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Alles I.O.? Adverse Effects of Recent Policy Measures from an Industrial Organization Perspective

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Preface

This dissertation consists of three loosely related essays resident in the industrial organization literature. All three analyze recent policies, namely, a prohibition of disposal, a reduction in fine for convicted cartelists, and the recent loose monetary policy. I study how these policies affect firms' strategies and their consequences for consumers. The structure follows the timeline of the policies' adoption.

In the first chapter, I study the *loi anti-gaspillage* (anti-waste law) recently debated in France, expected to come into effect in 2023. According to a government estimate, each year new products worth \$900 million are discarded all over France. The policy aims at mitigating the waste of resources: unsold products have to be donated or recycled, and it is prohibited to dispose of them in one way or another.

The less firms dispose of, the more products are on the market and prices are lower, thereby benefiting consumers. However, firms do not intentionally manufacture products to discard them: disposal typically results from a lower than expected demand. By forcing firms to recycle or donate their produced goods, firms' disposal costs increase; otherwise, cost minimizing firms would have already donated or recycled their products without the regulation. With higher costs for unsold products, firms reduce their production, resulting in a lower trade volume.

Moreover, the policy may affect the production timing on top of quantities produced. Firms may outsource their production for cost reasons. Goods produced abroad have to be transported to the home market and therefore require to be produced earlier.

Take, for example, the fashion industry: The biggest players on the European market are Hennes & Mauriz (H&M) and Inditex, which holds Zara, Pull&Bear, Massimo Dutti, and more. H&M mainly produces in Asia and ships its products to the European market; Inditex largely manufactures in Europe, close to the market. It claims that within two weeks of the original design clothes are in retail. Merely the shipment from Asia to Europe takes more time. In the fast fashion industry, multiple products are introduced on a weekly basis. Accordingly, H&M produces earlier to compete with Inditex.

As a consequence, firms that produce later to manufacture with more information benefit from the policy. Their competitors decrease their production to mitigate costs if demand is lower than expected, resulting in a competitive advantage for the former. Depending on disposal costs, firms postpone their production leading to a change in the market structure.

In general, the policy accomplishes to decrease disposal, yet at the consumers' cost.

In the second chapter with Winand Emons, we analyze a policy encouraging private settlement negotiation following anti-competitive convictions. Victims of an anti-competitive infringement may claim for damages. Private damage actions enforce antitrust rules in addition to the public enforcement by competition authorities. They are, however, rare in Europe compared to the US. To encourage private damage action, the EU recommends subtracting a part of the redress paid to the victim from the fine.

Some jurisdictions have followed this recommendation. In 2014, the Israeli Antitrust Tribunal approved a consent decree reached between Israeli banks and the Israeli Antitrust Authority to subtract the entire settlement payment from the wrongdoers' fine. Likewise, the Swiss Competition Commission subtracted half of the bid-rigging construction companies' settlement payment to the victim, the canton of Graubünden, from the wrongdoers' fines in 2019.

The rebate has two effects. First, the surplus created by an out of court agreement goes up. Second, the defendant's marginal costs decrease: for each unit the plaintiff receives the defendant only pays a share of it. Since negotiations are voluntary, both parties get a share of the surplus. The first effect thus benefits the plaintiff and the defendant. The second affects the defendant's bargaining behavior: the defendant settles for larger amounts. In our framework, the first effect dominates the second resulting in a lower payment for the defendant.

A leniency program is the most important investigative tool for detecting cartel activity. The leniency applicant does not pay a fine. Consequently, there is no fine that can be reduced; the measure does not affect a leniency applicant. However, it decreases the other cartelists' payment, thereby reducing the relative advantage of blowing the whistle. Overall, a leniency program may be weakened due to this policy.

Cartelists typically know the damage caused by their illegal activity better than consumers. Consequently, a defendant has an information advantage compared to the plaintiff when it comes to a trial. We study the case when the plaintiff has all the bargaining power yet an information disadvantage.

Due to the information asymmetry, some cases end up in court, although this is inefficient. Rebating part of the fine decreases the number of cases resulting in a ruling and thereby relieves courts. Nonetheless, the defendant's expected payment decreases due to the redress.

The policy accomplishes an increase in the settlement amount, thereby benefiting victims of anti-competitive conducts, yet it also lowers deterrence. Consumers may therefore suffer from augmented anti-competitive manner.

In the third chapter, I study how the current monetary policy affects firms' collusive behavior. Low interest rates mark the last decade: as a reaction to the financial crisis, central banks worldwide lowered the nominal interest rate to boost the economy. The real interest rate peaked around 2009 and has declined since. Nowadays, with the additional challenge of a pandemic, central banks are expected to continue their loose monetary policy.

It is well known that the interest rate determines the time value of money. When interest rates are low, a dollar today has almost the same value as a dollar tomorrow; future values are little discounted.

Colluding firms set higher prices than if they competed to make additional profits to the detriment of consumers. A cartelist could, however, deviate from the collusive agreement: by undercutting the price, the deviating firm could capture a large market share and ensure an even higher profit. Yet, when a cartelist undercuts the collusive price, the cartel breaks down. After a firm's deviation, firms no longer collude and start competing, resulting in lower future profits. Consequently, if interest rates are low, a large immediate profit does not outweigh constant high future profits, and cartels are stabilized.

In my framework, an additional effect comes into play. Typically, firms finance their production with outside capital borrowed on the financial market. The interest rate thereby directly affects a firm's balance sheet: the higher the interest rate, the higher the firm's costs. If costs are high, it is not profitable to serve a large market share. Thus, it does not pay to undercut the cartel price to increase demand. By contrast, if interest rates are low and thus costs are low, firms can inexpensively invest in their production. They have the financial means to serve large parts of the market. Thus, deviating from the collusive agreement is more profitable. Accordingly, cartels are destabilized if interest rates are low.

While the former effect facilitates cartel formation in times of low interest rates, the latter fosters break-ups. The time value of money is most affected by low interest rates: it is doubled if the interest rate moves from 1% to 2%, yet less than doubled if it increases from 2% to 3%. By contrast, the latter effect is small for low interest rates. The cost increase cause firms to serve fewer customers. The lost consumers are, however, the ones with the lowest willingness to pay, i.e., the least valuable customers. Accordingly, for a low interest rate the first effect dominates, and for a relatively high interest rate, the second effect dominates, resulting in a U-shaped relation between a cartel's stability and the interest rate.

Analyzing a dataset of 615 firms active in 114 cartels convicted by the European Commission yields empirical evidence supporting the theory. Cartels are stable if interest rates are low or relatively high and are vulnerable for intermediate values. More precisely, stability is measured as the probability that a cartel does not break-up or, alternatively, as the duration of a firm's participation in the cartel. The empirical evidence has to be treated with caution since only convicted cartels are in the dataset resulting in a biased sample.

The current loose monetary policy is, thus, accompanied by the adverse effect of stabilizing existing cartels and encouraging new ones' formations.

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Chapter 1

Imperfect Competition with Costly Disposal

Abstract

This chapter studies the disposal costs' effect on consumer surplus and firms' profits. The costlier disposal, the less is disposed of, firms' competition for market shares increases, thereby benefiting consumers. Yet firms decrease their production to mitigate costs, affecting consumer surplus negatively. We present a model with ex ante homogeneous firms producing inventories either early at low cost and with little information about demand, or later with more information yet at higher costs. Unsold products are disposed of. In equilibrium, firms may be asymmetric. Disposal goes down with costs but so do inventories. In our set-up, the negative effect on the trade volume dominates decreasing consumer surplus and firms' profits. We show, however, that low disposal costs substitute information about demand. Increasing disposal costs improve a firm's information advantage and may increase its profits.

1.1 Introduction

A wide variety of commodities is produced in advance. Firms manufacture their products anticipating future demand, determining inventories while their product's popularity is unknown. Accordingly, production costs are sunk when products are put for sale. If demand turns out to be lower than expected, firms may hold back some quantity to increase the market price.

This behavior has been increasingly observed over the last years. Investigative journalists have uncovered several cases where firms have discarded new, unsold products. One of the most infamous scandals was uncovered in 2010 by the New York Times. A Hennes and Mauritz (H&M) store in New York City discarded new clothes at their back entrance, cutting them to make sure they will never be worn. The same course of action was used by a Nike store in 2017. In reaction to the negative headlines, firms usually pledge improvement, yet disposing of unsold products is an open secret in the fashion industry.[1]

Discarding new products is not confined to the apparel industry. French Amazon dumped almost 3 million unsold products in 2018. All over France, new products worth $900 million are discarded each year according to an estimate by the government.[2] The disposal of unused products is considered as a waste of resources and an environmental burden, which led the French government to legislate.

In 2016 France already passed a law prohibiting grocery stores from disposing of food as long as it is still edible. With the new *loi anti-gaspillage* (anti-waste law), regulators broaden the prohibition of disposal to non-food products, including textiles, electronics, and daily hygiene products. Unsold products must be donated or recycled.[3] The new regulation is expected to come into effect in 2023.

This chapter studies how firms respond to a regulatory increase in their disposal costs and the effects on consumer surplus. The literature on this subject is scarce.[4] Environmental economists usually discuss policies to reduce waste and increase recycling.[5] The focus is usually on the failure of the first welfare theorem resulting from externalities. Instead of looking at an efficient mechanism to reduce disposal, we focus on the costly disposal's effect in a market with imperfect competition, thereby abstracting from externalities.

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[1] Not all firms keep it a secret. Burberry literally burnt almost $40 million of stock in 2018. The fashion brand reported the deed in their annual report and specified that the energy was used to make the process environmentally friendly.

[2] https://www.nytimes.com/2019/06/05/world/europe/france-unsold-products.html (last accessed September 30, 2020).

[3] Projet de loi relatif à la lutte contre le gaspillage et à l'économie circulaire (TREP1902395L).

[4] The literature on operation research considers the costs of unsold products for the inventory's optimization. Choosing the optimal inventory is known as the newsvendor problem, e.g., Rosenfield (1989) or van der Laan and Salomon (1997).

[5] For example, Dinan (1993) argues that taxing disposal instead of a virgin tax can increase efficiency in newspaper markets. In his model, disposing of newspapers creates a cost, which is internalized by taxing total output. A virgin tax, however, only leads to the substitution of input factors, i.e., firms use recycled old newspapers instead of virgin material.

The larger disposal costs are, the less firms dispose of. Thus, given its inventory, a firm competes more aggressively for a larger market share if disposal is costly, thereby benefiting consumers. However, firms adjust their inventory strategy in response to costly disposal. They decrease their inventories to mitigate costs if demand is lower than expected. Disposal decreases, yet consumers are negatively affected. Firms, furthermore, may adjust their location choice if disposal costs increase leading to a change in the market structure.

In our model, firms first choose their manufacturing location, which determines their production timing. They produce their commodities either abroad at low costs and with little information about demand, or at home close to the market with more information yet at higher costs. If demand is lower than expected, firms can hold back quantities to increase the market price. Restrained or unsold products are not perfectly reversible; firms may even incur a per-unit cost to dispose of commodities. Each unsold unit is, therefore, not only a loss in revenue, it also increases costs.

There exist three different types of equilibria in pure strategies: (i) If demand is highly uncertain, both firms produce close to the market. They delay their production until they have full information. Consequently, firms dispose of nothing, and an increase in disposal costs has no effect. (ii) If demand is reasonably predictable, both firms produce abroad at low costs. An increase in disposal costs decreases the expected disposal yet also expected consumer surplus and firms' expected profits.

(iii) For intermediate levels of demand uncertainty, one firm produces abroad, while the other one close to the market. The firm abroad manufactures at lower costs, yet the firm close to the market has an information advantage. The higher disposal costs are, the lower is the expected disposal. Consumer surplus, however, is also lower. The abroad firm's expected profits decrease, while the other one's increase. The information advantage is more valuable, the higher disposal costs. At some point, the abroad firm may postpone its production closer to the market, too. Due to the change in the market structure, profits and consumer surplus may change discontinuously.

The subgame perfect equilibrium in pure strategies is unique, except for type (iii), where an equivalent equilibrium exists with the firms' label interchanged. Although firms are ex ante symmetric, they may choose an asymmetric market structure. The ordering of firms' profits is ambiguous: The firm abroad has a cost advantage, while the other an information advantage. The former's reaction to a demand below expectations is expensive if disposal costs are high. Due to this costly reaction to new information, the latter's information advantage is more valuable if disposal is expensive.

By contrast, without disposal costs, the firm producing abroad does not incur additional costs. Any reaction to new information comes for free. Low disposal costs substitute information about demand. To be more specific, take the example of a monopolist. If demand realization is known, the firm produces the monopoly quantity. Now suppose demand is uncertain, yet the firm's inventory is perfectly reversible, i.e., disposal costs are zero. The monopoly produces its inventory equal to the monopoly quantity for the greatest possible demand. If a lower demand materializes, the monopolist reverses parts of its inventory and sells again the monopoly quantity, equivalent as if the firm had known its demand. Information about demand is, therefore, more valuable if disposal is costly.

In our set-up, a regulatory increase in disposal costs fulfills its purpose to decrease expected disposal. Yet, consumers are generally worse off. Although competition for market shares increase, firms decrease their production and thereby the trade volume. We extend our model to test the robustness of the negative effect's domination over the positive competitive effect. First, we allow firms to produce in both locations. Firms manufacture first their inventory at low costs while demand is uncertain. Both firms can then react to new information about demand either by disposing of or producing additional quantities. In the unique, symmetric equilibrium, the disposed of amount decreases. Yet consumer surplus and firms' profits also decrease.[6]

Second, we study the same model when firms observe their competitor's quantity. Companies announce their targeted sales to inform investors. These targets are publicly announced. Thus, competitors may not directly observe the inventory but can infer its size. If inventories are observed, there may exist additional asymmetric equilibria. Extensive stocks send the message of large intended sales. The firm with a larger inventory can only credibly commit to selling large parts if disposal is costly. This effect benefits the larger firm. However, costly disposal increases the costs to adjust to demand below expectations. Due to the two opposing effects, the larger firm's expected profits are ambiguous, precisely, U-shaped in disposal costs. The smaller firm produces mainly after the demand's realization. Its information advantage becomes more valuable with costly disposal, resulting in higher expected profits. Consequently, both firms' profits may increase in disposal costs, yet consumer surplus decreases.

Furthermore, we discuss different forms of competition, namely, perfect competition and price competition. In general, a regulatory increase in dis-

[6]In the supplementary materials, we study an extension to $N \geq 2$ firms - consumer surplus increases in the number of firms, yet the disposal, too. Competition increases at the cost of a larger number of disposers. Policymakers concerned about the disposed of amount face a trade-off between competition and the disposed of amount.

posal costs decreases the disposed of amount. Yet the expected trade volume decreases, thereby putting consumers in a worse position.

Related Literature. The literature on inventory is closely linked to the capacity literature. Technically, firms first choose an upper bound of their next stage's sales volume. In a capacity game, firms have to incur additional costs in the second stage, while production costs are sunk in an inventory game. Whenever the costs in the second stage are normalized to zero, the games are therefore formally equivalent. In their seminal paper, Kreps and Scheinkman (1983) show that capacity choice followed by price competition yields an outcome equivalent to the Cournot outcome.

Their result depends on the rationing rule (see, e.g., Davidson and Deneckere (1986)), furthermore a pure strategy equilibrium may not exist if uncertainty is introduced (e.g. Hviid (1991) or Reynolds and Wilson (2000)). Nonetheless, Young (2010) confirms the Cournot equivalence with a multiplicative demand shock and relatively high capacity costs. He avoids a rationing rule by introducing product differentiation. A recent paper by Montez and Schutz (2018) studies a similar game, in which firms can not observe their competitor's inventory and price. Firms' may hold back some of their inventories, which are at most partly reversible.[7] When production costs tend to full reversibility, the outcome ends to Bertrand competition. Conclusively, the inventories' observability determines the difference between the Cournot and Bertrand outcome.

None of the previous papers allow for additional costs to discard unsold products. By contrast, Saloner (1986) provides in his seminal paper a model allowing for additional costs to dispose of. Inventory is not fully reversible, and firms may even incur additional costs for unsold products. First, firms choose (simultaneously or sequentially)[8] their inventory, which is observed by their competitor and later compete in sales volume. Since there is no demand uncertainty, in the end, firms dispose of nothing. The higher the disposal costs, the more credible it is for a firm to dispose of nothing. Inventories indicate, therefore, intended sales. We rule out this effect by assuming that inventories are unobserved by the competitors. However, we relax our assumption in an extension.[9]

[7] Pashigian (1988) showed that clearance sale prices are below marginal costs in the apparel industry, presenting empirical evidence for the imperfect reversibility.

[8] Maggi (1996) studies a reduced form model with demand uncertainty, which predicts a sequential outcome in pure strategies. By contrast, Pal (1993) studies the Saloner model with mixed strategies and argues that the sequential outcome is just a realization of a symmetric equilibrium in mixed strategies.

[9] Recently, different effects of inventory have been studied in the literature. Antoniou and Fiocco (2019) analyze the inventory's impact on future prices to prevent stockpiling of

Mitraille and Moreaux (2013) study a two-period model where firms can manufacture in each period. Storing is costly and observed by the competitors. The stored commodities' production costs are sunk, resulting in zero effective marginal costs. When firms compete in the second stage, firms with storage have thus a cost advantage.[10] Firms seek leadership at the cost of storing the commodity. Sales volume increases resulting in a lower market price if firms can store.

By contrast, Thille (2006) finds in an infinitely repeated game that storage does not affect prices in the absence of depreciation. With depreciation, firms incur higher costs to maintain their stock of inventory, resulting in lower sales are higher market prices.

We do not explicitly model storage costs. In our set-up, storing costs would decrease the cost advantage of early production. Since inventories are not observable and demand is uncertain, firms postpone their production. Similar to the latter, sales go down and the price increases.

Dada and van Mieghem (1999) also study production timing. A monopolist chooses inventory, sales volume, and prices, either before or after demand realization. The monopolist restrains some products to affect the market clearing price. Anupindi and Jiang (2008) extend the model to a three-stage version with competing firms, whereby firms invest in capacity before demand materializes. Flexible firms produce after the demand realization, while inflexible firms produce ex ante. Firms trade-off the value of commitment to flexible production. None of these papers studies costly disposal nor competition with unobserved inventories.

We follow Hamilton and Slutsky (1990) and have a pre-game stage where firms choose their production timing without committing to quantities. By contrast, Liu (2005) and Wang and Xu (2007) study a sequential move game where demand uncertainty decreases over time. In their set-up, the firm producing in the second stage makes higher profits if its information advantage is large. However, the authors implicitly assume infinitely high disposal costs. If the other firm can adjust its sales volume to the demand realization, their result remains only partly. We show that low disposal costs substitute information about demand.

In our set-up, ex ante symmetric firms may choose different strategies, as in Robson (1990). According to van Damme and Hurkens (1999), a sequential equilibrium is only stable if the first mover has a cost advantage. This is

consumers. Similar to Mitraille and Thille (2014), who study the presence of speculators: demand may be higher, but later competition increases due to the resellers. Dana and Williams (2019) and Qu et al. (2018) discuss the effect of inventory on intertemporal price discrimination.

[10]Technically, a disposal cost is a negative production cost expanding the cost advantage.

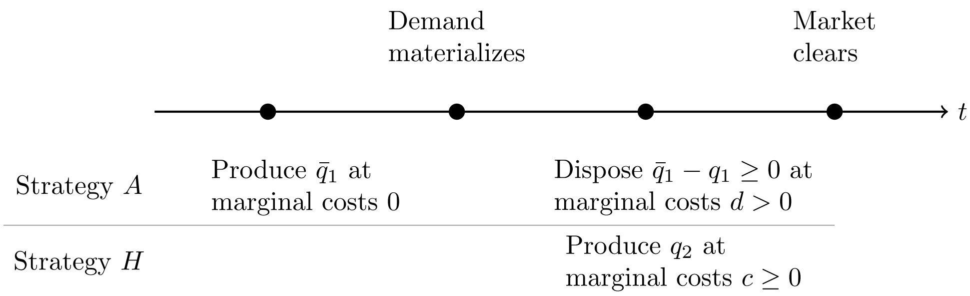


Figure 1.1: Timeline and production strategies.

also a necessary condition in our model. Additionally, we require a follower's information advantage and no free disposal for the existence of an asymmetric equilibrium.

The rest of the chapter is structured as follows. The next section presents the model. We derive the equilibrium in section 1.3. Section 1.4 extends the model to multiple manufacturing locations. Furthermore, we discuss the effect of observable inventories; a formal analysis is contained in the supplementary materials. Finally, we discuss other forms of competition. Section 1.5 concludes. All proofs are relegated to the appendix.

1.2 Model

Two firms produce a homogeneous commodity. Demand is linear. The inverse demand function's slope is random, reflecting an unknown number of identical consumers. Formally, let the inverse demand function in state $s \in \{l, h\}$ be $P_s(Q) = a - b_s Q$, where Q is the total sales volume. The intercept $a > 0$ denotes the maximal willingness to pay and is commonly known. The slope b_s takes on one of two values, $b_l = 1 + \beta$ or $b_h = 1 - \beta$, each with equal probability. The difference between the two is measured by $\beta \in [0, 1)$, which we refer to as demand uncertainty. If b_h materializes, the willingness to pay is higher for any quantity. Therefore, we refer to b_h (b_l) as the high (low) demand state. With this set-up, the expected inverse demand function is independent of β.[11]

[11]Commonly, demand uncertainty is modeled with a linear demand curve and a random intercept (e.g. Gilpatric and Li (2015) or a random slope (e.g. Daughety and Reinganum (1994) or Malueg and Tsutsui (1996)). In Klemperer and Meyer (1986), firms facing a random slope prefer to fix quantities and let prices adjust depending on the demand realization. In our model, firms also prefer to fix quantities and let prices adjust if disposal costs are high.

First, firms choose their location, determining their timing of production. They either produce the quantity $\bar{q}_1$ in the first period at marginal costs normalized to zero or postpone their production until the demand has materialized and manufacture $q_{2,s}$ at marginal costs $c \in [0, a/2]$. Producing at an early stage is less expensive, e.g., firms have time to adjust processes to substitute input factors. Firms can off-shore their production to decrease their costs. However, products manufactured abroad need to be shipped to the home market. Production, therefore, has to precede in time. Firms trade-off costs and uncertainty: producing at a lower cost with less information or defer the manufacturing until more information is available, yet production is more expensive.

We denote the strategy to produce (abroad) before the demand materializes by A and the strategy to produce in the second stage by H (home). If a firm chooses strategy A, it can hold back its goods after the demand has materialized. Let a firm's sales volume be $q_{1,s}$, thus $\bar{q}_1 - q_{1,s}$ is the quantity held back. We denote its marginal cost as $d > 0$, reflecting costs to dispose of products.[12] We restrict parameters such that the consumers' willingness to pay is relatively large, formally $a \geq 2c + d$. This assumption guarantees that both firms are active in equilibrium. Figure 1.1 summarizes the timing strategies.[13]

Henceforth, we suppress the state index s for quantities. Formally, the two strategies' expected profits are

$$\mathbb{E}[\pi_1(q_1, \bar{q}_1)] = \mathbb{E}[P_s(Q)q_1 - d(\bar{q}_1 - q_1)], \tag{1.1}$$

$$\mathbb{E}[\pi_2(q_2)] = \mathbb{E}[P_s(Q)q_2 - cq_2], \tag{1.2}$$

where Q is the sum of the firms' sales volume; (1.1) refers to the strategy A and (1.2) to strategy H.

Firms simultaneously choose their location, which is observed by the competitor. Thus, four cases exist in pure strategies: both firms choose strategy A (A,A), both choose strategy H (H,H), and one chooses strategy A and the other strategy H (A,H) and (H,A). By symmetry of the game, the latter two differ only in the firms' labels.

[12] The model can be generalized to costs of production in the first stage $\tilde{c} \geq 0$, with costs of production in the second stage $c \geq \tilde{c}$ and disposal costs $d \geq -\tilde{c}$. Note that for $d \in [-\tilde{c}, 0)$ parts of the inventory is reversible. For example, if products are reused or sold in a clearance sale. Our main results do qualitatively not change.

[13] We assume that only one timing strategy is feasible. We extend the model in section 1.4. For a model where firms can produce and sell in both periods, see, for example, Arvan (1985) or Mitraille and Moreaux (2013).

q_A	high demand	low demand
$d < \beta a$	$\frac{a-d}{3(1-\beta)}$	$\frac{a+d}{3(1+\beta)}$
$d \geq \beta a$	$\frac{a}{3}$	$\frac{a}{3}$

Table 1.1: Inventory and sales volume of the (A,A) subgame. Inventory equals the sales volume in the high demand state.

1.3 Equilibrium

We derive the subgame perfect equilibrium in pure strategies. Thus, we solve the game by backward induction. We first derive all equilibria following symmetric location strategies. Second, we derive all equilibria following the asymmetric ones. Each location strategy pair has a unique subgame equilibrium, which we then use to determine the firms' equilibrium location strategies.

Symmetric Subgames. Given firms choose the same location strategy, the subgame is symmetric and we denote one firm by i and the other by j. Furthermore, we use the index A to indicate equilibrium quantity and profits of the (A,A) game and H for the (H,H) game. We start by deriving the subgame equilibrium of the (A,A) game, i.e., both firms produce abroad.

After the demand realization, production costs are sunk, both firms take their inventory as given. Both choose their sales volume $q_i \in [0, \bar{q}_i]$ to maximize

$$\pi_{i,s}(q_i|\bar{q}_i) \quad = \quad P_s(Q)q_i - d(\bar{q}_i - q_i), \tag{1.3}$$

where $Q = q_i + q_j$. The best response function of firm i can be written as

$$q_i(q_j|\bar{q}_1) = \min\left\{\max\left\{\frac{a+d}{2b_s} - \frac{1}{2}q_j, 0\right\}, \bar{q}_i\right\}. \tag{1.4}$$

The best response function weakly decreases in the competitor's sales volume, and it can maximally sell its total inventory.

A firm's sales volume given by (1.4) increases in d for any q_j and $\bar{q}_i$. The costlier disposal, the less is disposed of. If inventories are fixed, increasing disposal costs make firms compete more aggressively for large market shares.

Firms do not observe their competitor's inventory. Nonetheless, each firm anticipates its own disposal behavior. Formally, the firms choose their inventory $\bar{q}_i \geq 0$ to maximize (1.1) subject to (1.4). The optimal inventory strategy of firm i can be written as

$$\bar{q}_i(q_{j,l}, q_{j,h}) = \max\left\{\frac{a}{2} - \frac{1+\beta}{4}q_{j,l} - \frac{1-\beta}{4}q_{j,h}, \frac{a-d}{2(1-\beta)} - \frac{1}{2}q_{j,h}, 0\right\}. \quad (1.5)$$

The best response function is explicitly derived in the appendix. We show that in the first part of the maximum operator, firm i sells its inventory regardless of the demand state. In the second, it disposes of if demand is below expectations. The inventory decreases with d. Firms decrease their inventory to mitigate costs if demand is lower than expected, thereby giving up profits in the high demand state.

We summarize the subgame's equilibrium sales volume in Table 1.1. In the high demand state, firms sell their total inventory, which decreases in d. In the low demand state, firms dispose of if $d < \beta a$. Firms dispose of less, the higher disposal costs are, the sales volume in the low demand state increases in d. If $d \geq \beta a$, nothing is thrown away, firms sell their total inventory regardless of the demand's size.[14]

Expected price, disposal, firm's profit, and consumer surplus are summarized in Lemma 1.1.

Lemma 1.1. *The (A,A) game's unique subgame perfect equilibrium implies an expected market price*

$$\mathbb{E}[P] = \frac{a}{3},$$

and expected disposal of

$$\mathbb{E}[\bar{q}_A - q_A] = \begin{cases} \frac{2(\beta a-d)}{3(1-\beta^2)}, & \text{if } d < \beta a; \\ 0, & \text{if } d \geq \beta a. \end{cases}$$

Furthermore, a firm's expected profits are

$$\mathbb{E}[\pi_A] = \begin{cases} \frac{(a-d)^2}{18(1-\beta)} + \frac{(a+d)^2}{18(1+\beta)}, & \text{if } d < \beta a; \\ \frac{a^2}{9}, & \text{if } d \geq \beta a, \end{cases} \quad (1.6)$$

and expected consumer surplus is

$$\mathbb{E}[CS_A] = \begin{cases} \frac{1(a-d)^2}{9(1-\beta)} + \frac{1(a+d)^2}{9(1+\beta)}, & \text{if } d < \beta a; \\ \frac{2a^2}{9}, & \text{if } d \geq \beta a. \end{cases} \quad (1.7)$$

Disposal costs decrease expected disposal, firm's profits, and consumer surplus.

[14]For general $\tilde{c} > 0$, the threshold can be rearranged to $\tilde{c} \geq (\beta a - d)/(1+\beta)$. Products expensive in manufacturing are not disposed of.

Expected prices are independent of d, while expected disposal decreases with its costs. Firms' profits decrease with d because any adjustment to a lower than expected demand is costly and firms compete more fiercely. However, expected consumer surplus also decreases: firms decrease their inventory and, thus, the expected trade volume. The lower inventories' negative effect dominates the positive effect of fiercer competition.

Next, we derive the equilibrium of the (H,H) game. Firms manufacture close to the market, thus delay their production until demand has materialized. Both firms choose $q_i \geq 0$ to maximize (1.2), technically, the firms play a Cournot game. Their best response can be written as

$$q_i(q_j) = \max\left\{\frac{a-c}{2b_s} - \frac{1}{2}q_j, 0\right\}. \tag{1.8}$$

By contrast to the best response in (1.4), the sales volume is not restricted anymore. Firms incur marginal costs of production c instead of disposal costs d. Formally, the disposal costs are likewise a negative production cost, as can be seen by comparing (1.4) to (1.8). Instead of incurring a cost for each unit sold, firms with disposal costs incur a cost for each unit unsold.

The subgame's equilibrium sales volume is $q_{H,s} = (a-c)/(3b_s)$. Since firms produce with full information, nothing is disposed of. The following Lemma summarizes the expected price, firm's profits, and consumer surplus.

Lemma 1.2. *The (H,H) game's unique subgame perfect equilibrium implies an expected market price*

$$\mathbb{E}[P] = \frac{a+2c}{3}.$$

Furthermore, a firm's expected profits are

$$\mathbb{E}[\pi_H] = \frac{(a-c)^2}{9(1-\beta^2)}. \tag{1.9}$$

and expected consumer surplus is

$$\mathbb{E}[CS_H] = \frac{2(a-c)^2}{9(1-\beta^2)}. \tag{1.10}$$

Firms produce with full information about demand, therefore, nothing is disposed of. Expected prices, profits, and consumer surplus are independent of disposal costs.

q_1	high demand	low demand
$d < \beta\frac{a+c}{2}$	$\frac{a-2d+c}{3(1-\beta)}$	$\frac{a+2d+c}{3(1+\beta)}$
$d \geq \beta\frac{a+c}{2}$	$\frac{a+c}{3}$	$\frac{a+c}{3}$

Table 1.2: Inventory and leader's sales volume depending on the demand state. Inventory equals the sales volume in the high demand state.

q_2	high demand	low demand
$d < \beta\frac{a+c}{2}$	$\frac{a+d-2c}{3(1-\beta)}$	$\frac{a-d-2c}{3(1+\beta)}$
$d \geq \beta\frac{a+c}{2}$	$\frac{a-2c}{3(1-\beta)} + \beta\frac{a+c}{6(1-\beta)}$	$\frac{a-2c}{3(1+\beta)} - \beta\frac{a+c}{6(1+\beta)}$

Table 1.3: The follower's sales volume depending on the demand state.

Asymmetric Subgame. Suppose one firm has chosen strategy A and the other strategy H. We denote the former as leader (she) and the latter as follower (he). The leader's expected profit is given by equation (1.1) and the follower's expected profit by equation (1.2), with $Q = q_1 + q_2$.

In the second stage, the leader's production costs are sunk. She chooses her sales volume $q_1 \in [0, \bar{q}_1]$ to maximize (1.3) yielding the best response function given by (1.4). The follower does not observe the leader's inventory. Yet, the leader anticipates her optimal disposal behavior. She maximizes (1.1) subject to (1.4), yielding the optimal inventory strategy in (1.5).

The follower produces after the demand realization. His best response function is given by equation (1.8). The leader's inventory and sales volume are given in Table 1.2.

The inventory of the leader decreases with disposal costs. She sells her total inventory if demand is high and disposes of if demand is low. Disposal costs increase the sales volume in the low demand state so that the disposed of amount decreases. She gives up some profits in the high demand state to mitigate costs if demand is low. If $d \geq \beta(a+c)/2$, nothing is thrown away.[15]

The follower's sales volume given in Table 1.3 moves in the opposite direction: if the leader decreases her sales volume, the follower increases his

[15]For general $\tilde{c} > 0$, the threshold can be rearranged to $\tilde{c} \geq (\beta a + \beta c - 2d)/(2(1+\beta))$. Similar as above, products expensive in manufacturing are not disposed of.

and vice versa. The assumption $a \geq 2c + d$ ensures that the follower's sales volume is positive. Entry blocking is thus not possible due to relatively low costs. Lemma 1.3 summarizes the expected price, disposal, firms' profits, and consumer surplus.

