves directly from *PreEntry* to *PostExit*.

⁹In the discrete version of the game, firm H cannot break even if the incumbent sets

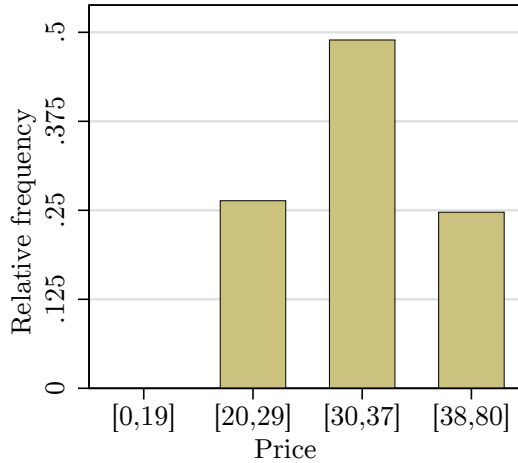


Figure 3: Incumbents' prices in the phase *Duopoly* of treatment LAISSEZFAIRE .

Wilcoxon signed-rank test¹⁰)

Figure 3 shows the frequency of incumbents' prices for a number of price ranges. No incumbent prices below his own marginal cost of 20, so there is no below-cost predatory pricing. There is, however, plenty of what Edlin refers to as “above-cost predatory pricing” in the next two categories of pricing. In particular, prices in the next category above the incumbent's marginal cost and below the entrant's marginal cost are quite frequent (26 percent). Around half of the observations (49 percent) are above the entrants' marginal cost and below the entrants break-even point. Taken together, we find that a large majority (75 percent) of the incumbents' respond to entry with above-cost predatory pricing.

As a consequence, entrants normally make a loss. The average profit is -235 per period and only in 13 percent of the cases entrants earn a positive payoff in any period when they are in competition with an incumbent. Presumably as a reaction most entrants often leave the market: Among the 93 cases where entrants join the duopoly market in stage two or three, 57 (61 percent) leave the market at some point, such that the incumbent is again in a monopoly.

Aside from the fact that entrants do not remain in the market, the most impor-

¹⁰This and all subsequent non-parametric tests are based on independent matching group averages.

tant effect of predatory pricing is that rivals do not dare to contest the incumbent in the first place. In fact, the only rational reason not to enter is a fear of predatory pricing. Over all rounds rivals stay out of the market throughout the game one-third of the time. Over the course of the seven rounds there is clear trend towards less entry, presumably as rivals realize the high frequency of above-cost predatory pricing. While in the first round 96 percent of the rivals enter the market, the percentage drops to 42 percent in the final round. Thus, by the time the rivals understand the likely reactions most do not enter.

When the incumbent successfully pushes the entrant out of the market, the game is in the *PostExit* phase. Price setting of the incumbents returns to monopoly pricing with an average of 51, again with the vast majority of cases (88 percent) at 50.¹¹

Result 1. *Under LAISSEZFAIRE, incumbents generally engage in predatory pricing, invariably above-cost predatory pricing, mostly succeeding in pushing the competitor out of the market, and discouraging most experienced rivals from entry.*

3.2 PreEntry prices under LaissezFaire, Baumol, Brooke, and Edlin legal regimes

Will the various predatory pricing policies improve matters? We begin by studying their impact upon *PreEntry* prices.

Theory predicts that in LAISSEZFAIRE, BROOKE, and BAUMOL in the *PreEntry* phase, the incumbent will charge the monopoly price of 50, because its price doesn't affect entry, while in EDLIN the incumbent will charge 46 in order to deter entry. The average price we observe during the *PreEntry* phase is in fact very close to the monopoly price of 50 in the first three treatments, with 49.6 in LAISSEZFAIRE, 49.1 in BROOKE, and 50.0 in BAUMOL. In EDLIN we observe a significantly lower average price of 46.2, very close to the theoretical prediction.¹²

¹¹There are a few instances where the incumbent leaves the market, making the entrant a monopolist. The average price in these situations is 55, which is the monopoly price for the entrant.

¹²The differences across all treatments are significant at $p = .011$ (Kruskal-Wallis test). The bilateral difference between EDLIN and LAISSEZFAIRE (BAUMOL) is significant at $p = .033$ ($p = .002$). In round 4 to 7 all bilateral differences between EDLIN and other treatments become

There is substantial variation in observed prices as shown in Figure 4. We bin the observations into three categories, low prices in $[0, 46]$, intermediate prices $[47, 53]$, and high prices $[54, 80]$. The bins are motivated by theory. The intermediate category contains the monopoly prices as well as slightly higher and lower prices; this category is what theory predicts we should expect under the first three treatments. Low prices are all prices which qualify as entry deterrent under the Edlin rule, by which we mean that it is the best response of the incumbent to make the entrant lose money. High prices, we do not expect, but they occur occasionally in the experiment.

The modal choice of the incumbent firms is clearly the monopoly price in all treatments. In fact, the figure would look very similar if the middle bin would contain only observations at 50. In LAISSEZFAIRE and BROOKE we observe a price of exactly 50 in 82.9 to 86.4 percent of the cases. In BAUMOL the frequency of the monopoly price is somewhat lower with 74.1 percent. The frequency is substantially lower in EDLIN with 37.7 percent, much as theory predicts.

Figure 4 makes it clear that while the first three treatments lead to similar PreEntry prices, In LAISSEZFAIRE, BAUMOL, and BROOKE, the incumbent generally prices at or near the monopoly level. EDLIN produces substantially different results with almost half pricing in the low price bin. Only in this treatment we observe a substantial amount of prices in the first bin (44.8 percent). This clearly indicates that firms systematically respond to the Edlin rule and frequently choose entry deterrent prices.

In Table 1 we use OLS estimates to investigate the effect of experience on the incumbents' prices in period 1 of the game. We explain the prices by treatment dummies (with LAISSEZFAIRE as omitted case) and the round in which the game was played ($1 - 7$). In later rounds subjects have more experience with the game. Given that the games are fairly complicated it would not be surprising to observe changes in the strategies with more experience. Model (1) confirms that the first three treatments are similar, while EDLIN results in significantly lower prices. We do not observe a significant effect across rounds. In Model (2) we include interaction terms between round and treatment to allow for treatment specific experience

significant at $p < .015$. For two-group tests we report p -values of exact Wilcoxon rank-sum tests. All tests use the independent matching group averages as observations.

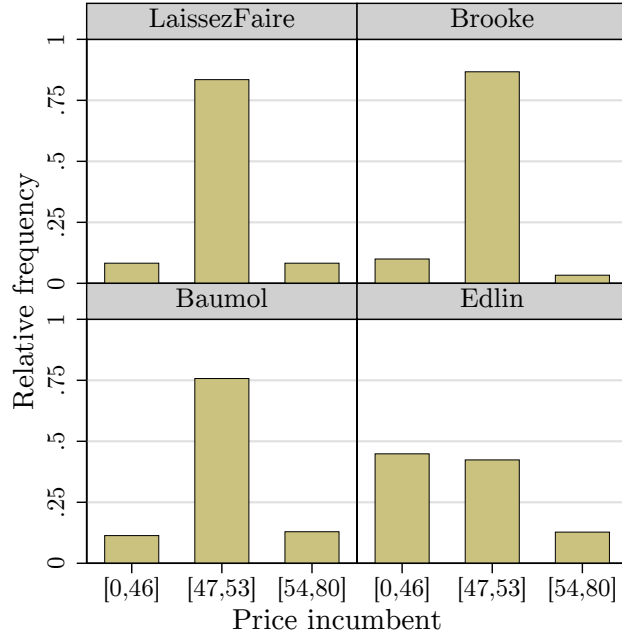


Figure 4: Distribution of incumbents' prices in the phase *PreEntry*.

effects. The results suggest that the price difference between EDLIN and the other treatments is particularly pronounced in later rounds of the experiment.

Result 2. *In the treatments LAISSEZFAIRE, BROOKE, and BAUMOL a large majority of the L firms set monopoly prices prior to entry. In sharp contrast, under EDLIN we observe that almost half the prices are in the entry deterrent range.*

3.3 To enter or not to enter: a comparison of the legal regimes

We now look at the rival's entry decision. Theory predicts no entry in any rule in equilibrium. In addition, there is no entry under LAISSEZFAIRE, BROOKE, or BAUMOL in any subgame equilibrium, even after off-equilibrium prices. Under EDLIN there should be no entry on the equilibrium path, but we should observe entry when the pre-entry price is greater than 46. Edlin (2002) sells it as a virtue of his rule that if the incumbent fails to price low, the rival will enter.

Table 1: Incumbents' prices and rival's entry

	Price in <i>PreEntry</i>		Rival's entry		Predatory price in <i>Duopoly</i>	
	(1)	(2)	(3)	(4)	(5)	(6)
Brooke	-1.405 (0.976)	-3.548 (2.888)	-0.065 (0.064)	-0.060 (0.096)	-0.083 (0.082)	0.047 (0.109)
Baumol	0.300 (0.921)	-1.669 (2.010)	0.088 (0.065)	-0.080 (0.083)	-0.119 (0.065)	-0.136 (0.124)
Edlin	-2.679* (1.044)	-1.340 (1.785)	0.209** (0.053)	-0.131 (0.080)	-0.444** (0.068)	-0.387** (0.119)
Round	-0.123 (0.163)		-0.074** (0.010)		0.058** (0.011)	
Round \times LaissezFaire		-0.281 (0.198)		-0.110** (0.012)		0.069** (0.021)
Round \times Brooke		0.254 (0.522)		-0.112** (0.016)		0.029 (0.023)
Round \times Baumol		0.211 (0.258)		-0.068** (0.019)		0.073** (0.023)
Round \times Edlin		-0.616** (0.203)		-0.025* (0.012)		0.053** (0.014)
Constant	50.598 (1.011)	51.232 (1.335)	0.812 (0.054)	0.958 (0.058)	0.509 (0.069)	0.471 (0.096)
<i>F</i> -test	2.8	3.9	22.3	24.9	19.4	12.3
Prob > <i>F</i>	0.042	0.003	0.000	0.000	0.000	0.000
<i>R</i> ²	0.024	0.033	0.134	0.155	0.162	0.166
<i>N</i>	798	798	798	798	541	541

Notes: OLS estimates. Dependent variables in model (1) and (2): incumbent's price in period 1. Model (3) and model(4): rival's entry decision in period 2. Model (5) and (6): dummy for predatory pricing by the incumbent ($p_I \leq 37$) in the period where the rival entered. Independent variables: treatment dummies, round, and interactions. Robust standard errors, clustered on matching group, in parentheses. * $p < 0.05$, ** $p < 0.01$.

