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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.

Keywords: Collusion, Interest Rate, Repeated Game, Survival Analysis
JEL: C41, D43, K21, L40

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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 paper, we analyze possible side-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.

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 profits 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

[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.

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

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 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 none 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

[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.

[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.

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 and product differentiation. Allowing one firm to capture the entire market also leads to a none 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 pro-cyclical when capacity constraints bind while it is counter-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 asymmet-

[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.

ric 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 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.

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 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.

[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.

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]

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

$$p_i^*(p_j) = \arg\max_{p_i} (p_i - C)F\left(\frac{p_j - p_i}{2t}\right) = C + 2t\frac{F\left(\frac{p_j - p_i^*(p_j)}{2t}\right)}{f\left(\frac{p_j - p_i^*(p_j)}{2t}\right)}. \tag{1}$$

[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 $F(0) = 1/2$.

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 1 gives an overview of how prices respond to different shocks. For example, if consumers perceive an increase 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.

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

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.

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 (1) to p_t,

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

The deviating firm makes a profit

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

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

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

$$\sum_{\tau=0}^{\infty} \delta^{\tau} \pi_t \geq \pi_d + \sum_{\tau=1}^{\infty} \delta^{\tau} \pi_c, \tag{3}$$

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

$$\delta^* := \frac{\pi_d - \pi_t}{\pi_d - \pi_c} = 1 - \frac{\pi_t - \pi_c}{\pi_d - \pi_c} \in [0, 1]. \tag{4}$$

Note that equation (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]

[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., $= f(1) \leq 2t/(U - 3t)$.

[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.

Proposition 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 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.

[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 $f(1) < \min\{2f(0), 4\}$.

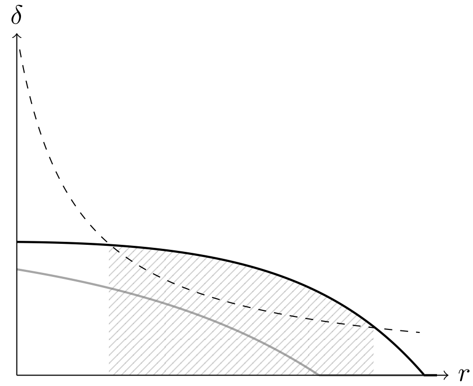

Figure 1: Discount factor. The solid black line refers to δ^* for parameter values $U = 10$, $c = 1$, $t = 1$, while the gray line refers to δ^* with $t = 1,5$. The distribution is single-peaked quadratic $f(x) = 2/3 - x^2/2$. The dashed line refers to the rational discount factor $\hat{\delta} = 1/(1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

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 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 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.

Lemma 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 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 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.

[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.

Formally,

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

where $s : [0, 1] \rightarrow [0, 1]$ 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 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

$$c \leq \frac{f(0)}{4t}\left(U - t - \frac{t}{2f(0)}\right)^2 \tag{5}$$

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

The main insight of Proposition 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 2 is best understood by plotting the stability's properties. Figure 2 illustrates the cartel's stability depending on the interest rate, assuming the same distribution and parameters as in figure 1. Generally, Proposition 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 $s : [0, \infty) \rightarrow [0, 1]$, 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 1 $\delta^* \leq 1/2 < 1 = \hat{\delta}$, thus the ratio decreases when the difference decreases. At $r = \bar{r}$, we know $\delta^* \rightarrow 0$, thus the ratio increases.

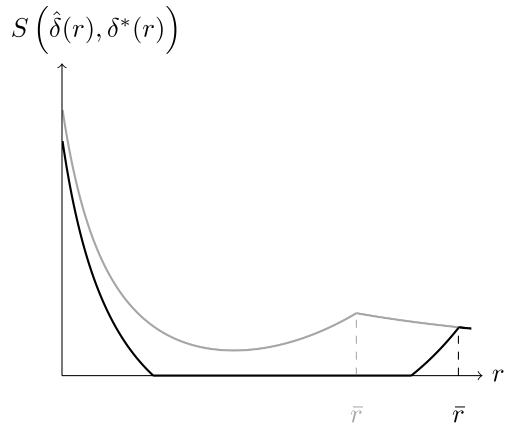

Figure 2: Cartel stability for parameter values as in figure 1, $U = 10$, $c = 1$, $t = 1$, while the gray line refers to $t = 1.5$. The distribution is single-peaked quadratic $f(x) = 2/3 - x^2/2$. The stability function is linear $s(z) = z$.

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 (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.

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 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.