Lemma 1.3. *The asymmetric location game's unique subgame perfect equilibrium implies an expected market price*

$$\mathbb{E}[P] = \frac{a+c}{3},$$

and expected disposal of

$$\mathbb{E}[\bar{q}_1 - q_1] = \begin{cases} \frac{\beta(a+c)-2d)}{3(1-\beta^2)}, & \text{if } d < \beta\frac{a+c}{2}; \\ 0, & \text{if } d \geq \beta\frac{a+c}{2}. \end{cases}$$

Furthermore, the leader's expected profits are

$$\mathbb{E}[\pi_1] = \begin{cases} \frac{(a-2d+c)^2}{18(1-\beta)} + \frac{(a+2d+c)^2}{18(1+\beta)}, & \text{if } d < \beta\frac{a+c}{2}; \\ \frac{(a+c)^2}{9}, & \text{if } d \geq \beta\frac{a+c}{2}, \end{cases} \tag{1.11}$$

the follower's expected profits are

$$\mathbb{E}[\pi_2] = \begin{cases} \frac{(a+d-2c)^2}{18(1-\beta)} + \frac{(a-d-2c)^2}{18(1+\beta)}, & \text{if } d < \beta\frac{a+c}{2}; \\ \frac{4(a-2c)^2+\beta^2(a+c)(5a-7c)}{36(1-\beta^2)}, & \text{if } d \geq \beta\frac{a+c}{2}, \end{cases} \tag{1.12}$$

and expected consumer surplus is

$$\mathbb{E}[CS_{AH}] = \begin{cases} \frac{(2a-d-c)^2}{36(1-\beta)} + \frac{(2a+d-c)^2}{36(1+\beta)}, & \text{if } d < \beta\frac{a+c}{2}; \\ \frac{(4a-2c-\beta(a+c))^2}{144(1-\beta)} + \frac{(4a-2c+\beta(a+c))^2}{144(1+\beta)}, & \text{if } d \geq \beta\frac{a+c}{2}. \end{cases} \tag{1.13}$$

Expected disposal, leader's profits, and consumer surplus decrease in disposal costs, while the follower's profits increase.

The expected price is independent of d, similar to the symmetric subgames. It only reflects production costs. In Lemma 1.1 both firms have zero production costs, in Lemma 1.2 both incur costs c, and in Lemma 1.3 one has zero costs, while the other has costs c. The realized price, however, depends on d: The price is higher in the high demand state and the difference between the materialized prices increases in d. Firms incur larger costs to adjust their sales volume to the demand realization. If d is small, firms inexpensively adjust to the materialized demand, thereby absorbing the effect of demand on the price.

Expected disposal decreases with its costs. The leader's reaction to a low demand becomes costlier if d increases. The follower's information advantage becomes more valuable. The competitors' profits respond, therefore, opposed to an increase in disposal costs. If inventory is, however, observable, disposal costs may increase both firms' profits. We discuss this case in section 1.4.

By assumption, the leader has lower production costs, while the follower has superior information about demand. The ordering of profits is thus ambiguous. The leader has an advantage if either disposal costs are low, demand uncertainty is low, or both.

With fully reversible inventories, the follower's information advantage is worthless. The leader bears no cost to decrease her quantity in response to low demand while having a cost advantage in production. By contrast, if the leader has no cost advantage, the follower expects higher profits than the leader. In the knife edge case of no cost advantage and fully reversible inventory, both firms expect the same profit.

Location Game. A firm's optimal location strategy maximizes its expected profits. Since the competitor observes the location, firms can anticipate their competitive behavior, respectively, the subsequent market structure. We use the expected profits given in Lemmas 1.1, 1.2, and 1.3 to derive the equilibrium.

It is useful to define the following two threshold functions. We first define the threshold function where the leader is indifferent between producing abroad or close to the market, let $\beta_H(d) := \{\beta | \mathbb{E}[\pi_H] = \mathbb{E}[\pi_1]\}$. Similarly, we define the threshold function $\beta_A(d) := \{\beta | \mathbb{E}[\pi_A] = \mathbb{E}[\pi_2]\}$ such that the follower is indifferent between strategy A and H. We derive explicit expressions of the functions in the appendix and show that they weakly decrease with d and $\beta_H(d) \geq \beta_A(d)$.

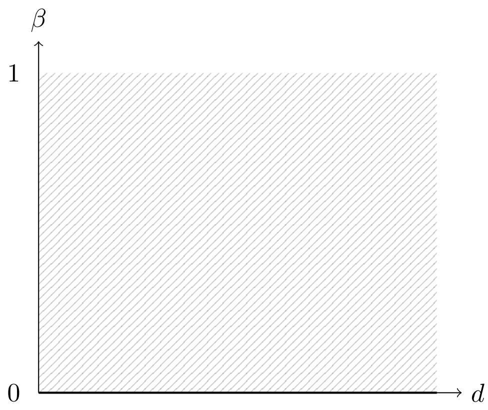
Proposition 1.1. *Generically, there exists a unique subgame perfect equilibrium.*

(i) If demand is highly uncertain, i.e. $\beta \geq \beta_H(d)$, both firms produce in the first stage by choosing strategy H.

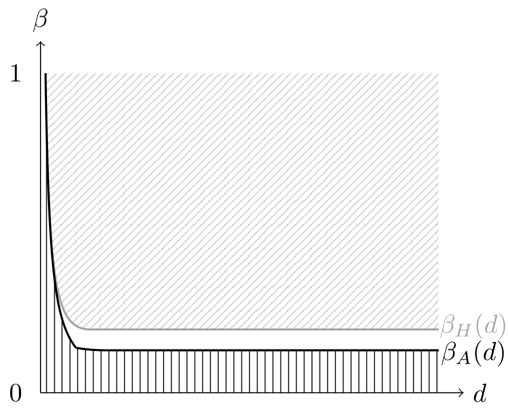
(ii) If demand is fairly predictable, i.e. $\beta \leq \beta_A(d)$, both firms produce in the second stage by choosing strategy A.

(iii) Otherwise, i.e. $\beta \in [\beta_A(d), \beta_H(d)]$, one firm chooses strategy A and the other strategy H.

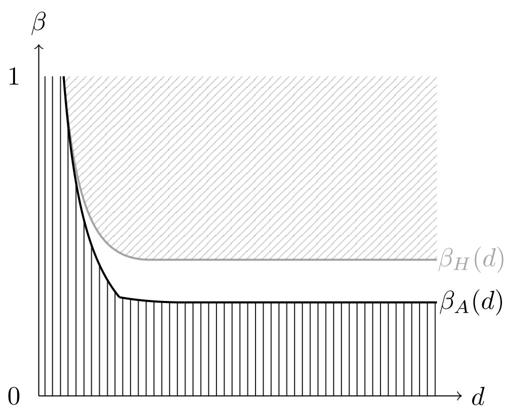
Figure 1.2 illustrates Proposition 1.1. Depending on the choice of parameters, each type of equilibrium can be supported. Moreover, types do not



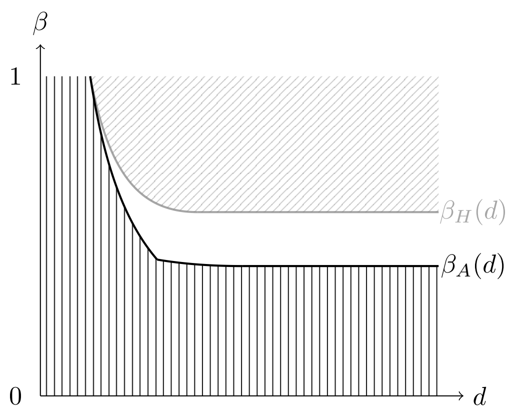
(a) No cost advantage ($c = 0$)



(b) Low cost advantage ($c = 0.1$)



(c) Medium cost advantage ($c = 0.5$)



(d) High cost advantage ($c = 1$)

Figure 1.2: Equilibrium. In the diagonally gray (vetically black) shaded area, both firms produce with strategy H (A). In the white area firms choose an asymmetric strategy, one chooses A and the other H. (Demand intercept $a = 10$.)

coexist, except by definition on the threshold function $\beta_A(d)$ and $\beta_H(d)$.[16] Due to the monotonic expected profit functions, the β functions are all decreasing: The information advantage is less crucial the lower the disposal costs. Low disposal costs enable an inexpensive reaction to the demand realization. Thus, there is a negative relationship between β and d.[17]

Firms face a trade-off between costs and information. They either produce at an early stage with low costs yet with uncertain demand or postpone their production until demand has materialized, yet production costs are higher. Without the early production cost advantage, the trade-off does not exist: both firms produce at a later stage. Whereas, if the cost advantage is large, firms may produce at an early stage. Production abroad is an equilibrium either if demand uncertainty is low, disposal costs are low, or both. An asymmetric equilibrium only exists if there is a cost advantage from early production, disposal is costly, and demand is uncertain.

Comparative Statics. Lemma 1.1, 1.2, and 1.3 already show that although disposal goes down with its costs, there is generally a negative effect on consumer surplus and profits. Firms dispose of less and compete stronger for market shares, yet inventories are lower. Firms give up some profits in the good demand state to mitigate costs in the bad demand state. The expected trade volume, therefore, decreases with d and accordingly, so does consumer surplus.

The only market participant profiting from an increase in disposal costs is the follower in the asymmetric equilibrium. Costlier disposal increases the valuation of his information advantage.

It remains to analyze how consumers and firms are affected if an increase in disposal costs leads to a change in the market structure. Firms may change their manufacturing location in response to an increase in disposal costs. For low disposal costs, both produce abroad. One firm may change its location close to the home market if d increases. Furthermore, the firm producing abroad may also change its location if d is costly.

Proposition 1.2 shows how expected disposal, expected consumer surplus, and firm's expected profits are affected by a regulatory increase in disposal costs. It is useful to invert the threshold function from above by $d_H(\beta) := \min\{d|\beta_H(d) = \beta\}$, thus, at $d_H(\beta)$ the leader is indifferent between producing

[16] By definition all equilibrium types can only be supported if $\beta_H(d) = \beta_A(d)$. The only exception where all equilibria coexist is at $d = c$ and $\beta \to 1$.

[17] In *(iii)* there also exists a symmetric equilibrium in mixed strategies. Strategy H's probability being played increases in d. This follows directly since expected profits with strategy A, precisely $\mathbb{E}[\pi_A]$ and $\mathbb{E}[\pi_1]$, decrease while expected profits under strategy H, precisely $\mathbb{E}[\pi_2]$ increase. In the supplementary materials, we show that the mixed equilibrium's expected profits are non-monotonic in d.

abroad or close to the market. Similarly, the follower is indifferent between strategy A and H at $d_A(\beta) := \min\{d|\beta_A(d) = \beta\}$.

Proposition 1.2. *A regulatory increase in disposal costs*

(i) decreases the expected disposal;

(ii) decreases expected consumer surplus except;

1. *the leader postpones her production close to the market, i.e.* $d = d_H(\beta)$, *expected consumer surplus increases discontinuously.*

(iii) decreases firms' expected profits except;

1. *one firm postpones its production becoming a follower, i.e. at* $d = d_A(\beta)$, *the leader's expected profits increase discontinuously;*
2. *in the asymmetric equilibrium, the follower's expected profit increases.*

We now discuss the disposal costs' effect throughout all types of equilibria. Suppose that d is low, such that both firms manufacture abroad. An increase in disposal costs decreases both firms' profits: If demand is below expectations, an increase in d induces firms to dispose of less, thereby, compete more intensively for a larger market share. Furthermore, firms decrease their inventory to mitigate costs if demand is low. Thus, the trade volume in the high demand state decreases.

Less disposal and fierce competition benefit consumers. However, lower trade volume decreases consumer surplus. The latter effect is stronger than the former, leading to an expected loss in consumer surplus.

At some point, $d = d_A(\beta)$, a firm, labeled as firm 2, expects the same profit from postponing its strategy close to the market. By definition of the equilibrium, firm 2's expected profits are continuous: he decides to postpone his production at $d_A(\beta)$, which is simply the inverse of $\beta_A(d)$ where $\mathbb{E}[\pi_2] = \mathbb{E}[\pi_A]$. The leader's profits, however, increase discontinuously. The change in the market structure results in a cost advantage for her. Although the follower has superior information about demand, the leader has an advantage if disposal costs are low. Low disposal costs enable an inexpensive reaction to the state of demand; the follower's information advantage is thus not crucial.

Expected consumer surplus decreases discontinuously due to the change of the market structure. While both firms produce abroad, they compete at equal strength and sell their total inventory if demand is above expectations. With the market structure change, the leader still offers her total inventory in the high demand state. However, the follower can increase his production and has monopoly power on the residual demand.

The leader's inventory decreases with costlier disposal resulting in an increase for the follower's residual demand. Expected consumer surplus, therefore, decreases further with d. The follower's market power increases and additionally, his information advantage becomes more valuable, resulting in higher expected profits. At the same time, the leader's profits decrease due to her cost increase. Consequently, at some point, the follower expects higher profits than the leader.

At $d = d_H(\beta)$, the leader's expected profit is continuous by the same argument as above. She postpones her production close to the market and gives up her cost advantage to gain information about demand. The follower's profits decrease discontinuously due to the change in the market structure. He loses his information advantage, which is relatively valuable for high d. Additionally, he loses his monopoly power on the residual demand. Firms become equal and compete for the total demand, benefiting consumers. Consequently, consumer surplus increases discontinuously at $d_H(\beta)$.

When both firms produce close to the market, disposal costs have no effect. Firms only produce after demand has materialized, therefore, no products are disposed of and disposal costs are irrelevant. Note that an increase in d does not always lead to a change in the market structure, as can be seen in figure 1.2: for low demand uncertainty, it is not possible to influence the market structure such that both firms (or even one) postpone its production.

1.4 Extensions

We now discuss several extensions to test our result's robustness. First, we relax the assumption of only one production location. Next, we allow firms to observe their competitor's inventory. Finally, we discuss alternative forms of competition, namely perfect competition or price competition.

Multiple Manufacturing Sites. We relax the assumption of only one production location and allow firms to manufacture at both locations. We show that expected disposal decreases in its costs yet also expected profits and consumer surplus decrease.

First, firms choose their inventory $\bar{q}_i \geq 0$ at zero marginal costs. After the demand's realization, firms choose either to dispose of at marginal costs $d > 0$ or to produce additional quantity at marginal costs $c > 0$. Firm i's expected profits can be written as

$$\mathbb{E}[\pi(q_i, \bar{q}_i)] = \mathbb{E}[P_s(Q)q_i - c\max\{q_i - \bar{q}_i, 0\} - d\max\{\bar{q}_i - q_i, 0\}], \quad (1.14)$$

q_i	high demand	low demand
$d < \min\{\beta a, c\}$	$\frac{a-d}{3(1-\beta)}$	$\frac{a+d}{3(1+\beta)}$
$\beta a \leq \min\{c, d\}$	$\frac{a}{3}$	$\frac{a}{3}$
$c < \min\{\beta a, d\}$	$\frac{a-c}{3(1-\beta)}$	$\frac{a+c}{3(1+\beta)}$

Table 1.4: Inventory and sales volume with multiple manufacturing sites. Inventory equals the sales volume in the high (low) demand's state if $d < \min\{\beta a, c\}$ ($c < \min\{\beta a, d\}$).

with $Q = q_i + q_j$. The first term is the revenue, the second are the costs of additional production to sell more than the inventory, and the third are the disposal costs.

In the second stage, firms take their inventories as given. They choose their sales volume $q_i \geq 0$ to maximize

$$\pi(q_i|\bar{q}_i) = P_s(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}.$$

The optimal strategy can be written as

$$q_i(q_j|\bar{q}_i) = \max\left\{\min\left\{\max\left\{\frac{a+d}{2b_s} - \frac{1}{2}q_j, 0\right\}, \bar{q}_i\right\}, \frac{a-c}{2b_s} - \frac{1}{2}q_j\right\}. \quad (1.15)$$

Similar as before, sales volume are increasing in disposal costs. The costlier it is to dispose of, the more firms compete for larger market share. We maintain the assumption that inventories are not observed by the competitor. Firm i therefore chooses her inventory $\bar{q}_i$ to maximize (1.14) subject to (1.15). The optimal inventory strategy of firm i can be written as

$$\bar{q}_i(q_{j,l}, q_{j,h}) = \begin{cases} \frac{a+c}{2(1+\beta)} - \frac{1}{2}q_{j,l}, & \text{if } d > c \text{ and } q_{j,h} - q_{j,l} < \frac{2(\beta a - c)}{1-\beta^2}; \\ \frac{a-d}{2(1-\beta)} - \frac{1}{2}q_{j,h}, & \text{if } c > d \text{ and } q_{j,h} - q_{j,l} < \frac{2(\beta a - d)}{1-\beta^2}; \\ \frac{a}{2} - \frac{1+\beta}{4}q_{j,l} - \frac{1-\beta}{4}q_{j,h}, & \text{else,} \end{cases} \quad (1.16)$$

whenever it is larger than zero.

The best response function's derivation is in the appendix. If marginal production costs are larger than the disposal costs, i.e. $c > d$, the optimal inventory strategy is equivalent to (1.5). With multiple manufacturing sites, firms can produce in the second stage and thus lower their inventory.

A firm's equilibrium inventory and sales volume are shown in Table 1.4. With low disposal costs, firms sell their inventory in the high demand state and dispose of if demand is below expectations. Note that the equilibrium is the same as in the last section: firms decrease their inventories as a response to an increase in disposal cost to mitigate costs if demand is below expectations. By contrast, if production costs in the second period are low, firms sell their inventory in the low demand state and produce additional quantities if demand is higher than expected. If disposal and production are costly, firms sell their inventory regardless of the demand.

We summarize expected prices, disposal, firms' profits, and consumer surplus in the following Proposition.

Proposition 1.3. *The unique, symmetric equilibrium implies an expected market price*

$$\mathbb{E}[P] = \frac{a}{3}$$

and expected disposal of

$$\mathbb{E}[\bar{q}_i - q_i] = \begin{cases} \frac{2(\beta a - d)}{3(1-\beta^2)}, & \textit{if } d < \min\{\beta a, c\}; \\ 0, & \textit{else.} \end{cases}$$

Furthermore, a firm's expected profits are

$$\mathbb{E}[\pi_i] = \begin{cases} \frac{(a-d)^2}{18(1-\beta)} + \frac{(a+d)^2}{18(1+\beta)}, & \textit{if } d < \min\{\beta a, c\}; \\ \frac{a^2}{9}, & \textit{if } \beta a \leq \min\{c, d\}; \\ \frac{(a-c)^2}{18(1-\beta)} + \frac{(a+c)^2}{18(1+\beta)}, & \textit{if } c < \min\{\beta a, d\}. \end{cases} \tag{1.17}$$

and expected consumer surplus is

$$\mathbb{E}[CS] = \begin{cases} \frac{(a-d)^2}{9(1-\beta)} + \frac{(a+d)^2}{9(1+\beta)}, & \textit{if } d < \min\{\beta a, c\}; \\ \frac{2a^2}{9}, & \textit{if } \beta a \leq \min\{c, d\}; \\ \frac{(a-c)^2}{9(1-\beta)} + \frac{(a+c)^2}{9(1+\beta)}, & \textit{if } c < \min\{\beta a, d\}. \end{cases} \tag{1.18}$$

Expected disposal, firm's profits, and consumer surplus decrease in disposal costs.

With this set-up, firms always choose a symmetric strategy. None of the two gives up the production abroad. Thus the results are comparable to the ones in the last section. In the previous section, whenever it is less expensive to dispose of manufactured products compared to produce new ones, $d \leq c$, both firms produce abroad. The models' equilibrium is equivalent.

The expected price is independent of d. It reflects again only the first period production costs that we normalized to zero. Disposal decreases in its cost, yet profits and consumer surplus decrease, too. Firms decrease their inventories due to costly disposal and, therefore, the expected trade volume is lower.

In the supplementary materials, we extend the model to N firms. Expected consumer surplus increases in the number of firms, yet also expected disposal. An increasing number of firms results in a competitive market but also a rise in the number of disposers. Total expected disposal decreases stronger in its costs, the larger the number of firms.

However, firms expect a lower profit if disposal costs increase. Accordingly, some firms may leave the market, resulting in a lower number of firms. Competition is lowered, thereby additionally decreasing consumer surplus. The firms staying in the market are negatively affected by higher disposal costs, yet benefit from fewer competitors. Their expected profit may thus increase. The positive effect of lower disposal and, thereby, more intense competition for market shares is not noticeable for consumers. With this set-up, competition may even decrease in response to an increase in disposal costs.

Observable Inventories. We discuss in this section an extension to observable inventories. A formal analysis can be found in the supplementary materials.[18] In reality, firms may not perfectly observe their competitor's inventories. Public companies, yet, announce their targeted sales to inform investors. Those announcements are observed by the competitors, who can infer the inventory from it. For simplicity, we assume in our model that inventories are perfectly observable.

If inventories are observable, an additional, opposing effect exists. With higher disposal costs, firms sell large parts of their inventories even if demand is lower than expected. Extensive inventories, therefore, send the message of large intended sales. A firm can only credibly commit to selling its total inventory if disposal is expensive.

Generally, disposal costs decrease inventories, yet, the neglected effect works in the opposite direction. If firms observe their competitors' inventories, the equilibrium may not be unique, nor is it monotone, due to the opposing effects. Although firms are ex ante symmetric, there may exist asymmetric equilibria, where one firm has a larger inventory than the other. The firm with the smaller inventory produces additional quantities if demand is higher than expected, while the other disposes of if demand is lower than

[18] An earlier version of this chapter also contained an extension of the location game in section 1.2. Results are qualitatively similar. Please contact the author to access it.

expected. Expected disposal decreases in its costs. Furthermore, inventories still decrease in disposal costs. Due to the lower trade volume, consumer surplus decreases.

A regulatory increase in disposal costs fulfills its purpose to decrease the disposed of quantity yet at the consumers' cost. Competition for market shares is not achieved by this policy, even if inventories are observable.

Similar to the main model, the firm producing (primarily) abroad is negatively affected by an increase in disposal costs, since any reaction to new information about demand becomes more costly. By contrast, observability strengthens its dominant position in terms of market share. It can signify large targeted sales with a large inventory. The costlier disposal, the less does a firm dispose of its inventory. The inventory's credibility to indicate targeted sales increases with d, strengthening the firm's competitive advantage. Profits are, thus, ambiguously affected by an increase in disposal costs. Precisely, the larger firm's expected profits are U-shaped.

The other firm has a small inventory and manufactures large parts of its production after the demand's realization. Accordingly, it has an information advantage, which is more valuable if the other firm's reaction to new information is costly. Similar to the main model, the smaller firm's expected profits increase with d.

To sum up, the increasing credibility benefits the larger firm if demand is lower than expected, while the information advantage benefits the smaller firm if demand is higher than expected. By contrast to unobserved inventories, both firms' expected profits may increase in disposal costs.

H&M and Zara[19], the two most prominent players in the European fashion market increased their recycling standards over the last years. According to our model, this leads to higher costs, which may increase profits. Our model is consistent with the market structure: H&M mainly produces in Asia and ships its product to the European market; Zara manufactures mostly in Europe. Zara manufactures close to the market. The firm claims that within two weeks of the original design, clothes are in retail. The shipment from Asia to Europe already takes more time. Consequently, H&M's clothes are manufacture earlier. In the fast fashion industry, multiple products are introduced in a single week to stay on-trend. In order to compete trendily, according to our model, H&M produces large parts of its inventory abroad and has larger expected disposal than Zara. This is consistent with the fact

[19]Zara is part of the Inditex holding, which also includes Pull&Bear, Massimo Dutti, Oysho, and others. Although we mean Inditex in lieu we refer to Zara because it is the flagship of Inditex.

that Zara only discards 10% of its products, which is half of the industry average.

Besides the discussed asymmetric equilibria, there always exists the same symmetric equilibrium described in Proposition 1.3.[20] The difference between observable and unobservable inventories is, therefore, the asymmetric equilibria's existence. We use numerical simulations to compare the equilibria and find that both firms' expected profits may be higher in the symmetric equilibrium. Note that the firms can guarantee to be in the symmetric equilibrium if inventories are unobservable. However, there exists parameters, where one firm, either the smaller or the larger, expects higher profits in an asymmetric equilibrium, i.e. prefers if inventories are observable.

Perfect Competition. New firms may enter a profitable market in the long run, resulting in a perfectly competitive market. Firms make zero expected profits with both timing strategies. Higher disposal costs decrease firms' inventories and consumer surplus: Suppose there are many firms in both timing allocations and expected profits are zero. Firms with strategy A may dispose of if demand is below its expectation, i.e., incur costs. They have, therefore, to turn positive profits if demand is above expectations. An increase in disposal costs forces those firms to decrease their inventory. Otherwise, firms turn negative expected profits because the loss in the bad state outweighs the gains in the good state. Due to the lower inventory, firms in the second period increase their production, but these quantities come at a higher production cost. Introducing additional costs in an efficient market decreases consumer surplus.

Price Competition. Instead of quantity competition in the second stage, Kreps and Scheinkman (1983) and Montez and Schutz (2018) used price competition. Both firms choosing timing strategy H results in zero profits à la Bertrand. Both choosing timing strategy A results in a model similar to de Frutos and Fabra (2011): firms end up with different capacity/inventory levels. Given an asymmetric timing, the leader has to set prices weakly below the follower's marginal costs, or else the latter undercuts the price. It depends on the rationing rule how demand is shared with equal prices. For example, one could use equal demand sharing as de Frutos and Fabra (2011). If the leader's inventory is not large enough to satisfy total demand, the follower becomes a monopolist for the residual demand. The follower sets prices strictly above marginal costs and the leader tries to undercut them. No pure strategy equilibrium may exist.

[20]Dubey and Shubik (1981) show generally that any pure strategy equilibrium with unobservable inventories is also an equilibrium if inventories are observed.

1.5 Conclusion

For each unit not sold firms incur a cost if inventory is not fully reversible. An unsold unit is not only a loss in revenue, it also causes additional costs. As we show in this chapter, firms thus discard less of their commodities if disposal costs increase. Therefore, competition for sales increases. Accordingly, one would expect consumer surplus to increase and firms' expected profits to decrease.

Although correct, this expectation is shortsighted. Firms adjust their inventories if disposal costs increase. The higher the disposal costs, the costlier it is for a firm to adjust to a demand below expectations. To mitigate costs, a firm lowers its inventory, which leads to lower profits if demand is high.

In our model, firms either produce their inventory earlier, at a low cost and little information about demand or later, with more information yet at higher costs. Although firms are ex ante symmetric, firms may choose asymmetric production strategies. We derive three necessary conditions for an asymmetric equilibrium: First, early production has to yield a strict cost advantage. Second, disposal has to be strictly costly. Third, demand has to be uncertain, yet, not too much. If demand uncertainty is considerable, firms jointly produce with more information, yet at higher costs. If demand uncertainty is low, firms jointly produce at low costs with little information about demand.

We showed that a regulatory increase in disposal costs decreases the expected disposal. Yet consumers do not benefit from increasing competition for market sales. The lower trade volume impairs them. In general, consumers do not benefit from an increase in disposal costs. There is, however, an exception. In an asymmetric equilibrium, the firm manufacturing close to the market has monopoly power over the residual demand. Increasing disposal costs may change the market structure, and the competitor postpones its production close to the market, too. Firms become equal and competition increases, benefiting consumers.

Generally, firms expect a lower profit, the costlier disposal is. However, there are also some exceptions. With an increase in disposal costs, information about demand become more valuable. Disposing of products as response to a demand below expectations becomes costlier. Firms may, therefore, postpone their production with increasing disposal costs. Changes in the market structure may benefit a firm. Furthermore, in the asymmetric equilibrium, one of the two firms has an information advantage. Since costlier disposal increases the information's value, the firm expects a higher profit.

We also discussed the case when firms observe their competitor's inventory. This gives rise to another effect: a firm's inventory sends the message of its intended sales. However, a company can only credibly commit to selling large parts of its inventory if disposal is costly. Due to this opposing effect, each firm's profits may increase separately in disposal costs. Firms may profitably agree on costlier disposal, e.g., in the form of higher recycling standards. Expected disposal decreases, yet consumer surplus, too.

In our set-up, a regulatory increase in disposal costs impairs firms and consumers. We discuss some exceptions, whereby firms may benefit more often than consumers. Our model is consistent with the market structure in the fashion market. Furthermore, our model explains the 'reshoring' of firms. If cost advantages abroad decline or disposal costs increase, information about demand becomes more valuable. Thus, firms produce closer to their home market.

We studied demand uncertainty. However, in some markets, demand is relatively predictable, but costs may vary due to input factor prices. Commodities that are expensive in production are less often disposed of. Studying cost uncertainty may, therefore, be of interest.[21] Another interesting question is how disposal costs affect collusive behavior. Paha (2017) studies collusion with capacities; Rotemberg and Saloner (1989) study the use of inventory for strategic collusion. US data of the aluminum industry analyzed in Rosenbaum (1989) reveals markups' negative correlation with inventory, but a positive with excess capacity. Low disposal costs allow an inexpensive firm's adjustment, it is thus easier to deviate, and strategic collusion may be aggravated.

[21]In Thille (2006) the prediction of the model crucially depends on the primary uncertainty. Less competitive market structures have a relatively low price variance when uncertainty is primarily due to uncertain cost and relatively high price variance when uncertainty is mainly due to uncertain demand.

1.A Proofs

This section contains all Lemmas' and Propositions' proofs and derives the best response (1.5) and (1.15).

Proof Equation (1.5). Firm i maximizes (1.1) subject to (1.4). Note that by (1.4) the sales volume equals not always the inventory. To simplify notation, we write $\bar{q}_i$ explicitly whenever $q_i = \bar{q}_i$ and use $\hat{q}_i$ when the sales volume is lower than the inventory.

Suppose first, $q_{j,h} - q_{j,l} \leq 2\beta(a+d)/(1-\beta^2)$, thus, firm i's expected profits can be written as

$$\mathbb{E}[\pi_i] = \begin{cases} \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h})+d)\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l})+d)\bar{q}_i - d\bar{q}_i, & \text{if } \bar{q}_i < \frac{a+d}{2(1+\beta)} - \frac{q_{j,l}}{2} =: \tau; \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h})+d)\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+q_{j,l})+d)\hat{q}_i - d\bar{q}_i, & \text{if } \tau \leq \bar{q}_i < \frac{a+d}{2(1-\beta)} - \frac{q_{j,h}}{2}; \\ \frac{1}{2}(a-(1-\beta)(\hat{q}_i+q_{j,h})+d)\hat{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+q_{j,l})+d)\hat{q}_i - d\bar{q}_i, & \text{else.} \end{cases}$$

In the first part firm i sells its total inventory regardless of the demand's state, yielding the interior solution $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 + (1-\beta)q_{j,h}/4$. In the second part, firm i disposes of if demand is below expectations, yielding the interior solution $\bar{q}_i = (a-d)/(2(1-\beta)) - q_{j,h}/2$. The third part is strictly decreasing. Whenever $2(\beta a - d) \leq (1-\beta^2)(q_{j,h} - q_{j,l})$, the second part is decreasing and the first interior solution is the global maximum. Otherwise, the first part is increasing and the second interior solution is the global maximum. This can be rewritten as the best response function given in (1.5).

It remains to show that for $q_{j,h} - q_{j,l} > 2\beta(a+d)/(1-\beta^2)$ no other maximum exists. The second part of the expected profit function changes: firm i disposes of in the high state and sells its inventory in the low demand state. This implies that the sales volume in the high state is lower than in the low state, $q_{i,h} \leq q_{i,l}$. However, the right-hand side in the inequality above is weakly positive, yielding a contradiction. Thus (1.5) is indeed firm i's best response. □

Proof Lemma 1.1. We prove that the unique equilibrium is given in Table 1.1. Therefore, we look for fixpoints for the best response function of (1.4) and (1.5). We go step by step through all three parts in (1.5) and derive thereby all equilibria.

First we show that $\bar{q}_i = 0$ is never an equilibrium. Therefore, we show that $q_{i,s} = 0$ is never an equilibrium. Both firms' sales volumes are strictly positive in both demand states. Firm j's best response to $q_{i,s} = 0$ is

$$q_{j,s} = \min\left\{\frac{a+d}{2b_s}, \max\left\{\frac{a}{2}, \frac{a-d}{2(1-\beta)}\right\}\right\},$$

implying that $q_{j,s} \leq \min\{(a+d)/b_s, (a-d)/(1-\beta)\}$. Accordingly, firm i's sales volume $q_{i,s} > 0$. This proofs that both firms sell a strictly positive quantity. Hence, $\bar{q}_i > 0$.

Next, suppose firm i sells its inventory in both demand state. Hence, $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 - (1-\beta)q_{j,h}/4$ and $q_{i,l} = q_{i,h} = \bar{q}_i$. Firm j's best response is $\bar{q}_j = \max\{a/2 - \bar{q}_i/2, (a - d/(2(1-\beta)) - \bar{q}_i/2\}$.

Suppose first $d < \beta a$, hence, $\bar{q}_j = q_{j,h} = (a - d/(2(1-\beta)) - \bar{q}_i/2$ and $q_{j,l} = (a+d)(2(1+\beta)) - \bar{q}_i/2$. Direct calculation imply $\bar{q}_i = a/3$, and $q_{j,h} = (\beta a - d)/(2(1-\beta))$. A necessary condition is that $a/3$ is the maximum of (1.5), which simplifies to $3d \geq 2a + \beta a$, which yields a contradiction, thus there is no equilibrium where firm i sells its inventory in both states but firm j disposes of.

Suppose now that also firm j sells its inventory in both states, $d \geq \beta a$. Direct calculation imply that $\bar{q}_i = q_{i,l} = q_{i,h} = a/3$, which forms a symmetric equilibrium if $d \geq \beta a$. This proofs the second part in Table 1.1.

Finally, suppose firm i disposes of if demand is below expectations, thus $\bar{q}_i = (a-d)/(2(1-\beta)) - q_{j,h}/2$. By the arguments above $\bar{q}_j = (a-d)/(2(1-\beta)) - q_{i,h}/2$. Direct calculations imply the symmetric equilibrium candidate $\bar{q}_i = q_{i,h} = (a-d)/(3(1-\beta))$ and $q_{i,l} = (a+d)/(3(1+\beta))$. The necessary condition that $(a-d)/(3(1-\beta))$ is the maximum of (1.5) simplifies to $d < \beta a$. This proofs the first part in Table 1.1.

Hence, the equilibrium is unique. Plugging in the sales volume yields the expected expressions in Lemma 1.1. Since $\beta \in [0,1)$, the negative effect of d is more weighted than the positive. Thus, d's negative effect follows directly. □

Proof Lemma 1.2. Firms know the demand's state and maximize (1.2). Note that similar as in Lemma 1.1, $q_{i,s} = 0$ is never an equilibrium. Therefore, best response functions are linearly and strictly decreasing in the relevant part and a unique equilibrium exists. Exploiting the symmetry directly implies $q_{H,s} = (a-c)/(3b_s)$. Plugging in the sales volume yields the desired result. □

Proof Lemma 1.3. The leader's best response function is given by (1.5), the follower's by (1.8). Similar to the proof of Lemma 1.1, we analyze the best response function step by step to find all equilibria.