In the experiment, there is substantial entry in all regimes but, as theory suggests, most in EDLIN. In period 2, we observe that 51.8 percent enter in LAISSEZFAIRE, and 45.2 percent in BROOKE. BAUMOL seems to encourage entry with 60.6 percent, perhaps because entrants hope that the incumbent is reluctant to fight in view of the Baumol restriction. We find the highest fraction of entry decisions in EDLIN with 72.7 percent.¹³

Model (3) and (4) of Table 1 provide evidence on the role of experience. We use linear probability models to explain the rival's entry decision. Model (3) shows that EDLIN encourages significantly more entry than the other treatments, while there is a strong overall trend towards less entry in later rounds. In Model (4) we allow for separate effects of experience. The results suggest that the pronounced differences between LAISSEZFAIRE and EDLIN only appear in later rounds of the game. If at all, EDLIN seems to produce slightly less entry in the beginning. The interactions of round with the treatment dummies indicate that the reduction in entry over time is strongest in LAISSEZFAIRE and BROOKE, weaker in BAUMOL, and much weaker in EDLIN.

How does the incumbent's pre-entry price affect entry? According to Proposition 2, under the Edlin rule, entry is the best response to prices above the entry deterrent price of 46, whereas under the other rules, entry is a poor choice regardless of the incumbent's pre-entry price.

Figure 5 shows the fraction of entrants entering the market, conditional on the incumbent's price in the previous period. For the figure we use all periods in which the entrant can enter. We use the same bins for the incumbent's price in the previous period as in Figure 4. Spikes indicate standard errors, calculated with clustering on matching group. In all treatments prices above the monopoly price seem to encourage entry, ranging from 63.3 percent in BAUMOL to 85.4 percent in EDLIN. The figure documents striking differences of entry behavior in the intermediate price range. If the incumbent price is close to the monopoly price, then we observe relative low entry frequency in LAISSEZFAIRE and BROOKE (30.8 and 25.4 percent). In BAUMOL we observe somewhat more entry with 43.7 percent. For all these treatments, there is a significant difference between entry after monopoly

¹³Differences across all treatments are significant at $p = .005$, differences between EDLIN and LAISSEZFAIRE or BAUMOL are significant at $p < .003$.

(middle bin) and above-monopoly (right bin) prices at $p < 0.23$. In stark contrast, EDLIN produces more than twice as much entry as the other treatments with 86.0 percent of high-cost firms entering the market if the incumbent sets a price close to monopoly price.

For the first three treatments, entry frequency when the incumbent prices low or in the monopoly region (the first two bars) is statistically indistinguishable. LAISSEZFAIRE, BROOKE, and BAUMOL ($p > .3$ for each). Taken together we observe very similar results in the first three treatments. Entry does happen quite frequently, and entry is especially encouraged by prices above the monopoly price.

In contrast, the increase in EDLIN between the frequency of entry when price is in the entry-deterrent region and the monopoly region is highly significant ($p < .0005$). In EDLIN entry follows roughly speaking the predicted pattern. It happens mostly when the incumbent sets prices above the entry deterrent level. On the other hand, even for entry deterrent prices we still observe 38.2 percent of the firms entering the market.

Result 3. *We observe frequent market entry in all treatments. Consistent with the theory of off-equilibrium path behavior, we observe that entry in EDLIN mainly happens in cases where the incumbent does not set entry deterrent prices. In the other treatments, entry is particularly frequent when the incumbent uses above-monopoly prices; there is no difference between prices below and close to monopoly.*

3.4 Duopoly under different legal regimes

Advocates of strict predatory pricing rules want to reduce the frequency of predatory pricing. Laissez faire advocates worry about the consumer loss from discouraging price wars. Contrary to theory, we see entry in 30 percent of the cases even under LaissezFaire, so that we wind up with duopoly. We can therefore test whether predatory pricing actually arises, and how this differs across policy regimes.

When there is duopoly, we find that predatory pricing occurs at the rate of 75 percent in LAISSEZFAIRE, 70 percent under BROOKE, 66 percent in BAUMOL and 50 percent under EDLIN. (see left panel of Figure 6) LAISSEZFAIRE cannot be statistically distinguished from either BROOKE or BAUMOL in terms of the fre-

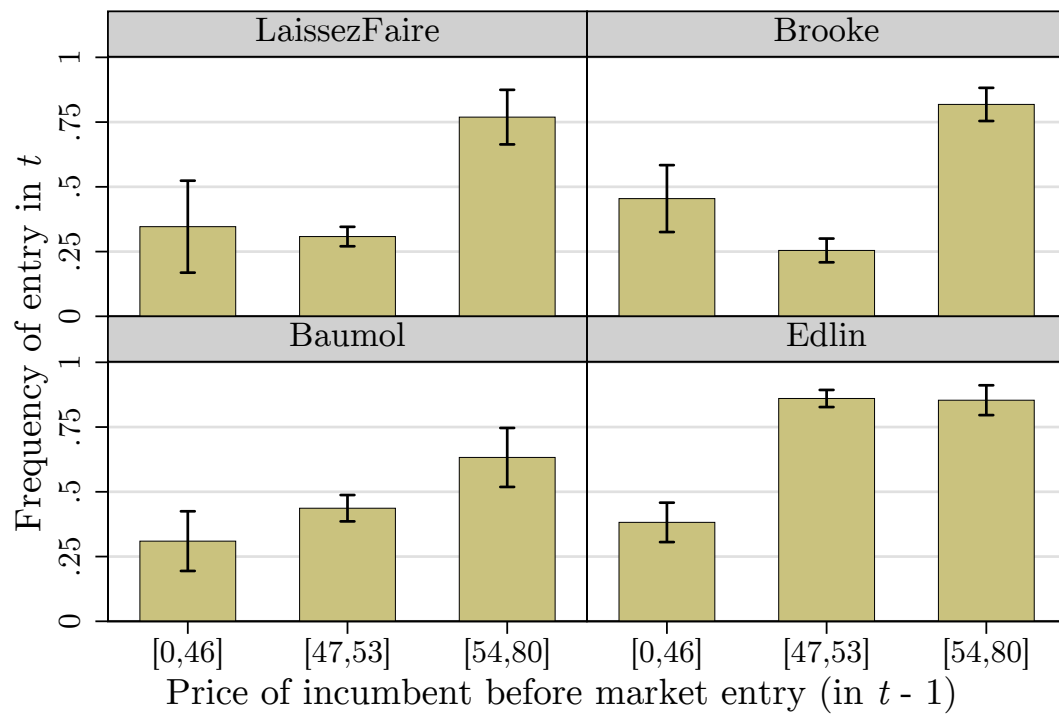


Figure 5: Frequency of entry for different incumbent's prices in the previous period.

quency of predatory pricing ($p > .129$). The Edlin rule on the other hand reduces predatory pricing from 75 percent to 50 percent, which is both economically and statistically significant ($p = .001$).

Model (5) and (6) of Table 1 present the results from linear probability models for the incumbent's predatory pricing in the period where entry happened. Model (5) shows that, compared to LAISSEZFAIRE, predatory pricing is substantially less frequent in EDLIN. We observe a positive effect of experience, indicating that incumbents' pricing becomes more aggressive in later rounds of the experiment. In Model (6) we allow for treatment specific round effects. The increase in the frequency of predatory prices with experience does not seem to differ substantially across treatments.

Not surprisingly, average market prices move inversely with the incidence of predatory pricing. Consumers suffer steadily higher prices as we move from LAISSEZFAIRE to BROOKE to BAUMOL to EDLIN as shown in the right panel of Figure 6. Market prices rise from an average of 31.8 in LaissezFaire to 34.9 under Edlin. The difference between EDLIN and LAISSEZFAIRE is statistically significant ($p = .003$), the difference between BAUMOL and LAISSEZFAIRE is weakly significant ($p = .091$).

These two observations are quite consistent with the finding that entry is highest under Edlin. Entrants are sensibly attracted by the lower frequency of predatory pricing and the higher average prices under Edlin. These results are significantly more pronounced in later rounds of the game when players have a better understanding.

Result 4. *Predatory pricing is frequent in LaissezFaire, Brooke, and Baumol. Edlin substantially reduces the frequency of predatory pricing at the expense of higher average prices; LaissezFaire, Brooke, and Baumol are statistically indistinguishable in these dimensions.*

3.5 Exit and Post Exit

In a next step we look at the duration of the entrants' presence in the market and the determinants of exit. Provided that entry occurred, the entrant can remain in the market between 1 and 3 periods. In LAISSEZFAIRE the average duration is

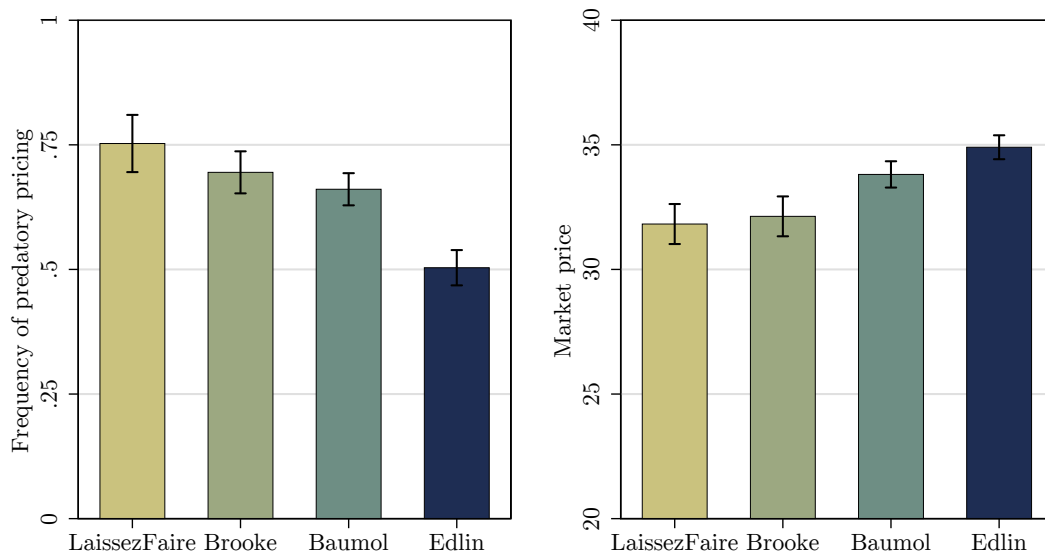


Figure 6: Left panel: Frequency of predatory pricing by the incumbents across treatment. Right panel: Market prices across treatment.

1.89 periods. BROOKE and EDLIN have similar durations of 1.72 and 1.76 periods, while BAUMOL results in the shortest average duration of 1.54 periods.¹⁴ These durations indicate that many firms enter just for one period. In LAISSEZFAIRE, where the average duration is longest, 44.6 percent of the entrants leave after one period. In the other treatments the percentage is 54.5 in BROOKE, 59.7 in BAUMOL, and 51.9 in EDLIN.

Given that incumbents on average undercut the prices of the entrants in the duopoly phase it is not surprising that many entrants sooner or later exit the market. What are the determinants of the exit decision?

Table 2 shows the results of linear probability models for the decision to exit the market. Again we consider only the first period after entry and control for treatment dummies and round effects. Model (1) shows that incumbents are less likely to exit, and in accordance to the numbers on duration of market participation of the entrants we find that exit is highest in BAUMOL, followed by EDLIN and BROOKE. In Model (2) we control for round effects and whether the profit in

¹⁴The overall differences are significant at $p = .014$.

the period of duopoly play affects the decision to exit. The coefficient for round is positive and significant, indicating that the duration of market participation decreases over the rounds. Surprisingly, the profit earned in the duopoly period does not seem to have a systematic impact on the decision to remain in the market. However, splitting the sample (Model (3) and (4)) reveals that high profit decreases the exit probability of incumbents; whereas there is no such effect for entrants. Moreover, the effect of time is opposite: incumbents exit becomes less frequent in later rounds, while the opposite is true for entrants.