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

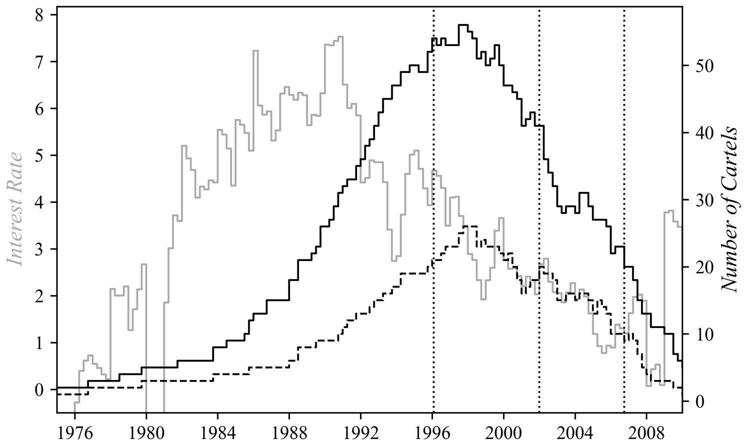

Figure 3: Real interest rate and number of active cartels. The solid black line refers to the total number of active cartels, dashed are the ones with a natural break-up. The vertical lines indicate leniency programs.

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 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

[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`

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

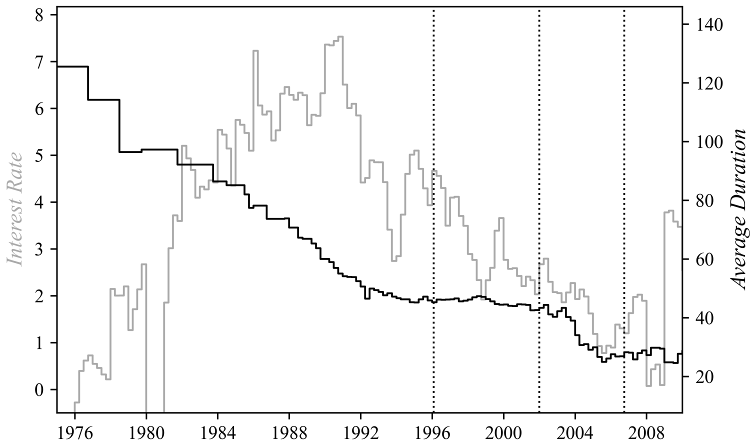

Figure 4: Real interest rate and participation duration. The solid black line refers to the active firms' average participation duration in month. The vertical lines indicate leniency programs.

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 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 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

[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.

	(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 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 4.

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

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

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

Parameters are quantified using Maximum likelihood estimation controlling for random effects. Estimates are presented in Table 12, whereby we only give a subset of the coefficients; all estimates are presented in the Appendix Table 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,

[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: 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 7.

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 7, of which we present a subset in Table 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 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.

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

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]

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]

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

[38] The data is accessible at `https://www.openicpsr.org/openicpsr/project/130650/version/V1/view`.

[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 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 (2006).

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 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 sta-

[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.

[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.

ble 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.

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.

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Appendix

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 (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

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

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 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

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

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 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 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 2 and Proposition 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 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 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 $c \leq (U-t-2t/f(0))^2f(0)/8t$, δ^* decreases stronger, which shows that Proposition 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.

[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.

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 paper.

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 1 shows the shaded area for $\delta^* \geq \hat{\delta} \Leftrightarrow IRR \leq r$, 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 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

$$c_0 + \sum_{t=1}^{\infty} \frac{c}{(1+r)^t}. \tag{6}$$

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 (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) 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 (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 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.

Proofs

Proof Lemma 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 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 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

$$\pi_d'(\gamma(r)) = \frac{\pi_d(r) - \pi_d(\bar{r})}{r - \bar{r}}, \tag{7}$$

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 (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 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 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

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

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

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

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

$\gamma(U)$ 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 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 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 (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 $r \leq \bar{r}$. $\square$

Proof Proposition 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 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 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. □

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 4 presents the logit model from the main text with a treatment effect of less than 5%. Estimates are mostly insignificant. Table 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 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 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 8 we restrict the data to a subsample after 1995. Results are similar yet less significant. In Table 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 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 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 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 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 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

$$z = \operatorname{sign}(\kappa) \frac{\log(t) - \beta^{\intercal} x_{i,t}}{\sigma}.$$

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 4: Logit Models

	(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 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 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 7: Duration Models

	(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)
$\ln(\kappa)$	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 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 9: Duration Models 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(κ)	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 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 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 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 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 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(σ)	-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
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$