Suppose $\bar{q}_1 = 0$, directly implying $q_{1,g} = q_{1,b} = 0$ and thus $q_{2,s} = (a - c)/(2b_s)$. However, the leader's best response is $\bar{q}_1 > 0$, hence there is no equilibrium with zero inventory.

Next, suppose $\bar{q}_1 = a/2 - (1+\beta)q_{2,b}/4 + (1-\beta)q_{2,g}/4$, i.e. the leader sells her inventory in both states. Combining this with the best response of the follower yields $\bar{q}_1 = (a+c)/3$, which is indeed an equilibrium if $\beta(a+c)/2 \leq d$.

Lastly suppose $\bar{q}_1 = (a-d)/(2(1-\beta)) - q_{2,g}/2$, combining this with (1.8) yields $\bar{q}_1 = (a-2d+c)/(3(1-\beta))$, which is indeed an equilibrium if $\beta(a+c)/2 > d$.

No other equilibria exist since it would not be on firm 1's best response function. Therefore, the equilibrium is unique. Plugging in the sales values yields directly the expected expressions. Similar to the proof of Lemma 1.1, d's effect follows directly. □

Proof Proposition 1.1. Both firms choose strategy H if $\mathbb{E}[\pi_H] \geq \mathbb{E}[\pi_1]$, where the expressions are given in (1.9) and (1.11). We show that

$$\beta_H(d) = \begin{cases} \frac{2ac+2d^2}{d(a+c)}, & \text{if } d < \beta\frac{a+c}{2}; \\ \frac{2\sqrt{ac}}{(a+c)}, & \text{if } d \geq \beta\frac{a+c}{2}, \end{cases}$$

with $\beta \geq \beta_H(d)$ the strategy pair (H,H) is an equilibrium. First, for $d < \beta\frac{a+c}{2}$ the inequality can be rearranged to $\beta d(a+c) \geq ac + d^2$, hence, the first part directly follows. Note that the left-hand side increases stronger in d than the right-hand side, since $d \leq \beta(a+c)$. By definition, the first part of $\beta_H(d)$ therefore decreases. For $d \geq \beta\frac{a+c}{2}$ the inequality simplifies to $\beta^2(a+c)^2 \geq 4ac$, which concludes the proof of (i).

Both firms choose strategy A if $\mathbb{E}[\pi_A] \geq \mathbb{E}[\pi_2]$, where the expressions are given in (1.6) and (1.12). We show that

$$\beta_A(d) = \begin{cases} \frac{c}{d}, & \text{if } d < \beta\frac{a+c}{2}; \\ \frac{\sqrt{a^2d^2+4(a+c)(5a-7c)(d^2+4(a-c))}-4ad}{(a+c)(5a-7c)}, & \text{if } \beta\frac{a+c}{2} \leq d < \beta a; \\ 4\sqrt{\frac{c}{9a+7c}}, & \text{if } d \geq \beta a, \end{cases}$$

with $\beta \leq \beta_A(d)$ the strategy pair (A,A) is an equilibrium. First, note that $\beta a \geq \beta(a+c)/2$. For $d < \beta(a+c)/2$ the inequality simplifies to $\beta d \leq c$, which concludes the first part. Obviously, it decreases in d. For $d \in [\beta(a+c)/2, \beta a]$, the inequality can be written as $\beta^2(a+c)(5a-7c)+8\beta ad-16c(a-c)-4d^2 \leq 0$. The left-hand side is convex and at $\beta = 0$ negative and increasing. Hence, the larger root is the relevant one, which is explicitly given in the second part.

We use the implicit function theorem to show $\beta_A(d)$'s second part has a negative slope. The left-hand side's derivative with respect to d is $8(\beta a - d) > 0$; the derivative with respect to β is $2\beta(a+c)(7a-7c) \geq 0$. Hence, the implicit function theorem implies that $\beta_A(d)$ decreases.

For $d \geq \beta a$ the inequality simplifies to $\beta^2(9a+7c) \leq 16c$, which concludes the proof of (ii).

Inverting the inequalities proves (iii). It remains to show that $\beta_A(d) \leq \beta_H(d)$ to proof the generical uniqueness. We show in the following proof that the inequality holds. □

Proof Proposition 1.2. We first compare the leader's and follower's profits. The leader's profits are larger if and only if $\mathbb{E}[\pi_1] \geq \mathbb{E}[\pi_2]$, where the expressions are given in (1.11) and (1.12). Equating the two expressions and rearranging yields

$$\beta_{AH}(d) = \begin{cases} \frac{2ac-c^2+d^2}{2ad}, & \text{if } d < \beta\frac{a+c}{2}; \\ \sqrt{\frac{4c(2a-c)}{(3a-c)(a+c)}}, & \text{if } d \geq \beta\frac{a+c}{2}. \end{cases}$$

Thus, $\beta \leq \beta_{AH}(d)$ implies $\mathbb{E}[\pi_1] \geq \mathbb{E}[\pi_2]$ and $\beta \geq \beta_{AH}(d)$ implies $\mathbb{E}[\pi_1] \leq \mathbb{E}[\pi_2]$.

Hence, it is sufficient to show that $\beta_A(d) \leq \beta_{AH}(d) \leq \beta_H(d)$. If this is the case, a firm's profits increase discontinuously if the other delays its production. Technically, at $\beta_A(d)$ by definition $\mathbb{E}[\pi_A] = \mathbb{E}[\pi_2]$ and by the inequality above $\mathbb{E}[\pi_1] \geq \mathbb{E}[\pi_2]$. Similarly at $\beta_H(d)$ by definition $\mathbb{E}[\pi_H] = \mathbb{E}[\pi_1]$ and by the inequality above $\mathbb{E}[\pi_2] \geq \mathbb{E}[\pi_1]$. Thus, the leader's profit jumps up at $\beta_A(d)$ while the follower's jumps down at $\beta_H(d)$.

For $d < \beta(a+c)/2$, the two inequalities above can be simplified to $2ac^2 \leq ac^2 - c^3 + ad^2 + cd^2 \leq 2ad^2$, i.e. for the existence of an asymmetric equilibrium it has to hold that $c^2 \leq d^2$. The two inequalities can be rewritten as $(a+c)(d^2-c^2) > 0$ and $(a-c)(c^2-d^2) < 0$, which both are true whenever an asymmetric equilibrium exists.

Since $\beta_H(d)$ and $\beta_{AH}(d)$ are continuous and constant while $\beta_A(d)$ decrease for $d \geq \beta(a+c)/2$ the relevant inequality holds. This directly concludes the proof for the firms' part.

For the consumer surplus, we first show a discontinuous decrease at $\beta = \beta_A(d)$ and finally we prove a discontinuous increase at $\beta = \beta_H(d)$.

First, at $\beta = \beta_A(d)$, $\mathbb{E}[CS_A] > \mathbb{E}[CS_{AH}]$, where the expressions are given by (1.7) and (1.13). For $d < \beta(a+c)/2$ the inequality simplifies to $8ac - 2c^2 + 6d^2 > 4\beta d(c-6a)$, where the left-hand side is strictly positive while the right-hand side is strictly negative. For $d \in [\beta(a+c)/2, \beta a)$, the inequality simplifies to $32ac - 64ad - 8c^2 + 32d^2 + \beta(a+c)(16a-8c) - 2\beta^2(a+c)^2 > 0$. The left-hand side is a concave function in β. Suppose $\beta \to 0$, this implies $d \to 0$, hence, the inequality is satisfied for low β. The left-hand side is positive and increasing at $\beta = 0$, furthermore, its maximal value is at $\beta = (4a-2c)/(a+c)$, which is strictly larger than 1. Hence, the inequality holds for any $\beta \in [0,1)$. Since the expected consumer surplus is continuous and constant for $d \geq \beta a$, this concludes the first part.

Next we show that at $\beta = \beta_H(d)$, $\mathbb{E}[CS_H] > \mathbb{E}[CS_{AH}]$, where the expressions are given by (1.10) and (1.13). For $d \leq \beta(a+c)/2$ the inequality simplifies to $4\beta d(2a-c) > 2(4ac - 3c^2 + d^2)$. Plugging in $\beta_H(d)$ we can simplify the expression to $(d^2 - c^2)(a-c) > 0$. This is a necessary condition for the existence of an asymmetric equilibrium as discussed above. Since both functions are continuous and constant for $d \geq \beta(a+c)/2$ this concludes the proof for the consumer surplus.

It remains to prove that expected disposal decreases in its cost. First note that in the (H,H) subgame, expected disposal is always zero. Next, using Lemma 1.1 and 1.3, we derive that expected disposal in the (A,A) subgame equilibrium is larger than in the (A,H) if and only if $\beta \geq c/(3a)$. This is independent of d. From Proposition 1.1 it follows directly that the minimal uncertainty for (A,H) to form an equilibrium is $\beta = \sqrt{16c/(9a+7c)}$. The direct comparison yields that whenever (A,H) may be an equilibrium, the expected disposal is lower since $9ac(a-c) + 135a^2c - 7c^3 > 0$. This concludes the proof. $\square$

Proof Equation (1.15). Similar as in Equation (1.5)'s proof we use again $\bar{q}_i$ if the sales volume equals the inventory and else $\hat{q}_i$. To simplify notation let

$$\begin{aligned}
\vartheta_1 &:= \frac{a-c}{2(1-\beta)} - \frac{1}{2}q_{j,h}, \\
\vartheta_2 &:= \frac{a+d}{2(1+\beta)} - \frac{1}{2}q_{j,l}, \\
\vartheta_3 &:= \frac{a+d-(1-\beta)q_{j,h}}{2(1-\beta)},
\end{aligned}$$

and

$$\vartheta_4 := \frac{a-c-(1+\beta)q_{j,l}}{2(1+\beta)}.$$

With this expected profits can be written as

$$\mathbb{E}[\pi_i] = \begin{cases} \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h}))\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l}))\bar{q}_i, & \text{if } \vartheta_1 \leq \bar{q}_i < \vartheta_2; \\ \frac{1}{2}(a-(1-\beta)(\bar{q}_i+q_{j,h}))\bar{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\hat{q}_i+q_{j,l})+d)\hat{q}_i - d\bar{q}_i, & \text{if } \max\{\vartheta_1,\vartheta_2\} \leq \bar{q}_i < \vartheta_3; \\ \frac{1}{2}(a-(1-\beta)(\hat{q}_i+q_{j,h})-c)\hat{q}_i + \\ \frac{1}{2}(a-(1+\beta)(\bar{q}_i+q_{j,l}))\bar{q}_i + c\bar{q}_i, & \text{if } \vartheta_4 < \bar{q}_i < \min\{\vartheta_1,\vartheta_2\}; \\ \frac{1}{2}[(a-(1-\beta)(\hat{q}_i+q_{j,h}))\hat{q}_i - \\ \max\{d(\bar{q}_i-\hat{q}_i), c(\hat{q}_i-\bar{q}_i\}] + \\ \frac{1}{2}[(a-(1+\beta)(\hat{q}_i+q_{j,l}))\hat{q}_i - \\ \max\{d(\bar{q}_i-\hat{q}_i), c(\hat{q}_i-\bar{q}_i\}], & \text{else.} \end{cases}$$

In the first part, firm i sells its inventory in both states, yielding the interior solution $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 + (1-\beta)q_{j,h}/4$. In the second part firm i disposes of if demand is below expectations, yielding the interior solution $\bar{q}_i = (a-d)/(2(1-\beta)) - q_{j,h}/2$. In the third part, firm i produces additional quantities if demand is above expectations, yielding the interior solution $\bar{q}_i = (a+c)/(2(1+\beta)) - q_{j,l}/2$. The fourth part is strictly in or decreasing, depending on c and d. If $c = d$ there may exists multiple maxima, where the firm disposes of if demand is below expectations or produces if it is above expectations. However, all yield the same expected profit as if the firm only produces, or only disposes of instead of doing both, since the expected profit function is continuous.

If $\max\{2(\beta a - c), 2(\beta a - d)\} \leq (1-\beta^2)(q_{j,h} - q_{j,l})$, the first part is indeed an interior solution and the second part is strictly decreasing; the third strictly increasing, hence it is the unique maximum. Furthermore, for the region's existence we need that $q_{j,h} - q_{j,l} \geq 2\beta a - (1+\beta)c - (1-\beta)d$, which is satisfied in equilibrium.

If $d < c$, and $2(\beta a - c) \leq (1-\beta^2)(q_{j,h} - q_{j,l}) \leq 2(\beta a - d)$, the first part is strictly increasing, the second has an interior solution and the third is strictly increasing. Thus the second part is the global maximum.

Finally, if $d > c$ and $(1-\beta^2)(q_{j,h} - q_{j,l}) \leq 2(\beta a - d)$, the first and second part are strictly decreasing and the third part is an interior solution. The global maximum is thus the third part. This yields the best response function (1.15). □

Proof Proposition 1.3. By the similar argument as in Proposition 1.1's proof firm i's sales volume is strictly positive in both demand states. The best response simplifies therefore to

$$q_i(q_j) = \max\left\{\min\left\{\frac{a+d}{2b_s} - \frac{1}{2}q_j, \bar{q}_i\right\}, \frac{a-c}{2b_s} - \frac{1}{2}q_j\right\},$$

where $\bar{q}_i$ is given by (1.15). The inventory is strictly positive: production is costly in the second stage, firms produce at least the low demand's state sales volume in the first period.

To derive all equilibria, we analyze the best response function step by step.

We start with (1.15)'s first part: suppose $\bar{q}_i = (a+c)(2(1+\beta)) - q_{j,l}/2$, which implies $q_{i,h} = (a-c)/(2(1-\beta)) - q_{j,h}/2$ and $q_{i,l} = \bar{q}_i$.

First, suppose $\bar{q}_j = q_{j,l} = (a+c)(2(1+\beta)) - q_{i,l}/2$ and $q_{j,h} = (a-c)/(2(1-\beta)) - q_{i,h}/2$. By symmetry we directly get $q_{i,h} = (a-c)/(3(1-\beta))$ and $\bar{q}_i = q_{i,l} = (a+c)/(3(1+\beta))$, which indeed forms a symmetric equilibrium if $c < \min\{\beta a, d\}$.

Second, suppose $\bar{q}_j = q_{j,l} = q_{j,h} = \frac{a}{2} - \frac{1+\beta}{4}q_{i,l} - \frac{1-\beta}{4}q_{i,h}$. We directly get that $\bar{q}_j = a/3$ and $q_{i,h} = (a+c)/(2(1+\beta)) - a/6$ and $q_{i,l} = (a-c)/(2(1-\beta)) - a/6$. Hence, $q_{i,h} - q_{i,l} = (\beta a - c)/(1-\beta^2)$, which has to be positive. Yet in order to have firm j play a best response it has to be negative, hence, a contradiction.

Lastly, note that $\bar{q}_j = (a-d)(2(1-\beta)) - q_{i,h}/2$ is never a best response since it contradicts $d > c$. This concludes the first part of (1.15).

Next, suppose $\bar{q}_i = a/2 - (1+\beta)q_{j,l}/4 - (1-\beta)q_{j,h}/4$, which implies $q_{i,l} = q_{i,h} = \bar{q}_i$.

First, suppose $\bar{q}_j = q_{j,l} = q_{j,h} = \frac{a}{2} - \frac{1+\beta}{4}q_{i,l} - \frac{1-\beta}{4}q_{i,h}$, by symmetry we directly get $\bar{q}_i = q_{i,h} = q_{i,l} = a/3$, which indeed forms a symmetric equilibrium if $\beta a \leq \min\{c, d\}$.

Second, suppose $\bar{q}_j = q_{j,h} = (a-d)(2(1-\beta)) - q_{i,h}/2$ and $q_{j,l} = (a+d)(2(1+\beta)) - q_{i,l}/2$. Direct calculation yield $\bar{q}_i = a/3$ and $q_{j,h} = (a-d)/(2(1-\beta)) - a/6$ and $q_{j,l} = (a+d)/(2(1+\beta)) - a/6$, hence, $q_{j,h} - q_{j,l} = (\beta a - d)/(1-\beta^2)$, which has to be positive. Yet a necessary condition for firm i's strategy to be a best reply is $d \geq \beta a$, yielding a contradiction.

This concludes the second part of (1.15). Finally, suppose $\bar{q}_i = q_{i,h} = (a-d)(2(1-\beta)) - q_{j,h}/2$ and $q_{i,l} = (a+d)(2(1+\beta)) - q_{j,l}/2$. The remaining case is the symmetric one for $\bar{q}_j = q_{j,h} = (a-d)(2(1-\beta)) - q_{i,h}/2$ and $q_{j,l} = (a+d)(2(1+\beta)) - q_{i,l}/2$. We directly get $\bar{q}_i = q_{i,h} = (a-d)/(3(1-\beta))$ and $q_{i,l} = (a+d)/(3(1+\beta))$, which forms a symmetric equilibrium if $d < \min\{\beta a, c\}$.

Plugging in the sale volumes yields the expected values. The disposal cost's negative effect immediately follows from Lemma 1.3. □

1.B Supplementary Materials

Mixed Equilibrium. This section derives the unique symmetric equilibirum. Note that we have shown in section 1.3 that the equilibrium is unique and symmetric whenever (A,A) or (H,H) forms an equilibrium, see Proposition 1.1 for details. Whenever the asymmetric equilibirum exists, there exists a second asymmetric equilibrium with the firms label interchanged. Furthermore, there exists a symmetric equilibrium in mixed strategies, where the probability to play strategy H is

$$p = \frac{\mathbb{E}[\pi_A] - \mathbb{E}[\pi_2]}{\mathbb{E}[\pi_A] - \mathbb{E}[\pi_2] + \mathbb{E}[\pi_H] - \mathbb{E}[\pi_1]},$$

respectively, $1-p$ to play strategy A. Taking the derivative with respect to d yields

$$\frac{\partial p}{\partial d} = \frac{\frac{\partial \mathbb{E}[\pi_1]}{\partial d}(\mathbb{E}[\pi_A] - \mathbb{E}[\pi_2]) + (\frac{\partial \mathbb{E}[\pi_A]}{\partial d} - \frac{\partial \mathbb{E}[\pi_2]}{\partial d})(\mathbb{E}[\pi_H] - \mathbb{E}[\pi_1])}{(\mathbb{E}[\pi_A] - \mathbb{E}[\pi_2] + \mathbb{E}[\pi_H] - \mathbb{E}[\pi_1])^2} \geq 0.$$

The sing follows from the expected profits derived in Lemma 1.1-1.3, furthermore, existence requires $\mathbb{E}[\pi_A] \leq \mathbb{E}[\pi_2]$ and $\mathbb{E}[\pi_H] \leq \mathbb{E}[\pi_1]$. Note that p is continuous in d and the derivative exists everywhere except for $d = \beta(a+c)/2$ and $d = \beta a$. Thus, the probability to play strategy H increases in d.

The expected profits in the mixed equilibrium can be written as

$$\mathbb{E}[\pi_M] = p\mathbb{E}[\pi_H] + (1-p)\mathbb{E}[\pi_2].$$

It follows that

$$\frac{\partial \mathbb{E}[\pi_M]}{\partial d} = (1-p)\frac{\partial \mathbb{E}[\pi_2]}{\partial d} - \frac{\partial p}{\partial d}(\mathbb{E}[\pi_2] - \mathbb{E}[\pi_H]),$$

where both terms are positive. Plugging in p's derivative yields

$$\begin{aligned}\frac{\partial \mathbb{E}[\pi_M]}{\partial d} \quad = \quad & -\frac{\partial \mathbb{E}[\pi_2]}{\partial d}(\mathbb{E}[\pi_1] - \mathbb{E}[\pi_H])(\mathbb{E}[\pi_A] - \mathbb{E}[\pi_1]) + \\ & \frac{\partial \mathbb{E}[\pi_A]}{\partial d}(\mathbb{E}[\pi_1] - \mathbb{E}[\pi_H])(\mathbb{E}[\pi_2] - \mathbb{E}[\pi_H]) + \\ & \frac{\partial \mathbb{E}[\pi_1]}{\partial d}(\mathbb{E}[\pi_2] - \mathbb{E}[\pi_A])(\mathbb{E}[\pi_2] - \mathbb{E}[\pi_H]).\end{aligned}$$

By the analysis in the main text we have close to $\beta_H(d)$ that $\mathbb{E}[\pi_1] \approx \mathbb{E}[\pi_H]$ and $\mathbb{E}[\pi_2] \geq \mathbb{E}[\pi_A]$. Thus, expected profits decrease in d. However, expected profits may also increase. For example at parameters $a = 1$, $c = 1/5$, $\beta = 2/3$, and $d = 1/3$, the expected profits are 0.1417, yet at $d = 0.334$ expected profits are 0.1418.

By contrast to the main text, expected profits are continuous. The non-monotonicity follows from the same economic effect discussed in the main text. Disposal costs decrease expected profits under strategy A, precisely $\mathbb{E}[\pi_A]$ and $\mathbb{E}[\pi_1]$, thus firms play strategy A with a smaller probability if d increases. However, in the mixed equilibrium an asymmetric outcome arises with probability $p(1-p)$. In this asymmetric outcome, the second firm has an information advantage; its valuation increases in d. The probability p increases in d, and whenever it is close to 1, this positive effect is a rare event. Therefore, only the negative effect remains, and expected profits decrease.

N Firms. In this section we extend the model from section 1.4 in the main text to N symmetric firms. Lets repeat the set-up. Each firm produces inventory $\bar{q}_i$ at zero marginal costs. After demand's realization, firms choose their sales volume q_i. On the one hand, if the sales volume exceeds the firm's inventory, the additional quantity induces marginal costs of $c > 0$. On the other hand, if a firm's sales volume deceeds its inventory, the disposed of quantity induces marginal costs of $d > 0$. A firm's profits can be written as

$$\mathbb{E}[\pi(q_i, \bar{q}_i)] = \mathbb{E}[P_s(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}],$$

where the inverse demand is $P_s(Q) = a - b_s(Q)$. The intercept $a > \max\{c, d\}$ is common knowledge, while the slope b_s takes on the value $b_l = 1 + \beta$ or $b_h = 1 - \beta$, each with equal probability. Q is the total sales volume, i.e., the sum of q_i over all N.

As in the main text, we assume that firms do not observe their competitors' inventories. In the second stage, a firm takes its own inventory as given and chooses $q_i \geq 0$ to maximize

$$\pi(q_i|\bar{q}_i) = P_s(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\}.$$

The optimal strategy can be derived as in the main text and written as

$$q_i(Q_{-i}|\bar{q}_i) = \max\left\{\min\left\{\max\left\{\frac{a+d}{2b_s} - \frac{1}{2}Q_{-i}, 0\right\}, \bar{q}_i\right\}, \frac{a-c}{2b_s} - \frac{1}{2}Q_{-i}\right\},$$

where $Q_{-i} = \sum_{j \neq i} q_j$ is the other firms' sales volume. Since firms compete with a homogeneous product, it is of now matter for firm i how Q_{-i} is complied.

By the same argument, we immediately get the optimal inventory strategy

$$\bar{q}_i(Q_{-i,l}, Q_{-i,h}) = \begin{cases} \frac{a+c}{2(1+\beta)} - \frac{1}{2}Q_{-i,l}, \text{if } d > c \text{ and } Q_{-i,h} - Q_{-i,l} < \frac{2(\beta a - c)}{1-\beta^2}; \\ \frac{a-d}{2(1-\beta)} - \frac{1}{2}Q_{-i,h}, \text{if } c > d \text{ and } Q_{-i,h} - Q_{-i,l} < \frac{2(\beta a - d)}{1-\beta^2}; \\ \frac{a}{2} - \frac{1+\beta}{4}Q_{-i,l} - \frac{1-\beta}{4}Q_{-i,h}, \text{else.} \end{cases}$$

q_i	high demand	low demand
$d < \min\{\beta a, c\}$	$\frac{a-d}{(N+1)(1-\beta)}$	$\frac{a+d}{(N+1)(1+\beta)}$
$\beta a \leq \min\{c, d\}$	$\frac{a}{(N+1)}$	$\frac{a}{(N+1)}$
$c < \min\{\beta a, d\}$	$\frac{a-c}{(N+1)(1-\beta)}$	$\frac{a+c}{(N+1)(1+\beta)}$

Table 1.5: N-firms' inventory and sales volume with multiple manufacturing sites. Inventory equals the sales volume in the high (low) demand state if $d < \min\{\beta a, c\}$ ($c < \min\{\beta a, d\}$).

We immediately obtain the symmetric equilibrium inventories and sales quantities summarized in Table 1.5.

Comparing Table 1.5 with Table 1.4 in the main text, shows that the equilibrium is similar and thus the results in Proposition 1.3 remain valid for any number of firms. However, an interesting trade off for policymakers arises in the number of firms. Suppose $d < \min\{\beta a, c\}$, thus, firms dispose of if demand materializes below expectations. Expected consumer surplus can be written as

$$\mathbb{E}[CS] = \left(\frac{N}{2(N+1)}\right)^2 \left(\frac{(a-d)^2}{1-\beta} + \frac{(a+d)^2}{1+\beta}\right).$$

Expected consumer surplus increases in the number of firms, $N/(N+1) < (N+1)/(N+2) \Leftrightarrow N^2 + 2N < N^2 + 2N + 1$, which generally results from increased competition. The expected disposal, however, also increases in the number of firms. It can be written as

$$\mathbb{E}[N(\bar{q}_i - q_i)] = \frac{2N}{(N+1)} \frac{\beta a - d}{(1-\beta)^2}$$

and by the same formal argument as above, expected disposal increases in the number of firms. Disposal costs decrease the disposed of quantity, as in the main text, moreover even stronger the more firms are in the market.

In this set-up, increasing competition due to the number of firms benefits consumers yet increases the disposal. Policymakers concerned about the discarded quantities, therefore, face a trade-off.

Suppose firms face fixed costs, such that there exists an upper bound on N where firms expect positive profits. Let's denote the fix cost by F, firms' expected profits can be written as

$$\mathbb{E}[\pi_i] = \frac{1}{2(N+1)^2}\left(\frac{(a-d)^2}{1-\beta} + \frac{(a+d)^2}{1+\beta}\right) - F.$$

Increasing disposal costs decrease profits. Consequently, the upper bound on N decreases, and some firms leave the market. A decrease in firms' number decreases competition and thus consumer surplus, while firms may benefit from fewer competitors. Generally, consumers are worse off if disposal is costly due to the lower inventory hold by firms and, additionally, to a decrease in the number of firms.

Observable Inventories. This section contains the formal derivation of the discussion in section 1.4. We use the same model as above for $N = 2$. By contrast, we assume that firms observe their competitor's inventories before choosing their sales volume. Remind that we assume $a \geq 2c + d$ to ensure that both firms are active.

In the second stage, firms take their inventory as given and maximize their profits

$$\pi(q_i|\bar{q}_i) = P_s(Q)q_i - c\max\{(q_i - \bar{q}_i, 0\} - d\max\{(\bar{q}_i - q_i, 0\},$$

yielding the best response function (1.15) in the main text.

$$q_i(q_j|\bar{q}_i) = \max\left\{\min\left\{\max\left\{\frac{a+d}{2b_s} - \frac{1}{2}q_j, 0\right\}, \bar{q}_i\right\}, \frac{a-c}{2b_s} - \frac{1}{2}q_j\right\}.$$

Since competitors observe inventories, we derive the sales game's subgame equilibrium following any firm's inventory choice. Lets denote the firm with the larger inventory as 1 and the other by 2, i.e., we assume without loss of generality $\bar{q}_1 \geq \bar{q}_2$. Combining the best response functions, we can derive the unique subgame equilibrium for different ranges of parameters, which we summarize in the following Lemma.

Lemma 1.4. *Let $\bar{q}_1 \geq \bar{q}_2$. The unique subgame equilibrium sales volumes following the inventories*

(i) $\bar{q}_1 \leq \frac{a-c}{3b_s}$ *are*

$$q_1 = q_2 = \frac{a-c}{3b_s};$$

(ii) $\bar{q}_1 \in [\frac{a-c}{3b_s}, \frac{a+c+2d}{3b_s}]$ *and* $\bar{q}_2 \leq \frac{a-c}{2b_s} - \frac{1}{2}\bar{q}_1$ *are*

$$q_1 = \bar{q}_1 \text{ and } q_2 = \frac{a-c}{2b_s} - \frac{1}{2}\bar{q}_1;$$

(iii) $\bar{q}_1 \leq \frac{a+d}{2b_s} - \frac{1}{2}\bar{q}_2$ *and* $\bar{q}_2 \geq \frac{a-c}{2b_s} - \frac{1}{2}\bar{q}_1$ *are*

$$q_1 = \bar{q}_1 \text{ and } q_2 = \bar{q}_2;$$

(iv) $\bar{q}_1 \geq \frac{a+c+2d}{3b_s}$ *and* $\bar{q}_2 \geq \frac{a-2c-d}{3b_s}$ *are*

$$q_1 = \frac{a+c+2d}{3b_s} \text{ and } q_2 = \frac{a-2c-d}{3b_s};$$

(v) $\bar{q}_1 \geq \frac{a+d}{2b_s} - \frac{1}{2}\bar{q}_2$ *and* $\bar{q}_2 \in [\frac{a-2c-d}{3b_s}, \frac{a+d}{3b_s}]$ *are*

$$q_1 = \frac{a+d}{2b_s} - \frac{1}{2}\bar{q}_2 \text{ and } q_2 = \bar{q}_2;$$

(vi) $\bar{q}_2 \geq \frac{a+d}{3b_s}$ *are*

$$q_1 = q_2 = \frac{a+d}{3b_s}.$$

Only in subgames (ii) and (iii) does firm i sell its inventory. Otherwise, it always produces additional quantities or disposes of.

To derive all equilibria, we first exclude inventory ranges that are never optimal and, therefore no candidates for an equilibrium. Start with $\bar{q}_1 < (a-c)/(3(1+\beta))$, both firms produce additional quantity even if demand is below expectation. By increasing their inventory, firms decrease their costs. Similarly if $\bar{q}_2 > (a+d)/(3(1-\beta))$, both firms dispose of even if demand is above expectations. Firms decrease their costs by decreasing their inventory.

The maximal quantity that firm 1 could sell is $(a+c+2d)/(3(1-\beta))$, thus any larger inventory is never optimal. Similarly, the minimal quantity that firm 2 could sell is $(a-2c-d)/(3(1+\beta))$, thus any lower inventory is never optimal.

If $\bar{q}_1 > (a+d)/(2(1-\beta)) - \bar{q}_2/2$, firm 1 disposes of even if demand is above expectations. By decreasing its inventory the firm decreases its costs. Similarly, if $\bar{q}_2 < (a-c)/(2(1+\beta)) - \bar{q}_1/2$, firm 2 decreases its costs if it increases its inventory since it produces additional quantities even if demand is below expectations.

There remain six different areas for the inventory's equilibrium strategy. We summarize them in the following Lemma.

Lemma 1.5. *Let $\bar{q}_1 \geq \bar{q}_2$. The following six areas may contain an equilibrium.*

(i) If $\bar{q}_1 \leq \frac{a-c}{3(1-\beta)}$ and $\bar{q}_2 \geq \frac{a-c}{2(1+\beta)} - \frac{1}{2}\bar{q}_1$, firms sell their inventory in the low demand state and produce additional quantities if demand is above expectations.

(ii) If $\bar{q}_1 \leq \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2$ and $\bar{q}_2 \geq \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1$, firms sell their inventories regardless of the demand's realization.

(iii) If $\bar{q}_1 \leq \frac{a+d}{2(1-\beta)} - \frac{1}{2}\bar{q}_2$ and $\bar{q}_2 \geq \frac{a+d}{3(1+\beta)}$, firms sell their inventories if demand is above expectations and disposes of otherwise.

(iv) If $\bar{q}_1 \in [\frac{a-c}{3(1-\beta)}, \frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2]$ and $\bar{q}_2 \in [\frac{a-c}{2(1+\beta)} - \frac{1}{2}\bar{q}_1, \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1]$, firm 1 sells its inventory regardless of the demand's realization, while firm 2 sells its inventory if demand is below expectation and produces additional quantities otherwise.

(v) If $\bar{q}_1 \in [\frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2, \frac{a+d}{2(1-\beta)} - \frac{1}{2}\bar{q}_2]$ and $\bar{q}_2 \in [\frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1, \frac{a+d}{3(1+\beta)}]$, firm 1 sells its inventory if demand is above expectation and disposes of otherwise, while firm 2 sells its inventory regardless of demand's realization.

(vi) If $\bar{q}_1 \in [\frac{a+d}{2(1+\beta)} - \frac{1}{2}\bar{q}_2, \frac{a+c+2d}{3(1-\beta)}]$ and $\bar{q}_2 \in [\frac{a-2c-d}{3(1+\beta)}, \frac{a-c}{2(1-\beta)} - \frac{1}{2}\bar{q}_1]$, firm 1 sells its inventory if demand is above expectation and disposes of otherwise, while firm 2 sells its inventory if demand is below expectations and produces additional quantities otherwise.

Next, we analyze each area for an equilibrium. We use as in the proof in the main text $\hat{q}_1$ if the sales volume is not equal to the inventory and explicitly $\bar{q}_1$ if it equals the inventory. In (i) firm 1's profits are $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\hat{q}_1+q_{2,h}-c))\hat{q}_1+(a-(1+\beta)(\bar{q}_1+q_{2,l})-c)\bar{q}_1]/2+c\bar{q}_1$, implying a unique symmetric interior solution $\bar{q}_i = (a+c)/(3(1+\beta))$ if $c < \min\{\beta a, d\}$, in (ii), $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\bar{q}_1+q_{2,h}-c))\bar{q}_1+(a-(1+\beta)(\bar{q}_1+q_{2,l}))\bar{q}_1]/2$ implying the unique symmetric equilibrium $\bar{q}_i = a/3$ if $\beta a \leq \min\{c, d\}$, and in (iii), $\mathbb{E}[\pi_1] = [(a-(1-\beta)(\bar{q}_1+q_{2,h}+d))\bar{q}_1+(a-(1+\beta)(\hat{q}_1+q_{2,l})+d)\hat{q}_1]/2 - d\bar{q}_1$ implying the unique symmetric equilibrium $\bar{q}_i = (a+d)/(3(1+\beta))$ if $d \leq \min\{\beta a, c\}$. For the technical details see the proof of Proposition 1.3 in the main text; the symmetric equilibrium is equivalent. Hence, the same symmetric equilibrium exists regardless if inventory is observed or not.

