BRUEGEL WORKING PAPER 2016/02

THE DYNAMICS OF LENIENCY APPLICATION AND THE KNOCK-ON EFFECT OF CARTEL ENFORCEMENT

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Highlights

- We study the timing of leniency applications using a novel application of multi-spell discrete-time survival analysis for a sample of cartels prosecuted by the European Commission between 1996 and 2014. The start of a Commission investigation does not affect the rate by which conspirators apply for leniency in the market investigated, but increases the rate of application in separate markets in which a conspirator in the investigated market also engaged in collusion. The revision of the Commission's leniency programme in 2002 increased the rate of pre-investigation applications. Our results shed light on enforcement efforts against cartels and other forms of conspiracy.

Classification numbers: D43; D84; K21; K42; L41
Keywords: Leniency, Cartels, Collusion, Multi-Market Contact, Knock-on Effect of Investigation, Revelation of Undetected Cartels

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FEBRUARY 2016

1. Introduction

Leniency programmes offer conspirators – who by volunteering information contribute to the discovery and conviction of a cartel – a reduction of fines. Such programmes have become increasingly popular in many jurisdictions around the world (OECD, 2002, 2003; Harrington, 2011). This paper studies conspirators' incentives for leniency application, from the date that a conspirator joins a cartel, to the time that it applies for leniency, and up until the closure of the competition authority's investigation. Our results have implications for market efficiency and enforcement efforts against cartels and other forms of conspiracy.

Much of our extant knowledge regarding conspirators' incentives for leniency application come from competition authorities (Hammond, 2001, 2004, 2010; Masoudi, 2007; Suurnäkki and Tierno Centella, 2007; Kloub, 2010)[1], antitrust litigation firms (Baker & McKenzie, 2010; Latham & Watkins, 2011)[2], and economists (Harrington, 2008, 2011; Chang and Harrington, 2010)[3], who consistently describe leniency programmes as a 'race': cartel members rush to confess in order to outrun their co-conspirators to the authority's door[4]. If the 'race' were as close-run as theory and anecdote appear to suggest, one might be tempted to conclude, based on the fact that detection was infrequent prior to the introduction of the leniency programmes (Miller, 2009; Hammond, 2004), that leniency created *"distrust and panic among the cartel members"* (Hammond, 2004), destabilised cartels (Masoudi, 2007), freed up investigatory resources that would be otherwise spent to detect the cartels being reported (Kaplow and Shavell, 1994; Buccirossi and Spagnolo, 2005), and enhanced the competition authorities' detection capabilities (Miller, 2009; Zhou, 2012).

Statistics reveal a different story. Marx, Mezzetti, and Marshall (2015) estimate that approximately 80-90 percent of leniency applications that the US Department of Justice (DOJ) received happened after the DOJ launched an investigation, by which time the DOJ already incurred expense to discover the cartel. A glance at the European Commission (EC) cartel decisions for 1996-2014 reveals that 184 (54 percent) of the 338 leniency applications are filed after an investigation is opened. Figure 1 shows the distribution of leniency applications around the start of an EC investigation (Figures are shown at the end of the paper). Delving further into the EC decisions reveals that leniency applications in a cartel tend to happen sequentially with, on average, approximately 32 weeks in between each application[5].

[1] For example, as Director of Criminal Enforcement at the Antitrust Division of the U.S. Department of Justice, Scott D. Hammond stated that *"The Amnesty Programme… sets up a race, and this dynamic leads to tension and mistrust among the cartel members"* (United States Department of Justice website, http://www.justice.gov/atr/speech/when-calculating-costs-and-benefits-applying-corporate-amnesty-how-do-you-put-price-tag). As Deputy Assistant Attorney General at the Antitrust Division of U.S. Department of Justice, Gerald F. Masoudi stated that *"…the [leniency] programme can serve to … to destabilise [cartels] by causing members to turn against one another in a race to the government"* (United States Department of Justice website, http://www.justice.gov/atr/speech/cartel-enforcement-united-states-and-beyond). Jindrich Kloub, a case handler in the cartel division of the EC, stated that *"The fact that the greatest protection, immunity from sanctions, is granted only to the first cartel member to report, induces strategic behaviour … hence creating conditions for a race to the door of a competition authority"*.