Table 2: Explaining exit

	Dependent variable: Exit			
	(1) All	(2) All	(3) Incumbents	(4) Entrants
Incumbent	−0.433*** (0.028)	−0.428*** (0.032)		
Brooke	0.057** (0.028)	0.059** (0.029)	−0.001 (0.039)	0.120** (0.055)
Baumol	0.119*** (0.034)	0.116*** (0.034)	0.022 (0.023)	0.207*** (0.059)
Edlin	0.099*** (0.025)	0.092*** (0.026)	0.019 (0.032)	0.125** (0.056)
Round		0.011* (0.006)	−0.014** (0.007)	0.035*** (0.010)
Profit		−0.015 (0.027)	−0.061** (0.024)	0.041 (0.064)
Constant	0.412*** (0.026)	0.368*** (0.033)	0.095*** (0.031)	0.252*** (0.055)
<i>F</i> -test	64.4	49.4	2.6	5.1
Prob > <i>F</i>	0.000	0.000	0.043	0.001
<i>R</i> ²	0.245	0.248	0.031	0.043
<i>N</i>	1082	1082	541	541

Notes: OLS estimates. Dependent variable: exit decision after duopoly. Robust standard errors, clustered on matching group, in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

In the phase *PostExit* the firm remaining in the market has a monopoly and does not face the threat of market entry. Unless restricted, we would expect that such firms set the monopoly price. This is indeed the case as we observe incum-

bents' average prices of 49.5 in EDLIN to 50.3 in LAISSEZFAIRE.¹⁵ In BAUMOL we observe significantly lower prices due to the price cap. When the Baumol price cap applies, 97.8 percent of the firms choose a price which is equal to the restriction. The average *PostExit* price of the incumbents is 37.3.

Result 5. *A large fraction of the entrants exit the market after one period. Surprisingly we observe the lowest frequency of exit in LAISSEZFAIRE, while the highest frequency of exit is observed in BAUMOL. The profit in the duopoly does not seem to be an important predictor of the decision to remain in the market for the entrants.*

3.6 Overall comparison of the policies

The results presented so far clearly illustrate that two of the three policies result in significantly different market outcomes than under a laissez faire regime. BAUMOL results in substantially lower prices in the *PostExit* phase, while EDLIN results in lower prices prior to entry. The outcome of BROOKE is very similar to LAISSEZFAIRE. While the treatment differences within these phases are substantial, the overall effectiveness of the policies depend importantly on the frequency with which these phases are entered and their duration. Figure 7 shows the frequency of entrants' market entry and exit over the course of the seven rounds. In the first round we observe entry in almost all groups. The differences across treatments are insignificant in round one.¹⁶ After that, LAISSEZFAIRE and BROOKE show a clear tendency towards the equilibrium play with a strong increase in the cases where no entry happens during all four periods of the game. In the final round of the experiment we observe that 58.3 percent of the games in LAISSEZFAIRE and 75.0 percent of the games in BROOKE result in no entry. The percentage is lower in BAUMOL with 35.0 percent, and much lower in EDLIN with only 8.2 percent. The differences across treatments in the final round are significant at $p = .003$. When entry happens we typically also observe exit. In all treatments the fraction

¹⁵In the cases where the incumbent exited we observe prices close to the monopoly price of the entrants of 55 (54.5 to 55.6).

¹⁶ $p = .268$, Pearson χ^2 statistic with correction for dependence within group, see Rao and Scott (1984)

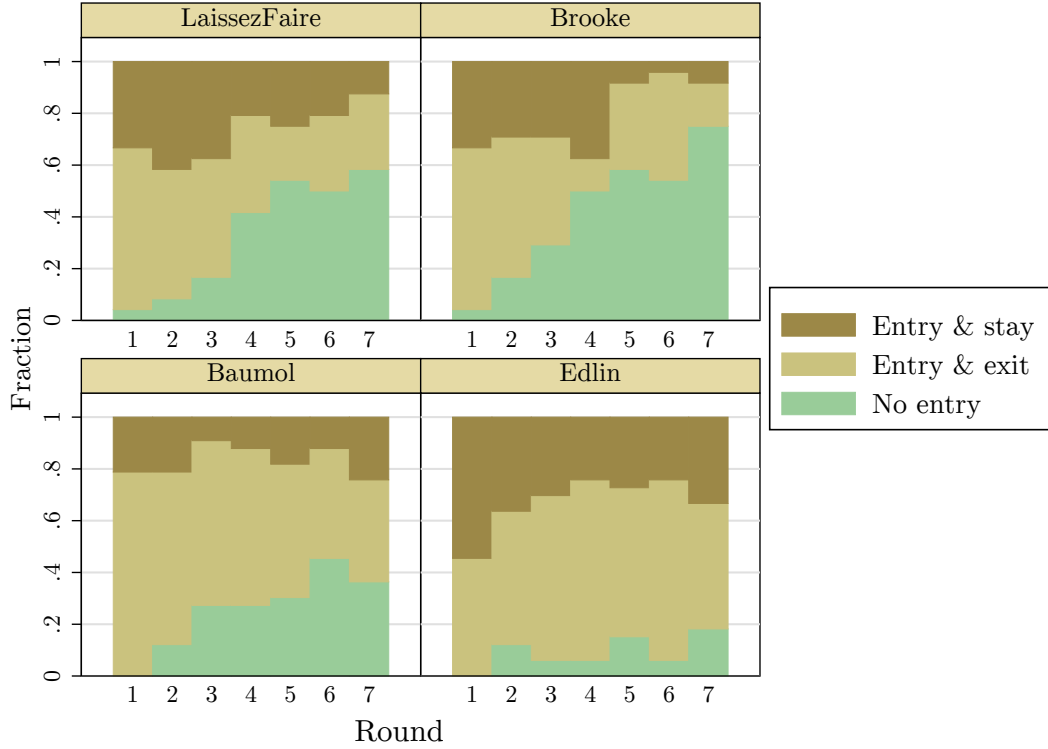


Figure 7: Dynamics of market entry over the seven rounds by treatment.

of games with entry and exit is higher than the fraction of games in which the entrant stays in the market until the final period.¹⁷

While Figure 7 gives us some indication that the policies give rise to differences in how competitive the market is, the ultimate criterion should be a welfare criterion. Figure 8 shows the welfare comparison. We calculate total welfare as the sum of consumer welfare and the two firms' profits. In accordance to the previous analysis we consider only period one to three for this comparison, thereby excluding the final period of the game in which there is no threat of entry. The horizontal lines indicate predicted welfare, which is equal to 1050 for the first three treatments, and 1156 for EDLIN. To control for the dynamics across rounds we plot separate figures for the first half of the rounds (1 – 4), and the second half

¹⁷The observations in the category Entry & stay do not necessarily mean that the entrant spends more time in the market than in Entry & exit, because it could be that the entrant entered only very late in the game.

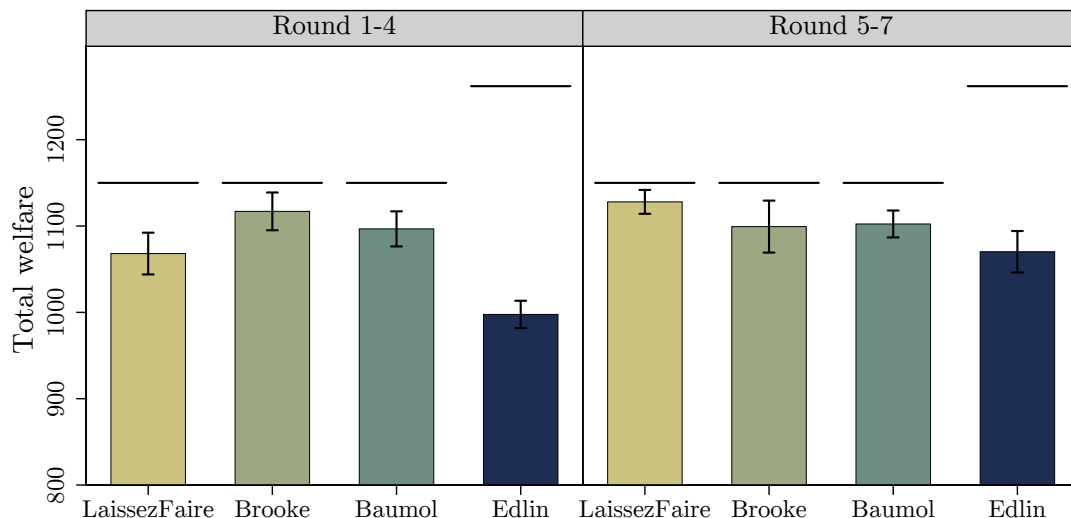


Figure 8: Total welfare.

of the rounds (5 – 7). Average welfare falls short of the predicted welfare in all treatments.

Figure 9 shows the consumer surplus generated in the four treatments. We consider only period one to three for this analysis, because period four is the (commonly known) final period of the game. The results depend strongly on whether players are experienced (round 5-7) or not (round 1-4). In the former case which is presumably more relevant, the consumer surplus is highest for EDLIN, followed by BAUMOL, LAISSEZFAIRE and BROOKE.

The theoretical analysis suggests two main reasons why prices should be lower in EDLIN: Lower pre-entry prices and more entry. The second effect arises only if one takes entry incentives at off-equilibrium prices into account. Our experimental analysis confirms that these expectations are both confirmed and thus consumer surplus is highest under EDLIN. However, while lower pre-entry prices are unambiguously beneficial for welfare, greater entry is not, as it involves inefficient duplication of fixed costs. The low welfare under EDLIN compared to the other treatments reflects this effect.

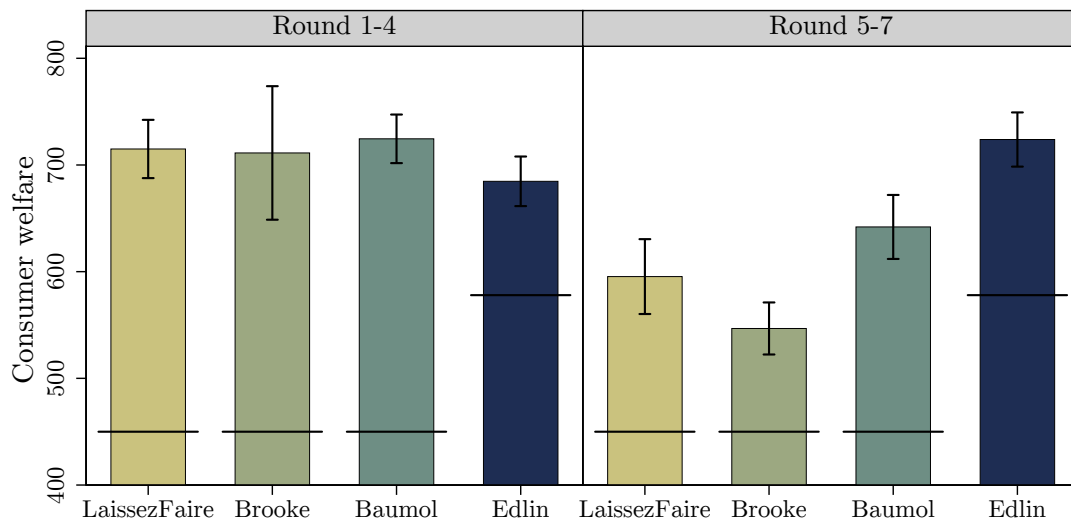


Figure 9: Consumer surplus.

