Are Cartels Forever? Global Evidence Using Quantile Regression Analysis

Polemis, Michael

University of Piraeus, Hellenic Competition Commission, Hellenic Open University

23 March 2024

Are Cartels Forever? Global Evidence Using Quantile Regression Analysis

Michael L. Polemis[1,2,3]

[1] University of Piraeus, Department of Economics, email: mpolemis@unipi.gr

[2] Hellenic Competition Commission, Athens, Greece

[3] Hellenic Open University, Patras, Greece

Abstract

The longevity of cartels has been a highly contested topic among economists and managers, with numerous researchers arguing that cartels are inherently unstable and their endurance is usually short-lived. Understanding the main factors that influence a cartel duration is essential from a managerial point of view let alone the competition policy perspective. Despite having a large body of literature, there has been no systematic evaluation of the existing driving factors to determine the current understanding and identify potential paths for future research. The present paper employs quantile regression techniques thus allowing for a more thorough and precise depiction of the data in terms of estimations compared to the traditional OLS analysis. The empirical findings support that the number of cartelists imposes an asymmetric effect, reducing (increasing) the lifespan of the collusion only in the short (long) lived cartels. Operating internationally and having a third-party facilitator both lengthen cartels, but the magnitudes of these effects decline monotonically over the range of the distribution. Relative to price-fixing, bid-rigging lengthens cartels in the bottom 20% of the distribution but has no significant effect elsewhere. Finally, the prevalence of leniency programs appears to have no significant effect on cartel duration, except at the very bottom of the distribution where the effect is small in magnitude.

Keywords: Collusion; Longevity; Cartelists; Sanctions; Quantiles
JEL codes: L41; L13; D43; C31

1. Introduction

"*People of the same trade seldom meet together, even for merriment and diversion, but the conversation ends in a conspiracy against the public, or in some contrivance to raise prices*" Adam Smith, (1776). An inquiry into the Wealth of Nations.

With this famous phrase, Adam Smith successfully identified the core of collusion that creates a cartel, resulting in an agreement to raise prices and harm consumers. The term cartel is used to describe a group of firms that come together to limit competition in the market often using price-fixing. Cartel activity, however, can appear in other ways than just price-fixing, such as output limitations (e.g., production quotas), the sharing of customers (including bid-rigging agreements), territorial exclusivity, and other restrictive practices, that allow the members of a cartel to reap the benefits of a monopoly (Garz and Maaß, 2021; Motta, 2004; Harrington, 1989;1991;2006a; Zhou, 2012). Cartels can be found in many industries, ranging from oil and gas to pharmaceuticals and telecommunications.

Cartel longevity has been the subject of much debate, with many researchers arguing that cartels are inherently unstable and that their longevity is often limited (Rob, 2003). While some cartels have been able to survive for extended long periods (i.e. OPEC), many cartels are often limited in their longevity due to external factors including government intervention and increased competition from other firms (see among others Levenstein and Suslow, 2016; 2011 and 2006; De, 2020; Rob, 2003; Symeonidis, 2002). Furthermore, even when cartels are initially successful in achieving their goals, they may remain vulnerable to the actions of their members and can disintegrate quickly if members fail to adhere to the previously agreed-upon terms

(Rob, 2003). The duration of a cartel is a critical factor in determining its effectiveness and sustainability, as well as its potential to harm consumers. All in all, a collaboration between competing firms (coopetition), has been perceived as a double-edged sword, presenting both potential advantages and risks for businesses (see among others Peng et al, 2012; Ritala, 2012; Kim and Parkhe, 2009).

Studying cartel formation and survival in management science provides useful insights into the dynamics of collusion, price-fixing, and anti-competitive behavior within industries. This knowledge enables managers to identify and combat such unlawful activities, thereby promoting fair and effective competition and thus protecting consumer welfare. From a managerial perspective, analyzing the driving factors of cartel behaviour enhances decision-making strategies and corporate governance by unveiling the potential risks associated with unethical practices and the importance of applying ethical standards in business operations. While there is a significant public interest in discouraging firms from engaging in anticompetitive behavior (e.g., price fixing, collusive tendering, market foreclosure, etc) recent studies have indicated that top managers of public companies find this behavior appealing raising serious doubts about the effectiveness of antitrust legislation (see for example González et al., 2019).

The scope of this study is to investigate the main factors that influence the duration of cartels, focusing on the role of government intervention, the impact of cartel behavior, and the dynamics of the market. This work aims to identify the key elements that enable cartels to sustain over time. A sample of 180 international hardcore cartels drawn from 50 different countries over the period 2012-2021 is scrutinized using quantile regression techniques. Understanding the factors that sustain collusion may

help antitrust agencies design policies like leniency programs (Miller, 2009) or screening (Harrington, 2006), which might deter or uncover cartels.

This is one of the few studies that uses quantile methodology which supports a more comprehensive and accurate description of the data by providing an in-depth analysis of the entire distribution of the dependent variable. This means that it can capture extreme values that other econometric methods (see OLS) may have difficulty capturing. For this reason, is more robust to outliers, as it can identify extreme values and their potential impact on the regression results. Moreover, a multiple quantile regression analysis is one of the appropriate econometric techniques to correct for selection bias (Bos et al., 2018).

The study closest to ours is the work of Bos et al., (2018), who investigate the deterrent impact of anti-cartel enforcement on a sample of 107 (legal and illegal) cartel episodes before 1945 and after 1975 employing a multiple quantile regression model alongside a propensity score matching quantile procedure. The authors argue that the distribution of overcharges for illegal cartels displays a reduced concentration in both the lower and upper tails when contrasted with the overcharge distribution for legal cartels. Although this study provides useful empirical insights and policy implications targeted at the competition authorities it does not delve into the main driving factors that determine cartel duration.

Our study adds to the existing empirical literature on the main determinants of cartel duration in various ways. Unlike other studies on the field, we argue that the distribution of cartel duration is right-skewed. Since longer-lasting cartels have a more significant impact on consumers, this work focuses on the right tail of the cartel duration distribution (i.e., third quantile or 90^{th} percentile). Given the above considerations, this study departs from the existing empirical studies, by employing quantile regression

analysis. The latter emerges as the more suitable approach (over the traditional OLS method) for gaining meaningful insights into the longevity of cartels, as it allows us to delve deeper into the critical aspects of the data.

The rest of this study unfolds as follows. In the next section, we briefly describe the related literature on the topic. Then we present in detail the necessary conceptual motivation for shaping the main testable research hypotheses of this paper. Furthermore, the sample variables and the empirical methodology used in the present study are examined. In addition, our econometric results concerning similar studies are discussed and analyzed. Finally, we draw important conclusions from our findings, both in terms of theoretical, policy, and managerial implications. We also discuss possible limitations and identify potential directions for future research.

2. Literature Review

The study of cartel duration has been a topic of interest for researchers for many years. One of the earliest studies of cartel duration was conducted by Hirsch and Yoon (1985). They use a dataset of 31 cartels in the United States and find that cartels have an average duration of just over two years. They also argue that large cartels (e.g., more than ten firms), tend to last longer than smaller cartels. Subsequent studies of cartel duration have used more sophisticated methods, such as duration models (Wang et al., 2009). Duration models allow researchers to estimate the average duration of cartels and the effect of various covariates, such as cartel size and degree of competition in the industry, on cartel duration. These studies have generally found that cartels tend to be longer lasting in countries with weaker enforcement, suggesting that antitrust enforcement is an important factor in regulating cartel behavior. In addition, several works have examined the effect of antitrust enforcement on cartel duration (Baer et al., 2005; Corts and Gilbert, 2002).

In a seminal paper, Friedman (1971) suggests that to analyze the sustainability and therefore the likelihood of collusion one must evaluate the ability to sustain collusion and that is related to the incentives of each firm to do so. Harrington (1989) considers the role of asymmetric (firm-specific) discount factors. Lambson (1994, 1995) studies asymmetric capacities in homogenous product industries and argues that slight asymmetries can reduce the danger of tacit coordination because the firm with greater capacity may have the greatest incentive to undercut its rivals (cheat) and the greatest ability to punish deviation by others. Compte et al. (2002) explore this logic in greater detail and argue that asymmetric capacities can indeed make collusion more difficult to sustain when aggregate capacity is limited.

Vasconcelos (2005) extends previous studies (see Rothschild, 1999; Harrington, 1991), to argue that the smallest firms (in his case the highest-cost firm) are the most difficult to induce coordinate while the largest ones are hardest to induce to credibly punish. Kühn (2004) provides an important theoretical contribution to this literature. The relevant work is in alignment with the study of Vasconcelos (2005) in that, all else equal, small firms may be hardest to incentivize to coordinate while large firms may be hardest to induce to punish credibly since they will suffer most from severe punishment periods.