[2] Baker & McKenzie stated that *"…cartel members race to self-report violations and obtain amnesty"* (Baker & McKenzie website, http://www.bakermckenzie.com/AntitrustCompetition/). Latham & Watkins stated that *"Leniency systems create a race against the clock"* (Latham & Watkins website, https://www.lw.com/presentations/international-coordination-in-competition-enforcement).

[3] For instance, in Harrington (2008), when the probability that a competition authority discovers and successfully prosecutes a cartel is sufficiently high, cartel collapses and all firms race for leniency. Harrington refers to this as the *"Race-to-the-Courthouse"* effect.

[4] An exception is Gärtner and Zhou (2012) who empirically document that conspirators often apply for leniency long after a cartel collapses.

[5] The median number of weeks elapsed between each application is approximately 16 weeks.

Figure 2 shows the distribution of time between adjacent applications in a cartel. The sharp difference between the statistics and the rhetoric of the competition authorities and the legal practitioners helps motivate our analysis.

Why do conspirators not appear to race for leniency? Can policy and enforcement effort create a 'race'? This paper describes the distribution of leniency applications over time and examine the determinants of the application timing. We focus on two issues. First, we examine the effect of cartel investigation in one market on the timing of leniency applications in the other markets. Recent theories suggest that an investigation may display a knock-on effect on application decisions across multiple markets (Lefouili and Roux, 2012; Marx, Mezzetti, and Marshall, 2015). But to our knowledge, no empirical analysis has studied the potential knock-on effects of cartel investigations. We take the first step towards filling this gap between the theory and the empirical studies.

The second issue we focus on is the impacts of the EC's new leniency programme on pre-investigation applications, ie applications that inform detections. In 2002, the EC revised its leniency programme, with the intent of enhancing its detection capabilities. The new programme commits the EC to the lenient prosecution of early applicants. In particular, it promises 100 percent reduction of the fine to the first applicant to provide evidence before the EC opens an investigation. A recent empirical literature is ambiguous regarding the impacts of the programme. Independently, De (2010) and Zhou (2012) evaluate the programme. Whereas no significant policy impacts are found in De (2010), Zhou (2012) finds that the new leniency programme has the intended effect.

Our data are from cartel decisions issued by the EC between October 1996 and December 2014. We use these decision documents to construct a sample of leniency applications. The EC's 'dawn raids', unannounced and simultaneous inspections of multiple cartel members' premises and seizure of company documents, mark the opening of an investigation and identify the investigation's impact[6]. When cartels in different markets overlap in membership, leniency applications in one market tend to closely follow the dawn raids in the other markets (see Figure 3). In 78 (44 percent) of the 176 applications from those cartels, a firm applied within a half year following a dawn raid in a separate cartel in which one or more firms in the cartel being reported also engaged in collusion[7, 8].

The introduction of the new leniency programme on February 19, 2002, provides an exogenous shock that identifies the effect of the policy change on leniency application rate. After the date, fine reductions have become automatic and guaranteed for first-in cartel confessors who self-reported before an investigation had started. Whereas the EC received a leniency application before its investigation started in only 24 percent of the cartels detected between July 18, 1996 and February 19, 2002, the rate nearly tripled after February 19, 2002.

We use multiple-spell discrete-time hazard regression to test whether cartel investigation in a market increases the rate of leniency application in a separate market and whether the introduction of the new leniency programme increases pre-investigation applications. We are able to control for changes in antitrust policies (Marx, Mezzetti, and Marshall, 2015; Lefouili and Roux, 2012; Gärtner and Zhou, 2012), macroeconomic conditions (Harrington and Chang, 2009; Gärtner and Zhou, 2012), a

[6] For explanatory notes on the EC's investigative steps during a dawn raid, see European Commission website, http://ec.europa.eu/competition/antitrust/legislation/explanatory_note.pdf.

[7] In what follows, each cartel in our discussion corresponds to a distinct relevant product and geographic market (as identified by the EC in its published decisions). But sometimes it is appropriate to view a group of cartels as a single overarching conspiracy.