Finally, we analyze asymmetric equilibria. Focus first on (iv), firm's best replies are technically already derived in the proof of Proposition 1.3. The unique equilibrium candidate is $\bar{q}_1 = q_{1,h} = q_{1,l} = 2a/(5+2\beta)$ and $\bar{q}_2 = q_{2,l} = (3a+5c+2\beta c)/(2(1+\beta)(5+2\beta))$, which is indeed an interior equilibrium if $\beta a \geq c$, $c(5+2\beta)+a-8\beta a \geq 0$ and $(c-2d)(5+2\beta)+a+4\beta a \leq 0$. Note that this equilibrium is independent of d, only its existence depends on the disposal costs. If disposal costs are low, this equilibrium does not exist.

We show next, that in (v) no equilibrium exists. The unique candidate is given by $\bar{q}_1 = q_{1,h} = (3a - d(5-2\beta))/(2(1-\beta)(5-2\beta))$, $q_{1,l} = (3a - 4\beta a + d(5-2\beta))/(2(1+\beta)(5-2\beta))$, and $\bar{q}_2 = q_{2,h} = q_{2,l} = 2a/(5-2\beta)$. Necessary condition for its existence are $d \leq \beta a$ and $d \geq (a+8\beta a)/(5-2\beta)$, hence, the range for d only exists if $a + 3\beta a + 2\beta^2 a \leq 0$, which yields a contradiction.

Lastly we derive the equilibrium in (vi). The inventories' first order conditions are already derived in the proof of Proposition 1.3. This implies the unique equilibrium candidate $\bar{q}_1 = q_{1,h} = (a+c-2d)/(2(1-\beta))$, $q_{1,l} = (a-2c+3d)/(4(1+\beta))$, $\bar{q}_2 = q_{2,l} = (a+2c-d)/(2(1+\beta))$, and $q_{2,h} = (a-3c+2d)/(4(1-\beta))$. This indeed forms an interior equilibrium if $d \geq (a+c)/10$, $(7+\beta)d \leq a + 3\beta a + 4c$, and $4d \geq a - 3\beta a + 7c - \beta c$. We summarize the equilibrium in the following Proposition.

Proposition 1.4. *If* $\max\{(a+c)/10, (a+7c-3\beta a-\beta c)/4\} \leq d \leq \min\{(a+4c+3\beta a)/(7+\beta), a-2c\}$, *the firms' inventories are*

$$\begin{aligned} \bar{q}_1 &= \frac{a+c-2d}{2(1-\beta)}; \\ \bar{q}_2 &= \frac{a+2c-d}{2(1+\beta)}, \end{aligned}$$

and sale volumes

$$\begin{aligned} q_{1,h} &= \bar{q}_i; & q_{1,l} &= \tfrac{a-2c+3d}{4(1+\beta)}; \\ q_{2,h} &= \tfrac{a-3c+2d}{4(1-\beta)}; & q_{2,l} &= \bar{q}_2. \end{aligned}$$

Firm 1 *disposes of if demand is lower than expected; firm* 2 *produces additional quantities if demand is higher than expected, otherwise firms sell their inventories. Expected prices, disposal, profits, and consumer surplus* *are*

$$\begin{aligned}
\mathbb{E}[P] &= \frac{2a-c+d}{8}; \\
\mathbb{E}[\bar{q}_1 - q_1] &= \frac{a+3\beta a+4c-(7+\beta)d}{4(1-\beta^2)}; \\
\mathbb{E}[\pi_1] &= \frac{(a-2c+3d)^2}{32(1+\beta)} + \frac{(a+c-2d)^2}{16(1-\beta)}; \\
\mathbb{E}[\pi_2] &= \frac{(a-3c+2d)^2}{32(1-\beta)} + \frac{(a+2c-d)^2}{16(1+\beta)}; \\
\mathbb{E}[CS] &= \frac{(3a-c-2d)^2}{64(1-\beta)} + \frac{(3a+2c+d)^2}{64(1+\beta)}.
\end{aligned}$$

Expected disposal and consumer surplus decreases with disposal costs, while expected prices and firm 2's profits increase; firm 1's expected profits are ambiguous.

By contrast to the other cases, expected prices increase in disposal costs. Firms decrease their inventories, and thus expected trade volume decreases, implying higher prices. Firms' hand an increase in disposal costs over to consumers. Interestingly, expected prices decrease with c. The higher the production cost in the second period, the more firms increase their inventory, which is produced at zero costs. Parts of this reduced production costs are handed over to consumers.

Expected disposal decreases in its costs, as in the other cases. The larger firm is the one disposing of if demand is below expectations. Higher disposal costs decrease the firm's inventory and disposal. Therefore, its sales volume in the high demand state is lower, yet higher if demand is below expectations. By contrast, the smaller firm sells less if demand is below expectations and increases its sales volume if demand is above expectations.

Profits and consumer surplus are convex in d. Firm 1's profits are ambiguously affected by d. On the one hand, firm 1's cost increase if demand is below expectations. On the other hand, firm 1's sales volume also increases, resulting in a larger market share. The total effect on profits is thus ambiguous.

Firm 2 produces mainly in the second period, thus, with an information advantage: the higher disposal costs, the more severe this information advantage, increasing firm 2's profits.

Consequently, there exist parameter ranges, where both profits increase. Consumer surplus, however, decreases in d. Firms produce less inventory if disposal is costly. If demand is higher than expected, firms indeed produce additional quantity yet at higher costs. Therefore, the trade volume decreases and, thereby, consumer surplus.

For further discussion see the main text. Conclusively, we present next the numerical simulation to show that firms may oppose to observe their competitor's inventory. Suppose $a = 1$, $c = 1/4$, and $\beta = 3/4$. With $d = 1/2$ it follows $\mathbb{E}[\pi_2] = 0.231 \geq \mathbb{E}[\pi_i] = 0.1746 \geq \mathbb{E}[\pi_1] = 0.087$, thus the smaller firm prefers if inventories are observable but the larger one is worse off. With $d = 1/3$, $\mathbb{E}[\pi_i] = 0.1746 \geq \mathbb{E}[\pi_2] = 0.1536 \geq \mathbb{E}[\pi_1] = 0.1252$, thus both firms prefers if inventories are private. Finally, with $d = 1/5$, $\mathbb{E}[\pi_1] = 0.2022 \geq \mathbb{E}[\pi_i] = 0.1879 \geq \mathbb{E}[\pi_2] = 0.1132$, thus the larger firm prefers if inventories are observed.

Chapter 2

Rebating Antitrust Fines to Encourage Private Damages Negotiations

Abstract

To encourage private negotiations for damages in antitrust cases some jurisdictions subtract a fraction of the redress from the fine. We analyze the effectiveness of this policy. Such a rebate does not encourage settlement negotiations that would otherwise not occur. If, however, the parties settle without the rebate, the introduction of the reduction increases the settlement amount, yet at the price of reduced deterrence for those wrongdoers who are actually fined. Under a leniency program the rebate does not affect the leniency applicant: she doesn't pay a fine that can be reduced. The overall effect of a fine reduction on deterrence is, therefore, negative.

2.1 Introduction

Antitrust rules are enforced publicly by competition agencies, typically by way of fines. Moreover, they can be enforced privately by the victims of an infringement through damage actions. In quite a few jurisdictions there is concern about the underdevelopment of private antitrust enforcement. For example, while in the US private cases already amount to at least 90% of antitrust enforcement, in the EU no more than 10% of antitrust enforcement was private.[1] During the period 2006-2012 less than 25% of the Commission's

[1] EU (2007), p. 28.

infringement decisions were followed by private damages actions. Cases were mostly brought in Germany, the Netherlands, and the United Kingdom, while no follow-on actions were reported in 20 out of 28 member states.[2]

Several factors contribute to this underdevelopment: Typically, jurisdictions in Europe do not allow for collective actions and do not award punitive damages. Furthermore, the plaintiff in a civil suit does not have the means of an antitrust authority like dawn raids etc. to prove the infringement.[3] Finally, the plaintiff assumes substantial expense risk, in particular if the English cost allocation rule applies and contingency fees are not allowed.

To encourage private antitrust enforcement the EU adopted Directive 2014/104/EU in 2014. The Directive establishes the right of victims to obtain full compensation for the harm caused by an anti-competitive conduct. Full compensation includes actual losses and loss of profit, plus interest from the time the harm occurred until compensation is paid. In order to ensure that the right to full compensation is effectively guaranteed, the Directive introduces a number of measures which should facilitate antitrust damages claims in EU Member States.[4]

One measure that has been put forward lately is to subtract part of a voluntary redress paid to the victims from the fine. For example, in its decisions *Strassenbau* and *Engadin II* (3.9.2019), the Swiss Competition Commission subtracted half of the settlement payment paid by the bid rigging construction companies to the victim (the Canton of Graubünden) from the wrongdoers' fines.[5] Likewise, in June 2014 the Israeli Antitrust Tribunal approved a consent decree reached between Israeli banks who allegedly exchanged information and the Israeli Antitrust Authority providing that the entire settlement payment would be subtracted from the wrongdoers' fine.[6]

The EU also allows for this possibility. For instance, the Directive (EU) 2019/1 of the European Parliament and of the Council states: (47)... " NCAs [national competition authorities] should be able to take into account any compensation paid as a result of a *consensual settlement*" [our emphasis] and in Article 14(2) "Member States shall ensure that national competition authorities may consider compensation paid as a result of a *consensual settlement* [our emphasis] when determining the amount of the fine to be imposed

[2]OECD (2015), p. 5.

[3]The burden of proof is, however, lower in a civil than in an administrative suit.

[4]For details about the measures, see, e.g., OECD (2015).

[5]www.newsd.admin.ch/newsd/message/attachments/58229.pdf (last accessed March 15, 2021).

[6]See H″43129-03-10 Bank Hapoalim Ltd. v. Director General of the Israeli Antitrust Authority (15.6.2014).

for an infringement of Article 101 or 102 TFEU, in accordance with Article 18(3) of Directive 2014/104/EU."[7]

In this chapter we analyze whether rebating fines indeed stimulates private damage negotiations. Furthermore, we study the effects on deterrence, in particular if a leniency program applies.

A firm has been fined by the antitrust authority for anti-competitive behavior. The victim seeks damages. The victim and the firm may settle the case out-of-court. The competition authority subtracts a fraction of the settlement payment from the wrongdoer's fine. If they do not reach a settlement, the victim can take the case to court.

The players' payoffs from going to court determine their threat points in the bargaining stage. Bargaining is of the random offeror type.[8] If the plaintiff does not go to court in the last stage, his outside option whilst bargaining is zero. The defendant will, therefore, not settle. This holds independently of the amount that is subtracted from the defendant's fine. Rebating the fine thus does not stimulate settlements that would otherwise not occur.

If the plaintiff goes to court, the parties settle without the rebate. Introducing the reduction increases the settlement amount: the rebate increases the surplus and at the same time lowers the defendant's marginal cost of settling. Thus, if parties settle without the rebate, its introduction increases the settlement amount.

Ex ante the prospect of paying the fine and the settlement potentially deter the defendant. The rebate lowers the fine and at the same time increases the settlement. In our set-up the first effect is stronger than the second one—deterrence, therefore, goes down.

[7]https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2019:011: FULL&from=EN (last accessed March 15, 2021). In two cases, *Pre-Insulated Pipes Cartel* [1999] OJ L24/1 and *Nintendo* [2003] OJ L255/33, the European Commission granted reductions of fines in recognition of the fact that the wrongdoers had paid substantial compensation. The European Commission refused to grant reductions in other cases. The EC Court of First Instance confirmed in *Archer Daniels Midland v Commission* [2006] ECR II-3627 that there is no obligation to grant such reductions. The UK offers to reduce the fine by 5-10% should an undertaking make a voluntary redress in the processing on imposing penalty. In Korea the competition agencies can apply a 20-30% reduction. In Turkey the fine can be reduced at a rate of 25-60%. In Canada restitution is a factor that can be taken into account by a court in imposing a sentence for a criminal offence. The Dutch and Spanish competition authorities take into account voluntary compensation as a mitigating circumstance in setting the fine. In the US the Department of Justice does not grant rebates; there voluntary compensation is one of the conditions for obtaining leniency. See Wils (2009), OECD (2015), and Cartel Working Group (2019).

[8]In the first appendix we extend our results to the Nash Bargaining Solution.

Then we look at a leniency applicant under a leniency program. Since the leniency applicant is exempted from the fine, she does not care about the rebate. The rebate reduces deterrence for non whistle blowers. It does not affect deterrence for the leniency applicant. The relative incentive to turn the cartel members in, therefore, goes down. Consequently, the overall effect of a rebate on deterrence is negative.

Finally, we show that our results remain true if the agents have asymmetric rather than symmetric information.

Rebating fines is thus not a clever idea in our framework. It does not stimulate settlements that would not occur absent the rebate. If parties settle without the reduction, the rebate increases the settlement amount—however, at the price of reduced deterrence. Moreover, the rebate makes it less attractive for a cartel member to blow the whistle under a leniency program.

Related Literature. We are not aware of any formal papers focusing on fine rebates. There is a literature concerning private and public enforcement of antitrust laws.[9] Shavell (1997) analyzes the divergence between the private and social motives to sue. When a plaintiff contemplates litigating, he does neither consider the legal costs incurred by others, nor does he recognize the positive effects on deterrence. Shavell discusses several corrective policies, one of which is to foster settlement over trial. McAfee et al. (2008) show that if courts are accurate, adding private to public enforcement increases welfare; if courts are not accurate, private enforcement increases welfare only if the government is inefficient in litigation. Bourjade et al. (2009) study antitrust litigation and settlement under asymmetric information. They find that increasing damages induce more private litigation of well-founded cases than reducing filing costs.

Buccirossi et al. (2019) analyze whether private actions for damages may jeopardize leniency programs. The evidence provided by the leniency applicant may be used in the damage action. Moreover, since the leniency applicant typically does not challenge the decision of the antitrust authority, under joint liability she may be the first one to be targeted in a private action.[10] Buccirossi et al. show that damage actions improve a leniency pro-

[9] See, e.g., Segal and Whinston (2007) for a survey.

[10] There are, however, exceptions. In the air cargo cartel Lufthansa received full immunity from fines under the European Commission's leniency program because it was the first to provide information about the cartel (europa.eu/rapid/press-release_IP-10-1487_en.htm?locale=en, last accessed March 15, 2021). Nevertheless, Lufthansa filed an appeal "based on legal considerations" (www.bloomberg.com/news/articles/2011-01-27/japan-airlines-appeals-48-8-million-antitrust-fine-at-eu-court, last accessed March 15, 2021).

gram if civil liability of the immunity recipient is minimized and full access to all evidence gathered by the competition authority is given to the claimants.

There is a fairly large literature on settlement bargaining. It typically finds that with symmetric information parties settle rather than file a costly suit. To generate litigation the literature resorts to asymmetric information. The workhorses are either screening models where the uninformed party screens for private information using the settlement proposals (Bebchuk (1984) and Nalebuff (1987)), or signalling models where the informed party signals private information with the settlement offers (Reinganum and Wilde (1986)).[11] We follow Nalebuff (1987).

The rest of this chapter is organized as follows. The next section describes the model. In section 3 we derive our results on settlement and deterrence under symmetric information. In section 4 we discuss the asymmetric information set-up. The last section concludes. In the appendix we derive the Nash Bargaining Solution which corresponds to the solution of the random offeror game. Finally, the appendix contains the derivation of the asymmetric information scenario.

2.2 Model

A firm has engaged in anti-competitive behavior by, e.g., participating in a cartel. The competition authority has, therefore, levied the firm a fine $f > 0$. After the fine is determined, the victim of the infringement contemplates obtaining damages from the wrongdoer.[12]

The parties first try to negotiate an out-of-court settlement; if successful, the victim gets $S \geq 0$ from the wrongdoer and drops the case. If settlement negotiations break down, the victim/plaintiff can take the firm/defendant to trial. Going to court costs each party to the conflict $c > 0$. The court awards (expected) damages $D > 0$ to the plaintiff. Going to court thus generates payoffs $D - c$ for the plaintiff and $-f - D - c$ for the defendant. Alternatively, the victim can drop the case and gets 0.[13]

The payoffs from the court's decision determine the players' outside options/threat points in the settlement negotiations. The settlement amount

[11] See, e.g., Kennan and Wilson (1993) or Spier (2007) for surveys.

[12] We model private enforcement as an action that follows on a public enforcement decision. Private enforcement can also be a stand-alone action—a civil action brought without any prior finding of competition law violation by an antitrust authority. In most jurisdictions private enforcement is, however, mostly represented by follow-on private actions; see OECD (2015).

[13] The firm made a profit and the victim suffered a loss from the anti-competitive behavior. Yet, these payoffs are sunk for the problem under consideration.

S is determined by random offeror bargaining: with equal probability either the plaintiff makes a take-it-or-leave-it demand or the defendant makes a take-it-or-leave-it offer.[14]

The antitrust authority wants to stimulate settlement negotiations. It will subtract the fraction $\lambda \in [0, 1]$ of the settlement payment from the fine. The wrongdoer will, therefore, end up with a net fine of $f - \lambda S$. To avoid tedious sub cases let f be sufficiently large so that the net fine is non-negative. The formal condition on f and the analysis of small fines are relegated to the appendix.

2.3 Results

We solve the game by backward induction. After negotiations have failed, the plaintiff takes the case to court if it has positive expected value, i.e., if $D - c > 0$; otherwise, he drops the case, leading to a payoff of 0 for the plaintiff and $-f$ for the defendant.

Let us now turn to the settlement stage. Consider first the case where the plaintiff goes to court. By settling the parties save the cost $2c$ and generate the subsidy λS. The least the plaintiff is willing to accept is his outside option $D - c$; the most the defendant is willing to pay is S that satisfies $S + f - \lambda S = D + c + f$ or $S = (D + c)/(1 - \lambda)$. The plaintiff when it is his turn, therefore, demands $(D + c)/(1 - \lambda)$ and the defendant when it is her turn offers $D - c$. This yields with equal probabilities of making the offer an expected settlement

$$\mathbb{E}[S] = \frac{1}{2}\left(D - c + \frac{D + c}{1 - \lambda}\right) =: s.$$

If the plaintiff drops the case, by settling the parties do not save the cost of going to court; the surplus consists only of the subsidy λS. The plaintiff's outside option in the bargaining process is 0, meaning he accepts 0. The defendant's threat point is f. She is willing to pay S up to $S + f - \lambda S = f$ or $S = 0$. The expected settlement is, therefore, $s = 0$.

In the first stage, the plaintiff will go for damages if $s > 0$ or, equivalently, $D - c > 0$; otherwise, he will not try to collect damages.

[14] The probability of the plaintiff making his demand in the random offeror game corresponds to his bargaining power in the Nash Bargaining Solution. In the appendix we fully characterize the Nash Bargaining Solution for any bargaining power. The Nash Bargaining Solution is thus also a solution of the random offeror game with varying probabilities of making the offer.

To sum up: If $D - c > 0$, the plaintiff goes for damages. The parties agree on the settlement payment $s = .5[D - c + (D + c)/(1 - \lambda)]$. Without settlement the plaintiff would take the case to court. The plaintiff ends up with payoff s while the defendant gets $-f - (1 - \lambda)s$. If $D - c \leq 0$, the plaintiff will not go for damages. He has payoff 0 and the defendant ends up with $-f$.[15]

Settlement Stimulation. This result has several interesting implications. If $D - c < 0$, the plaintiff will not litigate if asked to do so. In the negotiation stage, the threat to go to court is not credible. The solution concept of subgame perfection/backward induction implies that the defendant ignores empty threats and, therefore, does not settle. This result holds for any value of the rebate λ: Even if the full amount of the settlement can be subtracted from the fine (like in the Israeli case mentioned in the Introduction), there will be no settlement unless the plaintiff indeed takes the case to court.[16] To stimulate settlement negotiations that would otherwise not take place, subtracting the settlement payment from the fine is ineffective. To trigger settlement bargaining, the plaintiff has to be induced to actually take the case to court. This can, e.g., be achieved by increasing D or lowering c.[17]

Consider now the case $D > c$. Here the plaintiff would take the case to court and the parties, therefore, agree on the settlement $s = .5(D - c + (D + c)/(1 - \lambda))$. The settlement amount increases in λ at an increasing rate.[18] Thus, if the competition authority wants larger settlement amounts, increasing the fraction λ that can be subtracted from the fine is effective—given the parties engage in settlement negotiations in the first place.

The fraction λ affects the settlement via two channels. First, reducing the fine increases the surplus of not going to court, thus making the pie larger. Second, the higher λ the lower the defendant's marginal cost of settling: for each unit the plaintiff obtains, the defendant effectively only pays $(1 - \lambda)$. For example, in the aforementioned Israeli case where $\lambda = 1$, each Shekel the

[15]In an earlier version of this chapter we show that qualitatively the same results obtain if the parties exogenously split the surplus from settlement. See https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3527422 (last accessed March 15, 2021).

[16]For $\lambda = 1$ the defendant is actually indifferent as to s. Yet, with a small bargaining cost $s = 0$ is the unique outcome. If $D > c$, $\lambda = 1$ yields corner solutions such as, e.g., $s = f$ for net payments to be non-negative. See the appendix.

[17]It seems difficult for the competition authority to influence D and c which are after all in the realm of the civil court. The antitrust agency could, e.g., grant access to documents from the antitrust case to the plaintiff, thus lowering c and increasing D.

[18]Formally, $\partial s/\partial\lambda = (D + c)/2(1 - \lambda)^2 > 0$ and $\partial^2 s/\partial\lambda^2 = (D + c)/(1 - \lambda)^3 > 0$.

plaintiff got was entirely subtracted from the fine so that banks' marginal cost was zero.[19]

Deterrence. Let us now turn to deterrence. The defendant is deterred by the sum of the fine and damages. We denote this total expected payment which eventually deters by z.

If $D \leq c$, $s = 0$ and $z = f$. Consider now the interesting case $D > c$. Increasing λ increases the reduction in the fine, making the surplus from settlement larger. The surplus is shared, implying that not only the plaintiff but also the defendant benefits from a reduction in fine. Specifically, $z = f + (1-\lambda)s = f + D - .5\lambda(D-c)$; the first term measures public deterrence, the second term private deterrence, and the third term captures the effect of rebate. The total payment is decreasing in λ.[20] Increasing λ increases s—the marginal effect on the settlement. However, the fraction the wrongdoer deducts goes up as well and also applies to the inframarginal settlement amount. The effect from reducing the inframarginal units is stronger than the marginal effect: the total payment of a cartel member is lower, the higher the reduction in fine λ. Consequently, deterrence is weakened if firms anticipate the reduction in fine.

Given that the fine reduction weakens deterrence for an "ordinary" cartel member, it is interesting to analyze the effects on a leniency applicant under a leniency program; we use the subscript a for the applicant and no subscript for the other cartelists.[21] Suppose the leniency program grants full leniency to the first applicant. Since the applicant's fine is zero, it cannot be reduced in case of a settlement.

Consider now the two cases: If $D \leq c$, the plaintiff does not go to court so that $s = 0$; the applicant's total payment $z_a = 0$. If $D > c$, the plaintiff's threat to sue the applicant is credible. The total surplus from an out-of-court settlement is $2c$, there is no fine that can be reduced. The plaintiff has the outside option $D - c$ and the defendant $D + c$. Random offeror bargaining yields $s = D$ which implies $z_a = D$.

The leniency applicant's total payment z_a is thus either 0 or D. It is independent of λ. It is lower than her colleague's total payment z which is either f or $f + (1-\lambda)s$. Yet, for $D > c$ the colleague's total payment z is decreasing in λ, so that the difference $z - z_a$ also shrinks. Consequently, the relative attractiveness of blowing the whistle (alternatively, the loss of being the sucker) goes down with λ. This argument actually holds for any level of

[19] The two effects are reminiscent of the income and substitution effects in consumption resulting from a price decrease.

[20] Formally, $\partial z/\partial\lambda = -(D-c)/2 < 0$.

[21] There is a fairly large literature on leniency programs; see, e.g., Motta and Polo (2003), Spagnolo (2004), or Chen and Rey (2013). For a survey see Harrington (2006b).

liability of the leniency applicant.[22] The fact that she pays no fine that can be reduced drives the result.[23]

Whether the reduced deterrence is detrimental or not depends on the status quo. If we start out with underdeterrence, rebating the fine may increase underdeterrence. Suppose, by contrast, that the damage awarded by the court reflects the harm to the public. The total payment of damage plus fine exceeds the harm and potentially leads to overdeterrence. In this case, rebating the fine may reduce overdeterrence.[24]

2.4 Asymmetric Information

To illustrate the effects of a fine reduction under asymmetric information, we have to further specify the set-up, in particular the bargaining process. We choose the framework developed by Nalebuff (1987).[25] The defendant has superior information about the damage than the plaintiff.[26] Specifically, the defendant knows the realization D of the damages. The plaintiff only knows that damages are drawn from a probability distribution. In the appendix we consider the general case of log-concave distributions; here we confine our attention to damages being uniformly distributed on $[0, 1]$.

Bargaining proceeds as follows: In the first stage, the uninformed plaintiff makes take-it-or-leave-it demand S. In the second stage, the informed defendant either accepts or rejects the settlement demand. If she accepts, bargaining is over. Otherwise, there is a third stage where the plaintiff either drops the case or proceeds to court.

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[22]For example, in the EU Art. 11(4) of Directive 2014/104/EU provides "that an immunity recipient is jointly and severally liable as follows: (a) to its direct or indirect purchasers or providers; and (b) to other injured parties only where full compensation cannot be obtained from the other undertakings that were involved in the same infringement of competition law." In the US the 2004 Antitrust Criminal Penalty Enhancement and Reform Act eliminates treble damages and joint liability for the amnesty recipient.

[23]Note that we do not answer the general question of whether or not damage actions reduce the attractiveness of leniency programs. This issue is, e.g., addressed in Buccirossi et al. (2019).

[24]For these argument to be valid the firms must have several different possibilities to collude. With only one possibility, charging the monopoly price say, any sanction greater or equal to the harm deters monopoly pricing and there is no overdeterrence. To meaningfully talk about over- or underdeterrence, there must be more than one option to collude; see Emons (2020). For a discussion of sub-optimal cartel fines see, e.g., Bageri et al. (2013).

[25]Nalebuff (1987) extends Bebchuk (1984) to possible negative value claims.

[26]Osborne (1999) presents some empirical evidence that defendants actually do better in predicting court rulings than plaintiffs.

If the case has ex ante negative expected value, the defendant will reject any demand S. The plaintiff gets no new information through bargaining. He does not update his expectation and, therefore, does not litigate. This result corresponds to our symmetric information one and holds for any value of λ. Rebating the fine has thus no effect on deterrence.

Let us now turn to the other possibility where the case has ex ante positive expected value. Specifically, for our uniformly distributed damage example, assume the cost to go to court $c \leq 1/4$.

The equilibrium depends on the size of the fine. Let us sketch the outcome for a large fine $f \geq \lambda(1-c+2\lambda c)/(1-\lambda^2)$. The plaintiff demands $S = (1-c+2\lambda c)/(1-\lambda^2)$ which is increasing in λ. If the defendant accepts this demand, she incurs the cost $f+(1-\lambda)S$. If she rejects and the plaintiff takes the case to court, her cost is $f+D+c$. Defendants with $D \leq \hat{D} := (1-2c+\lambda c)/(1+\lambda)$, therefore, reject the demand; defendants with $D > \hat{D}$ accept. If the plaintiff takes the rejections to court, he expects to get $\hat{D}/2$ which exceeds the litigation cost for $c \leq 1/4$. The plaintiff, therefore, indeed takes the rejected demands to court.[27] Note that the parties go to court for low D even though this is inefficient—the typical outcome under asymmetric information; see Myerson and Satterthwaite (1983).

Let us now turn to deterrence. If $D \leq \hat{D}$, the defendant rejects, is taken to court, and ends up paying $f+D+c$. This total payment is independent of λ. If $D > \hat{D}$, the defendant accepts and her total payment is $Z = f+(1-\lambda)S = f+(1-c+2\lambda c)/(1+\lambda)$. This total payment is decreasing in λ.[28] Increasing λ increases S. Yet, the deductible fraction also goes up, with the second effect stronger than the first one. Thus, reducing the fine decreases deterrence.[29] Note that $\hat{D}$ decreases with λ: the higher the rebate, the fewer cases are prosecuted. This has, however, no effect on deterrence because type $\hat{D}$ is indifferent between accepting S and going to court.

2.5 Conclusion

In this chapter we have analyzed the effects of rebating fines by the redress paid to the victims. This policy turns out to be fairly ineffective, if not counterproductive, in our set-up. It does not stimulate settlements that would

[27] The results for medium and small fines are as follows: For all values of f the plaintiff goes to court. If $f \in (\lambda(1-c), \lambda(1-c+2\lambda c)/(1-\lambda^2))$, the plaintiff demands $S = f/\lambda$ and $\hat{D} = f(1-\lambda)/\lambda - c$. For $f \leq \lambda(1-c)$, $s = 1-c$ and $\hat{D} = 1-2c-f$.

[28] Formally, $\partial Z/\partial\lambda = (3c-1)/(1+\lambda)^2 < 0$ for $c \leq 1/4$.

[29] The same result holds for medium values of f. For small values of f increasing λ has no effect on deterrence.

otherwise not take place. If parties settle without the reduction, the rebate indeed increases the settlement amount—however, at the cost of reduced deterrence. Moreover, the rebate makes it less attractive for a cartel member to blow the whistle under a leniency program.

A few remarks are in order. Our results rely heavily on backward induction arguments. If the plaintiff does not take the case to court, he has no credible threat in the settlement negotiations. The defendant, therefore, rejects any settlement demand in the first place, independently of the rebate. Backward induction/subgame perfection is probably the most widely accepted refinement of the Nash equilibrium concept. Any results which are based on empty threats would not seem convincing to us.

For our findings on deterrence the defendant needs to rationally foresee the fine reduction. This applies, e.g., if the rebate is a well established policy of the antitrust authority. This was probably not the case in the Swiss decisions. The Swiss Competition Commission granted the rebate for the first time in 2019. It seems unlikely that the construction companies anticipated the fine reduction when they engaged in bid rigging during the years 2004-2012. If the rebate is an unexpected or a random event like in the EU, it has no or little effect on deterrence.

We have focused on follow-on private actions which is the prevailing form of private enforcement. The analysis of stand-alone private actions raises some additional issues: Are there at all follow-on public actions with a fine that can be reduced? Does the antitrust authority subtract only uncontested redress as in our set-up, or is contested redress also eligible? These questions are left for future research.

2.A Nash Bargainig Solution

In this appendix we completely characterize Nash Bargaining Solution (NBS) which is also the solution of the alternating offeror game.[30] Moreover, we deal properly with small fines, i.e., $f < D\lambda/(1-\lambda)$.

The NBS yields a reasonable outcome without explicitly modeling the bargaining game. Since the NBS corresponds to the expected settlement of the alternating offeror game, we denote it by s^*. Note that in our set-up the settlement is not only a transfer of surplus from the defendant to the plaintiff; it is also a means to increase the size of the surplus.

Let $\alpha \in (0,1)$ denote the bargaining power of the plaintiff and $(1-\alpha)$ the bargaining power of the defendant. The plaintiff settles if $s \geq \max\{0, D-c\}$. The defendant can at most reduce her fine to zero, i.e., she settles if $s + \max\{f - \lambda s, 0\} \leq D + c + f$.

First, consider the case $D \leq c$. The NBS s^* maximizes

$$s^{\alpha}\left(-s - \max\{f - \lambda s, 0\} + f\right)^{1-\alpha}.$$

We have $s^* = 0$ which is the same outcome as in the main text. Whenever the plaintiff has a non-credible threat, there is no settlement payment.

Next suppose $D > c$; the plaintiff's threat to sue is thus credible. If the parties settle, the plaintiff gets s and the defendant pays $s + \max\{f - \lambda s, 0\}$. The outside option if bargaining fails are $D - c$ for the plaintiff and $-D-c-f$ for the defendant. The NBS s^* maximizes

$$(s - D + c)^{\alpha}\left(-s - \max\{f - \lambda s, 0\} + f + D + c\right)^{1-\alpha}$$

which yields the solution

$$s^* = \begin{cases} \bar{s}, & \text{if } f \geq \lambda \bar{s}; \\ f/\lambda, & \text{if } \lambda \hat{s} \leq f < \lambda \bar{s}; \\ \check{s}, & \text{if } f < \lambda \hat{s}, \end{cases}$$

where $\bar{s} := (1-\alpha)(D-c) + \alpha(D+c)/(1-\lambda)$, $\hat{s} := (D - c(1-2\alpha))/(1-\lambda\alpha)$, and $\check{s} := D + c(2\alpha - 1) + \alpha f$.

First note that s^* is also the solution of the alternating offeror game where α denotes the probability that the plaintiff makes the offer.

If $s^* = \bar{s}$, we have qualitatively the same results as in the main text.[31] The settlement increases at an increasing rate in λ. The plaintiff's bargaining

[30] For more on the NBS see, e.g., Roth (1979). Binmore et al. (1986) analyze the relation between the static NBS and a sequential bargaining model à la Rubinstein (1982).