In a review of a large set of known cartels, Levenstein and Suslow (2006) find that the average longevity of an explicit cartel is about five years, whereas the distribution is bimodal. In other words, they argue that while some cartels last for decades, many others last for less than a year.

Previous research has looked at how different systematic factors, such as internal cartel organization and duration, region of operation, market concentration, and the legal environment, are associated with the level of cartel overcharges (Griffin 1989;

Connor and Bolotova 2006; Bolotova 2009; Bolotova et al. 2007; Bolotova et al. 2009). Among these studies, Bolotova (2009) stands out as one of the most comprehensive, combining theory with evidence from over 400 cartels dating as far back as the 18th century. The findings suggest that international cartels tend to have higher overcharges than domestic cartels, in Europe and the US compared to the rest of the world, in markets with fewer firms, with weak outside competition, for older cartels, and in environments where competition policy is not strict.

Abrantes et al., (2013) investigate the duration of cartels using a mixed proportional hazard model, taking into account various cartel characteristics including the agency responsible for detecting the cartel, the industry it operates in (whether it is a bid rigging or price fixing cartel), the number of countries affected, the volume of affected sales, and measures related to the economic cycle and trend. They argue that cartels first detected by agencies in the United States or European Union tend to have longer lifespans. Additionally, bid-rigging cartels tend to exhibit longer durations compared to other types of cartels. On the other hand, cartels that span across multiple geographies tend to have shorter lifespans. They also observe that the size of a cartel's affected sales and the severity of sanctions play a role in determining the duration of the cartel. Larger affected sales and more severe sanctions are associated with longer-lasting cartels (see also Connor, 2006).

In a subsequent study, Harrington, and Wei (2017) examine the potential bias in estimates of average cartel duration and the probability of cartel death each year. A birth-death-discovery process is proposed to explore the source and direction of any potential bias. By applying Bayesian inference, the related study argues that bounds on the amount of the bias can be determined and more accurate beliefs on the likelihood of cartel death can be established. The specific study employs data from discovered

cartels to form the estimates. However, it is argued that these estimates may not be an accurate representation of the entire population of cartels.

To sum up, the duration of a cartel is determined by a variety of factors, including government intervention, the behavior of the firms within the cartel, and the dynamics of the market. Governments play a critical role in determining the duration of cartels, as they can intervene in the market in several ways to prevent or discourage cartels from forming and operating. The behavior of the firms within a cartel, as well as the behavior of outsiders, can have a significant impact on its duration. Finally, the dynamics of the market, such as the level of competition and the profitability of the market, can also influence the duration of a cartel.

3. Conceptual framework

In this section, we develop the research hypotheses on possible determinants of the cartel duration. We build our framework around the five main explanatory variables. Despite not being guided by a strong theoretical model, we rely on the findings of several empirical studies to present a set of five distinct research hypotheses. These hypotheses are fully described below, and we provide several testable results based on our analysis (see Figure 1).

<Insert Figure 1 about here>

The number of firms involved in a cartel (cartelists) is an important factor that can affect the stability and longevity of the cartel. In general, smaller cartels are more likely to be successful and last longer than larger ones. This is because smaller cartels are easier to manage and control, and the participants are more likely to trust each other and maintain the agreement.

When a cartel has a small number of participants, each member has a larger share of the market and can benefit more from the cartel agreement. This gives them a stronger incentive to comply with the agreement and maintain the cartel. In contrast, when a cartel has many participants, each member has a smaller share of the market and may not benefit as much from the cartel agreement. This can lead to members breaking the agreement and trying to gain a larger market share by competing.

Moreover, having more cartelists in a cartel can make it more difficult to maintain collusion and can increase the likelihood of cheating, which could lead to a shorter cartel duration (see Levenstein and Suslow, 2006). This is because as the number of cartel members increases, it becomes more difficult for the cartel to monitor each member's behavior and ensure that they are complying with the agreed-upon production levels and prices. This is particularly true if the cartel operates across multiple geographic regions or industries. The larger and more diverse the members of the cartel, the more difficult it is to ensure that all members are adhering to the agreed-upon terms of the cartel. In addition, having more cartelists can increase the risk of regulatory intervention. In other words, antitrust authorities are more likely to investigate and act against larger cartels, particularly if they believe that the cartel is causing harm to consumers or distorting market outcomes.

However, in some cases, having many cartelists may increase the cartel's bargaining power *vis-a-vis* buyers or suppliers. This can help the cartel to maintain higher prices and profits over a longer period. In an earlier study, Posner, (1970) conducts a study and discovers that the duration of cartels increases with the number of firms involved. The study is based on a large sample of 989 cases from the US Department of Justice (DoJ) and argues that 52% of cartels with 10 or fewer members persisted for 6 years or more. Interestingly, the duration of cartels with more than 10

firms was even longer, with 64% lasting 6 years or more. Similarly, Dick (1996), argues that cartel duration increases with the share of the market controlled by cartel members. Based on the above, it is straightforward to hypothesize the following:

H1: An increase in the number of cartel participants (cartelists) reduces cartel longevity

The duration of cartels is sensitive to the level of fines imposed on its members. It is argued that higher fines for cartel members limit the duration of the cartel. This can be attributed to the fact that higher fines increase the cost of participation in the cartel, thus reducing its profitability. Besides, fines, constitute one of the most crucial enforcement tools in the combat against cartels (see for instance Katsoulacos et al., 2020).

According to economic models of cartels, it is proposed that cartel members make ex-ante conjectures, or predictions, about the expected level of sanctions they might face in the future (see among others Abrantes et al., 2013). If we assume that the actual sanctions imposed serve as reliable proxies for these conjectures, it is argued that when the prospect of facing low sanctions is perceived by the cartel members, it tends to stabilize the cartel. As a result, there is an inverse relationship between the level of sanctions and the duration of the cartel. In other words, when the anticipated sanctions are low, the cartel is more likely to last for a longer period.

Recent research has found that cartel duration is affected by the imposition of fines (see among others Connor 2006; Abrantes et al., 2013). Specifically, the introduction of fines has been found to reduce cartel duration and increase the likelihood of cartel dissolution (Smuda et al., 2015). This effect is because fines increase the costs of cartel participation, which in turn reduces the incentives to remain in a cartel. In addition, fines can create uncertainty and distrust among cartel members, making it difficult to maintain a functioning cartel.

The impact of fines on cartel duration is highly dependent on the size of the fine imposed. Research has found that when fines are relatively small, they have little impact on cartel duration. However, when fines are larger, they have a more pronounced effect, significantly reducing cartel duration. Thus, the effectiveness of fines in deterring cartels is dependent on the size of the fine imposed. Overall, fines have a significant effect on cartel duration.

Fines may have a direct effect on a cartel's longevity by deterring its members from continuing their collusive actions. By imposing heavy fines, antitrust authorities can make it more costly for cartel members to engage in these activities than to cease their collusive actions. This has the potential to drastically reduce the incentive for cartel members to continue their cartel and cause them to disband. Fines can also have an indirect effect on the duration of a cartel by weakening the cartel's ability to control the market. Fines can be very costly for cartel members and may reduce the resources available to be used in controlling the market. This can weaken the cartel's ability to maintain its market power and reduce its profit margins. This can lead to a decrease in the cartel's ability to function effectively, thus reducing its duration.

However, previous studies (see for example Connor, 2013), examine the determinative relationship of collusive duration to U.S. convicted companies' cartel fines. They hypothesize a positive relationship but only found a nonsignificant one. Similarly, Miller and Connor, (2010) argue that the cartel duration within the European Union is also unrelated to cartel fines. This may be attributed to the fact that the OLS regression analysis that has been used in both studies conceals the real nature of the cartel data (e.g., right-skewed) and thus leads to conflicting results.

Therefore, we test the following research hypothesis:

H2: An increase in the number of fines imposed on a cartel has a negative effect on cartel duration.

In recent years, the global economy has become increasingly interconnected, with businesses conducting business across borders, and consumers purchasing goods from all corners of the world. This increased globalization has had a significant impact on cartel duration, as cartels are a form of price-fixing collusion that can reap large profits for the participating firms.

The current global economic landscape has made it increasingly easier for cartels to form, as firms can easily coordinate prices and divide markets across borders. By forming a cartel, firms can reduce competition and reap large profits, as they can control pricing and the number of goods produced. This ability to coordinate across borders has allowed cartels to become larger and to last longer, as it has become easier to keep the cartel secret.