[8] These calculations are based on leniency applications of which the dates are reported in the EC's published decisions for 1996-2014.

conspirator's status as being a recidivist (Spagnolo, 2003), its experiences with authority enforcement (Wils, 2008; Marx, Mezzetti, and Marshall, 2015) and making leniency applications in the past, and other factors that may influence leniency applications.

Our first main finding is that the start of an EC investigation does not affect the rate by which conspirators apply for leniency in the market investigated but increases the rate of application in the other markets in which one or more conspirators in the investigated market also engaged in collusion. This finding lends some support to the recent theories that antitrust intervention in one market may affect the incentives for leniency applications in the other markets (eg Lefouili and Roux, 2012; Marx, Mezzetti, and Marshall, 2015). Our second main finding is that the introduction of the EC's new leniency programme increases the rate of leniency application if an investigation into the applicants' cartel is not already underway. But the effect disappears after the EC has opened an investigation. These results confirm the earlier empirical findings that the introduction of the EC's new leniency programme may have enhanced the EC's detection capabilities (Zhou, 2012), but indicate that there seems to be still room for improvement.

Our analysis is subject to two limitations. First, our sample is truncated at December 20, 2014 – the date of data collection. In this way, we exclude firms that engaged in collusion before but applied for leniency after the date. Valid inference is possible if leniency application dynamics and the other characteristics of the excluded firms are similar to those of the sampled firms in some fashion. Second, we measure the time to leniency application from the proven start date of collusion. Conventional wisdom holds that the actual start date may be observed with error and predate the proven date. To remedy this, at least in part, we consider multiple-spell hazard specifications and model leniency applications in a cartel as 'recurrent events', with the spells of the subsequent applications starting at the time of the preceding application. In this way, the second and subsequent spells are no longer affected by the measurement problem.

The paper is organised as follows. Section 2 discusses related literature. Section 3 describes the data. Section 4 characterises the distribution of leniency application decisions over time and examine the factors that influence the colluders' incentives for leniency application. Our sample of prosecuted cartels provides evidence that leniency application dynamics are strongly and significantly affected by enforcement efforts across markets and that the new leniency programme has the intended effect of enhancing the EC's detection capabilities. Section 5 discusses the main policy implications of our results. Concluding remarks and possible extensions follow.

2. Literature

Starting from the seminal work of Motta and Polo (2003), a large and growing game-theoretical literature has studied the impact of leniency on cartel stability by examining conspirators' incentives to expose a cartel[9]. The primary force in the analyses has been that leniency may destabilise cartels because conspirators can simultaneously cheat on a cartel and report it for reduced fines (eg Motta and Polo, 2003; Spagnolo, 2004; Chen and Harrington, 2007; Harrington, 2008, 2013; Gärtner, 2014). For instance, in Harrington (2008), when the probability of detection (in absence of leniency applications) is low, cartels are stable and conspirators never confess; when the probability is high, cartels collapse immediately and all conspirators race for amnesty. The incentives for leniency application also may depend on market concentration (Ellis and Wilson, 2003), the degree of firm heterogeneity (Motchenkova and van der Laan, 2005), and the relationship between penalties and cartel profits (Motchenkova, 2004).

[9] For reviews of this literature, see Rey (2003) and Spagnolo (2008).

Despite the extensive literature on leniency, application behaviour in multi-market cartels has received little attention. A notable exception is the recent theoretical paper by Marx, Mezzetti, and Marshall (2015), who study, among other things, the effects of antitrust enforcement on multi-market conspirators' incentives to apply for leniency across different markets. They show that a penalty-plus leniency programme that asks firms investigated for collusion in a market to attest to whether or not they are cartelising any other markets can decrease leniency applications in the subsequent markets. The EC does not have Penalty Plus or other policy provisions that link leniency across markets. Thus, Marx, Mezzetti, and Marshall's (2015) results are consistent with those presented here because they suggest that antitrust enforcement in one market can increase leniency applications in the other markets if the linkages across markets in leniency programme are removed.

Besides the aforementioned studies, other theoretical work on multi-market cartels has studied firms' incentives to form cartels in more than one market and the sustainability of cartels across markets under Amnesty Plus and Penalty Plus (Lefouili and Roux, 2012) and identified conditions under which multi-market contact facilitates collusion (Bernheim and Whinston, 1990; Spagnolo, 1999). The experimental results on leniency include Hinloopen and Soetevent (2008) and Bigoni *et al* (2012).