4 Discussion and Conclusion

The paper analyzes above-cost predatory pricing in a multi-period interaction between a low-cost monopolistic incumbent and a high-cost potential entrant. It compares a laissez-faire setting with unconstrained pricing and three different policy interventions. We consider the legal standard of the Brooke rule, according to which below-cost pricing is prohibited. In addition, we allow policies that prohibit strong post-entry price cuts (Edlin (2002)) or post-exit price increases (Baumol (1979)).

In subgame perfect equilibrium, there is no entry in any of these settings. In the Laissez-Faire, Brooke and Baumol cases, this is true even though the incumbents choose monopoly prices. Even if they were to deviate to any other prices, entry would not arise in the subsequent subgames. In the Edlin case, the incumbent chooses to price below monopoly. Higher prices would attract entry.

We investigate these claims in a laboratory experiment. In the Laissez Faire and Brooke cases, that is, without any policy intervention that discourages above-cost exclusionary pricing, pre-entry (and post exist) prices are at the monopoly level. There is some entry, but less than for Baumol and much less than for Edlin. As predicted, Edlin is the only case with pre-entry prices below the monopoly

level. Baumol has the expected effect that it reduces post-exit prices.

As a result, consumer surplus is highest under Edlin for experienced participants (lowest under Laissez Faire), whereas the opposite result arises for the producer surplus: The fact that Edlin encourages entry (and thereby helps to keep prices low) has the downside of fixed cost duplication. The ranking of the different policies thus depends strongly on the relative weight on producer and consumer surplus.

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Online Appendix

Above-Cost Predatory Pricing

A Proofs

We now provide careful statements of our theoretical results and proofs. We start by formulating several tie-breaking rules.¹⁸

(T1) In any situation where both firms charge the same price, but a profitable downward deviation for exactly one firm is feasible, this firm wins the entire market (and becomes dominant).

The condition addresses two types of situations. First, it applies in cases where one firm is at its marginal cost (and thus cannot profitably reduce its price).¹⁹ Second, it is relevant if one firm is at the Edlin constraint (and thus cannot reduce its price at all). The tie-breaking rule reflects the idea of a suitable discrete approximation.

In the Baumol case, we will occasionally invoke a tie-breaking rule which applies in specific constellations when no firm has already reached its constraint. It deals with situation where one firm wants to let the other firm win (so as to avoid being constrained in the next period), whereas the other firm is happy to win (and will exit in the next period).

(T2) Suppose in $t = 2, 3$ both firms charge the same price, but neither firm is constrained. Fix continuation strategies in $t + 1$ for both firms. Suppose firm i prefers leaving the market to j in period t rather than taking the market (and conversely for j). Then j wins the market.

Finally, we have a tie-breaking rule regarding participation:

¹⁸Our instructions assume that, for ties, firms share the profits 50-50. For the equilibrium analysis, we nevertheless need tie-breaking rules

¹⁹In this case, the tie-breaking rule generates the standard textbook outcome that both firms charge at c_H , but firm L receives the entire demand. The relevant implication of this outcome that firm L serves the entire market at price c_H can be generated more precisely in an equilibrium where firm H mixes on an interval of prices c_H and higher (see Blume 2003 and Kartik 2011).

- (T3) If firm H is indifferent between entering and not entering given the subsequent subgame strategies, it will not enter.

We maintain these tie-breaking assumptions throughout the paper.

A.1 Laissez Faire and Brooke Game

A.1.1 Proof of Proposition 1

The proof is identical for both games. There is a unique equilibrium strategy profile such that

- (i) both firms play their respective monopoly price in subgames when they are alone in the market;
- (ii) both firms choose the Bertrand duopoly price (c_H) in subgames when both firms are present;
- (iii) firm L enters for every history; firm H does not enter for any history.

Clearly, in period 4, the described monopoly strategies are optimal; the strategy profile in the duopoly case is the unique pure-strategy equilibrium of the asymmetric Bertrand game. Anticipating this, firm H only participates in period 4 if firm L has previously exited. In period 3, suppose L is the monopolist. It anticipates being the monopolist in period 4 independent of pricing, so it sets $p^M(c_L)$. The argument is analogous if H is the monopolist (meaning that L has exited). If both firms are present, they anticipate that firm L will be the monopolist in period 4, independent of pricing in period 3. Thus, they set prices without taking period 4 into account, and the short-term Bertrand equilibrium emerges in period 3. Anticipating this pricing behavior, it is clear that only firm L is expected to earn positive net profits in the market, unless firm H is the monopolist in period 3. This gives that the entry decision. The argument in the preceding periods is analogous.

A.2 Edlin

We first formulate a version of Proposition 2 that describes the equilibrium strategies in more detail. This result clearly implies the statement in the main text.

A.2.1 Re-Statement of Proposition

Proposition 4. *The Edlin Game has an SPE described in (i)-(ix) below. This equilibrium is not unique, but any SPE in pure strategies generates the same outcome.*

(i) *Player L stays in periods $t \leq 3$ for arbitrary histories. In period 4, L exits if and only if $p_3^L > p^*$ and H has not previously entered (or L was dominant in period 3).*

(ii) *H participates in period t only if he has not previously exited and (a) L has exited, or (b) L was dominant in period $t - 1$ with $p_{t-1}^L > p^*$.*

(iii) *In periods in which Player L is a monopolist, she sets prices as follows: If H has not yet entered in any periods $t \leq 3$, L sets $p_t^L = p^*$ (entry deterrence). Otherwise, L sets $p_4^L = p^M(c_L) = 50$.*

(iv) *If L has previously exited, Player H sets $p_t^H = p^M(c_H) = 55$.*

(v) *If both firms are in in period 4 and neither firm was dominant in period 3, both firms set $p_4^L = p_4^H = c_H$ (and firm L takes the market given the tie-breaking rule).*

(vi) *Suppose both firms are in in periods 4 and firm L was dominant in period 3:*

(a) *If $0.8p_3^L \in [0, c_H]$, $p_4^L = p_4^H = c_H$ and firm L takes the market;*

(b) *If $0.8p_3^L \in (c_H, 80]$, $p_4^L = p_4^H = 0.8p_3^L$ and firm H takes the market;*

Note: *In the special case that $0.8p_3^L = c_H$, the firms share the market, so that neither firm is dominant.*

(vii) *Suppose both firms are in in periods 4 and firm H was dominant in period 3:*

(a) *If $0.8p_3^L \in [0, c_H]$, $p_4^L = p_4^H = c_H$*

(b) *If $0.8p_3^L \in (c_H, 80]$, $p_4^L = p_4^H = 0.8p_3^L$ and firm H takes the market;*

Firm L takes the market in both cases.

(viii) *If both firms participate in periods $t = 2, 3$, and firm L was dominant in period $t - 1$, price-setting is as follows:*

(a) *If $0.8p_{t-1}^L \in [0, c_H]$, then $p_t^L = p_t^H = 0.8p_{t-1}^L$ and firm L takes the market;*

(b) *If $0.8p_{t-1}^L \in (c_H, p^M(c_H)]$, then $p_t^L = p_t^H = 0.8p_{t-1}^L$ and firm H takes the mar-*

ket;

(c) If $0.8p_{t-1}^L \in (p^M(c_H), 80]$, then $p_t^L \geq 0.8p_{t-1}^L$; $p_t^H = p^M(c_H)$, and firm H takes the market

(ix) If both firms are in in periods $t = 2, 3$ and firm H was dominant in period $t - 1$, price-setting is as follows:

(a) If $0.8p_{t-1}^L \in [0, c_H]$, then $p_t^L = p_t^H = c_H$;

(b) If $0.8p_{t-1}^L \in (c_H, p^*]$, then $p_t^L = p_t^H = 0.8p_{t-1}^L$;

(c) If $0.8p_{t-1}^L \in (p^*, 80]$, then $p_t^L = p^*$; $p_t^H \geq 0.8p_{t-1}^H$.

Firm L takes the market in all three cases.

(x) If both firms are in in period 3 and neither firm was dominant in period 2, both firms set c_H and firm L takes the market.

A.2.2 Proof

We define the *quasi-cost* of a firm with cost type $\theta \in \{L, H\}$ that was dominant in period $t - 1$ in period t as $\hat{c}_\theta = \max(0.8p_{t-1}^\theta, c_\theta)$. (The motivation for calling this a quasi-cost is that the constraint to price above $0.8p_{t-1}^\theta$ has a similar effect on behavior as the constraint not to price below marginal cost).

Existence Period 4: For period 4, consider pricing: Obviously, setting the monopoly price is optimal for a monopolist as the competitor cannot be present in the future (see (iii) and (iv)). In any case where both firms are present in the last period, the game corresponds essentially to a static asymmetric Bertrand game with marginal costs of the dominant firm replaced with the quasi-marginal cost \hat{c}_θ . By arguments similar to those from the Bertrand Game (together with the tie-breaking rule) a last-period price profile is a subgame equilibrium if and only if both firms price at $\max(\hat{c}_H, \hat{c}_L)$. The winner is the unconstrained firm by the tie-breaking rule. Together, these arguments show (v)-(vii). For $t = 4$, they also show (iii) and (iv).

For period 4, consider participation. Anticipating the pricing behavior of L , H chooses to participate only if it is possible to break even in the last period, which requires one of the two conditions (a) and (b) in (ii): For (a), H earns the monopoly profit in period 4; for (b) she earns a non-negative net profit by setting $p_4^H = 0.8p_3^L$. If neither of these conditions hold, undercutting of firm L does not

lead to positive net profits, so that entry is not profitable.

Anticipating the pricing behavior of H , Firm L only exits whenever she cannot set an entry-detering price; that is, whenever L was dominant in period 3 with $p_3^L > p^*$.

Period 3 Pricing: In any subgame starting after the period 3 participation decisions, players anticipate that the competitor chooses the equilibrium strategy in period 4 after any period 3 pricing decision. In particular, firm H anticipates that, if firm L is in the market in period 3, it will stay and set prices in period 4 such that firm H cannot obtain a positive net profit unless firm L is dominant in period 3 with $p_3^L > p^*$; similarly, firm L anticipates that firm H will participate in period 4 only if $p_3^L > p^*$ and firm H was dominant in period 3. With this in mind, consider the pricing decisions in period 3.

Suppose first both firms are in and H was dominant in period 2 (see ix).

First, let $0.8p_2^H \leq c_H$: With the proposed prices (and the tie-breaking rule), firm L earns a profit of $(c_H - c_L) D(c_H)$ in period 3. It induces exit of firm H and earns monopoly profits in period 4. Lower prices in period 3 would reduce the period 3 profits of firm L without resulting in more profit in period 4. Any prices above c_H would lead to zero profits in period 3 and, at most the monopoly profit in period 4. Thus, firm L is best-responding. Firm H earns no profits, but cannot avoid this given that firm L is limit pricing in period 3 (and thereby also setting an entry-detering price for period 4).