The increased globalization has also had a direct impact on cartel duration. Without the ability to coordinate across borders, cartels would be limited to a single country or region. This would limit the scope of the cartel, making it easier for competitors to break the cartel and for antitrust authorities to detect the cartel. With global coordination, cartels can span multiple countries and regions, making it much more difficult for competitors and authorities to detect and break the cartel. Finally, the increased globalization has allowed cartels to benefit from economies of scale, as they can take advantage of large production and distribution networks. This allows cartels to produce and distribute goods at a much lower cost, increasing their profits and allowing them to last longer.

Additionally, the global coverage of cartels has made them more difficult to break up. Cartels can use their global reach to coordinate their activities, making it

difficult for governments to intervene. This is particularly true when cartels are operating in multiple countries, as it is difficult to coordinate a response across multiple jurisdictions. Furthermore, the global coverage of cartels means that there is a greater pool of resources for them to draw from, making it harder for governments to successfully disrupt their operations. Finally, the global coverage of cartels has made them more resilient. Cartels can use their global reach to find new markets and adapt to changing conditions. This means that they can survive in the long term, making them more difficult to break up.

On the other hand, Abrantes et al., (2013), claim that cartels distributed across geographies tend to be shorter-lived. Overall, the increased globalization and global coverage have had a significant impact on cartel duration, as it has allowed cartels to become larger, easier to form, and more difficult to detect and break. By taking advantage of global coordination and economies of scale, cartels can last much longer and reap greater profits than they would be able to in a purely local market. Hence, the following hypothesis is put forward.

H3: A cross-border cartel with globalized geographical coverage extends its longevity.

Bid rigging is an illegal practice that involves groups of companies conspiring to inflate prices or reduce the quality of goods or services offered in public tenders (see among others Llorente-Saguer and Zultan, 2017). This anti-competitive behavior has cost governments and taxpayers billions of dollars each year in OECD countries. Public procurement accounts for about 12% of GDP in OECD countries and can be even higher in developing countries (OECD, 2012).

A bid-rigging cartel is an agreement between two or more competing companies to not bid against each other for a particular contract or sale. These cartels are illegal in many countries, and the consequences of being caught participating in one can be

severe, ranging from financial penalties to criminal prosecution. When a bid-rigging cartel is exposed, the consequences for the members involved can be catastrophic. Not only will they have to pay large fines and possibly face criminal prosecution, but the cartel itself will be dissolved. This means that any benefits the participants received from participating in the cartel will be lost, and the duration of the cartel will be drastically reduced.

Bid-rigging cartels involve collusion among bidders in public procurement or competitive bidding processes. The purpose is to manipulate the bidding process and secure contracts at inflated prices, disadvantaging other bidders and the procuring entity. Debarment or blacklisting debarment is a common enforcement mechanism used specifically in bid-rigging cases (Veljanovski, 2023). When companies are found guilty of bid-rigging, they can be debarred or blacklisted from participating in future bidding processes for a certain period. This means they are temporarily or permanently excluded from receiving government contracts, effectively preventing them from benefiting from public procurement opportunities. Debarment serves as a powerful deterrent by imposing significant economic consequences on companies involved in bid-rigging cartels. It sends a strong signal that such anti-competitive practices will not be tolerated, safeguarding the integrity of public procurement, and promoting competition.

The impact of a bid-rigging cartel on its duration can be seen in several ways. Firstly, it reduces the incentive of participants to continue cooperating, as they can no longer benefit from the arrangement. Secondly, it increases the likelihood of exposure and enforcement action, which further reduces the cartel's duration. Finally, it reduces the trust between the participants, which can hamper their ability to cooperate in the future.

Based on the above, it is noteworthy to highlight that bid-rigging cartels and standard cartels have some key differences in terms of enforcement, with debarment (or blacklisting) being one of the features that sets bid-rigging cartels apart. Standard cartels typically involve collusion among competitors in the same industry to control prices, restrict output, allocate markets, or engage in other anti-competitive practices. These cartels aim to eliminate competition and maximize profits by coordinating their actions. Standard cartel enforcement focuses on imposing fines and penalties on the participating companies.

In a related study, Abrantes et al., (2013) argue that bid-rigging cartels generally have significantly reduced detection hazards, meaning that this type of cartel tends to last for longer periods. Many bid-rigging schemes are directed at state and local construction agencies or national health services, and these buyers may be unequipped to detect collusion in bidding, relative to price-fixing cartels whose prices may more likely be public and subject to flagging of abnormal behavior.

Therefore, the impact of a bid-rigging cartel on its duration is straightforward since it drastically reduces the benefits of participating, increases the risk of exposure and enforcement action, and reduces the trust between cartelists. Based on these findings, it appears that coopetition alignment through bid-rigging has a positive impact on cartel longevity.

H4: A bid-rigging anti-competitive practice usually lasts longer than a non-collusive tendering cartel.

The existence of third parties (e.g., cartel "*facilitators*") has been found to have a significant impact on cartel longevity.[1] The role of facilitators in maintaining cartels is

[1] Facilitators are third parties that provide the means or environment for the formation and maintenance of cartels. They can take the form of professional advisors, such as lawyers, economists, and accountants, and can also include corporate entities, such as banks and investment funds.

twofold. Firstly, they provide logistical and operational support to the cartel members by offering services such as document preparation and enforcement of cartel agreements. By ensuring that the cartel members can meet their agreements, facilitators increase the likelihood of the cartel's success and its duration. Secondly, facilitators can provide a degree of insulation from legal liability, as they can act as intermediaries between the cartel members and the authorities. This can help to protect the cartel members from anti-trust action and enable the cartel to continue operating for longer than it otherwise would.

The impact of facilitators on the duration of cartels has been studied by economists. Previous studies have found that the presence of facilitators can increase the lifespan of a cartel by up to 40% (Dunne, 2020). This suggests that the presence of a facilitator can be an important factor in the longevity of a cartel and can have a significant impact on the overall success of a cartel.

In conclusion, the role of facilitators in cartels is an important one, as it has been found to have a significant impact on the duration of cartels. Facilitators provide logistical and operational support to the cartel members and can also provide a degree of insulation from legal liability. This can help to extend the lifespan of a cartel and increase its chances of success. Therefore, we proceed to the testing of the following hypothesis:

H5: The presence of cartel facilitators extends the life span of a cartel agreement.

4. Data and Methodology

4.1 Sample selection and variables

The data are drawn from the OECD International Cartels Database.[2] This database contains 200 cases related to international hard-core cartels since 2012 from

[2] https://qdd.oecd.org/subject.aspx?Subject=OECD_HIC

approximately 50 jurisdictions[3]. The included cartels are those in which competition authorities have issued decisions against (and possibly fined) cartels, and/or in which private damages have been collected. Table 1 lists the sample variables.

<Insert Table 1 about here>

Table 2 presents the descriptive statistics for the sample variables. As it is evident, the variable denoting the number of undertakings involved in a cartel case (*Cartelists*) exhibits the highest variation among the other variables. The average duration of the 180 investigated hardcore cartels included in the sample is roughly 6.2 years. The median distribution for cartel longevity is lower and estimated to be 5 years. This means that 50% of the distribution of the related variable (Duration) lies below the specific value (1,825 days) and the rest is above this "*threshold*". Since the (arithmetic) mean is greater than the median, the distribution is not symmetric.

<Insert Table 2 about here>

The relevant finding can be confirmed by the visual inspection of Figure 2 which displays the distribution of cartel duration. Notice that duration tends to be clustered around one and two years, which indicates that a large fraction of cartel cases are short-lived, while the rest part of the distribution is extended beyond two years. As it is evident, there is a large variation in years that creates a deviation of the distribution from normality (right-skewed). In other words, since those long cartels are most damaging to consumers, we need to pay special attention to the right tail of cartel duration distribution. Therefore, a right-skewed distribution of the cartel duration,

[3] The term "*hard core*" refers to anticompetitive agreements, concerted practices, or arrangements by actual or potential competitors to agree on prices, make rigged bids (collusive tenders), establish output restrictions or quotas, or share or divide markets.

indicates that quantile regression will reveal us more about the cartel data than OLS, making the former method more accurate than the latter.

<Insert Figure 2 about here>

Figure 3 plots the dependent variable (Duration) by quantiles across the whole sample. It is obvious that even at the 50th quantile (median) the cartel duration depicts relatively moderate rates (around 5 years). It is worth mentioning that the CDF of the dependent variable does not portray significant variation since it follows an increasing upward trend from the low quantiles (especially from the 25th) until the high quantiles (90th quantile). The above findings reveal that the CDF of the dependent variable does not follow a symmetric pattern.