[31] In the other two cases the net fine is zero.

power as measured by α determines the distribution of the surplus. The gains of the plaintiff are $\bar{s} - (D - c) = \alpha(2c + \lambda(D - c))/(1 - \lambda)$ and gains of the defendant amount to $(1-\alpha)(2c+\lambda(D-c))$. The plaintiff benefits more from the fine reduction than the defendant if $\lambda \geq (1 - 2\alpha)/(1 - \alpha)$. For α small, a large λ is necessary for the plaintiff to gain more than the defendant; for $\alpha \geq 1/2$ the plaintiff does better for any λ.[32]

In our set-up the plaintiff does not get the share α of the surplus $2c+\lambda s$. λ increases the surplus by decreasing the defendant's marginal cost: for each unit the plaintiff obtains, the defendant only pays $1 - \lambda$. The plaintiff's marginal utility is one while the defendant's marginal disutility is only $1 - \lambda$. Whenever parties' marginal utilities differ, the NBS does not yield the distribution $\alpha/(1 - \alpha)$ of the surplus: the party with the higher marginal utility gets more than his/her bargaining power.[33]

Finally, consider deterrence. Here we have $z = f +^{(} D - (1 - 2\alpha)c) - (\lambda(1-\alpha)(D-c))$; the first term measures public deterrence, the second term private deterrence, and the third term captures the effect of rebate. Private deterrence goes up with the plaintiff's bargaining power. The effect of λ on deterrence is negative, yet less so the stronger the plaintiff. A powerful plaintiff gets most of the surplus created by the rebate, resulting in a small effect on deterrence.

[32] $\bar{s}$ is a supermodular function in α and λ, thus the effect on $\bar{s}$ from increasing λ is stronger the higher α.

[33] See, e.g., Mas-Colell et al. (1995), p. 842-843 or Osborne and Rubinstein (1990), p. 18-19.

2.B Asymmetric Information

In this appendix, we derive the equilibrium under asymmetric information sketched in the main text for log-concave distributions. The defendant knows the realization of D while the plaintiff only knows its distribution. D is distributed on $[\underline{D}, \overline{D}]$ with density g and CDF G. The density has full support, is differentiable, and log-concave. Moreover, $\underline{D} < c$, i.e., negative value cases are possible. Let D define the defendant's type.

In the first stage of bargaining, the uninformed plaintiff makes a take-it-or-leave-it demand S. In the second stage, the informed defendant either rejects or accepts the settlement demand. If she accepts, bargaining is over. If she rejects, there is a third stage where the plaintiff either drops the case or proceeds to court. Denote the probability that the plaintiff litigates by η.

If the parties settle out of court, the plaintiff gets S and the defendant pays $Z := S + \max\{f - \lambda S, 0\}$. If the plaintiff litigates, he gets $D - c$ and the defendant pays $D + c + f$. When the case is dropped, the plaintiff gets zero and the defendant pays f.

For all possible values of S we will first derive Nash equilibria for the subgames starting in stage 2. Then we will determine the plaintiff's optimal demand S.

Consider first the defendant in stage 2. A defendant of type $D \geq D(S, \eta)$ accepts the settlement offer S, where

$$D(S, \eta) := \frac{Z(S) - \eta c - f}{\eta}.$$

Next consider the plaintiff in stage 3. Since negative expected value claims are possible, there exists a unique cut-off value $\hat{D}$ where the plaintiff is indifferent between litigating or dropping the case. $\hat{D}$ is defined by

$$\frac{1}{G(\hat{D})} \int_{\underline{D}}^{\hat{D}} xg(x) \, \mathrm{d}x = \mathbb{E}[D | D \leq \hat{D}] = c.$$

If $D < \hat{D}$, the plaintiff drops the case, thus $\eta = 0$. If $D > \hat{D}$, the plaintiff litigates, i.e., $\eta = 1$. If $D = \hat{D}$, the plaintiff is indifferent, accordingly, $\eta \in [0, 1]$. The cut-off $\hat{D}$ is independent of S and λ.

We distinguish between two possibilities: the case has a priori negative or positive expected value. Let us start with the easy one where $\mathbb{E}[D] \leq c$, i.e., the case has negative expected value. For all possible S, the defendant rejects the demand. The plaintiff learns nothing from the defendant's decision, sticks to his prior, and chooses $\eta = 0$ since $\mathbb{E}[D] \leq c$. This result holds for any value of the rebate λ. For negative expected value cases subtracting the settlement payment from the fine is, therefore, ineffective in stimulating settlement negotiations.

Let us now turn to the interesting possibility where $\mathbb{E}[D] > c$, i.e., the case has a priori positive expected value. Suppose $\eta = 1$. Then defendants with $D \leq D(S,1)$ reject the demand. If $\hat{D} \leq D(S,1)$, or equivalently $\mathbb{E}[D|D \leq D(S,1)] > c$, the plaintiff will indeed go to court. If $\hat{D} > D(S,1)$, or equivalently $\mathbb{E}[D|D \leq D(S,1)] < c$, the plaintiff will not go to court: a pure strategy equilibrium fails to exist. Therefore, we construct a mixed strategy equilibrium. The plaintiff is willing to mix in stage 3 if $D(S,\eta) = \hat{D}$ which immediately yields $\eta = (Z-f)/(\hat{D}+c)$. Defendants with $D < \hat{D}$ reject S. Plaintiffs are indifferent whether to drop the case or not.

We summarize these results in the following Lemma.

Lemma 2.1. *Let* $\mathbb{E}[D] > c$.

(i) If $\hat{D} \leq D(S,1)$*, the plaintiff litigates with* $\eta = 1$ *and defendants of type* $D > D(S,1)$ *accept while the others reject;*

(ii) if $\hat{D} > D(S,1)$*, the plaintiff litigates with* $\eta = (Z-f)/(\hat{D}+c)$ *and defendants of type* $D > \hat{D}$ *accept while the others reject.*

Lemma 2.1 establishes for any settlement demand S an equilibrium for the ensuing subgame. The plaintiff thus chooses S so as to maximize

$$(1 - G(D(S)))S + G(D(S))\eta(S)(\mathbb{E}[D|D \leq D(S)] - c),$$

where write $D(S)$ instead of $D(S,\eta(S))$.

With probability $(1-G(D(S)))$ the defendant accepts and pays S. With probability $G(D(S)))$ the defendant rejects the demand. The plaintiff litigates with probability $\eta(S)$ which yields in expectation $\mathbb{E}[D|D \leq D(S)]$ at a cost c. With probability $(1-\eta(S))$ he drops the case and gets nothing.

Rather than solving the plaintiff's problem directly for S, we determine the defendant's total payment Z where $S = \min\{(Z-f)/(1-\lambda), Z\}$. The plaintiff thus picks Z so as to maximize

$$V(Z) = (1 - G(q(Z)))\min\{\frac{Z-f}{1-\lambda}, Z\} + G(q(Z))\beta(Z)(\mathbb{E}[D|D \leq q(Z)] - c),$$

where $\beta(Z) := \min\{(Z-f)/(\hat{D}+c), 1\}$ and $q(Z) := (Z - \beta(Z)c - f)/\beta(Z)$. $V(Z)$ is continuous; furthermore, it is differentiable except at $Z = f/\lambda$ and $Z = \hat{D} + c + f$.

$V(Z)$ strictly increases if $Z \leq \hat{D} + c + f$: The condition implies the case (ii) of Lemma 1, i.e., defendants of type $D \geq \hat{D}$ accept the plaintiff's demand. The threshold type is independent of Z. Therefore, $G(q(Z))$ is constant in Z while all remaining terms increase in Z. Thus, the defendant's minimal payment to the plaintiff is $\hat{D}+c+f$, which is independent of λ.

The equilibrium payment Z is given by the following Proposition:

Proposition 2.1. *If $\lambda \leq f/(\hat{D}+c+f)$, the defendant pays:*

$$Z = \begin{cases} \hat{D}+c+f, & \text{if } V_1'(\hat{D}+c+f) < 0; \\ Z_1, & \text{if } V_1'(\hat{D}+c+f) \geq 0 > V_1'(f/\lambda); \\ f/\lambda, & \text{if } V_1'(f/\lambda) \geq 0 > V_2'(f/\lambda); \\ Z_2, & \text{if } V_2'(f/\lambda) \geq 0, \end{cases}$$

where $V_1'(\cdot)$, $V_2'(\cdot)$, Z_1, and Z_2 are defined in the proof. Z weakly decreases in λ.

If $\lambda > f/(\hat{D}+c+f)$, the defendant pays:

$$Z = \begin{cases} \hat{D}+c+f, & \text{if } V_2'(\hat{D}+c+f) < 0; \\ Z_2, & \text{if } V_2'(\hat{D}+c+f) \geq 0, \end{cases}$$

where $V_2'(\cdot)$ and Z_2 are defined in the proof. Z is independent of λ.

Proof. Consider first the case $\lambda \leq f/(\hat{D}+c+f)$. We split the plaintiff's problem into two parts:

$$\begin{aligned} &\max_Z V_1(Z) = (1-G(q(Z)))\frac{Z-f}{1-\lambda} + G(q(Z))(\mathbb{E}[D|D \leq q(Z)] - c) \\ &\text{s.t. } \hat{D}+c+f \leq Z \leq f/\lambda, \end{aligned} \tag{2.1}$$

and

$$\begin{aligned} &\max_Z V_2(Z) = (1-G(q(Z)))Z + G(q(Z))(\mathbb{E}[D|D \leq q(Z)] - c) \\ &\text{s.t. } Z \geq f/\lambda, \end{aligned} \tag{2.2}$$

with $q(Z) = Z - c - f$.

We first analyze problem (2.1) without constraints. The first order condition can be written as

$$(1-\lambda)V_1'(Z) = 1 - G(q(Z)) - g(q(Z))(2c(1-\lambda) + (Z-f)\lambda) = 0.$$

Plugging the first order condition into the second order condition

$$(1-\lambda)V_1''(Z) = -g(q(Z))(1+\lambda) - g'(q(Z))(2c(1-\lambda) + (Z-f)\lambda) < 0$$

and rearranging shows that the second order condition holds if

$$g^2(\cdot)(1+\lambda) + g'(\cdot)(1 - G(\cdot)) > 0,$$

which is true for log-concave $g(\cdot)$. Consequently, if it is interior, there exists a unique maximum Z_1.

With the implicit function theorem we derive the sign of $dZ_1/d\lambda$. Since $V_1''(Z) < 0$, the sign is determined by the sign of

$$\frac{\partial^2 V_1(Z;\lambda)}{\partial Z \partial \lambda}(1-\lambda)^2 = 1 - G(q(Z)) - g(q(Z))(Z - f).$$

Plugging in the first order condition shows that this expression is negative if and only if $g(q(Z))(1-\lambda)(-Z+f+2c) \leq 0$; this holds since $Z \geq \hat{D}+c+f \geq 2c+f$. We have thus shown that if the solution is interior, Z_1 decreases in λ, which implies that deterrence goes down with the fine's reduction. The solution is indeed interior if the following two conditions hold: $V_1'(\hat{D}+c+f) > 0$ and $V_1'(f/\lambda) < 0$.[34]

Next consider problem (2.2). Ignoring the constraints, the first order condition can be written as

$$V_2'(Z) = 1 - G(q(Z)) - g(q(Z))(2c+f) = 0.$$

The second order condition is

$$V_2''(Z) = -g(q(Z)) - g'(q(Z))(2c+f) < 0$$

and plugging in the first order condition and manipulating shows that the condition is equivalent to

$$g^2(\cdot) + g'(\cdot)(1 - G(\cdot)) > 0,$$

which holds for log-concave $g(\cdot)$. Thus, there exists a unique maximum Z_2 which is independent of λ. To have an interior solution, $V_2'(f/\lambda) > 0$.

Finally, consider the case $\lambda > f/(\hat{D}+c+f)$. The plaintiff's problem simplifies to

$$\begin{aligned} &\max_Z V_2(Z) = (1 - G(q(Z)))Z + G(q(Z))(\mathbb{E}[D|D \leq q(Z)] - c) \\ &\text{s.t. } Z \geq \hat{D} + c + f. \end{aligned} \tag{2.3}$$

Problem (2.3) has the same first order condition for an interior solution as problem (2.2). The solution does not depend on λ. The maximum is either $Z = \hat{D}+c+f$ or, if $V_2'(\hat{D}+c+f) > 0$, the interior solution Z_2. Thus, whenever $\lambda > f/(\hat{D}+c+f)$, there is no effect on the deterrence. □

[34]Note that $q(Z_1)$ also decreases, which implies that more defendants will accept the settlement demand: fewer cases will be taken to court.

When Z equals Z_1 or f/λ, deterrence goes down with the rebate. All other payments of the defendant do not depend on λ. Consequently, deterrence weakly decreases in the fine reduction.

Finally, we analyze how the reduction affects trials. Due to asymmetric information some cases go to court. Only defendants of type $D \geq D(S, \eta)$ accept the settlement offer. The plaintiff's offer S results in a subgame of case (i) in Lemma 1. The plaintiff always litigates when a defendant rejects his offer, i.e., $\eta = 1$. Thus, in the subgame perfect equilibrium, defendants of type $D \geq D(S, 1) = Z(S) - c - f$ accept the plaintiff's offer. It follows from Proposition 1 that the defendant's payment Z weakly decreases in λ. A reduction in fine encourages out of court settlement, yet only if the plaintiff credibly litigates.

The reduction in fine lowers the defendant's payment Z and thereby incentivizes her to accept the plaintiff's settlement offer. Consider the defendant's expected payment

$$z = \int_{\underline{D}}^{Z-c-f} (D + c + f) \; \mathrm{d}G(D) + \int_{Z-c-f}^{\bar{D}} Z \; \mathrm{d}G(D).$$

Using Leibniz rule we get

$$\frac{\partial z}{\partial \lambda} = Zg(Z - c - f) - Zg(Z - c - f) + \int_{Z-c-f}^{\bar{D}} \frac{\partial Z}{\partial \lambda} \; \mathrm{d}G(D) \leq 0.$$

Similar to symmetric information, the defendant's expected payment decreases in λ—resulting in lower deterrence.

Chapter 3

Cartel Stability in Times of Low Interest Rates

Abstract

We study the interest rate's effect on the stability of cartels. A low interest rate implies a high discount factor and thus increases cartel stability. If firms access the capital market, an additional effect comes into play: a low interest rate lowers investment costs, resulting in more profitable deviations from the collusive agreement. We propose a new measure for a cartel's stability regarding the two opposing effects. Stability is U-shaped in the interest rate. We test our theory using a dataset of 615 firms and find supporting evidence. We conclude that the current unusually low interest rate facilitates collusion.

3.1 Introduction

Low interest rates mark the last decade. The financial crisis heralded the start of a new era: worldwide, central banks keep interest rates down to stimulate the economy. Nevertheless, the recovery is sluggish, and interest rates remain low to boost the economy and inflation. In this chapter, we analyze possible adverse effects of the current monetary policy. More precisely, we study how the interest rate affects the formation and stability of cartels.

When interest rates are low, a dollar tomorrow has just about the same value as a dollar today. Accordingly, future values are only little discounted. The discount factor is inversely related to the interest rate. The higher the discount factor, the more patient are the market participants. Firms value long-term additional profits from collusion more than a large one-time gain by deviating from the collusive agreement. Technically, collusion's net present value increases when interest rates are low. Following this argument, the current monetary policy encourages formation of cartels and stabilizes them.

Although the argument is correct, it ignores another interesting channel. Typically, firms operate with borrowed capital under financial constraints. The interest rate determines a firm's capital cost. When interest rates are low, firms can borrow outside capital inexpensively and invest in production. Whereas if interest rates are high, firms' investments may be impossible if they do not have enough own means. Therefore, in times of high interest rates, competition may be weak because firms have not enough resources to compete for the entire market.

Moreover, cartelists have fewer incentives to deviate from their collusive agreement when they face binding financial constraints. Suppose the cartelists have colluded on how to split the market. Even if a cartel member deviates and tries to extend its production, it may lack the necessary means to serve large parts of the market. Low interests facilitate new investment opportunities; thus, numerous deviation strategies may arise.

We present a model to incorporate the interest rate's different effects and propose a new measure for a cartel's stability. In our set-up, firms are locally differentiated, i.e., our model incorporates heterogeneous consumers. Each period, firms choose their production quantity and price. Firms are capital constrained. They receive the consumers' payment when the goods go over the counter. Consequently, firms face a liquidity problem when investing in their production, which is overcome by a firm's access to the financial market. The interest rate determined on the financial market affects thereby the firm's investment (opportunity) costs. When interest rates are high, firms cannot afford to serve consumers near their competitor, resulting in relatively weak competition.

Instead of competing, firms may collude on prices or on segmenting the market. Firms observe their competitor's last period price; respectively, firms can infer the competitor's price from their sales and the market conditions.[1] Our framework yields interesting price patterns: When there is an exogenous shock in the consumers' willingness to pay, e.g., due to an increased income, collusive prices increase more than competitive ones. By contrast, if there is a shock in the firms' opportunity costs, competitive prices react more. When consumers perceive the firms less differentiated, e.g., due to new regulations,[2] prices become more important than the goods' origin. Competing firms lower their prices due to increased competition; cartelists increase their prices.

[1] By contrast, Green and Porter (1984) analyze situations where firms do not know if their low sales are due to a recession or the competitor's deviation.

[2] For example, the European Parliament discusses harmonizing charger leads.

Our model can also be applied to tacit collusion, where there exists no hard evidence of the collusive agreement. A high price, therefore, serves as a message to start or sustain collusion. We derive the necessary discount factor to sustain collusion, which we denoted as the critical discount factor.

The critical discount factor depends on the colluding profits and a firm's profit if it deviates from the collusive agreement. The interest rate increases costs, thereby decreasing profits and affecting the critical discount factor. Our proposed measure for a cartel's stability depends on the one hand on the critical discount factor. On the other hand, risk neutral firms' rational discount factor is directly implied by the financial market as $1/(1+r)$, whereby r is the interest rate. The larger the difference between the rational and the critical discount factor, the more profitable a cartel is. We assume that more profitable cartels are more stable, respectively, are more likely to be formed.[3]

Our model implies a U-shaped relation between the interest rate and a cartel's stability. The result arises from the interest rate's opposing effects on the discount factors. The rational discount factor reacts most to a change in interests when their rate is low. The money's time value is doubled when the interest rate increase from 1% to 2%, yet less than doubled if the interest increases from 2% to 3%.

By contrast, the critical discount factor is only little affected by a change in the interest rate when they are low. With low interest rates, a firm can afford to invest such that if it deviates from the collusive agreement, it can conquer large parts of the market. It can even serve consumers located close to its competitor, i.e., consumers with a relatively strong preference for its competitor. Yet, those consumers have a relatively small willingness to pay and are therefore the least valuable customers. For a higher interest rate, the marginal consumers have less extreme preferences resulting in more valuable customers for the firm, i.e., the interest rate's effect on profits intensifies.[4]

Nevertheless, for very high interest rates, firms cannot afford the investments to serve the whole market and become local monopolists resulting in a critical discount factor of zero. For low interest rates, the rational discount factor's effect dominates the effect on the critical discount factor; for larger interest rates, the latter effect dominates the first, resulting in a U-shape. For very high interest rates, the critical discount factor's effect vanishes, and

[3]Instead of the discount factor's difference, we also study the ratio of the two and find similar results.

[4]Moreover, when the distribution is symmetrically single-peaked, only a few customers have strong preferences; thus, the mass of marginal consumer increases, amplifying the effect.

stability decreases monotonically in the interest rate, resulting overall in a negative cubic shape.

We doubt that very high interest rates yielding local monopolists have been observed and therefore focus on the U-shape. We test our theoretical prediction using a dataset collected by Hellwig and Hüschelrath (2018) and find empirical support for our theory. The dataset contains 615 firms active in 114 cartels convicted by the European Commission between 1999 and 2016. We first test the interest rate's U-shape with a logit model, estimating the probability that a cartel breaks up. We find significant evidence in line with our theoretical prediction. Moreover, we follow Hellwig and Hüschelrath (2018) and use survival analysis to estimate a cartel's duration. Precisely, we estimate how a firm's duration of participation depends on the interest rate using a Weibull model. Again, we find significant estimates in line with our theory.[5]

We conclude that a cartel's stability and the likelihood of its formation depend on the financial market. The interest rate affects collusion non-monotonically. In current times of unusually low interest rates, we expect the cartels' stability to be weakened when interests increase. Thus, the current monetary policy may stabilize cartels and facilitates new ones.

Related Literature. Our set-up builds on the literature on cartel stability and product differentiation. This literature usually assumes a stage game in the form of a Prisoners' Dilemma that is infinitely repeated. It is well known that for homogeneous price competition, the cartel stability only depends on the number of firms. Deneckere (1983) studies differentiated products with Cournot and Bertrand competition and finds a non-monotonic relation between cartel stability and product differentiation.[6] Collie (2006) introduces quadratic production costs. Cartel stability increases with costs, similar to our set-up. However, in their models, cartels are always less stable than cartels in a market with a homogeneous product, even in the limiting case when firms become monopolists. In our set-up, monopolists are indifferent between colluding or not; their profits stay the same.

Similar to us, Chang (1991) studies a stage game à la Hotelling. He assumes a uniform distribution of consumers and allows for different symmetric locations. In line with the literature, he finds that cartels become more stable the more differentiated products are, as long as both firms are active. He abstains from the possibility that one firm can capture the entire market and wrongly concludes a monotonic relation between cartel stability

[5]There exist, however, several problems regarding the data's quality. There is a selection bias since only convicted cartels are collected in the dataset. Furthermore, a cartel's duration may be underestimated because of lacking evidence.

[6]Deneckere (1984) corrects some mistakes in the analysis.

and product differentiation. Allowing one firm to capture the entire market also leads to a non-monotonic relation similar to the ones above. The main difference is, however, that cartels are more stable than cartels in a market with a homogeneous product, by contrast to the former.

There exists a large theoretical and empirical literature studying collusion's counter- or pro-cyclicality. In the theoretical literature, business cycles are usually modeled as exogenous changes in demand. Results are, nevertheless, ambiguous.

Rotemberg and Saloner (1986) argue that collusion is counter-cyclical: Firms deviate from cartel agreements during booms. When demand is high, a one-time deviation is more profitable, and punishment follows in periods characterized by lower demand, making the punishment less severe. Haltiwanger and Harrington (1991) and Bagwell and Staiger (1997) argue to the contrary: Cartels tend to break-up during recessions. The one-time deviation profit is largest when demand is high, yet the discounted future profits' loss is lowest in a recession. Fabra (2006) introduces capacity constraints and shows that collusion tends to be counter-cyclical when capacity constraints bind while it is pro-cyclical for sufficiently large capacities.[7]

None of those papers discuss the interest rate's effect explicitly. All consider demand shocks and study a cartel's stability employing a critical discount factor. The lower the interest rate, the higher the discount factor, i.e., cartels become more stable. The literature neglects firms' financing decisions and commonly assumes no financial restrictions. We show that incorporating the financial decision by investing with outside capital leads to a non-monotonic effect of the interest rate on collusion.

The only paper we are aware of discussing the interest rate's effect on collusion is Paha (2017). He extends Besanko et al. (2010)'s model and incorporates capacity investments. Due to the models' complexity, they rely on numerical simulations. The interest rate's effect on costs is neglected; interest rates only determine the rational discount factor. Cartelists collude on prices yet not on investment strategies. Firms' capacities independently and randomly depreciate. Low interest rates lead to asymmetric capacities as the result of preemption races for a dominant position. Asymmetric firms are less likely to agree on a collusive price, resulting in fewer cartels when interest rates are low.

Related to the mechanism Liu et al. (2020) present an analytically tractable model focusing on innovation. When interest rates are low, competition is

[7]The theoretical literature lacks an explanation for the formation of new cartels. An exception is Bos and Harrington (2010), who present a theoretical model with endogenous cartel formation in a market with many firms. In our set-up, changes in the interest rate may lead to the formation of new cartels.

intensified if firms are on the same innovation ladder's stage. Accordingly, a leader is encouraged to innovate to prevent the competitive stage, while a follower is discouraged, resulting in more asymmetric firms.[8] They do not discuss collusive agreements.

Some empirical work includes the interest rate in collusion's study. Levenstein and Suslow (2016) analyze 247 cartels accused of price-fixing and brought to the US Department of Justice between 1961 and 2013. They argue in line with the literature mentioned above: interest rates are inversely related to a firm's discount factor and incorporate it as a control in their estimations. In their dataset, lower interest rates indeed stabilize cartels and facilitate the formation of new cartels.

By contrast to the latter, Hellwig and Hüschelrath (2018) find the opposite. They study 615 firms active in 114 cartels convicted by the European Commission between 1999 and 2016. In their dataset, firms' participation duration is significantly shorter when interest rates are low, resulting in destabilized cartels and fewer formations. The authors discuss their finding only shortly in lack of theoretical arguments.

Our theory explains the opposing empirical evidence. We use the data collected by Hellwig and Hüschelrath (2018) and incorporate the interest rate's U-shape: we find supporting evidence for our theoretical prediction. By contrast to Hellwig and Hüschelrath (2018), we use the real interest rate and other macroeconomic indicators measured in real terms. Rational agents base their decision on real terms. However, results do qualitatively not change if we use nominal units.

We distinguish between two channels of the interest rate. On the one hand, it affects costs and thereby directly a firms' balance sheet. On the other hand, it determines the time value of money. The second effect has been intensively studied by the experimental literature. Collusion in infinitely repeated games is commonly studied by a repeated Prisoners' Dilemma. The player's (rational) discount factor is thereby controlled by the probability of the game's repetition. Dal Bó (2005) and Dal Bó and Fréchette (2011) show that cooperation is more likely, the higher the discount factor.

Bruttel (2009) conducts an experiment and silences the first channel by a finite repeated game. By contrast to the former, she argues along Rosenthal (1981) and Normann and Wallace (2012) that an infinite game can be approximated with a finite game. She studies stage games with different critical discount factors and finds supporting evidence for a continuous stability measure similar to the one proposed by us.

[8]This phenomenon is known as the discouragement effect in the contest literature.

In the next section, we present our theoretical model to study cartels' stability. Following this, we test our theory in an empirical analysis. Finally, we conclude.

3.2 Theoretical Model

Two firms compete for consumers of mass one, each offering a single commodity. The market is differentiated; consumers prefer one firm in the form of lower transportation costs. To serve consumers, firms first have to produce their commodities. Production requires capital, which is obtained by retained profits or the financial market. Each period, firms first decide to issue bonds at the market interest rate and then set prices. Firms either compete or collude. By collusion, we mean that firms set prices to maximize their joint profits.[9]

Firms only collude on prices. As long as the competitor sets the collusive price, firms continue with the cartel. We analyze relatively weak forms of collusion, where there is no hard evidence. Outsiders with less information about the market than the firms can hardly detect anti-competitive behavior. Furthermore, we assume the set of consumers to be the same in each period. Next, we describe the stage game.

Stage Game. There is a unit mass of consumers symmetrically distributed between two firms. The cumulative distribution function $F(x)$ is twice continuously differentiable and strictly log-concave on its compact support. Without loss of generality, let F's support be $[-1, 1]$. We denote the density as $f(x) = F'(x)$, which we assume to be strictly positive on its support.[10] The distribution reflects heterogeneous consumers' preferences. Whenever relatively many consumers are indifferent between the two firms, $f(0)$ is high. A consumer located near the support's boundary has a strong preference for a firm; price differences are less relevant for those consumers.

Consumer $x \in [-1, 1]$ has utility $U - p_i - t|x_i - x|$ if she buys the good at firm i at price p_i, where $x_i \in \{-1, 1\}$ is the firm's location.[11] U is the utility of having the good in monetary units, and $t > 0$ is the transportation cost, representing competition's intensity. If consumer x does not buy the

[9] We denote the collusive price as the monopoly price. In an infinitely repeated game, firms could collude on any price between the competitive and the monopoly price, whereby the monopoly price is the payoff dominating allocation. Results are qualitatively similar if firms collude at a lower price. However, a cartel is more stable if firms collude on lower prices. We discuss this in the appendix.

[10] Technically, log-concavity means $f^2(x) - F(x)f'(x) > 0$ and symmetry $f(x) = f(-x)$.

[11] Results are qualitatively similar with quadratic transportation costs. We discuss this in the appendix followed by a discussion of endogenous product differentiation.

good, we normalize her utility to 0. We denote the firm at the support's lower bound as firm i, i.e., $x_i = -1$, and its competitor as firm j with $x_j = 1$. Accordingly, the participation constraint for a consumer to buy at firm i is $U - p_i - t(x+1) \geq 0 \Leftrightarrow x \leq (U - p_i - t)/t$, and for firm j the inequality is reversed.

Consumer x prefers buying at firm i instead of firm j if $U - p_i - t(x+1) \geq U - p_j - t(1-x) \Leftrightarrow x \leq (p_j - p_i)/(2t)$. Firm i's demand consists of the consumers participating in the market and preferring to buy its product, instead of buying at firm j. Formally,

$$D_i(p_i, p_j) = \min\left\{F\left(\frac{U - p_i - t}{t}\right), F\left(\frac{p_j - p_i}{2t}\right)\right\}.$$

We assume a constant marginal production cost $c > 0$. Costs $cD_i(p_i, p_j)$ accrue before firms sell their goods. Production has, therefore, to be financed in advance, either by firm i's own means $W_i \geq 0$ or by issuing bonds $b_i \in \mathbb{R}$. If $b_i < 0$, a firm invests in the capital market, else it borrows capital. The capital market pays an interest rate $r \geq 0$. Firm i's profit from the production and the capital market are thus $\pi_i(p_i, b_i) = (p_i - c)D_i(p_i, p_j) - rb_i - rW_i$, where the last term reflects the equity's opportunity cost. Firms can always ensure a return of rW_i resulting in zero economic profit. Using the constraint of costs incurring pre production implies $cD_i(p_i, p_j) = W_i + b_i$ and profits can be written as $\pi_i(p_i) = (p_i - (1+r)c)D_i(p_i, p_j)$. The marginal opportunity costs $C := (1+r)c$ depend on the capital market's interest rate.[12]

If $F((U - p_i - t)/t) \leq F((p_j - p_i)/(2t))$, the firm is a local monopolist. In this case, Firm i's optimal price is implicitly

$$p_m = \arg\max_{p_i}(p_i - C)F\left(\frac{U - p_i - t}{t}\right) = C + t\frac{F\left(\frac{U - p_m - t}{t}\right)}{f\left(\frac{U - p_m - t}{t}\right)}.$$

By F's log-concavity, the right-hand side decreases in p_m, while the left-hand side of the equation strictly increases, therefore, p_m is uniquely defined. Local monopoly pricing $p_i = p_j = p_m$ is an equilibrium if $F((U - p_m - t)/t) \leq F(0) \Leftrightarrow p_m \geq U - t$, which implies that firms serve less than the total market.[13]

[12]The assumption of perfect capital markets simplifies the analysis: There is only one price for capital, i.e., it is not necessary to distinguish between W_i and b_i. Therefore, a firm's dividend policy becomes irrelevant for the analysis.

[13]Firm j's condition is $1 - F((U - p_m - t)/t) \leq F(0)$ which simplifies to the same condition by the distributions symmetry $F(0) = 1/2$.

Otherwise, firms may compete. Firm i's best response function for any p_j is implicitly given by

$$p_i^*(p_j) = \arg\max_{p_i}(p_i - C)F\left(\frac{p_j - p_i}{2t}\right) = C + 2t\frac{F\left(\frac{p_j - p_i^*(p_j)}{2t}\right)}{f\left(\frac{p_j - p_i^*(p_j)}{2t}\right)}. \tag{3.1}$$

Again, by F's log-concavity, $p_i^*(p_j)$ is uniquely determined. There exits a unique and symmetric equilibrium with $p_i = p_j = p_c := C + t/f(0)$ resulting in firms' profits $\pi_c := t/(2f(0))$ if $p_c \leq U - t$.[14]

However, if $p_m \leq U - t \leq p_c$, firms serve the whole market and multiple equilibria exist with $p_i + p_j = 2U - 2t$. The only stable equilibrium to parameters' perturbations is the symmetric one with prices equal to $U - t$. We thus focus on the symmetric equilibrium when multiple equilibria exist in this corner solution.

Instead of competing, firms can collude and set prices to maximize their joint profits[15]

$$\max_{p_i, p_j}(p_i - C)D_i(p_i, p_j) + (p_j - C)D_j(p_j, p_i),$$

which are maximal for the maximal prices such that consumers still participate $p_i = p_j = p_t := U - t$. If firms trust each other and set prices p_t, a firm's profit is $\pi_t := (U - t - C)/2$. Again, this is only optimal as long firms are not local monopolists, i.e., $p_m \leq U - t$. Thus, cartelists set their price to p_t instead of competing, as long as they are not local monopolists anyways. Formally, cartel prices are p_t if $p_t \geq p_m \Leftrightarrow C \leq U - t - t/(2f(0))$ and p_m else; competitive prices are p_c if $p_c \leq p_t \Leftrightarrow C \leq U - t - t/f(0)$ and equal to the cartelists prices otherwise. The necessity of an agreement thus only arises if opportunity costs C are low, respectively, if firms are not local monopolists anyway. If $C \geq U - t - t/f(0)$, the competitive and collusive outcome are equivalent; thus, deviation only occurs for relatively low C.

Our framework predicts an interesting price pattern, which can be empirically evaluated.[16] Furthermore, antitrust authorities observing prices may use the pattern to uncover cartels. Table 3.1 gives an overview of how prices respond to different shocks. For example, if consumers perceive an increase

[14]Suppose there exists another equilibrium with $p_j^* > p_i^*$, thus $F((p_j^* - p_i^*)/(2t)) > 1/2$. Using the best reply functions we can write the difference $p_j^* - p_i^* = 2t(1 - 2F((p_j^* - p_i^*)/(2t)))/f((p_j^* - p_i^*)/(2t)) < 0$ resulting in a contradiction.

[15]In our framework, joint profit maximization is equivalent to the Nash Bargaining Solution.

[16]The price pattern is the same for any convexly increasing cost function as well as for quadratic transportation costs.

	U	C	t	f(0)
p_m	+	+	?	?
p_t	+	0	-	0
p_c	0	+	+	-

Table 3.1: Price Pattern. The table shows how prices react to exogenous shocks in the model's parameters.

in their income, their maximal willingness to pay for the product U increases, resulting in a price increase if firms are local monopolists or colluding, yet not affecting competitive prices. A cartel, like a local monopolist, competes against the consumers' outside option; the better the consumers' outside option, the lower the prices. By contrast, competing firms have to fight against their competitor's offer.