The empirical work on leniency so far has studied the effects of leniency programmes on antitrust authorities' cartel detection and deterrence capabilities. By exploring the time-varying patterns in detection rate (Miller, 2009) and average duration of detected cartels (Brenner, 2009; Levenstein and Suslow, 2011; Zhou, 2012) following a policy change, these papers provide valuable insights related to the evaluation of antitrust policies with missing information on undetected cartels – a task theretofore considered difficult because detected cartels might be a small and characteristically unrepresentative sample of the population of cartels. Together, they suggest that the introduction of the new leniency programmes in the United States and the EU have enhanced the competition authorities' detection capabilities and makes it more difficult for firms to sustain collusion.

A different approach is taken by Marx and Zhou (2015), who infer the effects on cartel sustainability of leniency programmes from (ex) cartel members' merger activities. They hypothesise that an effective leniency programme increases mergers among (ex) cartel members by decreasing the incremental profit of collusion over merger. They find evidence that supports the hypothesis.

Other empirical work includes Gärtner and Zhou (2012), who document the conspirators' incentives for delaying leniency applications after a cartel has collapsed and study the effects of leniency programmes and macroeconomics fluctuations on the length of delay and Brenner (2011) and Hoang *et al* (2014), who examine the relationship between firms' incentive for being the first confessor in a cartel and their individual characteristics (such as whether a firm is a cartel ringleader). In virtually all these models, the values of the variables affecting application decisions are *fixed over time* for each cartel member.

Our approach differs in two fundamental ways from the existing empirical literature. First, we are interested in understanding how the incentives for leniency application change over time and how the incentives are affected by multiple enforcement and institutional parameters whose values also vary with time. To do so, we consider a discrete-time hazard specification in which multiple time-varying factors can be simultaneously incorporated in an analysis. Second, our focus is on the *knock-on effect* of antitrust enforcement across markets.

The duration of cartels and their investigations tend to be long[10]. Factors potentially influencing application decisions, such as antitrust enforcement in related markets (Marx, Mezzetti, and Marshall, 2015), policies related to a leniency programme (Marx, Mezzetti, and Marshall, 2015; Lefouili and Roux, 2012; Gärtner and Zhou, 2012), macroeconomic conditions (Harrington and Chang, 2009; Gärtner and Zhou, 2012), a firm's status of being a recidivist (Spagnolo, 2003), and its experience in preparing evidence for leniency applications and dealing with authority investigations, may change along the courses of collusion and investigation. Therefore, application decisions may also change as time elapses. Discrete-time hazard model presents a natural way to look at the dynamics of leniency application, where the aforementioned influences are incorporated as time-varying covariates. The discrete-time hazard model approach allows us to show that a cartel investigation in a market displays a significant knock-effect on leniency application dynamics in the other markets and that changes in policies related to leniency programme significantly affect application rate; the magnitudes of these effects are affected by or associated with the various other time-varying factors included in the analysis.

3. Data

3.1 Data source

The primary data for our analysis are EC decisions on violations of Article 101 (formerly Article 81 and Article 85) of the EC treaty between October 30, 1996 and December 20, 2014 – the period following the introduction of the EC's 1996 Leniency Programme[11]. The data include 96 decisions. Each decision includes, among others, the names of the alleged firms (in the most of the cases), the affected geographic and product markets, a firm's suspected and proven start dates of infringement, the date that the EC launched a surprise inspection of a firm's premise, whether a firm applied for leniency, and the dates of leniency applications (in the most of the cases). These are the key variables of interest in this paper.

Some sampled firms have been prosecuted by the EC for collusion prior to the introduction of the 1996 Leniency Programme. The affected products in the pre-leniency decisions differ from those in the post-leniency decisions. To study the potential effects of firms' previous investigations and convictions on their leniency application behaviour in subsequent markets, we search for the firms' historical investigation and conviction records from EC cartel decisions between March 1964 and July 1996.