Second, let $0.8p_2^H \in (c_H, p^*]$: With the proposed prices (and the tie-breaking rule), firm L earns a profit of $(0.8p_2^H - c_L) D(0.8p_2^H)$ in period 3. It induces exit of firm H in period 4 and earns monopoly profits in period 4. Lower prices in period 3 would reduce period 3 profits without resulting in more profit in period 4. Higher prices in period 3 would lead to zero profits in period 3 and, at most the monopoly profit in period 4. Thus, firm L is best-responding. Firm H earns no profits, but cannot avoid this.

Finally, let $0.8p_2^H > p^*$. Firm H is constrained by the requirement that $p_3^H \geq 0.8p_2^H > p^*$. For any such price of firm H , by following the proposed strategy of setting $p_3^L = p^*$, firm L obtains a period 3 profit of $(p^* - c_L) D(p^*)$; moreover L induces exit of firm H and earns the monopoly profit in period 4. This is a best response for L : For any higher price, firm H would participate in period 4, so that

firm L would earn at most one monopoly profit (in period 3). For any lower price, firm L would still prevent entry and earn the monopoly profit in period 4, but period 3 profits would be lower than $(p^* - c_L) D(p^*)$. Firm H earns zero profits, but it cannot avoid this.

Next, suppose both firms are in and L was dominant in period 2 (viii):

First consider $0.8p_2^L \leq c_H$: In the proposed equilibrium both firms set c_H . If $0.8p_2^L < c_H$, by the tie-breaking rule, firm L wins in this period (with the maximum possible period 3 profit given $p_3^H = c_H$); as $c_H < p^*$, she obtains the monopoly profit in period 4. Thus, L is best-responding. Firm H earns zero profits, but cannot avoid this; thus H is also best-responding. If $0.8p_2^L = c_H$, the argument is essentially the same, except that the two firms share the market in period 3 (as both firms are constrained below, the tie-breaking rule does not apply).

Second, suppose $0.8p_2^L \in (c_H, p^*]$: In the proposed equilibrium, firm H undercuts firm L and is thus dominant. Hence, in the next period firm H does not enter according to her strategy, and firm L earns the monopoly profit. Firm H is best-responding, because she cannot avoid having zero profits in period 4 (as $p_3^L = 0.8p_2^L \leq p^*$) and her profit in period 3 is maximal given the behavior of firm L . Firm L is also best-responding: She earns the monopoly profit in period 4; moreover, given her constraint and the behavior of firm H she cannot prevent losing in period 3.

Third, let $0.8p_2^L \in (p^*, p^M(c_H)]$: In the proposed equilibrium, firm H undercuts L in period 3. Firm L earns the monopoly profit in period 4. It cannot undercut firm H in period 3; so it is best-responding. Firm H obtains the maximal possible profit in this period, $(0.8p_2^L - c_H) D(0.8p_2^L) - F$, but no profit in period 4. The only potentially profitable alternative would be to set a higher price and thereby avoid undercutting L . Then L would exit in period 4 (as $0.8p_2^H > p^*$) given its strategy, and firm H would earn $(p^M(c_H) - c_H) D(p^M(c_H)) - F$ in period 4, but would also have to pay the additional fixed cost in period 3. Thus, H is best-responding if $(0.8p_2^L - c_H) D(0.8p_2^L) - F \geq (p^M(c_H) - c_H) D(p^M(c_H)) - 2F$. The right-hand side is 125. The condition holds for $0.8p_2^L \in [37.679, 70.811]$, and, in particular, in the interval $(p^*, p^M(c_H)] = (44.544, 50]$ under consideration.

Fourth, suppose $0.8p_2^L \in (p^M(c_H), 80]$. Firm H earns the monopoly profit in period 3, and firm L earns the monopoly profit in period 4. Firm L cannot

undercut firm H in period 3; thus it is best responding. Firm H cannot prevent that firm L takes the market in period 4, unless it gives up on winning in period 3 and thus becoming dominant. Winning immediately, and thus not incurring the fixed cost in period 4 is preferable.

Now suppose both firms are in and neither was dominant in the previous period (x):

In this case, both firms are free to set arbitrary prices. The argument is as in an asymmetric Bertrand equilibrium, taking into account that firm H will exit in the next period and firm L will win the market.

Finally, consider situations with only one firm is in the market (iii) and (iv) for $t=3$. If firm H is monopolist, then this is because firm L has exited. There is no re-entry threat; firm H thus obtains the monopoly profit in two periods by applying her strategy, which clearly is optimal. If firm L is monopolist, this could be because firm H has exited or because it has never entered. In the former case, there is no re-entry threat; firm L thus obtains the monopoly profit in two periods by applying her strategy, which clearly is optimal. In the latter case, firm L has to take into account that firm H will enter in period 4 if and only if $p_3^L > p^*$. In the proposed equilibrium L deters entry by setting $p_3^L = p^*$. She thus earns a positive profit $(p^* - c_L) D(p^*) - F$ if she adheres to the equilibrium strategy. This is clearly the best possible response among those that deter entry. The best way not to deter entry is to set $p_3^L = p^M(c_L)$. This way, however, firm L only obtains the monopoly profit once, which is less than with the proposed equilibrium behavior.

Next, consider participation decisions in period 3.

First, consider player L . According to the proposed equilibrium strategies, she stays in the market. If she was not dominant in period 2, she expects a positive profit in both periods, so staying is optimal. If she was dominant in period 2 with $p_2^L < p^*$, this is also true, because she expects firm H to exit. If she was dominant with $p_2^L > p^*$, L expects that H will enter and undercut in period 3, so that L will earn no profit in period 3, and she will pay the fixed cost of 300. However, in period 4, she will be the monopolist and earn the net profit 600. Thus staying is a best response.

Second, consider player H . Clearly, if L has exited, participation (as proposed

by the strategy) is optimal for H. If L is in in period 3, H participates only if L was dominant in period 2 with $p_2^L > p^*$. By staying if $p_2^L > p^*$, H earns positive net profits in period 3. She will exit thereafter, but participating in period 3 is nevertheless profitable. By not participating if $p_2^L \leq p^*$, she earns zero profits in periods 3 and 4. Given the strategy of player L , she cannot avoid this.

The argument in period 2 is analogous to the argument for period 3. The only slightly larger difference concerns the case that L is in and $0.8p_1^L \in (p^*, p^M(c_H)]$: In the proposed equilibrium, firm H undercuts L in period 2 and Firm L earns the monopoly profit in periods 3 and 4. L cannot undercut firm H in period 2; so it is best-responding. Firm H obtains the maximal possible profit in this period, $(0.8p_1^L - c_H) D(0.8p_1^L) - F$, but no profit in periods 3 and 4. The alternative would be to avoid undercutting L . However, then L would still remain in the market in period 3 given its strategy, and firm H would earn at most $(p^M(c_H) - c_H) D(p^M(c_H)) - F$ in period 3 (and no profit in period 4). The deviation is thus even less attractive than in the corresponding situation in period 3 for $0.8p_2^L \in (p^*, p^M(c_H)]$.

In period 1, the only pricing deviation for firm 1 worth considering is that it chooses the monopoly price. Doing this yields a short term gain of $650 - 620.23 = 29.77$, but a loss of the monopoly profit (650) in the next period. Thus, the proposed strategy profile is a subgame perfect equilibrium.

Uniqueness We already saw that we cannot hope for more than outcome uniqueness. Clearly, any SPE must involve the above-described behavior in period 4.

Consider period 3.

Suppose both firms are in and H was dominant in period 2.

First suppose $0.8p_2^H \in [0, p^*]$. Consider an arbitrary equilibrium price candidate $p_3^H \in (c_L, p^*]$. Then it is always the unique best response of firm L to undercut marginally: Given period 4 behavior, this yields the monopoly profit in period 4 and, given p_3^H , the maximum possible profit in period 3. Thus, any equilibrium with $p_3^H \in (c_L, p^*]$ must have $p_3^L = p_3^H$ and firm L taking the market. Moreover, any such equilibrium must have $p_3^H = \hat{c}_H$, for otherwise firm H could profitably deviate downwards. Clearly, there can be no equilibrium with $p_3^H > p^*$: In this case, firm H could profitably undercut whenever $p_3^L > 0.8p_2^H$. If $p_3^L \leq 0.8p_2^H$, firm

L could profitably deviate by increasing the price to p^* . Finally, equilibria with $p_3^H \leq c_L$ can clearly not exist. Thus, all equilibria must contain prices in period 3 as described in (ix)

Second suppose $0.8p_2^H > p^*$. Then it is clearly the unique best response for firm L to set $p_3^L = p^*$. As (ix) allows for arbitrary behavior of H that is consistent with the Edlin constraint, there can be no other equilibrium than those mentioned in (ix).

Suppose both firms are in and L was dominant in period 2.

Suppose $0.8p_2^L \in [0, c_H]$. There can be no equilibrium with $p_3^L > p^*$, as firm L would thereby giving up period 4 monopoly profits, which it could avoid by setting p^* (this deviation could potentially lower period 3 profits, but never by an amount that would not make it worthwhile).

There can be no equilibrium with $p_3^H > c_H$. If firm H wins in such an equilibrium and $p_3^H < p^*$, firm L could undercut and earn a positive profit in period 3 (and still the monopoly profit in period 4). Now suppose firm L wins in such an equilibrium. We already saw there can be no equilibrium such that $p_3^L > p^*$. Thus suppose $p_3^L \leq p^*$. Then H can increase profits by marginally undercutting. Clearly there can be no equilibrium with $p_3^H = p_3^L = p^*$.

There cannot be an equilibrium with $p_3^\theta \in [0, c_L]$ for at least one $\theta \in \{L, H\}$ either. As firm H would earn (avoidable) negative gross profits, there can be no equilibrium with $p_3^H \leq p_3^L$ and $p_3^H \in [c_L, c_H]$. There can be no equilibrium with $p_3^L < p_3^H$ and $p_3^H \leq p^*$, as firm L could increase profits by increasing price (while still inducing exit). Finally, consider $p_3^H \in [c_L, c_H]$ and $p_3^H > p_3^L$. Firm L could profitably increase prices.

If $p_3^H \leq p_3^L$, firm L could profitably undercut firm H . Thus, the only remaining possibility is $p_3^H = p_3^L = c_H$.

Suppose $0.8p_2^L \in (c_H, p^*]$. For any allowable $p_3^L \in [0.8p_2^L, p^*]$, firm H knows that it will earn zero profits in period 4 no matter what it does in period 3. Thus, it has the unique best response to undercut marginally, so that $p_3^H = p_3^L$. Clearly, there can be no such equilibrium with $p_3^L > 0.8p_2^L$, as both firms could profitably undercut. Thus, we must indeed have $p_3^L = p_3^H = 0.8p_2^L$. Next consider $p_3^L > p^*$. If $p_3^L < p_3^H$, firm L would become dominant in period 3 and thus give up the monopoly profit in period 4. It could thus profitably deviate to p^* . If $p_3^H < p_3^L$,

firm H would benefit from increasing its price slightly. If $p_3^H = p_3^L$, H would benefit from undercutting marginally. Finally suppose $p_3^L = p^*$ and $0.8p_2^L < p^*$. If $p_3^H < p_3^L$, firm H would benefit from increasing its price slightly. If $p_3^H \geq p_3^L$, H would benefit from undercutting.