<Insert Figure 3 about here>

We must stress though that cartel duration could be affected by several other factors such as leniency applications or repeat offenders (see also Veljanovski, 2023). However, the information about whether the cartel is discovered due to application for leniency and whether the cartel participants are repeat offenders or not is not yet readily available in all OECD cases. For this reason, we have used a proxy variable (linear time trend) to quantify the impact of increasing leniency applications on cartel duration.[4]

4.2 Methodology

Quantile regression is an alternative to the more common Ordinary Least Squares (OLS) regression, which estimates the influence of independent variables on the mean of the dependent variable's conditional distribution. While OLS relies on a

[4] Alternatively, one could use country and firm fixed effects to capture the impact of leniency programs on cartel longevity within a panel data framework.

strong simplification, quantile regression permits consideration of the full conditional distribution of the dependent variable in contrast to the traditional OLS. The quantile regression analysis makes different assumptions compared to OLS. Specifically, instead of assuming a linear function for the mean, quantile regression assumes a linear function for quantiles. Thus, quantile regression does make a functional form assumption. Moreover, this method is not susceptible to extreme values. It is also useful when dealing with non-identically distributed data, allowing us to compare how much different quantiles are affected by a given set of covariates (see Koenker, 2005 and Powell, 1986). The estimated slopes of quantile regressions assess the change in a specific quantile of the dependent variable caused by a unitary change in the explanatory variable, providing a richer characterization of the data. Additionally, quantile regression is invariant to monotonic transformations such as natural logarithms.

Quantile regressions are a valuable tool for analyzing non-identically distributed data (Distante et al, 2018). These models allow us to estimate the *"slopes"* associated with different quantiles when considering a given set of covariates (Machado and Mata, 2000). These slopes quantify the change in each quantile of the dependent variable resulting from a one-unit change in the explanatory variable. This enables us to compare which quantiles are more affected by certain characteristics than other quantiles. Therefore, QR is beneficial in the presence of heteroskedasticity and/or non-normality in the error term (Buchinsky 1998). Moreover, quantile regressions provide a more comprehensive description of the data, allowing us to consider the effect of a covariate on the entire distribution of the dependent variable, not just its conditional mean. Additionally, quantile regression is insensitive to monotonic transformations such as natural logarithms.

All in all, quantile regression will reveal more about the cartel data than OLS. This holds since cartel duration has skewed distribution as it was analyzed. Since long cartels are most damaging to the consumers, we need to pay special attention to the right tail (e.g., third quantile or 90% percentile) of cartel duration distribution. As a result, quantile regression seems to be the most appropriate method (over the traditional OLS) to discover meaningful insights into cartel longevity.

To investigate the determinants of the cartel duration, we estimate the following semi-log equation:

$$Q_{logduration}(\tau_j \mid Z) = a_1 + b_1(\tau_j) \times log(Cartelists) + b_2(\tau_j) \times Fines + b_3(\tau_j) \times Cover + b_4(\tau_j) \times Bid + b_5(\tau_j) \times Third + b_6(\tau_j) \times Trend + u, \tau_j \, \varepsilon(0,1) \quad (1)$$

Where subscript j = 0.01, 0.05, 0.10 0.15. 0.20. 0.25. 0.30, 0.40, 0.50, 0.65, 0.75, 0.85, 0.90, and 0.95 represents the 1st, 5th, 10th, 15th 20th, 25th, 30th, 40th, 50th (median), 65th, 75th, 85th, 90th and 95th quantile (τ) of the conditional distribution of the dependent variable. Z denotes the vector of control variables. The reason for using a reduced-form approach is dictated by the fact that explicitly modeling all the cartel longevity mechanisms would be infeasible.

The interpretation of the independent variables comes as follows. Duration denotes the average case duration (measured in years) of each cartel case. Cartelists denote the number of participants per cartel case. Fines denote the total fines imposed by the National Competition Agency (NCA) on cartel participants per case (measured in million USD). Cover is a dummy variable equal to one if the cartel has global coverage and zero otherwise. Bid is a dummy variable equal to one if the cartelists made rigged bids (collusive tenders), and zero otherwise. Third is a dummy variable equal to one if there was support by third parties per cartel case and zero otherwise. Trend

denotes the (linear) time trend accounting for the increasing effect of leniency applications and awards given by the competition authorities to the cartel applicants. Moreover, u denotes the error term.

5. Results and discussion

Table 3 reports the empirical results of our analysis. Specifically, column 1 displays the regression findings using OLS and allowing for robust standard errors (Model 1), while the rest columns record the results at various quantiles obtained from the sequential regression quantile methodology allowing for 100 repetitions (Model 2). In the case of Model 1, it is evident that nearly all the coefficients are statistically significant. Specifically, the number of cartelists is positively correlated with the cartel duration and the relevant coefficient is estimated to be 0.223. This means that, for every one-unit increase in the number of firms, the cartel duration increases by about 25%[5]. This finding denotes that with more cartelists, there is a greater incentive to remain in the cartel as the profits are shared among a greater number of firms. Additionally, a larger number of cartelists increases the difficulty of defections due to the complexity of the coordination required to keep the cartel alive. Moreover, an increase in the number of firms involved in a cartel tends to increase the likelihood of successful enforcement of the cartel agreement as it dilutes the cost of enforcement among the cartelists.

<Insert Table 3 about here>

The sanctions (*Fines*) are also positively correlated with the cartel longevity, indicating that an increase in the fines for a cartel formulation, tends to extend its duration. This finding though statistically significant runs against the existing

[5] The relevant percentage can be estimated as 25% = exp (0.223-1) *100).

theoretical and empirical literature (see for example Abrantes et al., 2013) and is possibly attributed to the biasness of the OLS method compared to the QR analysis.

The extent of the geographical coverage of a cartel is positively correlated with its duration, indicating that a cross-border cartel characterized by an increased globalized coverage enhances its longevity. The estimated coefficient exceeds unity (1.161) and is statistically significant at a 1% level of significance. However, the relevant data and the empirical literature on the field point out that geographical coverage varies by the continent of cartel operation (see Abrantes et al., 2013; Bos et al., 2018). For this reason, we have used several binary variables (dummies) to account for the Europe and the US coverage. The results do not reveal significant heterogeneity across jurisdictions.[6]

Similar findings hold when looking at the impact of third parties (cartel facilitators) on cartel duration. The relevant coefficient comes with a positive sign (0,549) and is statistically significant, indicating that for every one-unit increase (decrease) in the number of third parties involved in the cartel, its duration increases by about 73%. On the contrary, we cannot support the H_4 research hypothesis that a bid-rigging anti-competitive behavior increases the cartel duration since the related coefficient though positive (0,053) is not statistically significant.

The econometric results generated using the sequential quantile regression method highlight a different pattern (see Model II, columns 2-15). From the careful inspection of Table 3, it is evident that the (logged) number of cartelists is statistically significantly correlated with the dependent variable. However, the estimated coefficient alternates in sign starting from negative (up to the 10^{th} quantile) to positive for the rest

[6] The results are available upon request.

quantiles (except for the 75th quantile) of the cumulative distribution function (CDF) of the dependent variable (*Lduration*).

We argue that at the lowest part of the conditional distribution of the dependent variable (up to 1,5 years), the number of cartelists poses a negative impact on cartel duration. This means that when a cartel has a limited number of members, each participant has a greater share of the market and can gain more from the cartel agreement. In contrast, when a cartel is made up of many members, each one has a much smaller share of the market and may not benefit as much from the agreement. Eventually, this can cause members to break the agreement and attempt to increase their market share by competing with one another. However, for the largest part of the CDF of the cartel duration (from 1.5 years up to 28 years), the relationship between the number of cartelized entities and cartel longevity turns out to be positive and statistically significant. The relevant magnitude of the (positive) estimated coefficients ranges from 0,0381 (65th quantile) to 0,357 (30th quantile). In other words, for every one-unit increase in the number of firms, the cartel duration shows an increase ranging from 3,9% to 42,9%. The relevant findings reject the validity of the H_1 hypothesis -at least for the largest part of the CDF of the dependent variable- unraveling the existence of possible non-linear effects on the impact of cartelists on cartel longevity. These empirical results have been already hidden by the OLS regression analysis that uses the mean of the distribution (see column 1).

It is noteworthy that a pecuniary sanction (*Fines*) imposed on a cartel has a negative effect on its longevity since the estimated coefficient is negative and statistically significant for most parts of the CDF of the dependent variable (except for the 65th, 75^{th,} and 85th quantile). The relevant findings are in alignment with the existing literature (see Andres et al., 2023; 2021 and Abrantes et al., 2013) thus leading to the

acceptance of the H_2 hypothesis. Moreover, the cartel duration seems to increase when there is global geographical coverage indicating that a cross-border cartel enhances its longevity leading to the validity of the H_3 hypothesis. The relevant estimates are positive and statically significant up to the 85th quantile depicting a significant variation (from 0,183 to 2,570). It is worth mentioning that on average the absolute estimate is getting smaller across the larger quantiles. The positive sign allows the cartels to leverage global coordination and economies of scale, to capitalize on larger operations, improved formation, and a more challenging detection and dismantling process. This enables cartels to last longer and generate higher profits than what would be possible in a localized geographical market.