Likewise, opportunity costs only increase competitive or local monopoly prices yet do not affect collusive ones. A cartel sets prices to extract most consumer surplus while still serving the whole market. A large increase in C can, nonetheless, lead to a change in the market structure such that firms become local monopolists.

An increase in transportation costs t increases competitive prices. The distance to a firm becomes crucial for a consumer's decision; prices are negligible. Thus, firms gain market power, and prices go up. By contrast, a cartel decreases its price. If the transportation cost increases, consumers have less money to spend, and therefore, the cartel lowers its price to extract the consumer surplus' rest. A local monopolist faces both effects, resulting in an ambiguous effect.[17]

Finally, we also look at a decrease of indifferent consumers $f(0)$. This may arise from a mean preserving spread of the distribution, e.g., form an increase in consumers heterogeneity. Relatively fewer consumers are indifferent between the two firms. The fewer consumers are indifferent, the lower are firms' incentives to compete for the mass of indifferent consumers. An increase in the consumer distribution's variance may thus lead to more market power of firms, resulting in higher prices. A cartel is only interested in covering the entire market, thereby only cares about the consumer with the largest transportation cost and not the consumers' distribution. Thus, there is no effect on collusive prices. Local monopolists' prices are affected ambiguously by a change in the distribution.

[17]For uniformly distributed customers, the local monopoly price is independent of t: the two effects cancel out.

Instead of colluding, firm i could undercut its competitor's price to increase its market share. The price deviation is implicitly given by the best response (3.1) to p_t,

$$p_d := p_i^*(p_t) = C + 2t\frac{F\left(\frac{U-t-p_d}{2t}\right)}{f\left(\frac{U-t-p_d}{2t}\right)}. \tag{3.2}$$

The deviating firm makes a profit

$$\pi_d := 2t\frac{F^2\left(\frac{U-t-p_d}{2t}\right)}{f\left(\frac{U-t-p_d}{2t}\right)}.$$

Whenever $C \geq U - t - t/f(0)$, there is no gain from deviation. Firms are local monopolists, competing yields the same outcome as colluding. We therefore focus on $C = (1+r)c \leq U - t - t/f(0) \Leftrightarrow r \leq \bar{r} := (U - t - t/f(0))/c - 1$.[18] Moreover, if $U - t - p_d \geq 2t \Leftrightarrow C \leq U - 3t - 2t/f(1) \Leftrightarrow r \leq \underline{r} := (U - 3t - 2t/f(1))/c - 1$, the deviating firm can capture the entire market. Note that $\underline{r}$ may be negative.[19]

Lemma 3.1. *If consumers are symmetrically log-concave distributed and $r \in [\underline{r}, \bar{r}]$,*

(i) π_c *is constant in* r*;*

(ii) π_t *is linear and decreasing in* r*;*

(iii) π_d *is convex and decreasing in* r*;*

(iv) $\pi_c = \pi_t = \pi_d$ *at* $r = \bar{r}$*.*

By definition profits are ordered by $\pi_d \geq \pi_t \geq \pi_c$ for an interior solution, and by Lemma 3.1, the difference between the profits decreases with r. For $r \geq \bar{r}$, firms are local monopolists. This concludes the analysis of the stage game.

Stability. We assume that firms set their prices each period simultaneously. Following the literature, we assume a Grim Trigger strategy. Firms set high prices p_t as long as both have set high prices last period. If one of the two

[18] Alternatively, $(1+\bar{r}) \geq (p_t - p_c)/c + (1+r) = (\pi_t - \pi_c)/c + (1+r)$, where the right-hand side are the relative gains from colluding.

[19] $\underline{r} \leq 0$ is ensured whenever there is only a low mass of consumers at the boundaries, i.e., $= f(1) \leq 2t/(U-3t)$.

deviates, firms play the competitive price forever. Formally, the cartel is stable if

$$\sum_{\tau=0}^{\infty} \delta^{\tau} \pi_t \geq \pi_d + \sum_{\tau=1}^{\infty} \delta^{\tau} \pi_c, \tag{3.3}$$

where δ is the firms' discount factor. Accordingly, the critical discount factor to sustain collusion is

$$\delta^* := \frac{\pi_d - \pi_t}{\pi_d - \pi_c} = 1 - \frac{\pi_t - \pi_c}{\pi_d - \pi_c} \in [0, 1]. \tag{3.4}$$

Note that equation (3.3) is satisfied for any δ if $C \geq U - t - t/f(0) \Leftrightarrow r \geq \bar{r}$, and thus the minimal critical discount factor $\delta^* = 0$. Firms only have an incentive to deviate from the colluding agreement if costs are low enough.

Before we study the effect of the interest rate on cartel stability, consider how δ^* depends on the parameters. We focus on interior solutions, thus a deviating firm cannot capture the total demand, $r \geq \underline{r}$, and firms are no local monopolists, $r \leq \bar{r}$.[20]

Proposition 3.1. *If consumers are symmetrically log-concave distributed and $r \in [\underline{r}, \bar{r}]$, the critical discount factor δ^**

(i) increases in U;

(ii) decreases in C;[21]

(iii) decreases in t.[22]

The consumers' monetary utility U does not affect competitive profits if the total market is served. Firms compete against each other, and the outside option of having the good or not becomes redundant. The profits of colluding firms increase in the consumers' appreciation; they can extract more from their customers. If U is low, undercutting the competitors' price increases a firm's demand. However, the new customers have only a low willingness to pay, thus profits from deviating are small. If U is large, collusive prices are

[20]Formally, a range exists whenever $f(0) \geq f(1)/(1 + f(1))$, which is true, e.g., for any symmetric single-peaked distribution.

[21]In the corner solution, where a firm can capture the entire market by deviating ($r \leq \underline{r}$), the critical discount factor linearly increase: $\pi_d = 2t/f(1)$, thus is constant in C, while π_t linearly decreases.

[22]In the corner solution, where a firm can capture the entire market by deviating ($r \leq \underline{r}$), the critical discount factor increases for symmetrically single-peaked distributions: $\partial\delta^*/\partial t = f(0)(4 - f(1))/(4f(0) - 2f(1)) \geq 0$ if $f(1) < \min\{2f(0), 4\}$.

high: by undercutting, the deviating firm can capture a large share of the market with a relatively high price. A deviation becomes more profitable; firms have to be more patient to form a cartel, i.e., δ^* increases.

The critical discount factor decreases in the interest rate r, or more generally in the opportunity costs $C = (1 + r)c$. With low opportunity costs, firms are able to conquer large parts of the market. By deviating from the agreement, firms may reach consumers located near its competitor. A large price cut is necessary to attract those customers with a strong preference. Nevertheless, this may be too costly, and the necessary price may even be below the production costs. The larger the production costs, the less of the market is served by the deviating firm. Accordingly, even if a firm deviates from the tacit price agreement, some customers remain for the competitor. The higher the costs, the lower is the firms' necessary discount factor to collude.

Finally, if t is low, firms find it harder to collude. When consumers have low transportation costs, a firm can capture large parts of the market by undercutting the competitor's price. Accordingly, deviating from the tacit agreement can almost double demand, while it has only little effect if t is low. More precisely, competitive profits increase in t since competitors gain market power; collusive profits decrease in t because consumers incur higher costs resulting in a lower net willingness to pay. Profits from deviating also go down in t, since fewer consumers are reached with a price cut. The first two effects lower the relative value of collusion yet are outweighed by the third effect, resulting in a lower δ^* when t increases.

In general, a deviating firm's profits are more affected than the competitive or collusive ones. By symmetry, competitive firms end up with equal market shares. Similarly, a cartel divides the market into equal shares. A firm deviating from the tacit agreement ends up with a larger share of the market; thus, its inframarginal effect is stronger.

Figure 3.1 sketches the critical discount factor δ^* as a function of the interest rate r for two different levels of t. The solid black line refers to relatively low transportation costs, while the gray line refers to higher transportation costs. In Lemma 3.1 we have shown that the critical discount factor decreases in C, which implies that it also decreases in r, since $C = (1 + r)c$. Note that the critical discount factor becomes zero at $\bar{r}$. As we show in the next Lemma, δ^* is concave for sufficiently high r, i.e., r close to $\bar{r}$. Whenever the distribution is sufficiently log-concave, the critical discount factor is also concave for relatively low r.

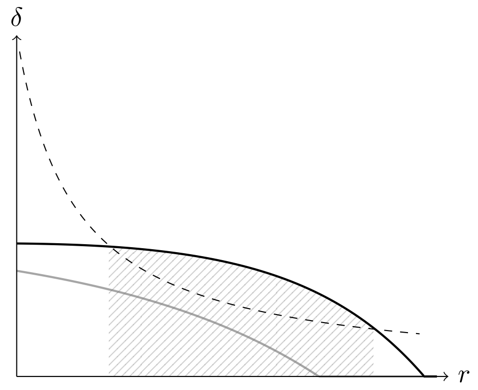

Figure 3.1: Discount factor. The solid black line refers to δ^* for parameter values $U = 10$, $c = 1$, $t = 1$, while the gray line refers to δ^* with $t = 1,5$. The distribution is single-peaked quadratic $f(x) = 2/3 - x^2/2$. The dashed line refers to the rational discount factor $\hat{\delta} = 1/(1+r)$. The gray area represents when cartels are unprofitable, i.e., $\delta^* \geq \hat{\delta}$.

Lemma 3.2. *For r lower yet close to $\bar{r}$, the critical discount factor δ^* is concave. If the consumer distribution $F(.)$ is sufficiently log-concave, δ^* is concave for all $r \leq \bar{r}$.*

For example, for the uniform distribution, δ^* is concave. Unfortunately, we have to rely on numerical evaluations for other distributions. Simulations show that δ^* is also concave for the truncated normal distribution. For the quadratic distribution $f(x) = 1/2 + s/3 - sx^2$, where $s \in (-1/5, 1/2]$ is a shape parameter, δ^* may be weakly convex for small r when the distribution is convex, i.e., has a relatively low mass in the middle. In all simulations, large interest rates affect the critical discount factor more than low interest rates.

An increase in the interest rate increases opportunity costs. Consequently, the deviating firm's price cut is less severe, and it reaches fewer customers. For low interest rates, the indifferent consumer lives relatively close to the competitor. An increase in r implies that the firm can no longer capture this customer by deviating. However, the customers the firm cannot reach are near the competitor, thus, have a lower willingness to pay due to their high transportation costs. Accordingly, the firm loses its least valued customers. The closer a customer is located to a firm, i.e., the stronger her preference, the more a firm can extract from this customer. When interest rates are high, the indifferent consumer is located near the firm's middle; thus, the deviating firm values them more, resulting in a stronger effect of the interest rate.

Moreover, if there are lots of indifferent consumers, i.e., the distribution has a large mass around its middle, the number of customers a firm cannot reach when interest rates are down is rather low, amplifying the interest rate's effect.

The interest rate does not only affect opportunity costs. It also determines a rational firm's discount factor. In our set-up, the discount factor is determined by the capital market by $\hat{\delta} := 1/(1+r)$, which we denote as the rational discount factor. Note that it only depends on the interest rate. Figure 3.1 shows the rational discount factor $\hat{\delta}$ as a dashed line.

Whenever the rational discount factor is larger than the critical discount factor, $\hat{\delta} \geq \delta^*$, a cartel is stable. Figure 3.1 shows that this is always true when δ^* is relatively low, for example, if the willingness to pay is low or transportation costs are high. Yet, there also exist parameters such that a cartel is unstable. Since $\hat{\delta}$ is convex and δ^* is concave for sufficiently log-concave distributions, the range of unstable cartels, whenever it exists, has to be intermediary. Consequently, for sufficiently low interest rates and sufficiently high interest rates, cartels are always feasible.

The profitability of a cartel can be measured by its internal rate of return IRR, formally, $\delta^* = 1/(1+IRR)$.[23] Whenever the internal rate of return is below the market's interest rate, it is unprofitable to continue or form a cartel, $IRR < r \Leftrightarrow \delta^* > \hat{\delta}$. The more profitable a cartel is, i.e., the larger IRR compared to r, the larger is the difference between the discount factors $\hat{\delta} - \delta^*$.

The literature typically assumes that a firm's decision to collude is dichotomous: if a cartel is profitable, collude; otherwise, don't.[24] Accordingly, even if a cartel is only marginally profitable, firms fully collude. We assume, by contrast, that the probability of colluding increases continuously in the profitability of a cartel. The more money is to be made by colluding, the higher the probability that firms engage in the infringement. Formally,

$$S\left(\hat{\delta}, \delta^*\right) = \begin{cases} s(\hat{\delta} - \delta^*), & \text{if } \delta^* \leq \hat{\delta}; \\ 0, & \text{if } \delta^* > \hat{\delta}, \end{cases}$$

[23] We show in the appendix that in our set-up, the IRR evaluation criterion is equivalent to the net present value (NPV) evaluation criterion.

[24] An exception is Emons (2020) analyzing a leniency program's efficiency when firms choose their degree of collusion.

where $s : [0,1] \to [0,1]$ is a strictly increasing function, with $s(0) = 0$ and $s(1) = 1$.[25] Accordingly, s is a cumulative distribution function and S can be interpreted as the probability to form or continue a cartel. Whenever the cartel is unprofitable, there is a zero probability; when the cartel becomes more profitable, the probability goes up. We present different microfoundations for our stability measure in the appendix. For example, industries differ in their risk premia or decision-makers have heterogenous priors to be prosecuted.

Proposition 3.2. *If consumers are symmetrically log-concave distributed and $r \in [0, \bar{r}]$, a cartel's stability S*

(i) decreases in r for low interest rates.

(ii) increases in r for high interest rates if

$$c \leq \frac{f(0)}{4t}\left(U - t - \frac{t}{2f(0)}\right)^2 \tag{3.5}$$

(iii) is quasiconvex for $r \in (0, \bar{r})$ if the consumer distribution $F(.)$ is sufficiently log-concave.

The main insight of Proposition 3.2 is the interest rate's non-monotone effect on stability.[26] If marginal production costs are low, or the market is competitive by either having low transportation costs t or many indifferent consumers, i.e., $f(0)$ large, stability increases for relatively large interest rates.

Proposition 3.2 is best understood by plotting the stability's properties. Figure 3.2 illustrates the cartel's stability depending on the interest rate, assuming the same distribution and parameters as in figure 3.1. Generally, Proposition 3.2 implies a local maximum at $r = 0$ and at $r = \bar{r}$, with none in between. Thus for relatively low interest rates, stability decreases; then it increases up to $\bar{r}$ and decreases afterward.

[25] Alternatively, we can measure the cartels profitability by $IRR - r = (\hat{\delta} - \delta^*)/\hat{\delta}\delta^* = 1/\delta^* - 1 - r$. For $r \geq \bar{r}$, the critical discount factor is zero, accordingly, the interests rates' difference is not defined. However, focusing on $r < \bar{r}$ and adjusting the strictly increasing $s : [0, \infty) \to [0,1]$, we can replace $\hat{\delta} - \delta^*$ by $IRR - r$ and get the same results for interior solutions: stability is U-shaped in the interest rate.

[26] Results are qualitatively similar when we use the ratio $\hat{\delta}/\delta^* = (1 + IRR)/(1 + r)$ instead of the difference $\hat{\delta} - \delta^*$ in our stability measure. However, for $r \geq \bar{r}$ the ratio is not defined since $\delta^* = 0$. Formally, the ratio decreases in r if and only if $\hat{\delta}'\delta^* \leq \hat{\delta}\delta^{*\prime}$, while the difference decreases if $\hat{\delta}' \leq \delta^{*\prime}$. At $r = 0$ we know from the proof or Proposition 3.1 $\delta^* \leq 1/2 < 1 = \hat{\delta}$, thus the ratio decreases when the difference decreases. At $r = \bar{r}$, we know $\delta^* \to 0$, thus the ratio increases.

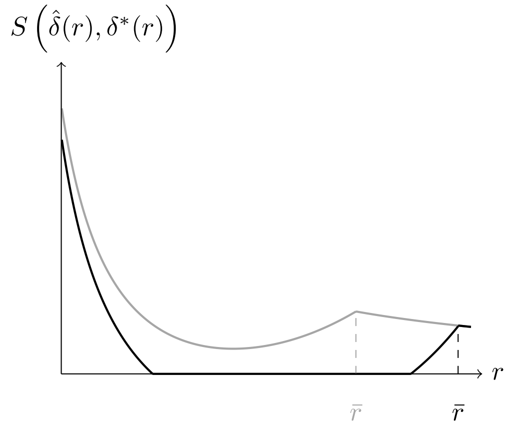

Figure 3.2: Cartel stability for parameter values as in figure 3.1, $U = 10$, $c = 1$, $t = 1$, while the gray line refers to $t = 1.5$. The distribution is single-peaked quadratic $f(x) = 2/3 - x^2/2$. The stability function is linear $s(z) = z$.

Stability is determined by the rational and the critical discount factor's difference. Both discount factors decrease in r. The rational discount factor $\hat{\delta}$ decreases in r since a larger r implies a larger time value of money. An increase from 1% to 2% doubles the capital's costs, yet an increase from 2% to 3% increases its cost by less than factor two. Consequently, the interest rate's effect on the rational discount factor is strongest for small interest rates.

The critical discount factor also decreases in the interest rate. If the interest rate is low, opportunity costs are low. Firms are thus able to conquer the total market. By deviating from the agreement, firms may reach the consumer with the strongest preference for their competitor. For larger interest rates, this is too costly. Thus, even if the competitor deviates from the tacit price agreement, some customers remain for the firm.

By contrast to the rational discount factor, the interest rate's effect on the critical discount factor is stronger for high interest rates. When interest rates are low, the deviating firm loses less valuable customers by an increase in the interest rate than when interest rates are high. The lower the interest rate, the nearer is the indifferent consumer located at the competitor. In order to convince a customer with strong preferences for the competitor to buy at the deviating firm, large price cuts are necessary, making the customer less valuable. If consumers are symmetrically single-peaked, only a small mass of consumers are near the competitor, amplifying the effect.

For low r, the effect on the rational discount factor $\hat{\delta}$ outweighs; for r close to $\bar{r}$ the effect on the critical discount factor δ^* dominates. For $r \geq \bar{r}$, firms are local monopolists and the critical discount factor is zero anyways, the rational discount factors effect dominates again, resulting in the two local maxima at 0 and $\bar{r}$.

Whenever (3.5) is satisfied, our theory yields a clear theoretical prediction of how the interest rate affects a cartel's stability. Production costs have to be low relative to the consumers' monetary utility, or competition has to be relatively strong. More precisely, competition is intense if transportation costs are low or a large mass of consumers is indifferent between the two firms. We believe that this condition is satisfied for a broad range of products. Moreover, we believe that the observed interest rates are below $\bar{r}$; thus, our theory predicts that stability is U-shape in the interest rate. In the following section, we present some empirical evidence in line with our theory.

3.3 Empirical Analysis

This section tests if the interest rate indeed affects cartel stability in a non-monotonic way, as predicted by our theory. A cartel's stability can be measured in different ways; we use two different approaches. First, we determine how the interest rate affects the probability that a cartel ends using a logit model. Second, we quantify the interest rate's effect on a firm's participation duration in a cartel using survival analysis. Next, we present the data.

Data. We use the dataset constructed by Hellwig and Hüschelrath (2018). It contains 615 firms participating in 114 cartels convicted by the European Commission between 1999 and 2016. The earliest cartel started its infringement in the second quarter in 1969, and the latest cartel in the dataset ended in 2012's second quarter. This gives us an unbalanced panel with 16'431 firm-quarter observations, respectively 3'232 cartel-quarter observations.

The dataset contains information about the infringement, firms' industries, and the cartels' spatial scope. Some cartel members entered after its start or left before the cartel ended. Hellwig and Hüschelrath (2018) analyzed the effect on cartel stability of late entries and early exits. Furthermore, the dataset contains information on the reason why an investigation started. Using this information, Hellwig and Hüschelrath (2018) classified a cartel's natural break-up if the European Commission started its investigation after the cartel ended, or in the case of a leniency applicant, if the cartel ended at least a year earlier.[27]

During the relevant period, the European Commission introduced three leniency programs to uncover illegal cartels. The first version was released

[27]For the dataset's detailed description we refer the reader to Hellwig and Hüschelrath (2018).

in the third quarter in 1996 and was inspired by the 1993 US Department of Justice's Corporate Leniency Policy. It was amplified in 2002' first quarter, whereby the main improvement was that reduction in fines became stricter aligned to the cooperation, and first applicants received automatic immunity resulting in less uncertainty in the law's interpretation. This was also the goal of the revision in 2006's fourth quarter, where a leniency applicant's duty was clarified. We construct for each revision a dummy variable equal to zero before its introduction and one afterward.

We use the long-term interest rate in the Euro area from OECD.[28] The time series refers to government bonds maturing in ten years. The interest rate is implied by the bond's trade price on the financial market and not the interest rate at which loans were issued. It starts in the first quarter of 1970, and to the best of our knowledge, it is the longest available time series for the Euro area. Firms borrowing may pay an individual risk premium, which is unfortunately unknown for the firms in our dataset.[29]

Firms decision is based on the real interest rate and not on the nominal rates. We use the Euro area's inflation rate from the World Bank,[30] which starts in 1970 and is yearly available. Under the assumption that market participants expected the actual inflation rate, we can calculate the real interest rate by subtracting the inflation rate from the nominal interest rate.[31] Alternatively, we have used nominal values instead of real ones and got similar results, yet less significant.

Figure 3.3 shows the real interest rate and the number of active cartels. The vertical lines indicate the leniency program's introduction and revisions. The figure suggests that the leniency program and its revisions were successful in decreasing the number of cartels. Marvao and Spagnolo (2014) present a detailed analysis of the leniency program's effectiveness. For the increasing cartel activity until 1995, we could only speculate. However, we tested our results additionally on a subset starting in 1995's first quarter, and results were similar, although less significant.

Figure 3.4 shows the interest rate and the active cartels' average duration in quarters. Before 1985 the sample includes only a few cartels, which lasted for two decades. The duration declines over time. Nonetheless, there may

[28] The time series is also available at FRED (IRLTLT01EZM156N).

[29] Alternatively, we use the Bank of England Official Bank Rate starting in 1975 to measure the interest rate; results are similar.

[30] https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG?locations=XC (last accessed March 15, 2021).

[31] Levenstein and Suslow (2016) use last year's inflation, which reflects a naive forecast. Following this approach, our results become less significant.

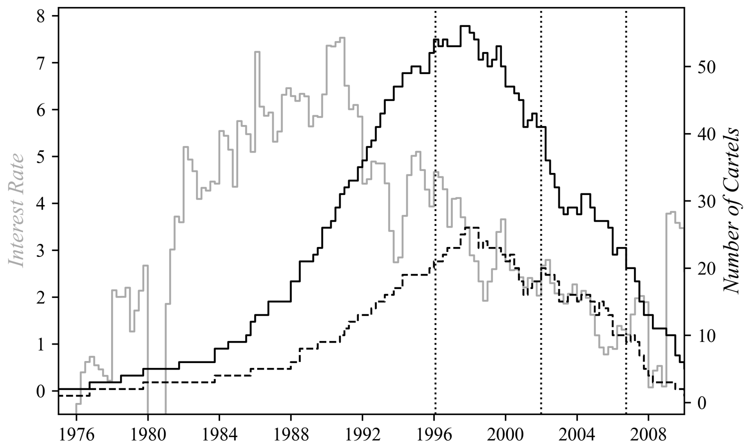

Figure 3.3: Real interest rate and number of active cartels. The solid black line refers to the total number of active cartels, dashed are the ones with a natural break-up. The vertical lines indicate leniency programs.

exist uncovered long-lasting cartels, which are not in our dataset. We discuss the biased sample problem at the end of the section.

Real GDP per capita in the Euro Area measured by the World Bank is unfortunately only yearly available. We use it to control for changes in demand resulting from a change in income.[32] Additionally, to control for Europe's general economic situation, we use the economic sentiment indicator available at Eurostat. The indicator is a weighted average of replies' balances to selected questions addressed to firms in different industries in the Eurozone.[33] It starts in the first quarter in 1985 and is measured monthly; we use a quarter's average.

Empirical Results. In our first approach, we quantify the interest rate's effect on a cartel's break-up probability. We, therefore, focus on the cartel level data. We create a variable equal to 1 if the cartel ends and zero otherwise. Thus, the variable is zero if the cartel existed and one at the time when it breaks up. Since all 114 cartels in the dataset ended and our cartel-quarter observations are 3'232, we have a treatment effect of less than 5%.[34] The binary variable of interest, cartel break-up, is denoted by Y. We use a logit

[32]Alternatively, we use the Production and Sales (MEI) from OECD statistics, which is quarterly available. Results are similar.

[33]The time series is seasonally adjusted and scaled to a long-term mean of 100.

[34]We did the same analysis with yearly instead of quarterly data; results were similar.

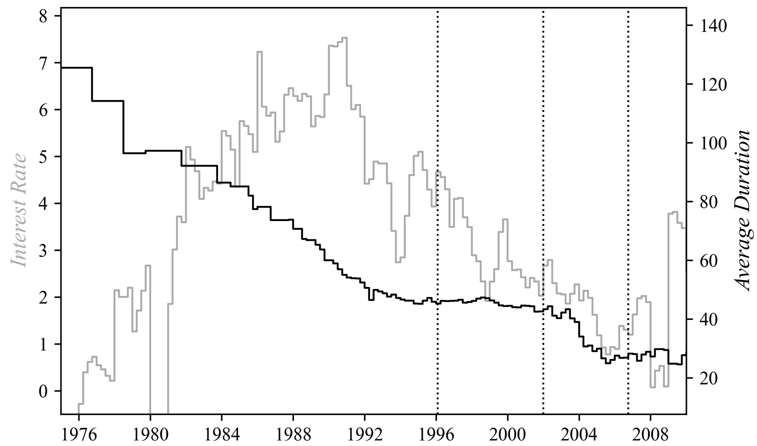

Figure 3.4: Real interest rate and participation duration. The solid black line refers to the active firms' average participation duration in month. The vertical lines indicate leniency programs.

model to quantify the interest rate's effect, i.e.,

$$P(Y_{i,t} = 1|x_{i,t}) = \frac{\exp(\beta^\intercal x_{i,t} + \varepsilon_i)}{1 + \exp(\beta^\intercal x_{i,t} + \varepsilon_i)},$$

where β is the parameters of interest's vector including a constant, x_i the covariates' vector and ε_i is a random effect.[35] To model the interest rate's non-monotonic effect, we use a second order polynomial. This is flexible enough, to allow for the structures imposed by Proposition 3.2, precisely, the U-shape relation between stability and the interest rate.

Generally, our theory predicts a shape resembling a negative cubic polynomial, whereby the decreasing effect for large interest rates follows from the fact that firms become local monopolists. Such high levels of interest rate are likely not observed in our data. Therefore, we focus on the U-shape in our empirical analysis.

We control the cartels' infringement, i.e., x_i contains information if a cartel fixed prices, market shares, or both. Furthermore, we control for the industry in which the cartel was active and whether it was active in the entire EU, only some countries or worldwide. We also include the number of cartel members, which may change over time, and control for cartels that did break-

[35]The error term is assumed to be independent and identically normal distributed.

	(1)	(2)	(3)	(4)
Interest Rate	0.61	0.70*	0.62	0.69*
	(0.32)	(0.33)	(0.34)	(0.34)
Interest Rate^2	-0.13*	-0.12*	-0.14*	-0.12*
	(0.05)	(0.06)	(0.05)	(0.06)
GDP p.c.		0.00*		0.00
		(0.00)		(0.00)
Economic Indicator			0.00	-0.00
			(0.01)	(0.01)
Observations	3'232	3'232	3'078	3'078

Table 3.2: Logit Models. Robust standard errors in parentheses and significance levels indicated by * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$. All models include a constant and controls for infringement, industries, spacial scope, members, natural death and leniency programs. All coefficients are reported in Table 3.4.

up naturally. Finally, we control for the leniency program's introduction and its revisions.

Parameters are quantified using Maximum likelihood estimation controlling for random effects. Estimates are presented in Table 3.12, whereby we only give a subset of the coefficients; all estimates are presented in the appendix Table 3.4. The probability that a cartel ends increases in the interest rate close to zero. At some point, the quadratic term decreases the break-up's probability. The estimates are in line with our theory; however, not always significantly different from zero. If we control for GDP per capita in columns (2) and (4), the estimates have the predicted sign and are significant.

For the second approach, we focus on a firm's participation duration in a cartel. Similar to Hellwig and Hüschelrath (2018), we focus on a firm's natural leave. We are interested in how long it takes a firm to leave a cartel after it entered. The firm's exit is called the event in survival analysis. The occurrence of the event is a random variable T and the probability that an event has not happened before period t is $P(T \geq t) = \mathcal{S}(t)$, where $\mathcal{S}$ is the survival function.

More precisely, we assume a Weibull model,

$$\mathcal{S}(t|x_{i,t}) = \exp(-\exp(\beta^\intercal x_{i,t})t^\kappa),$$

implying a hazard function

$$\frac{d\mathcal{S}(t|x_{i,t})/dt}{\mathcal{S}(t|x_{i,t})} = h(t|x_{i,t}) = \kappa \exp(\beta^\intercal x_{i,t}) t^{\kappa-1}.$$

The hazard function can be interpreted as the probability that the event happens at t if it has not happened before. κ is the distribution's shape parameter. If $\kappa > 1$, the baseline hazard $h(t|0) = \kappa t^{\kappa-1}$ increases monotonically over time; it becomes more likely that the event happens over time.

Depending on the covariates, the hazard function increases or decreases. Precisely, if $\beta^\intercal x_{i,t} > 0$, the hazard function is larger than the baseline hazard, and thus it is more likely for the firm i to experience the event, i.e., to leave the cartel. We use the same set of controls as above, except for natural break-up, since this is the event we study. Additionally, we include controls for the exit or entry of other cartel members within six months.[36]

The event we are studying is a firm's natural leave. Some firms in our dataset may be forced to leave a cartel due to an investigation resulting in a cartel break-up. Those firms did not experience the event, yet the cartel ended. The data is, thus, right censored. Let $\zeta_i = 0$ if the observation is censored and 1 otherwise. An uncensored observation's contribution to the likelihood is the information that the event did not happen until t and the event happening at t, formally $\mathcal{S}(t|x_{i,t})h(t|x_{i,t})$. If the data is censored, its contribution is the information that the event has not happened until t, formally $\mathcal{S}(t|x_{i,t})$. The likelihood function is accordingly

$$\mathcal{L} = \prod h(t|x_{i,t})^{\zeta_i} \mathcal{S}(t|x_{i,t}).$$

We estimate parameters β and κ, maximizing the likelihood function. All coefficients are reported in the appendix in Table 3.7, of which we present a subset in Table 3.3.

Again, we include a quadratic term and control for demand as well as for production factors. Results are significant and as predicted by our theory. The interest rate affects stability non-monotonically; precisely, stability is U-shaped in the interest rate.

The rest of our estimates are qualitatively similar to Hellwig and Hüschelrath (2018); we refer to their work for further information. More interestingly, Hellwig and Hüschelrath (2018) and Levenstein and Suslow (2016) use different datasets and include a linear term for the interest rate in their studies. They find opposing results: in Hellwig and Hüschelrath (2018) stability increase with the interest rate, while in Levenstein and Suslow (2016) it goes

[36] This was the main analysis of Hellwig and Hüschelrath (2018).

	(1)	(2)	(3)	(4)
Interest Rate	0.61**	0.73***	0.68**	0.76***
	(0.19)	(0.21)	(0.22)	(0.22)
Interest Rate^2	-0.14***	-0.13***	-0.15***	-0.14***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		0.00***		0.00**
		(0.00)		(0.00)
Economic Indicator			0.03**	0.02*
			(0.01)	(0.01)
Observations	16'264	16'264	15'631	15'631

Table 3.3: Duration Models. Robust standard errors in parentheses and significance levels indicated by * for $p < 0.05$, ** for $p < 0.01$, and *** for $p < 0.001$. All models include a constant and controls for infringement, industries, spacial scope, members, members' entry and exit, and leniency programs. All coefficients are reported in Table 3.7.

down. According to our theory, both effects may arise. On the one hand, low interest rates increase the time value of money, resulting in more patient players stabilizing cartels. On the other hand, low interest rate lowers investment costs, thereby increasing a firm's profit when it deviates from the collusive agreement, destabilizing cartels. The second effect directly affects a firm's balance sheet by increasing outside capital. Levenstein and Suslow (2016) control for firms' outside capital.[37] Consequently, the second effect is silenced; their estimates are in line with our theory.

By incorporating a quadratic term, we allow for the interest rate's non-monotonic effect and find supporting evidence in the data collected by Hellwig and Hüschelrath (2018). We also use the data collected by Levenstein and Suslow (2016) and introduce a quadratic term for the interest rate.[38] However, the dataset does not contain information about investigation reasons and, accordingly, no information about a cartel's natural break-up. Moreover, there are only around 2'000 cartel-year observations, resulting in no additional significant empirical support. Future research may use firm-specific data to quantify the two opposing channels identified in our theory.[39]

[37] They rely on industry averages due to the lack of firm-specific data.

[38] The data is accessible at https://www.openicpsr.org/openicpsr/project/130650/version/V1/view (last accessed March 15, 2021).

[39] We used aggregated investments in the Euro area in construction and equipment available at the Ameco database. However, construction and equipment usually do not

According to our estimates, cartel stabilization is the lowest when interest rates are around 3%. Estimates are, however, very noisy. Confidence intervals range from below 1% up to 10%. Current real interest rates are, nonetheless, below our estimates. Accordingly, cartels become less stable if interest rates increase. The estimates should, however, be taken with caution.