Suppose $0.8p_2^L \in (p^*, p^M(c_H)]$. Given the restrictions of L, firm H can always undercut marginally and thereby secure a profit of $(p_3^L - c_H) D(p_3^L) - F$. This is always a best response: Not undercutting would mean that she would induce exit of firm L, so that she would earn the monopoly profit in period 4, but she would have to pay the fixed cost twice. By previous arguments, not undercutting is not a profitable deviation. Pricing lower than p_3^L would mean profit losses in period 3, without any compensating gains. Finally, an equilibrium with prices above $0.8p_2^L$ cannot exist: Firm H could always increase profits by reducing its price, without any compensating losses.

Suppose $0.8p_2^L \in (p^M(c_H), 80]$. As (viii) does not restrict the strategy of L beyond the Edlin restriction, we only check whether there can be another price of H than $p^M(c_H)$ in any equilibrium. For any price of L, this would have to lead at least to one monopoly profit of firm H (as H can always secure this by setting $p^M(c_H)$). Given the strategy of L in period 4, getting a gross monopoly profit in period 4 is only possible for H if it does not undercut L in period 3 who then cannot avoid that firm H enters in period 4. However, any such strategy of firm 3 means that it wins only one (gross) monopoly profit, but has to pay the fixed costs twice. As the alternative of winning the monopoly profit immediately and paying the fixed cost only once is always available (independent of the behavior of L), pricing above L in period 3 cannot be a best response.

A.3 Baumol

We start by presenting a version of Proposition 3 that specifies the strategies in more detail. We then prove the result.

A.3.1 Re-Statement of Proposition

Proposition 5. *The Baumol Game has a unique SPE described as follows:*

Periods $t = 3, 4$: If a firm θ is alone in the market after the other firm has

previously exited, and θ had a market share of one in the period that the other firm exited, θ sets p_θ^β . In any other situation such that θ is alone in the market, it sets $p^M(c_\theta)$. If both firms are in the market, they set $p_t^H = p_t^L = c_H$.

In the participation subgame, there is a unique subgame equilibrium such that only L participates unless (i) L has exited in period $s < t$ and or (ii) firm L was dominant in period $t-1$ and set $p_{t-1}^L < p_L^B$. In case (i), there is a unique subgame equilibrium such that only H participates (a) firm L exited before there was a duopoly or (b) L exited after a duopoly period in which $p_{s-1}^H \geq p_B^H$; if $p_{s-1}^H < p_B^H$ nobody participates. In case (ii), there is no pure-strategy SPE of the period 4 subgame. However, there is a unique equilibrium where both firms mix over participation decisions. In this equilibrium, both firms (obviously) earn zero profits.

Period 2: Everything is as in periods 3 and 4, except in the duopoly situation. Then there is a continuum of equilibria such that both firms set prices in $[c_H, \tilde{p}_2]$ such that

$$3(\tilde{p}_2 - c_L)(80 - \tilde{p}_2) = 2(p^M(c_L) - c_L)D(p^M(c_L))$$

and firm H undercuts in period 2. \tilde{p}_2 is approximately 32.679.

In the participation game, the only equilibrium is for L to participate and for H not to participate.

Period 1: L participates and sets the monopoly price.

A.3.2 Proof of Proposition

Period 4: The only non-trivial part of the argument is the participation subgame in the case that there was a duopoly in period 3 where firm L was dominant with $p_3^L < p_L^B$. In this case, it is straightforward to show that there can be no pure-strategy participation equilibrium:

If neither firm participates, H can profitably enter. If both firms participate, H earns negative profits. If only L participates, it earns negative profits (as it is forced to price below break even). If only H stays, L would benefit from staying (and undercutting).

However, there is a mixed strategy equilibrium (with zero expected profits) where firm H stays with probability $r = \left\{ \frac{(p_3^L - 20)(p_3^L - 80) + 300}{(p_3^L - 20)(p_3^L - 80) + 500} \right\}$ and firm L stays with probability $q = \frac{11}{25}$. As usual, this comes from the indifference conditions

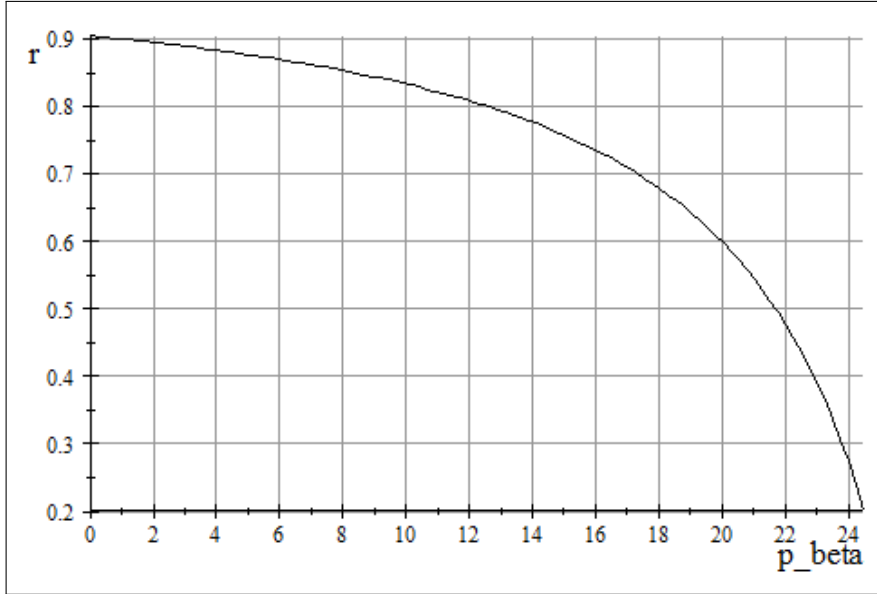
(between staying and exiting). For firm L this is

$$r((c_H - c_L)(80 - c_H)) + (1 - r)(p_3^L - c_L)(80 - p_3^L) - F = 0.$$

As Firm H earns the monopoly profit if it participates and L is not participating, indifference between staying and exiting requires

$$(1 - q)(p^M(c_H) - c_H)(80 - p^M(c_H)) - F = 0.$$

Together, these conditions give the above mixing probabilities. The function below plots r as a function of p_3^L : The lower the previous price was, the higher the required participation probability of firm H that makes L want to participate:



Period 3:

If a firm θ is alone in the market, because the other firm has previously exited and θ had a market share of one in the period that the other firm exited, θ sets p_θ^β .

It cannot set a higher price. A lower price will increase losses.

In any other situation such that θ is alone in the market, it sets $p^M(c_\theta)$.

This is obvious.

If both firms are in the market, they set $p_3^H = p_3^L = c_H$.

Firm H earns nothing, but cannot avoid this.

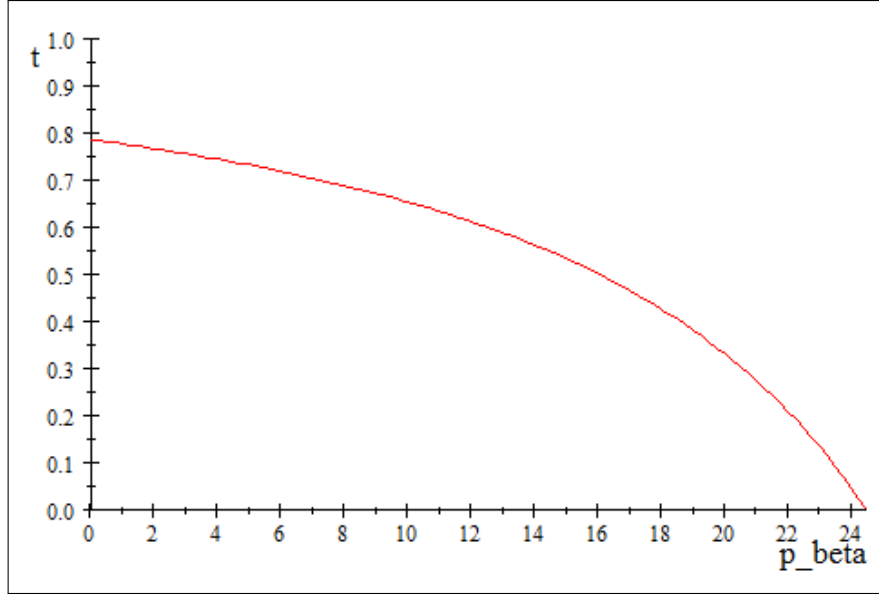
Firm L earns $2(c_H - c_L)(80 - c_H) - 2F = 400$ this way (because she takes the market today, she is Baumol constrained tomorrow). The only conceivable profitable deviation would be to let H win today. Then L could set the monopoly profit in period 4 and earn a total profit $(p^M(c_L) - c_L)D(p^M(c_L)) - 2F = 300$. This deviation is not profitable.

In the participation subgame, there is a unique subgame equilibrium such that only L participates unless (i) L has previously exited in period s and or (ii) firm L was dominant in period 2 with $p_2^L < p_L^B$. In case (i), there is a unique subgame equilibrium such that only H participates if $p_s^H \geq p_H^B$; otherwise nobody participates. In case (ii), there is no pure-strategy SPE of the period 3 subgame. However, there is an equilibrium where both firms mix over participation decisions. In this equilibrium, both firms earn zero profits.

This all straightforward except for the mixing equilibrium in participation decisions. Thus consider the case that L was dominant with $p_2^L < p_L^B$.

The argument for why there is no subgame equilibrium is essentially as in period 4: If neither firm participates, H can profitably enter. If both firms participate, H earns negative profits in period 3 (asymmetric Bertrand equilibrium); in the ensuing subgame in period 4 it earns zero on expectation. If only L participates, it earns negative profits (as it is forced to price below break even). If only H stays, L would benefit from staying (and undercutting); thereby earning positive profits in periods 3 and 4.

Let t be the staying probability of H in period 3. Indifference of firm L requires that $t = \frac{(p_2^L - 20)(p_2^L - 80) + 300}{(p_2^L - 20)(p_2^L - 80) + 700}$ (see the plot below)



To see this, suppose L stays. If H does not stay in period 3, firm L will make losses because of the Baumol constraint, and it will not be present in period 4 to avoid further losses. This gives a profit contribution $(1 - t) \left((p_2^L - 20) (80 - p_2^L) - F \right) < 0$. If H stays in period 3, firm L will earn $(c_H - c_L) (80 - c_H) - F$ in the asymmetric Bertrand equilibrium in period 3. Because $p_3^L = c_H > p_L^B$, firm H will exit and L will stay, but is constrained to set $p_4^L = c_H$. The expected profits from staying are thus

$$(1 - t) \left((p_2^L - 20) (80 - p_2^L) - F \right) + t (2 (c_H - c_L) (80 - c_H) - 2F).$$

Inserting parameters and setting this equal to zero gives the mixing probability.