Bid rigging behavior by cartel members seems to amplify the cartel longevity with the estimated coefficient positive and statistically significant up to the 20th quantile. The estimates range from 0,0493 (20th quantile) to 0,713 (first quantile), indicating that for every one-unit increase in the bid-rigged cartels, their longevity exhibits an upward trend from 5,1% to 104%. However, the trend is fully reversed after the 25th quantile and for the rest of the distribution. Specifically, the estimated coefficient is negative though not statistically significant demonstrating that the effect of this variable on the cartel duration is negligible, leading thus to the rejection of the H_4 hypothesis.

In addition, the impact of cartel facilitators (*third parties*) on the cartel duration when significant is positive across the quantiles and the estimated magnitude falls within a broad interval (from 0,145 on the 40th quantile to 1,689 on the first quantile). From the range of the estimated coefficients, we argue that a one-unit increase in the number of cartel facilitators incurs an increase of up to 200% in the cartel longevity. The positive sign of the QR coefficients supports the H_5 hypothesis indicating that the

presence of cartel facilitators extends the life span of a collusive agreement. Lastly, we notice that the linear time trend is positive and statistically significant up to the 20th quantile (0,00325) revealing that leniency programs and awards in the different cartel jurisdictions do not shrink the life span of the cartels at least 80% of the conditional distribution of the dependent variable.

Having investigated the empirical findings of the two models, it is intriguing to analyze how the impact of each covariate differs across quantiles and compare it with the estimates derived from the OLS model. For this reason, we employ the bootstrapped quantile regression analysis (QR) to illustrate how the impact of the key driving factors on cartel longevity may vary across the quantiles (see Figure 4). The results of this analysis reveal that the magnitude of the effects of certain quantiles can be markedly different from what is estimated by the OLS approach, with notably different confidence intervals around each coefficient. As has been already highlighted, the number of cartelists (expressed in its natural logarithm) exhibits a changing non-monotonic pattern on cartel duration. From the inspection of Figure 4, we notice that the impact on cartel longevity differs considerably across the quantiles, imposing a negative effect at lower quantiles (up to the 20^{th} quantile) though not statically significant considering the broad confidence bands (grey shaded area). However, the trend is reversed after crossing the 20^{th} quantile since the estimated coefficients are positive and statically significant. Moreover, we observe that the median estimate is close to the OLS point estimate and statistically significant.

The imposition of fines on a cartel case seems to reduce its duration, and thus lead to the acceptance of H_2. This is based on the negative estimates of the related coefficient of this variable (*Fines*) across the quantiles. However, the effect of this variable is more pronounced at the lower quantiles (up to the 30^{th} quantile) compared

to the higher quartiles where the relevant estimates though statistically significant seem to converge to zero.

Moreover, the global geographical coverage of a cartel is an important driving factor demonstrating a positive and statistically significant linear effect on cartel longevity, which is present at the median and the higher quantiles. This finding satisfies the H_3 hypothesis. The graphical illustration of the impact of rigged-bid anti-competitive behavior by the cartel members uncovers a less stable pattern since the relevant estimates alternate their signs across the CDF. This finding rejects the validity of the H_4 research hypothesis. On the contrary, the presence of third parties as cartel facilitators portrays a clear positive trend though not statistically significant up to the 20^{th} quantile. This means that the relevant driving factor increases the cartel life span leading to the validity of the H_5.

<Insert Figure 4 about here>

Lastly, we perform the test for the equivalence of the estimates across quantiles, which allows us to estimate the model for each of several quantiles in a single model, accounting for cross-equation hypothesis tests. The p-value (0.005) rejects the equality of the estimated coefficients for all the quantiles.

6. Conclusions and managerial implications

This study aims to investigate the main factors that shape the duration of cartels, with a focus on the role of government intervention, the impact of cartel behavior, and the dynamics of the market. To this end, a sample of 180 international hardcore cartels from 50 countries over the period 2012-2021 is examined using quantile regression techniques.

The empirical findings have verified most of the research hypotheses, suggesting that the duration of a cartel is determined by a variety of factors, such as the number of cartelists, the fines imposed, the geographical scope, the involvement of third parties, and the rigged bids by the cartelists. Moreover, the quantile analysis has uncovered some important non-linear effects already hidden by the existing literature and the OLS-based regression techniques.

This research builds upon existing knowledge concerning the effects of main driving factors on cartel longevity. The empirical results suggest several distinct theoretical implications. First and foremost, we utilize quantile techniques to provide a more detailed and accurate representation of the data than the conventional regression analysis which has been proposed as a significant growing path (Levenstein, and Suslow, 2016). By relying on this type of analysis, we can unravel non-monotonic relationships among some of the main driving factors of cartel longevity as discussed below.

Second, we argue that the number of cartel members (cartelists) has an asymmetric effect on cartel duration. At the lower quantiles of the distribution where cartels are short-lived (usually one year), our analysis supports the negative relationship between the number of cartelists and the duration of the cartel. This finding validates H1, revealing that larger cartels have been found to have shorter lifespans due to the increased competition and pressures on their members. The relevant finding is fully reversed after crossing the smaller quantiles of the distribution (e.g., medium to long-term cartels), implying that an increase in the number of cartel members exerts a positive impact on the cartel longevity, since it allows the cartel to expand its influence and control. With a larger membership, the cartel can better protect its interests and the interests of its members from outside interference. A larger membership base means

more resources to draw on, allowing the cartel to better fund its operations, as well as provide protection and security to its members.

Third, we add to the existing literature by revealing a hidden link between the bid-rigging behavior of cartelists and the lifespan of cartels. Our empirical results support that rigged bids by cartel members, appear to have a positive and statistically significant impact on cartel longevity mostly evident at the lower quantiles of the distribution (e.g., short-lived cartels).

Our findings have significant managerial implications. Firstly, firms engaging in cartel activities are at a heightened risk of detection due to the existence of legislative tools, such as the leniency program. The latter offers firms that provide relevant information about cartel agreements either full or partial immunity from fines. As such, it serves as a powerful incentive for firms to expose cartel behavior (see also Smuda et al., 2015; Ritala, 2012). When companies are aware of the potential consequences of cartel participation and the possibility of leniency for whistleblowers, they may be less inclined to form or join cartels in the first place. This can deter the formation and maintenance of cartels, reducing their time span (longevity).

Secondly, our study argues that the bid-rigging behavior may act as one of the driving factors extending the duration of short-lived cartels (e.g., under one year). This suggests that NCAs may establish more sophisticated tools like anonymous information systems (whistleblowing) for use by contracting authorities. This system will enable contracting authorities to gain access to information and complaints regarding the participation of undertakings in tender and contract-awarding procedures. By providing this kind of aid to the competition agencies, contracting authorities can help uncover bid rigging practices such as cover bidding, bid suppression, bid rotation, or market allocation and facilitate the swift and effective investigations that benefit final

consumers. Through a whistleblowing system, contracting authorities and other bodies can share valuable information about certain practices and collusive behavior, while remaining anonymous.

Another powerful tool for NCAs in their effort to mitigate the cartel duration is the settlement mechanism. Provided that certain conditions are met, the cartel participants may obtain a reduction of the imposed fine (e.g., 10%-15%) by making a clear and unequivocal acknowledgment of their participation and liability. The relevant procedure is designed to make the management of ongoing cartel cases simpler and faster. By streamlining the administrative process, the NCA, can become more efficient and quickly issue decisions regarding any collusive infringement. This procedure may also reduce the number of appeals made against the NCA's decisions to administrative courts and thus increase the overall efficiency of the competent competition body.

This research has some shortcomings that ought to be tackled. First, unobserved heterogeneity between countries has been shown to matter in several related topics and results can change fundamentally when they are accounted for. To alleviate this problem, future research may dwell on this issue by introducing fixed effects within a panel data framework. Second, the robustness of the empirical results could be tested more thoroughly. For instance, estimations with split samples according to relevant characteristics of the dataset such as size and age of the cartelists, market concentration, or the existence of maverick firms are some possible driving factors that should be tested. This might also allow the derivation of differential hypotheses that add to the ongoing theoretical literature.

Third, there might be selection bias in the sample. For example, if some cartels last longer because they are savvier at evading antitrust scrutiny, then discovered cartels

will have shorter durations than the true average. Furthermore, the OECD dataset only contains cartels that authorities have issued decisions against and possibly fined cartels, and/or in which private damages have been collected. It seems like a potential concern that the analysis is only conducted on cartels that have been caught. Potentially, many small cartels have not been caught because they are so small. This exclusion may, for example, create bias in the measurement of the effect of the number of cartelists on the duration of cartels.