Some remarks are in order. The dataset only contains convicted cartels; thus, there is an obvious selection bias that we are not able to address. Furthermore, a firm's duration in a cartel may be underestimated because of lacking evidence. We relied on aggregate data, whereas we neglected firm-specific risk premia. We, therefore, abstain from interpreting any estimates coefficient's size, which is generally challenging in the used models. Nonetheless, our results are in line with the literature and support our theory.[40]

3.4 Conclusion

We have shown that the interest rate affects a cartel's stability non-monotonically. More precisely, stability is U-shaped in the interest rate, and for a sufficiently large interest rate, it decreases; the overall shape resembles a negative cubic polynomial. Two opposing effects are at work. On the one hand, the time value of money implied by the interest rate makes firms more patient when interest rates are low, increasing cartel stability. On the other hand, low interest rates give rise to additional investment opportunities resulting in more profitable deviations from the collusive agreement. With high interest rates, firms lack the investments to capture a large market share. Cartel stability is, thus, weakened when interest rates are low. The first effect dominates for relatively low interest rates; otherwise, the second effect dominates. For sufficiently large interest rates, the second effect is exhausted, and only the first remains. For reasonable interest rates, stability is U-shaped in the interest rate.[41]

For simplicity, we assumed a symmetric set-up. However, firms may have different risk premia or technologies, resulting in a heterogeneous cost

depreciate heavily and are therefore different from the investments that we theoretically model.

[40]For a detailed discussion of the sample bias and related problems for empirical work on cartels, see Harrington (2006a).

[41]The U-shape is not robust to different forms of competition in the stage game. We used, for example, price competition with differentiated products similar to Collie (2006). The larger the interest rate, the higher opportunity costs and the lower the critical discount factor. However, stability decreases monotonically in the interest rate. The main difference is that colluding firms produce less than competitive firms; in our set-up, they produce the same quantity.

structure. Rothschild (1999) discusses collusion when firms have asymmetric costs. In his set-up, high or low cost firms have ambiguously more incentives to deviate. An inefficient firm's profits are relatively small, but so are the gains from deviating. In our set-up, the interest rate affects the opportunity cost multiplicatively, thereby increasing asymmetries. The more asymmetric firms are, the more challenging it is for them to agree on the collusive price, resulting in a negative effect of the interest rate on cartel stability.[42]

We used a dataset collected by Hellwig and Hüschelrath (2018) containing 615 firms participating in 114 cartels convicted by the European Commission during 1999 and 2016 to test our theoretical prediction. Using a logit model on the cartel level yields significant estimates in line with our theory. Additionally, we estimated a Weibull model and quantified the interest rate's effect on a firm's participation duration in a cartel.

Interestingly, Hellwig and Hüschelrath (2018) and Levenstein and Suslow (2016) find opposing linear effects of the interest rate on cartel stability. According to our theory, both findings are possible. By incorporating the interest rate's non-monotonic effect, we find in the former datasets supporting evidence for our predicted U-shape. In the latter dataset, there is, unfortunately, no information to control for investigation reasons. We do not find additional supporting evidence. Nonetheless, future empirical work should consider using a quadratic effect of the interest rate. As we have shown, the interest rate does not only affect the players' patience.

We conclude that the interest rate affects cartel stability non-monotonically. The current time of unusually low interest rates favors collusion by increasing cartel stability and the likelihood of cartel formation.

Generally, when the opportunity cost is relatively high, cartels are more stable. Firms have fewer incentives to deviate because it is costly to serve large shares of the market. When consumers have a poor outside option, cartels are less stable. Deviation is more profitable since consumers have a high willingness to pay, offering a high potential to extract by a deviating firm. Our theory predicts that cartels are less stable in highly competitive markets. When products become almost homogeneous, their individual attributes become irrelevant, and consumers react to little price differences. Thus by a deviation, a firm can capture almost the entire market, making it harder to collude. All factors also affect the collusion's profitability relative to the competitive outcome; however, these effects are relatively small to the one on deviation.

[42] For more on collusion with heterogeneous firms, see Harrington (1989) and Harrington (1991). The former discusses different (rational) discount factors, the latter heterogeneous costs. Products are homogeneous, and firms determine collusive prices according to the Nash Bargaining Solution.

Finally, our model contains another interesting mechanism helping to detect cartels, which may be explored in future research: Competitive prices react differently than collusive ones. While collusive ones react stronger to an increase in the consumers' willingness to pay, competitive prices react stronger to cost shocks. Moreover, if consumers' perception changes such that firms become less heterogeneous, competitive prices go down; by contrast, cartelists increase their prices.[43]

[43] Changes may be due to new regulation or new technologies. For example, quality regulation may result in less heterogeneous products. Hefti et al. (2020) present a model where firms manipulate the consumers' distribution, for example, by advertising.

3.A Extensions

Catel's Stability. In the main text, we used the simplifying assumption that firms collude on the price maximizing their joint profit. The monopoly price is a reasonable focal point and implies the payoff dominating equilibrium. However, in reality, the payoff dominating collusion is rarely observed. It has to be acknowledged that a monopolist's price is unknown. We present in this appendix rational reasoning why firms collude on less than the monopoly price.

Formally, let $p_t \in [p_c, U-t]$ be the price chosen by colluding firms. In the main text, we assumed it is equal to the upper bound. The critical discount factor depends on p_t, precisely,

$$\delta^* = \frac{\pi_d(p_t) - \pi_t(p_t)}{\pi_d(p_t) - \pi_c},$$

where $\pi_t(p_t) = (p_t - C)/2$, $\pi_d(p_t) = 2tF^2((p_t - p_d(p_t))/2t)/f((p_t - p_d(p_t))/2t)$, and π_c as in the main text, whereby $p_d(p_t) = p_i^*(p_t)$, as in the main text's equation (3.1). Taking the first derivative yields

$$\frac{\partial \delta^*}{\partial p_t} = \frac{\partial \pi_d/\partial p_t(\pi_t(p_t) - \pi_c) - \partial \pi_t/\partial p_t(\pi_d(p_t) - \pi_c)}{(\pi_d(p_t) - \pi_c)^2}.$$

Firms are interested to stabilize collusion, i.e., to decrease δ^*. The first order condition implies

$$\delta_0^* = 1 - \frac{\partial \pi_t/\partial p_t}{\partial \pi_d/\partial p_t},$$

whereby δ_0^* is the minimal necessary discount factor to sustain collusion. The second order condition implies that this is indeed a minimum if $\partial^2 \delta^*/\partial {p_t}^2 \geq 0$ around δ_0^*.[44]

In our set-up, $\partial \pi_t/\partial p_t = 1/2$ and

$$\frac{\partial \pi_d}{\partial p_t} = F\frac{2f^2 - Ff'}{f^2}\left(1 - \frac{dp_d}{dp_t}\right).$$

Using the implicit function theorem, we can derive $dp_d/dp_t = (f^2 - Ff')/(2f^2 - Ff')$ and thus $\partial \pi_d/\partial p_t = F((p_t - p_d(p_t))/(2t)) \in [1/2, 1]$. The deviation's marginal profit is larger when firms collude on high prices.[45] For example, if

[44]In our set-up, the condition simplifies to $\partial^2 \pi_d/\partial {p_t}^2 = (1 - dp_d/dp_t)f/2t \geq 0$, which is satisfied.

[45]Formally, $\partial^2 \pi_d/\partial p_t^2 = f^3/(2t(2f^2 - Ff')) \geq 0$.

firms collude close the lower bound $p_t = p_c$, the deviation's marginal profit goes to 1/2 and the critical discount factor thus goes to zero. The higher the collusive price, the higher is the critical discount factor, i.e., the harder it is to sustain the cartel's stability. Cartelists face trade-off between high profits and their agreement's stability. Our main insights do not change if firms collude on a lower price.

Transportation Costs. Here we show, that our results are qualitatively the same when consumers have quadratic transportation costs instead of linear ones.

With quadratic transportation costs, the utility function of consumer $x \in [-1, 1]$ becomes $U - p_i - t(x_i - x)^2$, when she buys the good at firm i, remind that i is located at the lower bound. Thus, she only participates if $U - p_i - t(x+1)^2 \geq 0 \Leftrightarrow x \leq \sqrt{(U - p_i)/t} - 1$. Moreover, she prefers to buy at firm i if $U - p_i - t(x+1)^2 \geq U - p_j - t(1-x)^2 \Leftrightarrow x \leq (p_j - p_i)/4t$. Accordingly, the demand function in the main text differs slightly. A local monopolist sets a price

$$p_m = \arg\max_{p_i}(p_i - C)F\left(\frac{\sqrt{U - p_i} - \sqrt{t}}{\sqrt{t}}\right) = C + 2t\frac{F(.)}{f(.)}\sqrt{\frac{U - p_m}{t}}.$$

Competing firms set prices

$$p_i^*(p_j) = \arg\max_{p_i}(p_i - C)F\left(\frac{p_j - p_i}{4t}\right) = C + 4t\frac{F(.)}{f(.)},$$

again, there exists a unique interior equilibrium at prices $p_c = C + 2t/f(0)$, resulting in firms' profits $\pi_c = t/f(0)$, which are double the profits in the main text. Competition is weaker since consumers' transportation costs when buying at the competitor are higher. Colluding firms choose prices to set consumers indifferent between buying the good or not. Thus they set a price $p_t = U - t$, which is the same as in the main text. Thus cartelists make the same profit $\pi_t = (U - t - C)/2$.

A deviating firm sets a price of

$$p_d = p_i^*(p_t) = C + 4t\frac{F((U - t - p_d)/4t)}{f((U - t - p_d)/4t)}$$

and makes a profit of $\pi_d = 4tF^2((U - t - p_d)/4t)/f((U - t - p_d)/4t)$. Similar as in the main text, deviation is only profitable when opportunity costs are low. $\pi_c = \pi_t = \pi_d$, if $C = U - t - 2t/f(0)$. Moreover, a deviating firm cannot capture the entire market if opportunity costs are high, formally $C \geq U - 3t - 2t/f(0)$.

We immediately get that π_c is constant in C, π_t is linearly decreasing and π_d decreases convexly. For the last part we can show $\partial\pi_d/\partial C = -F((U - t - p_d)/4t)$ and $\partial^2\pi_d/\partial C^2 = (f(.)/4t)dp_d/dC$. Since $C = (1+r)c$, Lemma 3.1 does qualitatively not change.

Next, note that π_c is constant in U, π_t increases linearly and π_d increases convexly. Again, for the last part we can show $\partial\pi_d/\partial U = F((U - t - p_d)/4t)$ and $\partial^2\pi_d/\partial U^2 = f^3(.)/4t(2f^2(.)-F(.)f'(.))$. Moreover, we π_c linearly increases, π_t linearly decreases and π_d decreases convexly in t. Again, for the last part we can show $\partial\pi_d/\partial t = -F((U - t - p_d)/4t)(U - p_d)/t$ and

$$\frac{\partial^2\pi_d}{\partial t^2} = \frac{(U - p_d)f(.)}{4t^3}\frac{4tF(.)f(.) + (U - p_D)(f^2(.) - F(.)f'(.))}{2f^2(.) - F(.)f'(.)} + \frac{(U - p_d)F(.)}{t^2}.$$

Since the proof of Proposition 3.1 only relies on the profit's functional form, which is the same as in the main text, it does qualitatively not change.

To study δ^*'s concavity, we can use the same steps as in the main text. The necessary condition used in the proof of Lemma 3.2 and Proposition 3.2 becomes

$$\frac{f^3[4F^2f(0) - f][f(0)(U - t - C) - 2t]}{8F^2ff(0)[f(0)(U - t - C) - 2t] - 8Ff(0)[4F^2f(0) - f]} \leq 2f^2 - Ff',$$

where we have neglected the functions argument $(U - t - p_d)/4t$. Note that for $C \to U - t - 2t/f(0)$ firms become local monopolists, similar to the main texts' condition $r \to \bar{r}$. The left-hand side goes to zero since the product decreases faster than the difference, while the right-hand side is positive by F's log-concavity. Thus, Lemma 3.2 does qualitatively not change, i.e., when F is sufficiently log-concave δ^* is concave for any interior solution.

As shown in the proof of Proposition 3.2, the slope of δ^* when firms become local monopolists is $-c\pi_d''/4(\pi_d')^2 \to -cf(0)/8t$; $\hat{\delta}$'s slope is $-c^2/(U - t - t/f(0))^2$, thus if $c \leq (U - t - 2t/f(0))^2 f(0)/8t$, δ^* decreases stronger, which shows that Proposition 3.2 remains qualitatively the same. Our results are thus robust to quadratic transportation costs.

Degree of Differentiation. It is well known that with linear transportation costs, there does not exist an equilibrium when firms can choose their degree of differentiation, e.g., Anderson (1988). With quadratic transportation costs, price competition leads to inefficiently high product differentiation. Firms choose to differentiate their product to avoid fierce price competition. A cartel silences the price competition's effect. Cartelists choose product differentiation to minimize consumers' transportation costs in order to increase the consumer's willingness to pay, resulting in the efficient degree of differentiation.[46] Accordingly, cartelists choose less differentiated products than competing firms, i.e., they are not located at the boundaries of the distribution's support.

Lower price cuts are therefore necessary to capture the entire market. A cartel's stability goes down if cartelists offer less differentiated goods – deviation is more profitable, see for example Chang (1991). The trade-off between stability and profitability is similar to the one with prices discussed above.

When firms can choose their degree of differentiation endogenously, a natural question is how rigid the firms' product characteristics (location) are. Can they only be chosen at the beginning of the game, or can they be adjusted? If they can be adjusted, how often can a firm adjust its product characteristics? And is it costly to change the product's characteristics (choose a different location)?

Friedman and Thisse (1993) assume that locations are fixed at the beginning of time and can not be adjusted. They show that firms choose the minimal degree of differentiation. Their result depends, however, on their profit-sharing rule. Jehiel (1992) shows that the result of minimal differentiation only holds if there is no transfer between cartelists.

A costly and rigid adjustment of firms' locations seems most realistic. A formal analysis is although beyond the scope of this appendix.

NPV versus IRR. In our set-up, δ^* implies an Internal Rate of Return by $\delta^* = 1/(1 + IRR)$. Our evaluation criterion is thus based on the comparison between the IRR and the interest rate r. Figure 3.1 shows the shaded area for $\delta^* \geq \hat{\hat{\delta}} \Leftrightarrow IRR \leq r$, i.e, where firms do not join a cartel.

The problem, however, with the IRR as an evaluation criterion is the implicit assumption that firms can invest their returns at the same interest rate. In reality, rarely a project satisfies this assumption. An alternative evaluation criterion that does not rely on this assumption is the Net Present Value. Formally, the NPV is the sum of discounted cash flows,

$$\sum_{t=0}^{\infty} \frac{c_t}{(1 + r_t)^t},$$

where c_t is the cash flow at time t and r_t the interest rate. In our set-up, we make the simplifying assumption that $r_t = r$; thus, the interest rate is constant over time. Formally, the IRR is defined by setting the NPV to zero. In our model, a project is continuing with the cartel or deviate. The cash

[46]In our framework, welfare (the sum of consumer surplus and firms' profits) is accordingly higher with collusion. Similar, Fershtman and Pakes (2000) argue that consumer surplus goes up when firms collude if product quality is taken into account.

flow from staying in a cartel is constant, while by deviating, the firm gets a large cash flow in period $t = 0$ and a smaller constant one for $t \geq 1$. The NPVs can thus generally be written as

$$c_0 + \sum_{t=1}^{\infty} \frac{c}{(1+r)^t}. \tag{3.6}$$

Accordingly, a project's IRR is implicitly defined by

$$c_0 + \sum_{t=1}^{\infty} \frac{c}{(1+IRR)^t} = 0.$$

In our simplified set-up, the two evaluation criteria are therefore equivalent. Whenever the NPV is positive given by (3.6), it follows directly that $IRR \geq r$ and vice versa. Firms choose the project with the highest NPV, which is in our set-up equivalent to choose to project with the highest IRR.
Microfoundation. Many different factors outside the model affect a firm's decision to collude. For example, some decision-makers may have stronger moral conflicts to break the law by forming a cartel than others. Yet, the larger the profits from a cartel, the more is one tempt to build one. Here, we present a formal microfoundation for our stability measure.

Let I be the set of industries. In each industry $i \in I$, there are two horizontally differentiated firms as in the main text. Industries differ in their cost of collusion $k(i)$. The difference may arise from a different perceived likelihood to be prosecuted by the competition authorities, resulting in heterogenous expected fines, or simply different morality costs of the decision-makers. Let the industries be sorted such that $k(i)$ is a strictly increasing function. Cost of collusion are relative to its gains: when firms do not gain from colluding, e.g., as local monopolists, costs are zero. Equation (3.3) becomes

$$\sum_{\tau=1}^{\infty} \delta^{\tau}(1-k(i))(\pi_t - \pi_c) \geq \pi_d - \pi_t,$$

resulting in a critical discount factor depending on the industry. Formally,

$$\delta^*(i) = 1 - (1-k(i))\frac{\pi_t - \pi_c}{\pi_d - \pi_c} = \delta^* + k(i)\frac{\pi_t - \pi_c}{\pi_d - \pi_c},$$

where δ^* is given by equation (3.4) in the main text. Note that the functional form does not change since $\delta^*(i) = (1-k(i))\delta^* + k(i)$ is a strictly monotone transformation of δ^*; hence, all our proofs remain valid. The larger the costs, the higher is the critical discount factor. Accordingly, the critical discount factor differs across industries and increases in i.

Firms in industry i form a cartel if $\hat{\delta} \geq \delta^*(i)$, the number of cartels in our framework is therefore

$$\int_{i \in I} \mathbb{1}(\delta^*(i) \leq \hat{\delta}) di,$$

where $\mathbb{1}(.)$ is the indicator function. In this framework, our stability measure is simply the number of cartels. To an observer, who does not know the industry's cost $k(i)$, yet knows its distribution, the number of cartels equals the likelihood of observing a cartel when the total mass of firms is normalized to one.

Alternatively, industries may also differ in the parameters, t, c, or U. Following Proposition 3.1, δ^* is again industry-specific and we reach the same conclusion.

Finally, one could also think that industries have different risk premia. The relevant interest rate on the financial market for a firm in industry $i \in I$ is $r(i) = r + \sigma(i)$, where $\sigma(i)$ is an industry specific risk premium. Consequently, $\hat{\delta}(i) = 1/(1 + r(i))$ depends on the industry. Again, firms in industry i collude if $\hat{\delta}(i) \geq \delta^*$, and the number of cartels becomes

$$\int_{i \in I} \mathbb{1}(\delta^* \leq \hat{\delta}(i)) di.$$

The above technical arguments can alternatively be interpreted in the following way. The antitrust authorities have less information about the market, i.e., do not exactly know the parameter values. However, the antitrust authorities have a belief about the parameters' distribution. Using this belief, it can calculate the probability that a cartel is formed. Introducing different industries is thus not necessary.

3.B Proofs

Proof Lemma 3.1. With a symmetric and log-concave distribution π_c, π_t, and π_d are uniquely determined. The first and second part follows directly from $\pi_c' := \partial\pi_c/\partial r = 0$ and $\pi_t' := \partial\pi_t/\partial r = -c/2$. For the third part we derive

$$\pi_d' := \frac{\partial \pi_d}{\partial r} = -\frac{2F(.)f^2(.) - F^2(.)f'(.)}{f^2(.)}\frac{dp_d}{dr},$$

and use the implicit function theorem to derive $dp_d/dr = cf^2(.)/(2f^2(.) - F(.)f'(.))$, hence,

$$\pi_d' = -cF\left(\frac{U-t-p_d}{2t}\right) \in [-c, \frac{-c}{2}].$$

The convexity follows from

$$\pi_d'' := \frac{\partial^2 \pi_d}{\partial r^2} = \frac{c}{2t}f\left(\frac{U-t-p_d}{2t}\right)\frac{dp_d}{dr} \geq 0,$$

since F's log-concavity implies $dp_d/dr \geq 0$, i.e., larger costs increase prices.

The last part follows from equating profits $\pi_c = \pi_t = \pi_d$, which implies $C = U - t - t/f(0)$. Using $C = (1+r)$ and rearranging yields the result. □

Proof Proposition 3.1. We start with proofing the second part. Remind that $C = (1+r)c$, i.e., the profit functions' derivatives with respect to C have the same sign as with respect to r. Therefore, we can use the derivatives derived in Lemma 3.1 and prove the statement with respect to r. Remind that at $\bar{r}$ $\pi_d = \pi_c$. Thus, by the Mean Value Theorem and π_d's convexity in r, there exists a unique $\gamma(r) \in (r, \bar{r})$ such that

$$\pi_d'(\gamma(r)) = \frac{\pi_d(r) - \pi_d(\bar{r})}{r - \bar{r}}, \tag{3.7}$$

where we have written the profit functions' argument explicitly. Using the implicit function theorem we can derive $\gamma'(r) = (\pi_d'(r) - \pi_d'(\gamma(r)))/((r - \bar{r})\pi_d''(\gamma(r))) \geq 0$. Using $\pi_t(r) - \pi_c(r) = \pi_t'(r)(r - \bar{r})$ and (3.7) we can write the critical discount factor as

$$\delta^* = 1 - \frac{\pi_t'(r)}{\pi_d'(\gamma(r))}$$

and directly get $\partial\delta^*/\partial r = \pi_t'(r)\pi_d''(\gamma(r))\gamma'(r)/(\pi_d'(\gamma(r)))^2 \leq 0$. Moreover, we have shown in Lemma 3.1's proof that $\pi_t' = -c/2$ and $\pi_d' \in [-c, -c/2]$, hence, $\delta^* \in [0, 1/2]$.

For the first part, we use a similar trick. First, we derive the profit functions' derivatives: $\partial\pi_c/\partial U = 0$, $\partial\pi_t/\partial U = 1/2$, and $\partial\pi_d/\partial U = (1 - dp_d/dU)(2F(.)f^2(.) - F^2(.)f'(.))/f^2(.)$. We use the implicit function theorem to derive $dp_d/dU = 1 - f^2(.)/(2f^2(.) - F(.)f'(.)) \leq 1$ and plugging in yields $\partial\pi_d/\partial U = F((U - t - p_d)/2t) \geq 0$. Moreover we can derive

$$\frac{\partial^2\pi_d}{\partial U^2} = \frac{1}{2t} f\left(\frac{U - t - p_d}{2t}\right)\left(1 - \frac{dp_d}{dU}\right) = \frac{1}{2t}\frac{f^3(.)}{2f^2(.) - F(.)f'(.)} \geq 0.$$

Thus π_c is constant, π_t linearly increasing and π_d convexly increasing in U. Similar as in Lemma 3.1 we can state $\pi_c = \pi_t = \pi_d$ at $U = C + t + t/f(0) =: \underline{U}$. We can thus write $\pi_t - \pi_c = (U - \underline{U})/2$. Next, by the Mean Value Theorem there exists a $\gamma(U) \in (\underline{U}, U)$, such that

$$\left.\frac{\partial\pi_d}{\partial U}\right|_{\gamma(U)} = \frac{\pi_d(U) - \pi_d(\underline{U})}{U - \underline{U}},$$

where we have written the profit function's argument explicitly. Since $\pi_d(\underline{U}) = \pi_c$, we can write

$$\delta^* = 1 - \frac{1/2}{\left.\frac{\partial\pi_d}{\partial U}\right|_{\gamma(U)}}$$

$$\frac{\partial\delta^*}{\partial U} = \frac{1}{2}\frac{\frac{\partial^2\pi_d}{\partial U^2}}{\frac{\partial\pi_d}{\partial U}}\left.\frac{\partial\gamma(U)}{\partial U}\right|_{\gamma(U)} \geq 0.$$

$\gamma(U)$ goes up in U since π_d increases convexly. This concludes the first part.

For the third part, we start again with the profit functions' derivatives: $\partial\pi_c/\partial t = 1/(2f(0))$, $\partial\pi_t/\partial t = -1/2$, and $\partial\pi_d/\partial t = 2F^2(.)/f(.) - ((U - p_d)/t + dp_d/dt)(2F(.)f^2(.) - F^2(.)f'(.))/f^2(.)$. Using the implicit function theorem, we can derive

$$\frac{dp_d}{dt} = \frac{2F(.)f(.)}{2f^2(.) - F(.)f'(.)} - \frac{U - p_d}{t}\frac{f^2(.) - F(.)f'(.)}{2f^2(.) - F(.)f'(.)}$$

and plugging in yields $\partial\pi_d/\partial t = -F(.)(U - p_d)/t \leq 0$. Thus, deviation is more profitable if the market is highly competitive, i.e., t is low. Next we derive

$$\begin{aligned}\frac{\partial^2\pi_d}{\partial t^2} &= \frac{f(.)(U - p_d)}{2t^3}\left(U - p_d + t\frac{dp_d}{dt}\right) + F(.)\frac{U - p_d}{t^2}\\ &= \frac{(U - p_d)f(.)}{2t^3}\frac{2tF(.)f(.) + (U - p_d)f^2(.)}{2f^2(.) - F(.)f'(.)} + \frac{(U - p_d)F(.)}{t^2} \geq 0.\end{aligned}$$

Hence, π_c linearly increases, π_t linearly decreases and π_d convexly decreases in t. Similar as in Lemma 3.1, $\pi_c = \pi_t = \pi_d$ if $t = (U - C)/(1 + 1/f(0)) =: \bar{t}$. δ^* decreases in t if

$$\begin{aligned} \frac{\partial \delta^*}{\partial t} &\leq 0 \\ \Leftrightarrow (1-\delta^*)\left(\frac{\partial \pi_d}{\partial t} - \frac{\partial \pi_c}{\partial t}\right) &\leq \frac{\partial \pi_t}{\partial t} - \frac{\partial \pi_c}{\partial t} \\ \Leftrightarrow \frac{\pi_t - \pi_c}{\pi_d - \pi_c} &\geq \frac{\frac{\partial \pi_d}{\partial t} - \frac{\partial \pi_c}{\partial t}}{\frac{\partial \pi_t}{\partial t} - \frac{\partial \pi_c}{\partial t}} \end{aligned}$$

We can simplify the left-hand side by using $\pi_t - \pi_c = (\bar{t} - t)\partial(\pi_t - \pi_c)/\partial t$ and by the Mean Value Theorem there exists $\gamma \in (t, \bar{t})$ such that $\pi_d - \pi_c = (\bar{t} - t)\partial(\pi_d - \pi_c)/\partial t$, where the right-hand side is evaluated at γ. Plugging in yields that δ^* decreases if

$$\left.\frac{\partial \pi_d}{\partial t}\right|_t \leq \left.\frac{\partial \pi_d}{\partial t}\right|_\gamma,$$

which is satisfied since π_d decreases convexly and $\gamma \geq t$. This concludes the third part. □

Proof Lemma 3.2. We start with an interior solution, i.e., $r \in [\underline{r}, \bar{r}]$. In this range, δ^* is concave if and only if

$$\begin{aligned} \frac{\partial^2 \delta^*}{\partial r^2} = \frac{1}{\pi_d - \pi_c}\left(\pi_d''(1-\delta^*) - 2\pi_d' \frac{\partial \delta^*}{\partial r}\right) &\leq 0 \\ \Leftrightarrow \frac{\pi_d''}{2\pi_d'} &\geq \frac{\frac{\partial \delta^*}{\partial r}}{1-\delta^*}. \end{aligned}$$

Using that $\partial\delta^*/\partial r = (1-\delta^*)\pi_d'/(\pi_d - \pi_c) - \pi_t'/(\pi_d - \pi_c)$, simplifies the right-hand side to $\pi_d'/(\pi_d - \pi_c) - \pi_t'/(\pi_t - \pi_c)$. Plugging in, yields that δ^* is concave if and only if

$$\begin{aligned} \frac{-cf^3}{2tF(2f^2 - Ff')} &\geq \frac{-2cFff(0)}{t(4F^2 f(0) - f)} + \frac{cf(0)}{f(0)(U - t - (1+r)c) - t} \\ \Leftrightarrow \frac{f^3[4F^2 f(0) - f][f(0)(U - t - (1+r)c) - t]}{8F^2 ff(0)[f(0)(U - t - (1+r)c) - t] - 4Ff(0)[4F^2 f(0) - f]} &\leq 2f^2 - Ff'. \end{aligned}$$

We simplified notation, precisely the argument of f and F is neglected, it is $(U - t - p_d)/2t$, where p_d is a function of r and implicitly defined by (3.2).

Note that the expressions in the square brackets go to zero when $r \to \bar{r}$: Firms do have no incentive to deviate, i.e., $F \to 1/2$. Since the product goes faster to zero than the difference, the expression on the left-hand side goes to zero. By log-concavity, the right-hand side is strictly larger than zero, thus for r close to $\bar{r}$, the critical discount factor δ^* is concave. Whenever the distribution is sufficiently log-concave, i.e., the right-hand side is sufficiently large, δ^* is concave for any $r \in [\underline{r}, \bar{r}]$.

Note that $\pi_d = 2t/f(1)$ is constant if $r \leq \underline{r}$, hence, δ^* linearly increases in r. Hence, if δ^* is concave for $r \in [\underline{r}, \bar{r}]$, it is concave for $r \leq \bar{r}$. □

Proof Proposition 3.2. Since s is a strictly increasing function, we can directly prove all statements in terms of the difference $\hat{\delta} - \delta^*$. Formally, if $\hat{\delta} \geq \delta^*$, $\partial S/\partial r = s'(.)(\partial(\hat{\delta} - \delta^*)/\partial r)$ and since $s'(.) > 0$, all results follow from $\partial(\hat{\delta} - \delta^*)/\partial r$.

To prove the first part, first note that for $r \to 0$, $\hat{\delta} = 1$ and $\delta^* \leq 1/2$, as shown in the proof of Proposition 3.1. Hence, $S(\hat{\delta}, \delta^*) = s(\hat{\delta} - \delta^*)$. Next, we show for $r \to 0$, $\partial\delta^*/\partial r \geq \partial\hat{\delta}/\partial r$. If $r < \underline{r}$, δ^* increases and the inequality is satisfied. For $r \in [\underline{r}, \bar{r}]$,

$$\frac{\partial\delta^*}{\partial r} = \frac{\pi_d'(\pi_t - \pi_c) - \pi_t'(\pi_d - \pi_c)}{(\pi_d - \pi_c)^2} = \frac{\pi_d' c\bar{r}/2 - c(\pi_d - \pi_c)/2}{(\pi_d - \pi_c)^2},$$

at $r = 0$. Furthermore, we know $\pi_d' \in [-c, -c/2]$, and $\pi_d - \pi_c \in [c\bar{r}/2, c\bar{r}]$. We can thus rewrite the expression as

$$\frac{\partial\delta^*}{\partial r} = \frac{c^2\bar{r}x - c^2\bar{r}y}{c^2\bar{r}z} = \frac{x - y}{z},$$

where $x \in [-1/2, -1/4]$, $y \in [1/4, 1/2]$, and $z \in [1/4, 1]$. The expression is thus bounded by the interval $[-1, 1]$. The slope of $\hat{\delta}$ is -1 for $r = 0$. This proofs the first part.

For the second part, note that $\delta^* = 0$ when $r \to \bar{r}$ and $\hat{\delta} > 0$ since $\bar{r} < \infty$. Hence, $S(\hat{\delta}, \delta^*) = s(\hat{\delta} - \delta^*)$. Next, we show for $r \to \bar{r}$, $\partial\delta^*/\partial r \leq \partial\hat{\delta}/\partial r$, if $c \leq f(0)(U - t - t/(2f(0)))^2/4t$.

For $r \to \bar{r}$

$$\frac{\partial\delta^*}{\partial r} = \frac{\pi_d'(\pi_t - \pi_c) - \pi_t'(\pi_d - \pi_c)}{(\pi_d - \pi_c)^2} \to \frac{0}{0}.$$

Using L'Hospital's rule twice

$$\frac{\partial\delta^*}{\partial r} \to \frac{\pi_d''(\pi_t - \pi_c)}{2(\pi_d - \pi_c)\pi_d'} \to \frac{\pi_d'''(\pi_t - \pi_c) + \pi_d''\pi_t'}{2(\pi_d - \pi_c)\pi_d'' + 2\pi_d'^2} \to \frac{\pi_d''\pi_t'}{2\pi_d'^2} = \frac{-c}{4}\frac{\pi_d''}{\pi_d'^2}.$$

Next, note that for $r \to \bar{r}$ we have $p_d \to U - t$. Since $F(0) = 1/2$ and $f'(0) = 0$ by symmetry, the expression simplifies to $-cf(0)/(4t)$.

The slope of $\hat{\delta}$ at $r = \bar{r}$ is $-1/(1+\bar{r})^2 = -c^2/(U - t - t/(f(0)))^2$. Hence, if $c \leq f(0)(U - t - t/(2f(0)))^2/4t$, δ^* decreases stronger than $\hat{\delta}$ hat $r = \bar{r}$. This proves the second part.

Whenever $F(.)$ is sufficiently log-concave Lemma 3.2 implies a concave δ^* for $r \leq \bar{r}$. The difference $\hat{\delta} - \delta^*$ is thus the difference of a convex decreasing function and a concave function, which is quasiconvex. Accordingly, S is a quasiconvex function, which may be bounded from below if $\delta^* > \hat{\delta}$, resulting in a quasiconvex function.

Suppose first, $\hat{\delta} \geq \delta^*$ for all r. Formally, $s(\hat{\delta} - \delta^*)$ is quasiconvex for $r \in (0, \bar{r})$ if $\mathcal{R} = \{r | \hat{\delta}(r) - \delta^*(r) \leq s^{-1}(x)\} \cap (0, \bar{r})$ is a convex set for any $x \in \mathbb{R}$, where $s^{-1}(.)$ is the inverse function of $s(.)$. Take $r_1, r_2 \in \mathcal{R}$, thus $\hat{\delta}(r_1) \leq \delta^*(r_1) + s^{-1}(x)$ and $\hat{\delta}(r_2) \leq \delta^*(r_2) + s^{-1}(x)$. Hence, for $\alpha \in (0, 1)$ is has to hold that $\alpha\hat{\delta}(r_1) + (1 - \alpha)\hat{\delta}(r_2) \leq \alpha\delta^*(r_1) + (1 - \alpha)\delta^*(r_2) + s^{-1}(x)$.