3.2 The sample

Data Organisation. Many cartels appear to be grouped in a single decision document. The decisions cover 127 distinct cartels. Each cartel corresponds to a distinct relevant market that is identified by the EC. In many decision documents, the EC groups multiple firms of the same business enterprise as a single 'undertaking'[12]. Leniency applications happen on the undertaking level. To facilitate analysis,

[10] Levenstein and Suslow (2011) estimate that international cartels of the 1990s take, on average, eight years to break up. Using a sample of cartels discovered by the EC for the years 1985-2012, Zhou (2012) estimates that the sampled cartels lasted, on average, nearly eight years. Our calculations based on 127 cartels decided by the EC between 1996 and 2014 show that EC investigations, measured from the start of the dawn raids at the firms' premises until the closure of the investigation, lasted on average 3.8 years.

[11] Decisions published after 2001 are available for download from the EC DG Competition web site, http://ec.europa.eu/competition/cartels/cases/cases.html. Decisions published before 2001 are available for download from http://ec.europa.eu/competition/antitrust/cases/older_antitrust_cases.html.

[12] An undertaking may consist of a parent company and its subsidiaries. For example, in the Exotic Fruit cartel, the

we group undertakings across separate cartels into a single unit, which we call a '*colluder*', if the undertakings overlap in firm[13]. If an undertaking has only participated in a single cartel, it corresponds to a *colluder* in our sample. We identify a total of 497 distinct *colluder*s.

More than half of the sampled *colluders* engaged in collusion in two markets (55.6 percent). Approximately one-fifth of the sampled *colluders* engaged in collusion in three markets (20.3 percent). Nearly a quarter of the sampled *colluders* engaged in collusion in four or more markets (24.1 percent). At this stage of the analysis, we organise our data in such a way that each of the n *colluders* in our sample contributes to a *Colluder-Cartel* data set in which there are N (with $N > n$) lines of data – one line for every cartel for which each *colluder* is observed. For example, if *colluder* j participated in mj cartels, then it has mj records (lines) of data, where each of the mj records corresponds to a distinct cartel.

Rule of selection into the sample. Many undertakings in the EC decisions were investigated by the DOJ for collusion in the United States. Anecdotal evidence suggests that an undertaking may be applying for leniency to the EC as a response to a DOJ investigation and that the DOJ's investigation often predates the EC's (Bloom, 2007; Marx and Zhou, 2014; Marx, Mezzetti, and Marshall, 2015)[14]. However, the DOJ maintains strict confidentiality regarding the schedules of its cartel investigations. Although it is possible to find data and make inference in some cases, more commonly the starting date of a DOJ investigation is unknowable from publicly available data[15]. In order to avoid spurious estimates of the effect of EC investigations, in the main regression sample we include only cartels in which no firm was under a DOJ investigation (81 of 127 cartels qualify). Moreover, we select colluder-cartel pairs for which the date of leniency application is reported by the EC in its published decisions (or available from the undertaking's press releases). We excluded 53 colluder-cartel pairs due to this restriction. Moreover, we drop colluder-cartel pairs in which the name of the alleged undertaking is not reported by the EC in its published decisions. Six additional colluder-cartel pairs are dropped due to this restriction.

Our requirements yield a sample of 344 *colluders*. They are from 81 cartels. We have in total 458 colluder-cartel pairs. The earliest leniency application happened on September 19, 1996. The last application happened on November 7, 2013.

Variable definition and summary statistics. The main variables and model parameters are defined in Table 1 (Tables and Figures are shown at the end of the paper), and the corresponding descriptive statistics of the colluder-cartel-event data set are presented in Table 2. A *spell* in this context refers to a period of events associated with a colluder-cartel pair, which starts at the later of July 18, 1996 (the

undertaking 'Chiquita' include the parent company – Chiquita Brands International, Inc. and its subsidiaries – Chiquita Portugal, Chiquita Banana Company BV and Chiquita Italia SpA. An undertaking may also consist of a single subsidiary company or a group of subsidiary companies without including the parent company. For example, in the CRT Glass Bulbs cartel the undertaking 'Samsung' consists of only Samsung Corning Precision Materials Co., Ltd., which is a subsidiary of Samsung Electronics Co., Ltd – the ultimate parent of many Samsung companies. In some decisions, an undertaking consists of only the parent company and does involve a subsidiary. For example, in the Refrigeration Compressors cartel the undertaking 'Panasonic' consists of only the Panasonic Corporation, which is the ultimate parent company of many Panasonic companies.