In addition to this, the dependent variable that shows the difference between the termination date and the starting date of each cartel case (Duration), might be characterized by a measurement error. This may be attributed to the fact that some antitrust agencies and cartels can negotiate over the official (i.e., publicly reported) duration (see Miller, 2009; Harrington and Wei, 2017).

Lastly, further research is needed to gain a better understanding of how certain screening detection tools such as leniency programs, settlement mechanisms, and whistleblowers impact cartel duration. All in all, we argue that these limitations could be addressed by future research and explored in greater detail to gain a better understanding of the driving factors of cartel longevity.

List of Tables & Figures

Table 1: Description of the sample variables

Variable	Definition	Type	Description
Dependent variable			
Duration	Cartel duration	Integer	The difference between the termination date and the starting date of each cartel case (measured in years)
Explanatory and control variables			
Cartelists	Number of cartel participants per cartel case	Integer	The number of entities (firms, organizations, etc) that appeared in each cartel case
Fines	Fines per cartel case	Binary variable	The dummy variable is equal to one if a fine is levied per cartel case and zero otherwise
Coverage	Geographical coverage of each cartel case	Binary variable	The dummy variable is equal to one if the cartel has global coverage and zero otherwise
Bid rigging	Bid rigging cartel	Binary variable	The dummy variable is equal to one if the cartelists made rigged bids (collusive tenders), and zero otherwise
Third parties	Support by third parties per cartel case	Binary variable	The dummy variable is equal to one if there was support by third parties per cartel case and zero otherwise
Trend	Time trend	Integer	Linear time trend taking values from 1 to 180 to capture the increasing number of leniency applications and awards

Source: The OECD International Cartels Database.

Table 2: Summary statistics

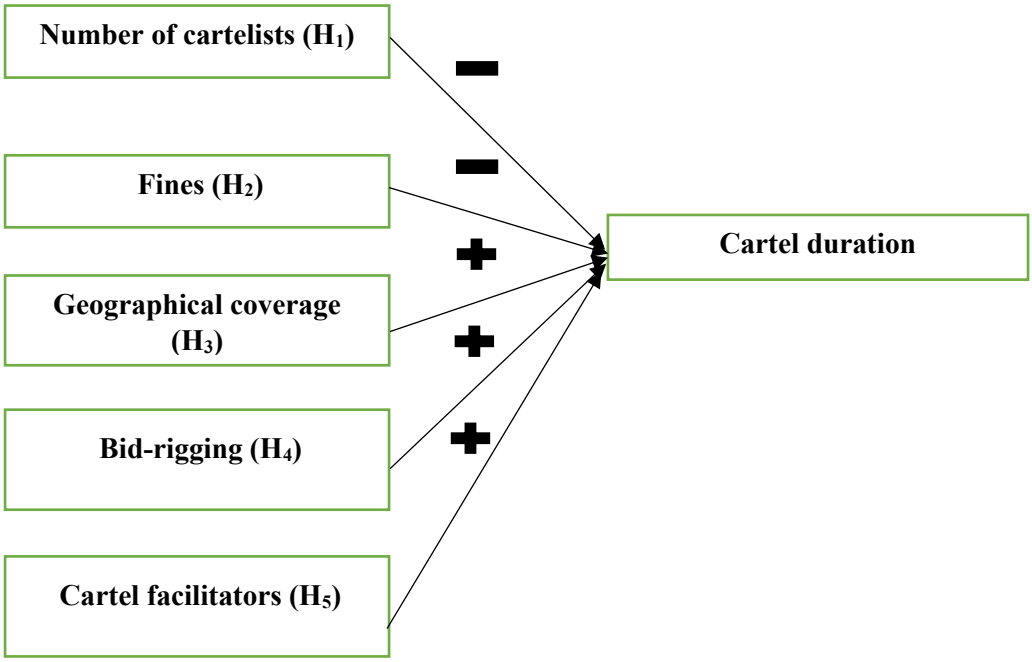
Variable	Obs	Mean	Median	Min	Max	Standard deviation	Skewness	Kurtosis
Duration	180	6.260	5	0.1	28	4.888	1.031	4.650
Duration (logged)	180	1.378	1.609	-2.303	3.332	1.165	-1.150	4.083
Cartelists	180	7.183	5	2	38	6.535	2.399	9.473
Cartelists (logged)	180	1.687	1.609	0.693	3.638	0.719	0.540	2.793
Fines	180	0.956	1	0	1	0.207	-4.421	20.55
Bid (Binary variable)	180	0.528	1	0	1	0.501	-0.111	1.012
Third (Binary variable)	180	0.0778	0	0	1	0.269	3.153	10.94
Cover (Binary variable)	180	0.156	0	0	1	0.363	1.901	4.613

Table 3: Estimation results (OLS and QR)

Variable	Model 1 (OLS)	Model 2 (QR)												
		Quantiles τ												
		Q (0.01)	Q (0.05)	Q(0.10)	Q(0.15)	Q(0.20)	Q(0.25)	Q(0.30)	Q(0.40)	Q(0.50)	Q(0.65)	Q(0.75)	Q(0.85)	Q(0.90)	Q(0.95)
Logged (cartelists)	0.223*	-0.791*	-0.437*	-0.0306***	0.161***	0.190***	0.309*	0.357***	0.244***	0.169*	0.0381***	-0.0442	0.0612***	0.143*	0.204**
	(0.12)	(0.424)	(0.354)	(0.0309)	(0.0246)	(0.0217)	(0.222)	(0.0256)	(0.0191)	(0.0981)	(0.0133)	(0.101)	(0.0118)	(0.109)	(0.105)
Fines	0.531*	-3.001***	-3.022***	-0.373***	-0.423***	-0.370***	-0.183***	-0.227***	-0.0583***	-0.0313***	-0.00690	0.00918	-0.00713	-0.0607***	-0.0615***
	(0.279)	(1.114)	(0.982)	(0.0760)	(0.0522)	(0.0354)	(0.0463)	(0.0360)	(0.0234)	(0.0230)	(0.198)	(0.203)	(0.221)	(0.0215)	(0.0122)
Cover	1.161***	2.570***	2.076*	2.083***	1.899***	1.894***	1.913***	1.818***	1.016***	0.866***	0.603***	0.487***	0.183***	0.0417	0.124
	(0.215)	(0.917)	(1.061)	(0.727)	(0.411)	(0.210)	(0.247)	(0.306)	(0.228)	(0.154)	(0.103)	(0.130)	(0.0192)	(0.174)	(0.175)
Bid	0.053	0.713*	0.531**	0.270**	0.175***	0.0493**	-0.263	-0.395	0.0204	-0.0339	-0.0804	-0.225	-0.235	-0.0981	-0.212
	(0.202)	(0.607)	(0.294)	(0.148)	(0.032)	(0.0245)	(0.252)	(0.331)	(0.226)	(0.181)	(0.222)	(0.208)	(0.173)	(0.154)	(0.152)
Third	0.549*	1.689**	1.491*	1.058*	0.791*	0.420***	0.452**	0.378***	0.145***	0.372***	0.632*	0.317*	0.162***	0.153*	0.267
	(0.283)	(0.826)	(0.793)	(0.768)	(0.595)	(0.108)	(0.217)	(0.143)	(0.023)	(0.110)	(0.338)	(0.286)	(0.049)	(0.087)	(0.265)
Trend	0.00224*	0.0229***	0.0208***	0.000384	0.00197	0.00325*	0.00161	0.00145	-0.000624	0.000144	5.35e-05	0.00111	0.00119	0.000942	0.000946
	(0.00153)	(0.00814)	(0.00741)	(0.00524)	(0.00274)	(0.0022)	(0.00211)	(0.00216)	(0.00173)	(0.000867)	(0.000951)	(0.0012)	(0.0011)	(0.00116)	(0.00151)
Constant	-	-0.248	-0.0903	-0.000498	-0.0923	-0.0434	0.0741	0.279	0.897**	1.209***	1.728***	2.119***	2.264***	2.284***	2.355***
		(1.131)	(0.955)	(0.612)	(0.503)	(0.500)	(0.633)	(0.659)	(0.452)	(0.269)	(0.364)	(0.299)	(0.271)	(0.249)	(0.264)
Observations	180	180	180	180	180	180	180	180	180	180	180	180	180	180	180
R-squared	0.6187	-	-	-	-	-	-	-	-	-	-	-	-	-	-
F-statistic	92.52***	-	-	-	-	-	-	-	-	-	-	-	-	-	-