By $\hat{\delta}(r)$'s convexity and $\delta^*(r)$'s concavity it follows $\alpha\hat{\delta}(r_1) + (1-\alpha)\hat{\delta}(r_2) \geq \hat{\delta}(\alpha r_1 + (1-\alpha)r_2)$ and $\alpha\delta^*(r_1) + (1-\alpha)\delta^*(r_2) \leq \delta^*(\alpha r_1 + (1-\alpha)r_2)$. Accordingly, $\alpha r_1 + (1 - \alpha)r_2 \in \mathcal{R}$, which proofs that $\mathcal{R}$ is a convex set and hence, $s(\hat{\delta} - \delta^*)$ is quasiconvex.

Now suppose that there exit $r \in (0, \bar{r})$ such that $\hat{\delta}(r) < \delta^*(r)$. Let this set be denoted by $\mathcal{Q} = \{r | \hat{\delta}(r) < \delta^*(r)\}$. Since $\hat{\delta}(0) > \delta^*(0)$ and $\hat{\delta}(\bar{r}) > \delta^*(\bar{r})$, the area where the inequality holds has to be intermediary, i.e., $\mathcal{Q} \subset (0, \bar{r})$. Since $s(0) = 0$, S is continuous and decreases in the neighborhood of $\mathcal{Q}$'s lower bound. By the same argument, S increases in the neighborhood of $\mathcal{Q}$'s upper bound. Thus to the left of $\mathcal{Q}$, S is quasiconvex, for $r \in \mathcal{Q}$, S is constant and then it becomes quasiconvex again. Since it is continuous, overall S is quasiconvex. This concludes the proof. □

3.C Empirical Results.

Our results are generally in line with Hellwig and Hüschelrath (2018), although we use real instead of nominal terms to control for macroeconomic factors. Moreover, we control for each leniency program's revision. The main insight of Hellwig and Hüschelrath (2018) is robust to these changes: firms' enter and exit create a dynamic within the cartel. For a detailed discussion, we refer the reader to their paper.

Table 3.4 presents the logit model from the main text with a treatment effect of less than 5%. Estimates are mostly insignificant. Table 3.5 uses averaged yearly data instead of quarterly data; the treatment effect is around 12%. However, heterogeneity is lost, and results are still insignificant. Except when we control for GDP p.c., estimates are significantly different from zero and in line with our theoretical prediction.

In Table 3.6 we use a probit model instead of a logit model. The probability of the cartel ending is accordingly

$$P(Y_{i,t} = 1|x_{i,t}) = \Phi\left(\beta^{\intercal} x_{i,t} + \varepsilon_i\right),$$

where $\Phi(.)$ is the standard cumulative normal. Results are similar.

Table 3.7 presents the estimates from the main text's Weibull model. Estimates are similar to Hellwig and Hüschelrath (2018). Moreover, the estimates yield significant support for our theory. In Table 3.8 we restrict the data to a subsample after 1995. Results are similar yet less significant. In Table 3.9 we present estimates with an alternative measure for GDP. Following Hellwig and Hüschelrath (2018) we use the Production and Sales (MEI) data for the Euro Area from OECD, which is quarterly available. Estimates are again similar to the main results.

Alternatively to the Weibull model, we estimate an exponential duration model in Table 3.10. This basically assumes $\kappa = 0$, i.e., the survival function and hazard rate are

$$\begin{aligned} \mathcal{S}(t|x_{i,t}) &= \exp(-\exp(\beta^{\intercal} x_{i,t})t) \\ h(t|x_{i,t}) &= \exp(\beta^{\intercal} x_{i,t}). \end{aligned}$$

This has the advantage of estimating one less parameter. However, the model loses some flexibility: the baseline hazard is constant over time.

Table 3.11 presents results of a Cox regression model. Similar to the duration models above, this assumes a proportional hazard rate

$$h(t|x_{i,t}) = h_0(t)\exp(\beta^{\intercal} x_{i,t}).$$

However, the Cox model uses a different approach to estimate the coefficient vector β. Let $\mathcal{C}_t$ be the set of active cartels. Thus, firms in $\mathcal{C}_t$ are at risk of leaving the cartel. The Cox model relates the firms leaving at time t to all the firms at risk. Accordingly, the maximum likelihood function is

$$\mathcal{L} = \prod \left(\frac{\exp(\beta^\intercal x_{i,t})}{\sum_{j \in \mathcal{C}_t} \exp(\beta^\intercal x_{j,t})} \right)^{\zeta_i}.$$

By contrast to the other proportional hazard models, the baseline hazard is not estimated. The results are similar to the above.

The proportional hazard models discussed assume that the covariates act multiplicatively on the hazard rate. Alternatively, the covariates may act multiplicatively on duration. We present some models with accelerated failure-time. Above, in a proportional hazard model, $\beta^\intercal x_{i,t} > 0$ increased the probability that a firm leaves a cartel given that it has not left it before. Now, in the accelerated failure-time models, $\beta^\intercal x_{i,t} > 0$ increases a firm's duration staying in a cartel. Thus, the estimates' signs should be the opposite as before, to be in line with our theory.

Table 3.12 presents a loglogistic model. The survival function takes the form

$$\mathcal{S}(t|x_{i,t}) = \frac{1}{1 + (t \exp(-\beta^\intercal x_{i,t}))^{1/\sigma}},$$

where σ is an ancillary parameter estimated additionally to β. Estimates are significant and in line with our theory.

In Table 3.13 we assume a lognormal model instead of a loglogistic model. Formally, the survival function is

$$\mathcal{S}(t|x_{i,t}) = 1 - \Phi\left(\frac{\log(t) - \beta^\intercal x_{i,t}}{\sigma}\right).$$

Results are similar and yield significant support for our theory.

Finally, we assume the most flexible model. Table 3.14 presents the results assuming a generalized gamma distribution. The survival function is

$$\mathcal{S}(t|x_{i,t}) = \begin{cases} 1 - I(\gamma, u) & if \kappa > 0; \\ 1 - \Phi(z) & if \kappa = 0; \\ I(\gamma, u) & if \kappa < 0 \end{cases}$$

where $I(.)$ is the incomplete gamma function and with $\gamma = \kappa^{-2}$, $u = \gamma \exp(|\kappa| z)$ and

$$z = \text{sign}(\kappa) \frac{\log(t) - \beta^\intercal x_{i,t}}{\sigma}.$$

This model nests the lognormal model if $\kappa = 0$. Moreover, it nests the Weibull distribution for accelerated failure-time if $\kappa = 1$. Accordingly, it also nest the exponential distribution for accelerated failure-time if $\kappa = 1$ and $\sigma = 1$. Again, estimates are significant and in line with our theory. Moreover, we can reject $\kappa = 1$ on the 0.01 significance level. Therefore, we can reject the Weibull and exponential distribution for accelerated failure-time.

All estimates are in line with our theory. We, therefore, abstain from testing which model fits the data best since all models yield significant results in line with our theoretical prediction: Cartel stability is U-shaped in the interest rate.

Table 3.4: Logit Models II

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.56*	0.53*	0.55*	0.53*
	(0.23)	(0.23)	(0.23)	(0.23)
Market Sharing	0.27	0.33	0.32	0.34
	(0.20)	(0.22)	(0.20)	(0.22)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	0.54*	0.54*	0.54*	0.53*
	(0.22)	(0.21)	(0.22)	(0.21)
Wholesale and Retail Trade	-0.18	-0.23	-0.18	-0.22
	(0.56)	(0.56)	(0.56)	(0.56)
Transportation and Storage	-0.10	-0.10	-0.10	-0.10
	(0.36)	(0.36)	(0.36)	(0.36)
Financial and Insurance Activities	0.48	0.49	0.50	0.48
	(0.30)	(0.32)	(0.31)	(0.33)
Others	-0.48	-0.48	-0.48	-0.48
	(0.37)	(0.39)	(0.37)	(0.39)
Spacial Scope (base: EU-wide)				
Worldwide	0.27	0.25	0.25	0.25
	(0.33)	(0.33)	(0.32)	(0.33)
Some Countries	0.07	0.07	0.05	0.07
	(0.15)	(0.16)	(0.15)	(0.16)
Members	-0.03	-0.03	-0.03	-0.03
	(0.03)	(0.03)	(0.03)	(0.03)
Natural Break-Up	0.01	0.01	0.02	0.02
	(0.18)	(0.19)	(0.18)	(0.19)
Leniency Program 96	1.19**	0.48	0.94*	0.51
	(0.42)	(0.55)	(0.44)	(0.54)
Leniency Program 02	0.62*	0.19	0.63	0.18
	(0.27)	(0.34)	(0.32)	(0.39)
Leniency Program 06	0.74**	0.29	0.73**	0.33
	(0.23)	(0.30)	(0.24)	(0.32)
Interest Rate	0.61	0.70*	0.62	0.69*
	(0.32)	(0.33)	(0.34)	(0.34)
Interest Rate^2	-0.13*	-0.12*	-0.14*	-0.12*
	(0.05)	(0.06)	(0.05)	(0.06)
GDP p.c.		0.00*		0.00
		(0.00)		(0.00)
Economic Indicator			0.00	-0.00
			(0.01)	(0.01)
Constant	-5.07***	-12.71***	-5.04***	-11.86**
	(0.65)	(3.61)	(1.38)	(4.26)
$\ln(\sigma_u^2)$	-13.26	-13.70	-13.25	-12.30
Observations	3'232	3'232	3'078	3'078

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.5: Logit Models with Yearly Data

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.52*	0.47	0.50*	0.47
	(0.25)	(0.26)	(0.25)	(0.26)
Market Sharing	0.32	0.38	0.37	0.38
	(0.21)	(0.24)	(0.21)	(0.24)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	0.36	0.40	0.36	0.40
	(0.39)	(0.28)	(0.39)	(0.28)
Wholesale and Retail Trade	-0.33	-0.42	-0.31	-0.42
	(0.54)	(0.54)	(0.55)	(0.55)
Transportation and Storage	-0.24	-0.24	-0.24	-0.24
	(0.39)	(0.38)	(0.39)	(0.38)
Financial and Insurance Activities	0.53	0.63	0.57	0.63
	(0.35)	(0.38)	(0.36)	(0.39)
Others	-0.65	-0.62	-0.64	-0.62
	(0.38)	(0.41)	(0.38)	(0.41)
Spacial Scope (base: EU-wide)				
Worldwide	0.24	0.23	0.22	0.23
	(0.38)	(0.39)	(0.37)	(0.39)
Some Countries	0.09	0.09	0.07	0.09
	(0.16)	(0.18)	(0.17)	(0.18)
Members	-0.01	-0.01	-0.01	-0.01
	(0.03)	(0.03)	(0.03)	(0.03)
Natural Break-Up	0.02	0.03	0.04	0.03
	(0.20)	(0.21)	(0.20)	(0.21)
Leniency Program 96	1.25**	0.12	0.90	0.14
	(0.43)	(0.66)	(0.52)	(0.68)
Leniency Program 02	0.69*	0.06	0.75	0.06
	(0.31)	(0.37)	(0.38)	(0.42)
Leniency Program 06	0.98**	0.17	0.99***	0.19
	(0.30)	(0.42)	(0.30)	(0.43)
Interest Rate	0.67	0.90*	0.72	0.89*
	(0.35)	(0.36)	(0.37)	(0.38)
Interest Rate^2	-0.14*	-0.11*	-0.15*	-0.11*
	(0.06)	(0.05)	(0.06)	(0.05)
GDP p.c.		0.00**		0.00*
		(0.00)		(0.00)
Economic Indicator			0.01	-0.00
			(0.02)	(0.01)
Constant	-3.95***	-17.34**	-4.36*	-16.93**
	(0.75)	(5.33)	(1.70)	(5.81)
$\ln(\sigma_u^2)$	-14.26	-12.91	-14.25	-12.91
Observations	892	892	852	852

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.6: Probit Models

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.27*	0.26*	0.26*	0.26*
	(0.11)	(0.11)	(0.11)	(0.11)
Market Sharing	0.11	0.14	0.13	0.14
	(0.09)	(0.09)	(0.09)	(0.09)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	0.29*	0.28*	0.29*	0.28*
	(0.11)	(0.11)	(0.12)	(0.11)
Wholesale and Retail Trade	-0.10	-0.13	-0.09	-0.12
	(0.26)	(0.26)	(0.26)	(0.26)
Transportation and Storage	-0.04	-0.05	-0.04	-0.05
	(0.18)	(0.18)	(0.18)	(0.18)
Financial and Insurance Activities	0.21	0.21	0.23	0.22
	(0.15)	(0.16)	(0.15)	(0.17)
Others	-0.23	-0.23	-0.22	-0.23
	(0.17)	(0.17)	(0.17)	(0.17)
Spacial Scope (base: EU-wide)				
Worldwide	0.17	0.15	0.15	0.15
	(0.16)	(0.16)	(0.16)	(0.16)
Some Countries	0.02	0.02	0.01	0.02
	(0.07)	(0.07)	(0.07)	(0.07)
Members	-0.01	-0.01	-0.01	-0.01
	(0.02)	(0.02)	(0.02)	(0.02)
Natural Break-Up	0.00	0.00	0.01	0.00
	(0.08)	(0.09)	(0.08)	(0.09)
Leniency Program 96	0.48**	0.14	0.34	0.14
	(0.16)	(0.21)	(0.18)	(0.22)
Leniency Program 02	0.30*	0.07	0.32*	0.09
	(0.13)	(0.16)	(0.15)	(0.19)
Leniency Program 06	0.37**	0.16	0.37**	0.17
	(0.12)	(0.14)	(0.12)	(0.15)
Interest Rate	0.27	0.34*	0.29	0.33*
	(0.14)	(0.15)	(0.16)	(0.16)
Interest Rate^2	-0.06*	-0.05*	-0.06*	-0.05*
	(0.02)	(0.02)	(0.02)	(0.02)
GDP p.c.		0.00*		0.00*
		(0.00)		(0.00)
Economic Indicator			0.00	0.00
			(0.01)	(0.01)
Constant	-2.58***	-6.38***	-2.82***	-6.19***
	(0.29)	(1.65)	(0.65)	(1.88)
$\ln(\sigma_u^2)$	-15.58	-15.96	-15.57	-15.98
Observations	3'232	3'232	3'078	3'078

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.7: Duration Models II

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.78***	0.74***	0.75***	0.72***
	(0.15)	(0.16)	(0.16)	(0.16)
Market Sharing	-0.10	-0.05	-0.06	-0.05
	(0.26)	(0.27)	(0.27)	(0.27)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	1.22***	1.19***	1.26***	1.23***
	(0.32)	(0.30)	(0.32)	(0.31)
Wholesale and Retail Trade	-0.55	-0.62	-0.59	-0.63
	(0.47)	(0.47)	(0.46)	(0.46)
Transportation and Storage	0.30	0.32	0.32	0.33
	(0.21)	(0.21)	(0.21)	(0.21)
Financial and Insurance Activities	0.42	0.41	0.46	0.44
	(0.47)	(0.48)	(0.48)	(0.48)
Others	-1.35	-1.39	-1.37	-1.38
	(0.71)	(0.71)	(0.71)	(0.71)
Spacial Scope (base: EU-wide)				
Worldwide	0.60***	0.58**	0.55**	0.56**
	(0.18)	(0.18)	(0.18)	(0.18)
Some Countries	-0.38**	-0.38*	-0.40**	-0.39**
	(0.15)	(0.15)	(0.15)	(0.15)
Members	-0.13***	-0.14***	-0.14***	-0.14***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	-0.56*	-0.56*	-0.53*	-0.52*
	(0.25)	(0.25)	(0.25)	(0.25)
Exit	0.85***	0.77***	0.77***	0.74***
	(0.15)	(0.15)	(0.15)	(0.15)
Leniency Program 96	0.78***	-0.02	0.17	-0.15
	(0.23)	(0.34)	(0.32)	(0.36)
Leniency Program 02	0.38**	-0.08	0.66***	0.26
	(0.15)	(0.18)	(0.18)	(0.22)
Leniency Program 06	0.20	-0.28	0.07	-0.23
	(0.17)	(0.20)	(0.18)	(0.20)
Interest Rate	0.61**	0.73***	0.68**	0.76***
	(0.19)	(0.21)	(0.22)	(0.22)
Interest Rate^2	-0.14***	-0.13***	-0.15***	-0.14***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		0.00***		0.00**
		(0.00)		(0.00)
Economic Indicator			0.03**	0.02*
			(0.01)	(0.01)
Constant	-5.69***	-14.06***	-8.00***	-13.52***
	(0.42)	(2.04)	(0.92)	(2.34)
ln(κ)	0.24***	0.24***	0.25***	0.25***
	(0.05)	(0.05)	(0.05)	(0.05)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.8: Duration Models Subsample

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.76***	0.75***	0.74***	0.74***
	(0.15)	(0.15)	(0.15)	(0.15)
Market Sharing	-0.06	-0.05	-0.05	-0.05
	(0.27)	(0.27)	(0.27)	(0.27)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	1.14***	1.14***	1.19***	1.19***
	(0.32)	(0.31)	(0.32)	(0.31)
Wholesale and Retail Trade	-0.61	-0.63	-0.62	-0.64
	(0.47)	(0.47)	(0.46)	(0.46)
Transportation and Storage	0.30	0.31	0.32	0.32
	(0.21)	(0.21)	(0.21)	(0.21)
Financial and Insurance Activities	0.32	0.32	0.36	0.36
	(0.47)	(0.47)	(0.48)	(0.48)
Others	-1.39*	-1.40*	-1.39*	-1.40*
	(0.70)	(0.70)	(0.70)	(0.70)
Spacial Scope (base: EU-wide)				
Worldwide	0.59**	0.59**	0.57**	0.57**
	(0.18)	(0.18)	(0.18)	(0.18)
Some Countries	-0.38**	-0.37*	-0.38**	-0.38**
	(0.15)	(0.15)	(0.15)	(0.15)
Members	-0.14***	-0.14***	-0.14***	-0.14***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	-0.50*	-0.50*	-0.48	-0.48
	(0.25)	(0.25)	(0.25)	(0.25)
Exit	0.80***	0.77***	0.76***	0.74***
	(0.15)	(0.15)	(0.15)	(0.15)
Leniency Program 96	-0.66	-0.74*	-0.70	-0.74*
	(0.34)	(0.35)	(0.36)	(0.36)
Leniency Program 02	0.30	0.13	0.53**	0.38
	(0.15)	(0.20)	(0.19)	(0.24)
Leniency Program 06	0.19	0.00	0.10	-0.02
	(0.17)	(0.22)	(0.18)	(0.22)
Interest Rate	0.58*	0.60*	0.53	0.55*
	(0.26)	(0.26)	(0.28)	(0.28)
Interest Rate^2	-0.15**	-0.14*	-0.13*	-0.12*
	(0.05)	(0.06)	(0.06)	(0.06)
GDP p.c.		0.00		0.00
		(0.00)		(0.00)
Economic Indicator			0.02*	0.02
			(0.01)	(0.01)
Constant	-3.98***	-7.61**	-5.99***	-8.36**
	(0.51)	(2.82)	(1.07)	(2.85)
ln(κ)	0.23***	0.23***	0.24***	0.24***
	(0.05)	(0.05)	(0.05)	(0.05)
Observations	10'975	10'975	10'975	10'975

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.9: Duration Models with Alternative GDP

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.78***	0.73***	0.75***	0.73***
	(0.15)	(0.16)	(0.16)	(0.16)
Market Sharing	-0.10	-0.07	-0.06	-0.06
	(0.26)	(0.27)	(0.27)	(0.27)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	1.22***	1.30***	1.26***	1.30***
	(0.32)	(0.29)	(0.32)	(0.30)
Wholesale and Retail Trade	-0.55	-0.66	-0.59	-0.64
	(0.47)	(0.47)	(0.46)	(0.47)
Transportation and Storage	0.30	0.33	0.32	0.33
	(0.21)	(0.21)	(0.21)	(0.21)
Financial and Insurance Activities	0.42	0.44	0.46	0.45
	(0.47)	(0.48)	(0.48)	(0.48)
Others	-1.35	-1.36	-1.37	-1.36
	(0.71)	(0.71)	(0.71)	(0.71)
Spacial Scope (base: EU-wide)				
Worldwide	0.60***	0.55**	0.55**	0.55**
	(0.18)	(0.18)	(0.18)	(0.18)
Some Countries	-0.38**	-0.41**	-0.40**	-0.41**
	(0.15)	(0.15)	(0.15)	(0.15)
Members	-0.13***	-0.14***	-0.14***	-0.14***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	-0.56*	-0.54*	-0.53*	-0.53*
	(0.25)	(0.25)	(0.25)	(0.25)
Exit	0.85***	0.77***	0.77***	0.76***
	(0.15)	(0.15)	(0.15)	(0.15)
Leniency Program 96	0.78***	0.13	0.17	0.04
	(0.23)	(0.33)	(0.32)	(0.34)
Leniency Program 02	0.38**	0.09	0.66***	0.37
	(0.15)	(0.17)	(0.18)	(0.23)
Leniency Program 06	0.20	-0.24	0.07	-0.14
	(0.17)	(0.21)	(0.18)	(0.21)
Interest Rate	0.61**	0.85***	0.68**	0.79***
	(0.19)	(0.22)	(0.22)	(0.23)
Interest Rate^2	-0.14***	-0.15***	-0.15***	-0.15***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP		0.07***		0.04
		(0.02)		(0.02)
Economic Indicator			0.03**	0.02
			(0.01)	(0.01)
Constant	-5.69***	-11.73***	-8.00***	-10.56***
	(0.42)	(1.60)	(0.92)	(1.79)
$\ln(\kappa)$	0.24***	0.25***	0.25***	0.25***
	(0.05)	(0.05)	(0.05)	(0.05)
Observations	16'264	16'166	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.10: Duration Models with Exponential Distribution

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.61***	0.56***	0.57***	0.54***
	(0.14)	(0.15)	(0.14)	(0.15)
Market Sharing	-0.11	-0.08	-0.07	-0.07
	(0.25)	(0.27)	(0.27)	(0.27)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	0.76*	0.72*	0.75*	0.74*
	(0.31)	(0.28)	(0.30)	(0.29)
Wholesale and Retail Trade	-0.65	-0.72	-0.68	-0.72
	(0.46)	(0.46)	(0.45)	(0.45)
Transportation and Storage	0.14	0.16	0.16	0.17
	(0.20)	(0.20)	(0.20)	(0.20)
Financial and Insurance Activities	0.17	0.17	0.19	0.18
	(0.42)	(0.42)	(0.43)	(0.43)
Others	-1.32*	-1.33*	-1.31*	-1.32*
	(0.67)	(0.67)	(0.66)	(0.66)
Spacial Scope (base: EU-wide)				
Worldwide	0.51**	0.50**	0.48**	0.48**
	(0.17)	(0.17)	(0.17)	(0.17)
Some Countries	-0.34*	-0.33*	-0.35*	-0.34*
	(0.14)	(0.14)	(0.14)	(0.14)
Members	-0.12***	-0.12***	-0.12***	-0.12***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	-0.77**	-0.78**	-0.75**	-0.76**
	(0.24)	(0.24)	(0.24)	(0.24)
Exit	0.94***	0.88***	0.88***	0.85***
	(0.14)	(0.15)	(0.15)	(0.15)
Leniency Program 96	0.85***	0.05	0.26	-0.06
	(0.23)	(0.34)	(0.31)	(0.35)
Leniency Program 02	0.35*	-0.11	0.59**	0.20
	(0.15)	(0.18)	(0.18)	(0.22)
Leniency Program 06	0.27	-0.19	0.15	-0.14
	(0.16)	(0.19)	(0.17)	(0.20)
Interest Rate	0.64***	0.78***	0.72**	0.80***
	(0.19)	(0.21)	(0.22)	(0.23)
Interest Rate^2	-0.14***	-0.14***	-0.16***	-0.15***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		0.00***		0.00**
		(0.00)		(0.00)
Economic Indicator			0.02**	0.02*
			(0.01)	(0.01)
Constant	-4.84***	-12.99***	-6.91***	-12.39***
	(0.36)	(1.99)	(0.88)	(2.31)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.11: Cox Regression

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	0.69***	0.63***	0.65***	0.62***
	(0.15)	(0.16)	(0.16)	(0.16)
Market Sharing	-0.14	-0.05	-0.08	-0.05
	(0.30)	(0.28)	(0.29)	(0.28)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	1.08**	1.06**	1.09**	1.08**
	(0.35)	(0.34)	(0.36)	(0.34)
Wholesale and Retail Trade	-0.52	-0.60	-0.58	-0.62
	(0.45)	(0.45)	(0.44)	(0.44)
Transportation and Storage	0.30	0.33	0.33	0.35
	(0.20)	(0.21)	(0.21)	(0.21)
Financial and Insurance Activities	0.37	0.36	0.41	0.40
	(0.43)	(0.43)	(0.44)	(0.44)
Others	-1.25	-1.33	-1.20	-1.26
	(0.66)	(0.69)	(0.65)	(0.67)
Spacial Scope (base: EU-wide)				
Worldwide	0.58**	0.54**	0.54**	0.53**
	(0.18)	(0.18)	(0.18)	(0.18)
Some Countries	-0.37**	-0.40**	-0.39**	-0.40**
	(0.14)	(0.15)	(0.14)	(0.15)
Members	-0.12***	-0.12***	-0.12***	-0.12***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	-0.76**	-0.75**	-0.72**	-0.72**
	(0.27)	(0.27)	(0.27)	(0.27)
Exit	0.77***	0.67***	0.68***	0.64***
	(0.15)	(0.16)	(0.16)	(0.16)
Leniency Program 96	0.74**	-0.14	0.10	-0.26
	(0.23)	(0.35)	(0.31)	(0.36)
Leniency Program 02	0.42**	-0.08	0.72***	0.28
	(0.15)	(0.19)	(0.19)	(0.23)
Leniency Program 06	0.19	-0.33	0.07	-0.27
	(0.18)	(0.21)	(0.19)	(0.22)
Interest Rate	0.62***	0.76***	0.71***	0.79***
	(0.18)	(0.20)	(0.21)	(0.22)
Interest Rate^2	-0.14***	-0.13***	-0.16***	-0.14***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		0.00***		0.00**
		(0.00)		(0.00)
Economic Indicator			0.03**	0.02*
			(0.01)	(0.01)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.12: Duration Models with Loglogistic Distribution

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	-0.63***	-0.56***	-0.55***	-0.52***
	(0.16)	(0.15)	(0.15)	(0.15)
Market Sharing	0.37	0.36	0.34	0.35
	(0.21)	(0.20)	(0.22)	(0.21)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	-0.53	-0.54	-0.54	-0.55
	(0.29)	(0.28)	(0.31)	(0.31)
Wholesale and Retail Trade	0.73	0.83*	0.60	0.67
	(0.38)	(0.39)	(0.39)	(0.39)
Transportation and Storage	-0.22	-0.25	-0.30	-0.30
	(0.24)	(0.25)	(0.23)	(0.24)
Financial and Insurance Activities	-0.07	-0.08	-0.05	-0.04
	(0.33)	(0.37)	(0.37)	(0.38)
Others	1.29*	1.32*	1.31*	1.33**
	(0.53)	(0.53)	(0.52)	(0.51)
Spacial Scope (base: EU-wide)				
Worldwide	-0.72***	-0.69***	-0.67***	-0.67***
	(0.20)	(0.20)	(0.19)	(0.20)
Some Countries	0.29*	0.27*	0.27*	0.26*
	(0.12)	(0.13)	(0.13)	(0.13)
Members	0.09***	0.10***	0.10***	0.09***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	0.48*	0.47*	0.46*	0.46*
	(0.19)	(0.20)	(0.20)	(0.20)
Exit	-1.03***	-1.02***	-1.06***	-1.06***
	(0.24)	(0.27)	(0.25)	(0.27)
Leniency Program 96	-0.56**	0.14	0.19	0.41
	(0.18)	(0.25)	(0.24)	(0.27)
Leniency Program 02	-0.32*	0.12	-0.72***	-0.43
	(0.15)	(0.19)	(0.17)	(0.22)
Leniency Program 06	-0.83*	-0.38	-0.83*	-0.59
	(0.40)	(0.43)	(0.41)	(0.44)
Interest Rate	-0.61**	-0.79**	-0.88***	-0.95***
	(0.20)	(0.24)	(0.24)	(0.25)
Interest Rate^2	0.12***	0.13***	0.17***	0.16***
	(0.03)	(0.03)	(0.04)	(0.04)
GDP p.c.		-0.00***		-0.00*
		(0.00)		(0.00)
Economic Indicator			-0.04***	-0.03***
			(0.01)	(0.01)
Constant	4.40***	12.27***	8.01***	12.12***
	(0.38)	(2.02)	(0.92)	(2.24)
ln(σ)	-0.54***	-0.54***	-0.56***	-0.55***
	(0.05)	(0.05)	(0.05)	(0.05)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.13: Duration Models with Lognormal Distribution

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	-0.64***	-0.56***	-0.53***	-0.51***
	(0.14)	(0.14)	(0.14)	(0.14)
Market Sharing	0.45*	0.44*	0.39	0.40
	(0.21)	(0.22)	(0.22)	(0.22)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	-0.43	-0.41	-0.48	-0.47
	(0.28)	(0.26)	(0.26)	(0.26)
Wholesale and Retail Trade	0.83*	0.92*	0.73*	0.79*
	(0.38)	(0.38)	(0.35)	(0.36)
Transportation and Storage	-0.15	-0.20	-0.24	-0.25
	(0.23)	(0.24)	(0.23)	(0.23)
Financial and Insurance Activities	0.01	-0.01	-0.06	-0.05
	(0.31)	(0.31)	(0.31)	(0.31)
Others	1.34**	1.40**	1.33**	1.36**
	(0.47)	(0.46)	(0.44)	(0.45)
Spacial Scope (base: EU-wide)				
Worldwide	-0.60***	-0.58**	-0.56**	-0.56**
	(0.18)	(0.18)	(0.18)	(0.18)
Some Countries	0.32*	0.27*	0.31*	0.28*
	(0.13)	(0.13)	(0.13)	(0.13)
Members	0.10***	0.11***	0.10***	0.10***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	0.40*	0.40*	0.38*	0.38*
	(0.19)	(0.19)	(0.18)	(0.18)
Exit	-1.06***	-1.03***	-1.01***	-1.01***
	(0.20)	(0.20)	(0.20)	(0.20)
Leniency Program 96	-0.61***	0.10	0.08	0.32
	(0.17)	(0.24)	(0.22)	(0.26)
Leniency Program 02	-0.29	0.19	-0.67***	-0.35
	(0.15)	(0.20)	(0.17)	(0.22)
Leniency Program 06	-0.66**	-0.21	-0.55*	-0.31
	(0.25)	(0.27)	(0.25)	(0.27)
Interest Rate	-0.54**	-0.70***	-0.75***	-0.82***
	(0.18)	(0.21)	(0.21)	(0.21)
Interest Rate^2	0.12***	0.12***	0.15***	0.14***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		-0.00***		-0.00*
		(0.00)		(0.00)
Economic Indicator			-0.04***	-0.03***
			(0.01)	(0.01)
Constant	4.23***	12.29***	7.61***	11.98***
	(0.34)	(2.00)	(0.81)	(2.20)
ln(σ)	0.03	0.03	0.01	0.01
	(0.05)	(0.05)	(0.05)	(0.05)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.14: Duration Models with Generalized Gamma Distribution

	(1)	(2)	(3)	(4)
Infringement (base: Multiple)				
Price Fixing	-0.62***	-0.55***	-0.54***	-0.51***
	(0.13)	(0.13)	(0.14)	(0.14)
Market Sharing	0.28	0.27	0.33	0.33
	(0.23)	(0.25)	(0.25)	(0.26)
Industry (base: Manufacturing)				
Agriculture, Forestry, And Fishing	-0.67*	-0.63*	-0.58	-0.58
	(0.30)	(0.29)	(0.33)	(0.32)
Wholesale and Retail Trade	0.65	0.74	0.68	0.73
	(0.39)	(0.40)	(0.36)	(0.37)
Transportation and Storage	-0.16	-0.19	-0.22	-0.22
	(0.20)	(0.20)	(0.22)	(0.22)
Financial and Insurance Activities	-0.22	-0.22	-0.17	-0.17
	(0.34)	(0.34)	(0.38)	(0.38)
Others	1.16*	1.21*	1.24**	1.26**
	(0.48)	(0.49)	(0.48)	(0.48)
Spacial Scope (base: EU-wide)				
Worldwide	-0.57***	-0.54**	-0.54**	-0.55**
	(0.17)	(0.17)	(0.17)	(0.18)
Some Countries	0.32**	0.30*	0.32*	0.30*
	(0.12)	(0.12)	(0.12)	(0.13)
Members	0.10***	0.11***	0.10***	0.10***
	(0.02)	(0.02)	(0.02)	(0.02)
Entry	0.43*	0.43*	0.39*	0.39*
	(0.18)	(0.19)	(0.18)	(0.18)
Exit	-0.89***	-0.86***	-0.93***	-0.91***
	(0.20)	(0.21)	(0.25)	(0.26)
Leniency Program 96	-0.60***	0.08	0.04	0.27
	(0.17)	(0.24)	(0.23)	(0.26)
Leniency Program 02	-0.31*	0.11	-0.64***	-0.33
	(0.14)	(0.18)	(0.17)	(0.21)
Leniency Program 06	-0.37	0.03	-0.41	-0.15
	(0.26)	(0.27)	(0.38)	(0.38)
Interest Rate	-0.51**	-0.64***	-0.70**	-0.75**
	(0.16)	(0.19)	(0.23)	(0.23)
Interest Rate^2	0.11***	0.11***	0.14***	0.13***
	(0.03)	(0.03)	(0.03)	(0.03)
GDP p.c.		-0.00***		-0.00*
		(0.00)		(0.00)
Economic Indicator			-0.03***	-0.03**
			(0.01)	(0.01)
Constant	4.33***	11.67***	7.29***	11.59***
	(0.32)	(1.84)	(0.99)	(2.20)
$\ln(\sigma)$	-0.06	-0.06	-0.02	-0.03
	(0.08)	(0.09)	(0.09)	(0.09)
κ	0.41	0.38	0.17	0.19
	(0.22)	(0.22)	(0.28)	(0.29)
Observations	16'264	16'264	15'631	15'631

Robust standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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Bern, 26. März 2021

Severin Jean-Jacques Lenhard