[13] As a representative example, the undertaking 'Chiquita' in the Exotic Fruit cartel includes Chiquita Brands International, Inc., Chiquita Banana Company BV, and Chiquita Italia SpA; the undertaking 'Chiquita' in the Bananas Supplier cartel includes Chiquita Brands International Inc., Chiquita International Ltd., Chiquita International Services Group NV, and Chiquita Banana Company BV. We group the two undertakings into a single 'colluder' in our sample.

[14] See Marx, Mezzetti, and Marshall (2015), footnote 10 and Bloom (2007), pp.8-9. According to Bloom (2007), about half of the leniency applications received by the EC followed leniency applications in the United States.

[15] Despite our best efforts, we were not able to find information about the starting dates of the DOJ's investigations for the majority of cartels that affected the US markets.

introduction of the EC's old leniency programme) and the start of the *colluder*'s infringement in the cartel. The first three columns of statistics in Table 2 are for all spells, including those did not apply for leniency and ended in an investigation closure (283 spells) or an acquisition by a co-conspirator of the same cartel (41 spells). The next three columns are for spells that ended in a leniency application (134 spells).

The results are quite stunning in terms of the long time that it takes before a colluder submits a leniency application (314.4 weeks; Row 1, Column 4). The final column of Table 2 reports the median values that correspond to the entries in column 4. Because of the skewed distributions of the DURATION variable, the median value is higher than the mean. Moreover, the table shows that a colluder is more likely to apply as the number of cartel participants decreases (Row 2); it is less likely to apply as the number of prior applications increases in a cartel (Row 3). Colluders engaged in a market-allocation or bid-rigging infringement are more likely to apply than colluders not engaged in these infringements (Rows 5 and 6).

3.3 Graphical analysis

We start by graphing the non-parametric Kaplan-Meier hazard functions. The empirical hazard is the ratio of the number of observations that apply for leniency in a week relative to the number that had not yet applied at the start of the week[16]. These functions plot the rates of leniency applications against the *analysis time,* described below.

Let the *spell start* be the later of July 18, 1996 (the old leniency introduction) and the date that the colluder joins the cartel. Let the *spell end* be the earlier of the time of censoring (ie investigation closure or acquisition by a co-conspirator of the same cartel) and the time of leniency application. The analysis time is the number of weeks elapsed between the spell start and the spell end. The hazards do not evolve monotonically over time (Figure 4). The hazard increases as time elapses and peaks around week 400. Then it quickly declines. The initial rises probably have followed the increased investigation activities in the other markets. An examination of Figure 5 provides some evidence points.

Figure 5 plots the distribution around the spell start of Commission dawn raids in the other markets in which one or more colluders in the spell's market also engaged in collusion. The rises in the hazard are roughly coincident with the rises in the frequency of dawn raids. This point will be examined in detail in the regression analysis.

The subsequent falls after roughly week 400 are probably caused by increases in the convicting evidence that the EC has obtained over time. Recall that a confessor qualifies for fine reductions only if it provides the EC with incriminating evidence that represents significant added value relative to what the EC already has obtained. An examination of Figure 6 provides some evidence on this point.

Figure 6 plots the distribution of the analysis times of the early applications in a cartel. Panel A plots the distribution for the first applications. Panel B plots the distribution for the second applications. The starting of decline in the hazard is roughly coincident with the weeks by which the great majority of the early applications have already been submitted.

[16] Formally, defining the risk set in week w, Rw, as the number of spells not experiencing a leniency application by the start of week m, and the number of applications in week w as Sw, the Kaplan-Meier empirical hazard is defined as Sw/Rw.

4. The empirical frameworks

The timing of leniency application decisions is analysed naturally in hazard model frameworks. Multiple colluders may apply for leniency in a cartel. In these cases, spells may be correlated with the cluster, violating the assumption of independent spells that is required in conventional duration analysis. To address this, we consider multiple-spell hazard specifications and model the sequential leniency applications as 'recurrent events', with the spell of the first event starting at the later of July 18, 1996 (the introduction of EC 1996 Leniency Programme) and the first-in leniency applicant's start date of collusion and the spells of the subsequent applications starting at the time of the preceding event.