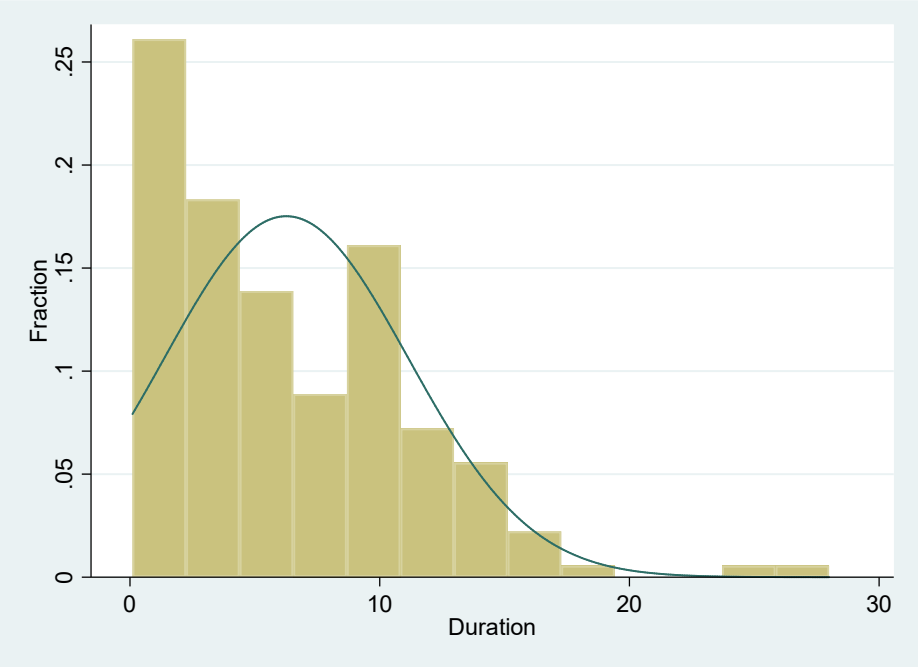
Notes: The dependent variable in both models is the logged cartel duration (*Lduration*). Model 1 was estimated using OLS and allowing for robust standard errors. Model 2 was estimated using the sequential quantile regressions methodology at different quantiles τ (0.01, 0.05, 0.10 0.15. 0.20. 0.25. 0.30, 0.40, 0.50, 0.65, 0.75, 0.85, 0.90 and 0.95) allowing for 100 repetitions. The numbers in parentheses denote robust standard errors. Significant at ***1%, **5%, and *10% respectively.

Figure 1: Conceptual framework of the research hypotheses



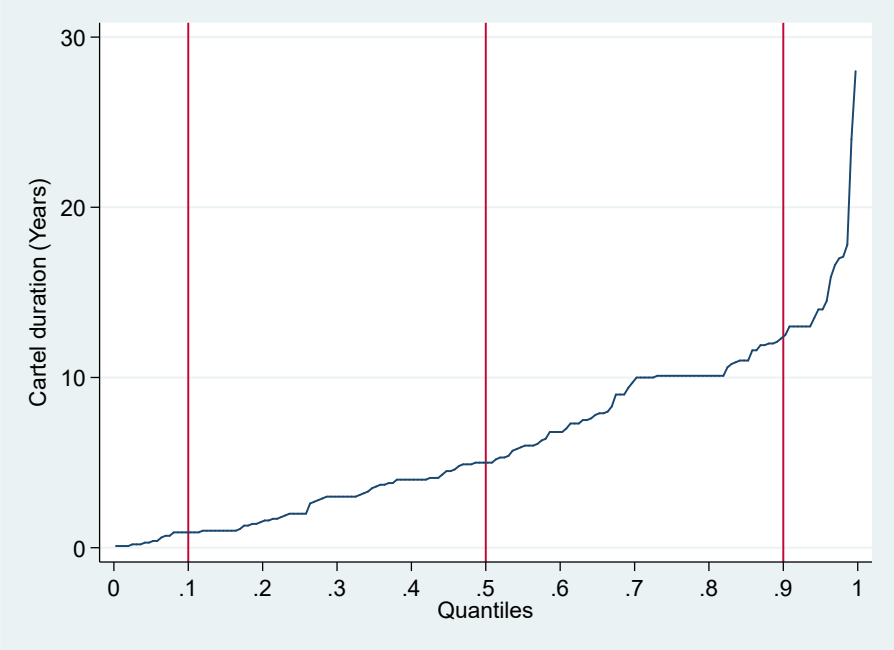
Notes: The sign represents the effect of each of the driving factors on the cartel duration.

Figure 2: Distribution of cartels duration *(N = 180 cases)*



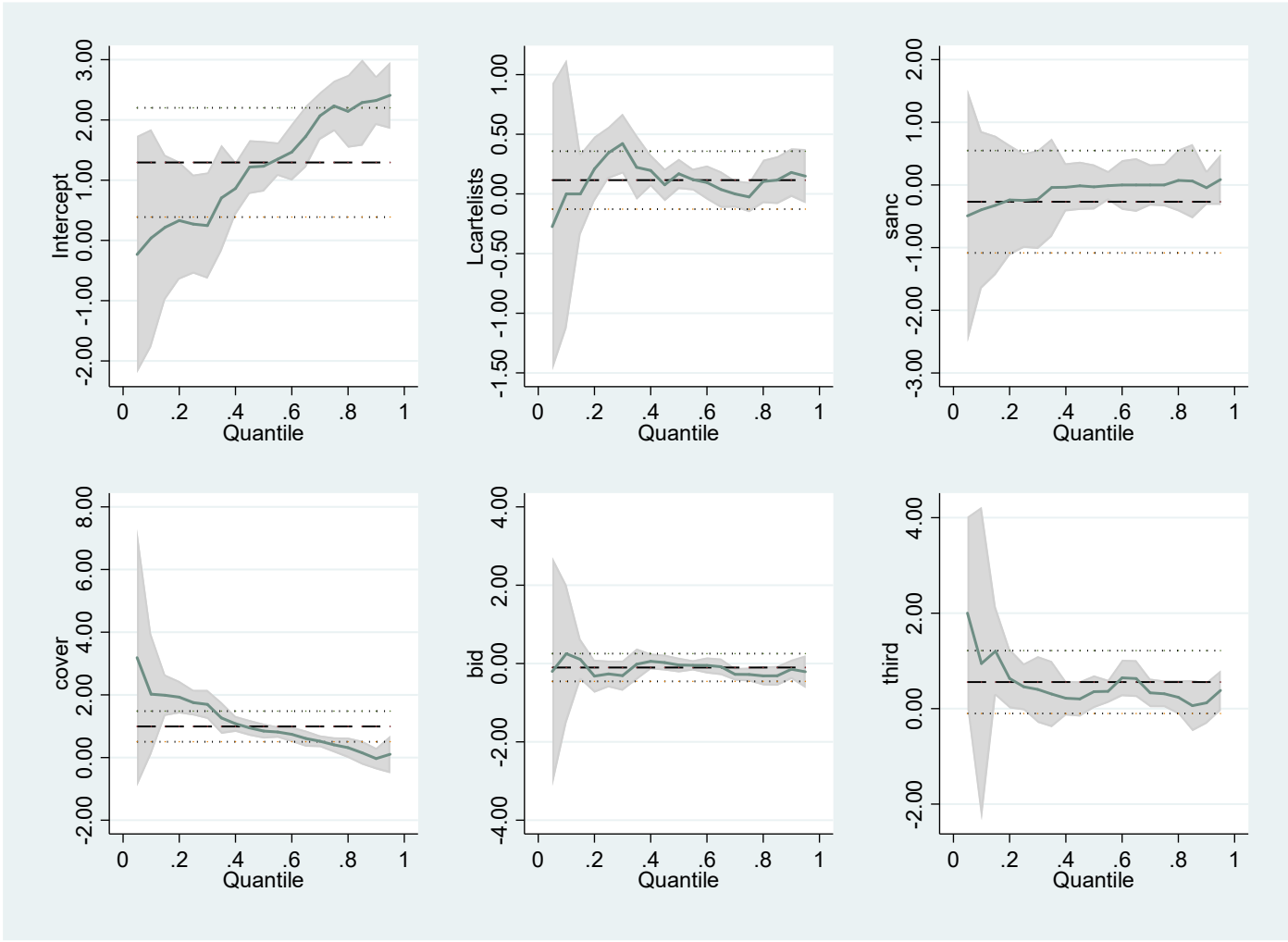
Notes: The blue line is inserted into the graph to add the normal (Gaussian) density for comparison.

Figure 3: Cumulative distribution function of cartel duration *(N = 180 cases)*



Notes: The continuous (blue) line is the estimated CDF of the dependent variable (Duration) across the various quantiles for the whole sample. The vertical (red) lines represent the 10th, 50th (median), and 90th quantile respectively.