If firm H stays, it earns positive profits only if firm L exits in Period 3. (If firm L stays, H will clearly not earn profits in period 3 and it will earn the zero expected MSE profits in period 4).

Let s be staying probability of L. If L does not stay, H wins the net monopoly profit in both periods. If L stays in period 3, H earns nothing in the resulting asymmetric Bertrand game. As L has then reverted to setting $p_3^L = c_H$ and hence above the Baumol price, H exits thereafter, thus earning a total net profit of -300 in periods 3 and 4. Thus the indifference condition is $(1 - s) (650) - s (300) = 0$,

yielding $s = \frac{13}{19}$.

Next consider period 2.

In this period, the Baumol constraint has no bite. Thus, any firm that is in the market is free to set its price without any constraints. However, in the duopoly case, the firms will be concerned about constraints that their pricing has on future prices in case of exit of the competitor.

In period 2, consider the suggested prices in $[c_H, \tilde{p}_2]$: Firm L leaves the market to firm H in period 2 (but pays the fixed cost) and then earns twice the monopoly profit in the remaining periods; thus total profits are $2(p^M(c_L) - c_L)(80 - p^M(c_L)) - 3F$. The only conceivable profitable deviation would be to underbid the competitor; which would then also mean L has to set the same price in the future. This would give profits of at most $3(\tilde{p}_2 - c_L)(80 - \tilde{p}_2) - 3F$. By construction of \tilde{p}_2 , firm L is indifferent between these two profits if $p = \tilde{p}_2$ because

$$3(\tilde{p}_2 - c_L)(80 - \tilde{p}_2) = 2(p^M(c_L) - 20)(80 - p^M(c_L)) = 1800$$

For any price equilibrium candidate p_2 in $[c_H, \tilde{p}_2)$, $3(p_2 - c_L)(80 - p_2) < 3(\tilde{p}_2 - c_L)(80 - \tilde{p}_2)$; firm L thus strictly prefers firm H to win.

Given that both firms set the same price and firm H wins the market with a positive gross profit, she cannot earn higher short-term profits. By avoiding to undercut, H would earn zero gross profits today. But this would not increase profits in the next period, as it would exit anyway (as any price in $[c_H, \tilde{p}_2]$ is above the break-even price of L, who will stay).

Period 1: By setting the monopoly price, L can guarantee itself four times the monopoly profit. Clearly this is optimal.

B Instructions

[Instructions for the Laissez-Faire treatment, translated from German. The parts that are different in the instructions for the Brooke, Edlin and Baumol treatments are reported in boxes]

General Instructions: We are pleased to welcome you to this economic study.

Please read the following instructions carefully. During this study, you have the opportunity to earn a fair amount of money in addition to the 5 Euros that you receive as an initial endowment for participating. The exact amount depends on your decisions and the decisions of the other participants. You remain anonymous during the entire study.

During the study, we do not speak of Euros but of points. Your entire income will first be calculated in points. The total amount of points you earn will be converted to Euros at the end of the study. The following conversion rate applies:

$$600 \text{ points} = 1 \text{ Euro}$$

To start with, you receive 1500 points to cover potential losses. At the end of today's session, you will receive your earnings from the study plus the initial endowment of 5 Euros in cash.

We will explain the exact procedure of the study in the next pages. These instructions are solely for private use, please do not communicate with the other participants during the study. If you have any questions, please contact the supervisors.

The Study: This study is divided into 7 separate rounds. In each round, you are paired with another participant selected at random from those present in the room. In each round, you are assigned one of two roles. Either you are firm A or firm B. If you are assigned the role of firm A, the other participant in your group is assigned the role of firm B and vice-versa. These roles are randomly allotted at the beginning of each round and remain unchanged throughout this round. Each round consists of four periods.

Firms A and B produce a homogenous good and sell this in the same market. In each period that your firm participates in the market, you have to set the price at which you want to sell the good. At the beginning of each period, if you currently participate in the market, you can decide to exit the market and, if you currently do not participate in the market you can decide to enter it for this period. If you decide to exit the market, you will not be able to enter it anymore for the entire round.

Firm A and firm B differ in two respects:

1. Firm A produces the good at a lower cost than firm B.
2. Firm A starts off in the market at the beginning of period 1 whereas firm B can enter the market only at the beginning of period 2.

The procedure in a particular round is as follows (see figure A1).

Period 1:

- (1) Firm A is alone in the market and sets a price (see (iii)).
- (2) The profit of firm A is realized. Both firms learn the price, the quantity sold and the profit of firm A (see (iv)).

Period 2 and all subsequent periods until the round ends:

- (1) Each firm that participates in the market decides whether to exit the market. Once a firm has exited the market, it cannot enter it anymore in this round. In each period in which firm B has not entered the market previously in this particular round, it decides whether to enter the market (see (i)).
- (2) Each firm learns the exit, respectively, entry decision of the other firm (see (ii)).
- (3) Each firm that participates in the market sets a price (see (iii)).
- (4) Profits are realized. Both firms learn prices, quantities sold and profits (see (iv)).

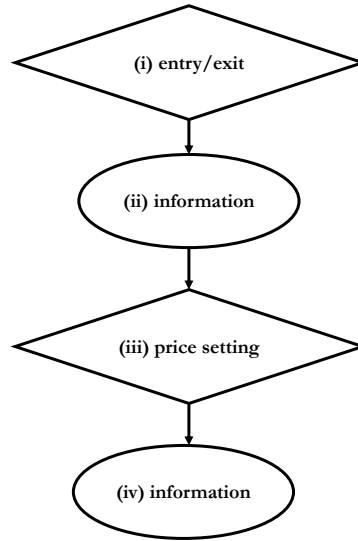


Figure A1: Sequence of Events

The profits are summed up across all periods in each round. After four periods a round ends, and a new round begins. For the new round, participants are newly paired, and the roles of firm A and B are randomly reassigned within these groups. In every round, you are informed only about the decisions of the other firm in your group. When a new round starts and you are matched with a new firm, neither of you will know anything about the decisions of the other firm in prior rounds.

Per-Period Profit: Your profit in each period depends on whether you participate in the market or not:

- (i) Each period in which you do not participate in the market, you earn a fixed amount of 50 points with certainty.
- (ii) Each period in which you participate in the market, the factors market demand, costs and price setting behavior determines your profit. How these factors determine your profit is explained below.

Market Demand: In each period, each firm that participates in the market has to decide which price to set. Both firms set their price at the same time. However, only the firm with the lower price can sell the good. If the lower price is P the

firm who sets this price sells Q units of the good. The quantity Q is determined as follows:

$$Q = 80 - P$$

Example: Suppose that you set a price of 70, and you are the firm with the lower price. In this case, you sell 10 units. However, if you are the firm that sets the higher price you do not sell anything. If both of you chose the same price then you both sell half of the quantity Q . For example, both set a price of 10 and share the resulting quantity (70) and sell 35 units each.

Costs: Each firm has two kinds of costs:

- (i) Each selling firm pays a unit cost of production. This cost is 20 per unit for firm A and 30 per unit for firm B.

Example: Suppose that you are firm A and sell 10 units. Your production cost is then $10 \times 20 = 200$. If you are firm B and you sell 10 units, your production cost is $10 \times 30 = 300$.

- (ii) For each period in which a firm participates in the market, it has to pay a fixed cost of 250. This cost is the same for firms A and B, and it is independent of production.

Example: Suppose that you participate in the market but do not sell anything. Hence, you make a revenue of zero and pay no unit cost of production. However, you have to pay the fixed cost, and, thus, you make a loss of 250.

Price Setting: Prices are integers in between 0 and 80. You can choose any price in this range.

Price Setting BROOKE:

In certain situations, however, not the entire price range between 0 and 80 is available. The graph below illustrates these situations. The upper part of the graph corresponds to the market situation in an arbitrary period t . Three situations are to be distinguished:

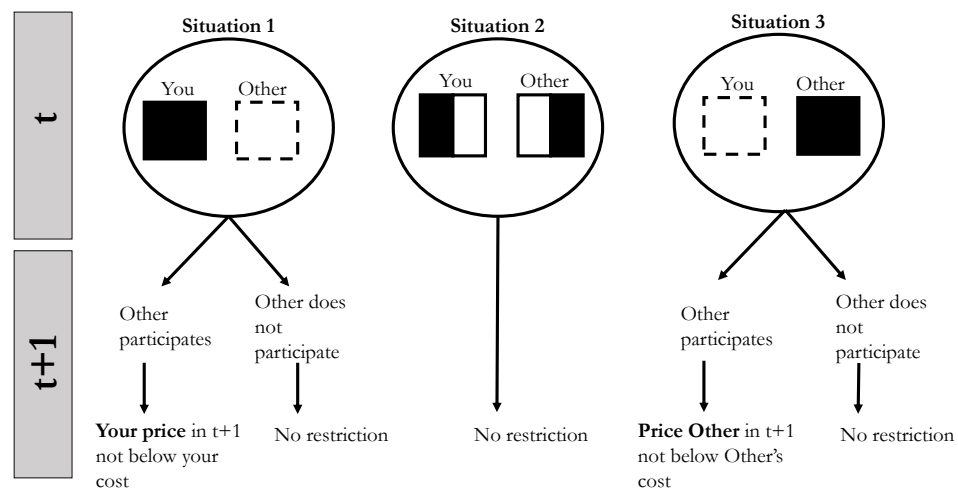
- In Situation 1, only you sell the good (black box) in period t while the other firm does not sell anything (white box). The reason why the other firm does not sell anything in period t may be twofold (dashed line):
 1. The other firm does not participate in the market in period t or
 2. The other firm set a higher price than you did in period t .

If now the other firm participates in the market in the next period $t + 1$ you are not allowed to set a price in period $t + 1$ that is below your own unit cost of production. No restriction applies to the other firm. If the other firm does not participate in the market in period $t + 1$ no restriction applies to you.

Example: Suppose that your unit cost of production is 20 and that, currently, only you sell 10 units at a price of 70. If the other firm participates in the market in the next period, you are not allowed to set a price in the next period that is below 20. The other firm can set any price between 0 and 80.

- In Situation 2, both you and the other firm set the same price in period t and thus, both sell half of the total quantity each. In the next period $t + 1$, neither you nor the other firm are restricted in their price setting.
- In Situation 3, only the other firm sells the good in period t . You do not sell anything because, either you do not participate in the market in period t or you set a higher price than the other firm did. If now the other firm participates in the market in the next period $t + 1$, it is not allowed to set a price in period $t + 1$ that is below its own unit cost of production. If it does not participate in the market, it cannot set any price. In period $t + 1$, no restriction applies to you.

Price Setting BROOKE:



In a nutshell, the following rule applies: the firm that sells the good in t , must not set a price in $t + 1$ that is below its own unit cost of production if the other firm participates in the market in $t + 1$.