Moreover, failure times may be tied across spells. Ties are present if different colluders share in common two (or more) adjacent events of interest (i.e., leniency applications or censoring). Such a data structure makes discrete-time hazard models a natural candidate for our analysis because the discrete-time methods give consistent estimates of the coefficients and their associated variance in the presence of ties[17].

The additional advantages of the discrete-time hazard models include: (i) they can easily handle multiple time-varying covariates (such as the authority's investigation activities, changes in antitrust policies and macroeconomic conditions); (ii) they can easily be extended to account for unobserved individual heterogeneity, even if the sample size is large; and (iii) by using the discrete-time hazard models, we can circumvent the rather restrictive proportional hazards assumption that sometimes plagues continuous time specifications (eg Weibull)[18].

Let T_s be the continuous, non-negative random variable that measures the length of a particular spell s. In a discrete-time framework, the core of duration analysis is formed by the probability that a particular *colluder* experiences an event (eg applying for leniency in a market) within a given period $[t_k; t_{k+1})$, where $k = 1, \ldots, K$ and $t_1 = 0$, conditional on not experienced the event at the beginning of the interval and given the explanatory variables included in the regression model. This conditional probability is termed the *discrete-time hazard rate*. Its function is given by

$$h_{sk} := \text{Prob}\{T_s < t_{k+1} \mid T_s \geq t_k, \mathrm{x}_{sk}\} = F(\mathrm{x}'_{sk}\beta + \gamma_k),$$

where x_{sk} is a vector of potentially time-varying covariates and γ_k is a function of time that allows the hazard rate to vary across different periods within a spell. $F(\cdot)$ is a cumulative distribution function ensuring that $0 \leq hsk \leq 1$. Here, the subscript s denotes separate spells. The parameter vector β is the vector of coefficients, measuring the influence of observed characteristics. The term $\mathrm{x}'_{sk}\beta$ shifts the hazard function $F(\cdot)$. A positive coefficient indicates that sk the observed characteristics increase the leniency application hazard and reduce the expected time to leniency application.

For each spell, we record the last week in which an event is observed. In the following, this terminal week is denoted k_s. The subscript s indicates that it may differ across spells. We introduce a binary variable $y_{sk} = 1$ if spell s is observed to cease during the kth week, and let $y_{sk} = 0$ otherwise. The log-likelihood for the observed data is given by

[17] Alternative approaches to handle tied failure times in continuous-time hazard frameworks have been developed in the literature. See, eg Breslow (1974). While computationally undemanding, Breslow's method will be inaccurate if there are many ties in the data set, which happens to be my case.

[18] Multi-spell discrete-time hazard models have been used in Marx and Zhou (2015) for studying merger dynamics among (ex) cartel members.

$$\ln L = \sum_{s=1}^{n} \sum_{k=1}^{ks} [y_{sk} \ln(h_{sk}) + (1 - y_{sk}) \ln(1 - h_{sk})].$$

Assuming that $F(\cdot)$ follows a logistic distribution, the parameters can be estimated using logit models[19].

4.2. Regression analysis

We start by reformatting our data for a discrete-time survival analysis. Although initially each *colluder* had one record (line) of data for each event of interest, we re-organise the data so that the *n* spells in the original sample contribute multiple independent observations to a *Colluder-Cartel-Spell-Period* data set in which there are $\Sigma_s k_s$ lines of data – one observation for every time period within every spell for which each Colluder-Cartel pair in the original sample was observed. Each spell period has seven days.

Next, we create three types of new variables for the newly created Colluder-Cartel-Spell-Period data set: (1) a time period identifier, (2) the event indicator variable, and (3) time-varying covariates. The time period identifier TIME$^t_{ij}$ is a sequence of positive integers. It equals one during the first 7-day period after the spell has started, two during the second period, and so on. The event indicator APPLY $^t_{ij}$ is a period-specific binary variable. It equals one if j applied for leniency in cartel i during the period $(t - 7$ days, $t]$, it equals 0 otherwise. Finally, we create a set of time-varying covariates to track changes in enforcement and leniency applications activities across markets and a number of other factors that potentially influence application decisions. They are described in Table 1. The descriptive statistics for the newly created data set are given in Tables 3, 4 and 5. In the remaining of this section, we will only discuss the main regressors and main control variables.