Figure 4: Variation of cartel duration estimates across quantiles *(N = 180 cases)*



Notes: The dependent variable in both models (OLS and QR) is the logged cartel duration (Lduration). The bold dotted horizontal line denotes the (fixed) OLS estimate. The black dotted lines denote the confidence bands for the OLS estimates. The grey shaded area denotes the confidence bands for the bootstrapped QR estimates that are generated by 100 repetitions.

References

Abrantes-Metz, Rosa M., J. Connor, and Metz, A. (2013). The Determinants of Cartel Duration.,SSRN: https://ssrn.com/abstract=2263782 or http://dx.doi.org/10.2139/ssrn.2263782

Andres, M., Bruttel, L., Friedrichsen, J. (2023). How communication makes the difference between a cartel and tacit collusion: A machine learning approach, *European Economic Review*, **152**, 104331

Andres, M., Bruttel, L., Friedrichsen, J. (2021). 'How do sanctions work? The choice between cartel formation and tacit collusion', Beiträge zur Jahrestagung des Vereins für Socialpolitik 2021: Climate Economics, ZBW - Leibniz Information Centre for Economics, Kiel, Hamburg.

Baer, W., Burdekin, R., & Sarkar, S. (2005). 'Cartel duration and antitrust enforcement: Evidence from the United States, Europe, and Japan', *Journal of Law and Economics*, **48**, pp. 531–558.

Bos, I., Davies, S., Harrington, J.E., Ormosi, P. (2018). "Does enforcement deter cartels? A tale of two tails", *International Journal of Industrial Organization*, 59, 372-405

Buchinsky M. (1998). 'Recent advances in quantile regression models', *Journal of Human Resources*, **33(1)**, pp. 88–126.

_____ (1995). 'Estimating the asymptotic covariance matrix for quantile regression models: A Monte Carlo study', *Journal of Econometrics*, **68**, pp. 303–338.

Compte, O Jenny, F and Rey, P (2002), 'Capacity Constraints, Mergers and Collusion, *European Economic Review'*, **46**, pp. 1–29.

Connor, J., 2006. Effectiveness of Sanctions on Modern International Cartels, *Journal of Industry, Competition, and Trade* **6**: 195-223.

Connor, J.M., (2013). Cartel Fine Severity and the European Commission: 2007-2011 (October 24, 2012). *European Competition Law Review* 34, 58-77.

Corts, K. S., and Gilbert, R. J. (2002). 'The impact of antitrust policy on cartel duration', *International Journal of Industrial Organization*, **20**, pp. 113–141.

De, O. (2010). Analysis of Cartel Duration: Evidence from EC Prosecuted Cartels, *International Journal of the Economics of Business*, **17**, pp. 33-65

Dick, A. (1996). 'When Are Cartels Stable Contracts?', *Journal of Law and Economics*, **39(1)**, pp. 241-83.

Distante, R., Petrella, I., and Santoro, E. (2018). 'Gibrat's law and quantile regressions: An application to firm growth', *Economics Letters*, **164**, pp. 5–9.

Dunne, N. (2020). 'Characterizing Hard Core Cartels Under Article 101 TFEU', *The Antitrust Bulletin*, **65(3)**, pp. 376–400.

Garz, M., and Maaß, S. (2021). 'Cartels in the European Union, antitrust action, and public attention', *Journal of Economic Behavior and Organization*, **186**, pp. 533-547.

Harrington, J.E., and Wei, Y. (2017). 'What Can the Duration of Discovered Cartels Tell Us About the Duration of All Cartels?', *The Economic Journal,* **127(604)**, pp. 1977-2005.

Harrington, J., (2006a). 'How do cartels operate?' Foundations and Trends in Microeconomics, **2(1)**, pp. 1-105

_____ (2006b). 'Behavioral Screening and the Detection of Cartels'. EUIRSCAS/ EU Competition 2006 – Proceedings.

_____ (1991). 'The Determination of Price and Output Quotas in a Heterogeneous Cartel', *International Economic Review*, **32**, pp. 767–792

_____ (1989). 'Collusion Among Asymmetric Firms: The Case of Different Discount Factors', *International Journal of Industrial Organization*, pp. 289–307

Hirsch, B. T., and Yoon, Y. (1985). 'Duration of cartels', *Journal of Industrial Economics*, **33**, pp. 321–337.

Katsoulacos, Y., Motchenkova, E., and Ulph, D. (2020). 'Combining cartel penalties and private damage actions: The impact on cartel prices', *International Journal of Industrial Organization*, **73**, 102604, https://doi.org/10.1016/j.ijindorg.2020.102604.

Kim, J. and A. Parkhe (2009). 'Competing and cooperating similarity in global strategic alliances: an exploratory examination', *British Journal of Management*, **20**, pp. 363–376.

Koenker R. (2005). *Quantile regression*. New York: Cambridge University Press.

Kühn, K-U (2004), 'The Coordinated Effects of Mergers in Differentiated Product Markets', John M Olin Center for Law and Economics, Working Paper Series, paper 34

Levenstein, M., and Suslow, V. (2016). 'Price Fixing Hits Home: An Empirical Study of US Price-Fixing Conspiracies', *Review of Industrial Organization*, **48(4)**, pp. 361-379.

_____ (2011). 'Breaking Up Is Hard to Do: Determinants of Cartel Duration', *Journal of Law and Economics*, **54(2)**, pp. 455-492.

_____ (2006). 'What Determines Cartel Success? *Journal of Economic Literature'*, **44(1)**, pp. 43-95.

Llorente-Saguer, A., Zultan, R. (2017). Collusion and information revelation in auctions, *European Economic Review*, **95**, pp. 84-102.

Miller, D.J. and Connor, J.M., (2010). 'The Predictability of Global Cartel Fines'. *Concurrences: Review of Competition Law*, 2.

Miller, Nathan H., (2009). 'Strategic Leniency and Cartel Enforcement'. *The American Economic Review* 99 (3), 750–768.

Motta, M. (2004). Competition policy: theory and practice. Cambridge University Press.

OECD, (2012). 'Recommendation of the Council on OECD Legal Instruments Fighting Bid Rigging in Public Procurement', Organization for Economic Co-operation and Development. Paris.

Peng, T.-J.A., Pike, S., Yang, J.C.-H. and Roos, G. (2012), 'Is Cooperation with Competitors a Good Idea?', *British Journal of Management*, **23**, pp. 532-560.

Posner, R. (1970). 'A Statistical Study of Antitrust Enforcement', *Journal of Law and Economics*, **13(2)**, pp. 365-419.

Powell J. (1986). 'Censored regression quantiles', *Journal of Econometrics*, **32**, pp. 143–155.

Ritala, P. (2012), 'Coopetition Strategy – When is it Successful? Empirical Evidence on Innovation and Market Performance', *British Journal of Management*, **23**, pp. 307-324.

Rob, R. (2003). 'Cartel longevity: An economic analysis', *The Journal of Economic Perspectives*, **17(1)**, pp. 127-144.

Rothschild, R (1999), 'Cartel Stability when Costs are Heterogeneous', *International Journal of Industrial Organization*, **17**, pp. 717–734.

Smith., A. (1776). An Inquiry into the Nature and Causes of the Wealth of Nations

Smuda, F., Bougette, P., and Huschelrath, K., (2015). 'Determinants of the Duration of European Appellate Court Proceedings in Cartel Cases', *Journal of Common Market Studies,* **53(6)**, pp. 1352–1369.

Suslow, V. (2005). Cartel contract duration: empirical evidence from inter-war international cartels, *Industrial and Corporate Change*, 14(5), pp. 705–744.

Symeonidis, George, (2002). 'Cartel stability with multiproduct firms', *International Journal of Industrial Organization*, **20(3)**, pp. 339-352.

González, T.A., Schmid, M., and Yermack D. (2019) Does Price Fixing Benefit Corporate Managers?. *Management Science* 65(10):4813-4840.

Vasconcelos, H (2005). 'Tacit collusion, cost asymmetries, and mergers', *RAND Journal of Economics*, **36**, pp. 39–62

Veljanovski, C. (2023). An Empirical Assessment of the European Commission's Cartel Prosecutions, 2010–2019. *The Antitrust Bulletin*, 0(0). https://doi.org/10.1177/0003603X231180252

Wang, T., Chen, Y., and Pappas, V. (2009). 'Cartel duration and antitrust enforcement: Evidence from US, European and Japanese markets', *Journal of Competition Law and Economics*, **5**, pp. 353–379.

Zhou, J., (2012). Endogenous Lysine Strategy Profile and Cartel Duration: An Instrumental Variables Approach, Discussion Paper 2012-009, Tilburg University, Tilburg Law, and Economic Center.