Price Setting EDLIN:

In certain situations, however, not the entire price range between 0 and 80 is available. The graph below illustrates these situations. The upper part of the graph corresponds to the market situation in an arbitrary period t . Three situations are to be distinguished:

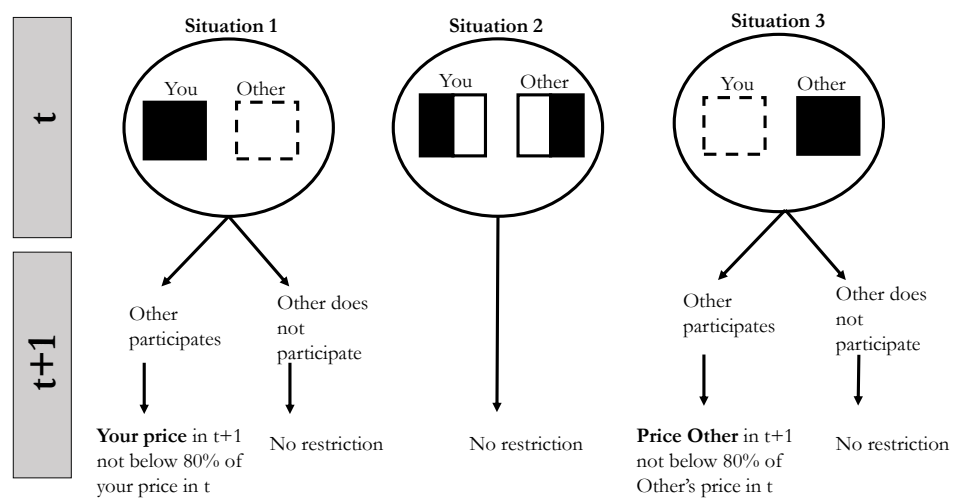
- In Situation 1, only you sell the good (black box) in period t while the other firm does not sell anything (white box). The reason why the other firm does not sell anything in period t may be twofold (dashed line):
 1. The other firm does not participate in the market in period t or
 2. The other firm set a higher price than you did in period t .

If now the other firm participates in the market in the next period $t+1$ you are not allowed to set a price in period $t+1$ that is below 80% of your price in period t (rounded to integers). No restriction applies to the other firm.

Example: Suppose that, currently, only you sell 10 units at a price of 70. If the other firm participates in the market in the next period, you are not allowed to set a price in the next period that is below 56 ($= 0.8 \times 70$) (see supplementary sheet). The other firm can set any price between 0 and 80.

- In Situation 2, both you and the other firm set the same price in period t and thus, both sell half of the total quantity each. In the next period $t+1$, neither you nor the other firm are restricted in their price setting.
- In Situation 3, only the other firm sells the good in period t . You do not sell anything because, either you do not participate in the market in period t or you set a higher price than the other firm did. If now the other firm participates in the market in the next period $t+1$, it is not allowed to set a price in period $t+1$ that is below 80% of its price in period t . In period $t+1$, no restriction applies to you.

Price Setting EDLIN:



In a nutshell, the following rule applies: the firm that sells the good in t , must not set a price in $t + 1$ that is below 80% of its price in t (rounded to integers) if the other firm participates in the market in $t + 1$.

Price Setting BAUMOL:

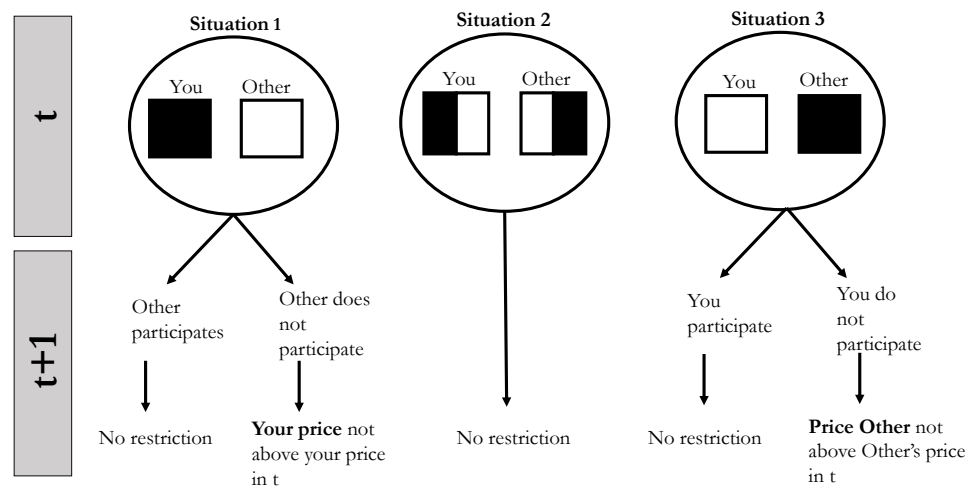
In certain situations, however, not the entire price range between 0 and 80 is available. The graph below illustrates these situations. The upper part of the graph corresponds to the market situation in an arbitrary period t . Three situations are to be distinguished:

- In Situation 1, both you and the other firm participate in the market but only you sell the good in period t ; the other firm sells nothing. If now the other firm exits the market and thus does not participate in the market in the next period $t + 1$, you are not allowed to increase your price in $t + 1$ and in all subsequent periods in this round. If the other firm participates in the market in the next period $t + 1$ no restriction applies to you or the other firm.

Example: Suppose that, currently, both participate in the market, but that you are the one who set the lower price, say, 70. In the current period, only you sell the good, namely, 10 units. If the other firm exits the market in the next period you are not allowed to increase your price above 70 in the next and all subsequent periods in this round.

- In Situation 2, both you and the other firm set the same price in period t and thus, both sell half of the total quantity each. In the next period $t + 1$, neither you nor the other firm are restricted in their price setting.
- In Situation 3, both you and the other firm participate in the market but only the other firm sells the good in period t ; you sell nothing. If now you exit the market and thus do not participate in the market in the next period $t + 1$, the other firm is not allowed to increase its price in $t + 1$ and in all subsequent periods in this round. If you participate in the market in the next period $t + 1$ no restriction applies to you or the other firm.

Price Setting BAUMOL



In a nutshell, the following rule applies: the firm that sells the good in t , must not increase its price in $t + 1$ and until the end of this round if the other firm exits the market in $t + 1$.

Calculation of Per-Period Profit: The per-period profit is calculated as follows: each firm makes a revenue which equals price times units sold ($P \times Q$). Subtracting the total cost incurred, that is, the sum of the production cost and the fixed cost, gives the per-period profit.

Example: Suppose that you currently sell 10 units at a price of 70. With the cost of firm A, the profit yield is $70 \times 10 - 10 \times 20 - 250$, that is, 250. With the cost of firm B, the profit yield is $70 \times 10 - 10 \times 30 - 250$, that is, 150.

Procedure: In each period, each firm that participates in the market sees the input screen. In period 1, this screen appears only for firm A. Firm A thus sees the following input screen:

Remaining time [sec]: 26	
Round 1 of 4	Period 1
What-if calculator	Firm A: Choose your price
<div style="display: flex; justify-content: space-around;"> Your price Your profit </div>	Your costs per unit: 25
Your price <input style="width: 100px;" type="text"/>	Your price <input style="width: 100px;" type="text"/>
<input type="button" value="erase table"/> <input type="button" value="calculate"/>	<input type="button" value="OK"/>

The upper part of the screen shows the round in which you are in on the left; in this example, it is round 1 of 7. On the right, you see a time specification in seconds which indicates how much time you have left to enter your price. Please try to reach your decision in the given time. Below the time indication, you see in which period you are in. In this example, it is period 1. The remaining part of the screen is divided into two sections. On the left, you can see the “What-if-calculator”. You can use this tool to determine your per-period profit using different prices. On the right, the screen reminds you of your unit cost of production; in this example, 20 is shown as a value. Below the cost information, you can enter the price you want to set in this period. In order to confirm a price, you must click on the “OK” button. You can revise your price until you click on this button. Once you have done this, you can no longer revise your decision for this period.

Notice that the layout of this screen as well as the “What-if-calculator” adapts to the situation, namely, whether only one or both firms are in the market. In particular, when both firms participate in the market, the input screen appears as follows:

Round 1 of 4				Period 2	
What-if calculator				Firm B: Choose your price	
Your price	Price other firm	Your profit	Profit other firm	The other firm is also in the market Your costs per unit: 35 Per unit costs of the other firm: 25	
Your price		<input type="text"/>		Your price <input type="text"/>	
Price other firm		<input type="text"/>			
<button>erase table</button>		<button>calculate</button>		<button>OK</button>	

Here, in the example, you see the input screen of firm B in period 2 of round 1. The left part of the screen shows again the “What-if-calculator”. Now you can calculate your profit as a combination of your price and the price of the other firm. On the right, you can see, in addition to your unit production cost, the unit production cost of the other firm as well as whether this firm participates in the market.

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If either your or the other firm’s price range is restricted, it is always indicated on this input screen below the cost information. If none of the price ranges is restricted in any way, nothing is indicated. In this example, neither your nor the other firm’s price range is restricted: You can both set any price between 0 and 80.

After both firms have entered their price, it will be determined who serves the market. Both firms will be informed on the prices, quantities and profits in this period. Note that you can also incur losses.

Remaining time [sec]: 56		
Round 1 of 4		Period 2
Firm A: Result period 2		
	You (Firm A)	Other (Firm B)
In market	Yes	Yes
Price	46	50
Quantity	54	0
Revenue	2484	0
Costs	$1350 + 20$	$0 + 20 + 25$
Profit	1114	-45
Your total profit in this round (all periods)		2444
<div>continue</div>		

Once you have read this information, please click on the “Continue” button. In each period (other than period 1), prior to the price setting decision, each firm that currently participates in the market has to decide whether to exit the market for this and all subsequent periods in this particular round. Once a firm has exited the market, it cannot enter it anymore in this round.

Remaining time [sec]: 7			
Round 1 of 4		Period 2	
What-if calculator		Firm A: Market exit for the next period	
Your price	Price other firm	Your profit	Profit other firm
<div> <div> <div></div> <div></div> </div> <div> <div></div> <div></div> </div> </div>			
Your price		<div></div>	
Price other firm		<div></div>	
<div>erase table</div>		<div>calculate</div>	
		Do you want to exit the market? <div>remain</div> <div>exit</div>	

In each period (other than period 1) in which firm B has not entered the market previously in this particular round, firm B has to decide whether to enter the market for this period. Only if firm B enters the market, it can set a price. Below the cost information, the screen reminds firm B of the price that firm A set in the previous period.

Remaining time [sec]: 17			
Round 1 of 4		Period 2	
What-if calculator		Firm B: Market entry for the next period	
Your price	Price other firm	Your profit	Profit other firm
		Your costs per unit: 35 Per unit costs of the other firm: 25	
Your price <input type="text"/> Price other firm <input type="text"/>		Do you want to enter the market for next period?	
<input type="button" value="erase table"/> <input type="button" value="calculate"/>		<input type="button" value="enter"/> <input type="button" value="not enter"/>	

Each firm learns the exit, respectively, entry decision of the other firm. Each firm that participates in the market in this period then goes on to price setting via the input screen as it is explained above. Each firm that does not participate in the market in this period can set no price and will be informed on the price, quantity sold and potential profits at the end of this period.

Do you have any further questions? If so, please raise your hand. The supervisors will come to you at your workplace. Otherwise, we kindly ask you to answer the control questions on your screen.