4.2.1 Description of main regressors

A. The Knock-On Effect of Investigation Across Markets

Our first set of regressors captures the potential knock-on effects of cartel investigations across markets. RAID-OTH-MKT1$^t_{ij}$ equals one if by time t the EC has opened an investigation on *colluder j* for its collusion related to market $-i$ $(-i \neq i)$ in which one or more of j's co-conspirators in market i also engaged in collusion; it equals zero otherwise. This variable corresponds to a situation where several *colluders* jointly appear in two or more cartels, one of which is under investigation. We distinguish between this situation and situations where the authority investigates a market in which only one *colluder* from the other market also engaged in collusion. RAID-OTH-MKT2$^t_{ij}$ equals one if by time t the EC has opened an investigation on *colluder j* for its collusion in market $-i'$ $(-i' \neq i)$ in which none of j's co-conspirators in market i also engaged in collusion; it equals zero otherwise. RAID-OTH-MKT3$^t_{ij}$ equals one if by time t the EC has launched an investigation in market $-i''$ $(-i'' \neq i)$ in which one or more *colluders* in market i except for j also engaged in collusion; it equals zero otherwise.

To see whether an investigation in a market delays a knock-on effect in the other markets, we run the following statistical tests. Because the regression model generates an increase in leniency application rate if the coefficients of RAID-OTH-MKT1$^t_{ij}$, RAID-OTH-MKT2$^t_{ij}$ and RAID-OTH-MKT3$^t_{ij}$ are positive, we test the hypotheses:

[19] We obtain similar results from probit models.

$$H_0: \beta \text{ RAID-OTH-MKT1}^t_{ij} \leq 0 \text{ versus } H_1: \beta \text{ RAID-OTH-MKT1}^t_{ij} > 0$$

$$H_0: \beta \text{ RAID-OTH-MKT2}^t_{ij} \leq 0 \text{ versus } H_1: \beta \text{ RAID-OTH-MKT2}^t_{ij} > 0$$

$$H_0: \beta \text{ RAID-OTH-MKT3}^t_{ij} \leq 0 \text{ versus } H_1: \beta \text{ RAID-OTH-MKT3}^t_{ij} > 0$$

Where β RAID-OTH-MKT1$^t_{ij}$, RAID-OTH-MKT2$^t_{ij}$ and RAID-OTH-MKT3$^t_{ij}$ denote the RAID-OTH-MKT1$^t_{ij}$, RAID-OTH-MKT2$^t_{ij}$ and RAID-OTH-MKT3$^t_{ij}$ coefficients, respectively.

B. Investigation in the spell's market

We are interested in comparing the effect of investigation in a market with that across markets. RAID t equals one if the EC has opened an investigation on *colluder j* in market *i* by time *t*; it equals zero otherwise. To see whether an investigation affects leniency applications in the investigated market, we run the following statistical test. Because the regression model generates an increase in leniency application rate if the coefficient of RAID$^t_{ij}$ is positive, we test the hypothesis:

$$H_0: \beta \text{ RAID}^t_{ij} \leq 0 \text{ versus } H_1: \beta \text{ RAID}^t_{ij} > 0$$

where β RAID$^t_{ij}$ denotes the RAID$^t_{ij}$ coefficient.

Investigation activities may be linked across markets. For instance, with cartel profiling the authority increases the probability of investigation for other products produced by firms detected to be engaged in collusion (Marx, Mezzetti, and Marshall 2015). Moreover, leniency applications in a market may trigger or be triggered by an investigation in the market. When an undetected cartel is reported, an investigation is expected within weeks (Figure 1)[20]. The majority of late applications appear to follow the opening of an investigation closely. Figure 1 shows that the application rate remains high in the first 15 weeks after an investigation. RAID$^t_{ij}$ therefore controls for the potential effects of an investigation on and its association with both leniency applications in the investigated market and investigation activities in the other markets.

C. EC's 2002 leniency revision

Our next main regressor POLICY^t is a time-varying categorical variable that indicates the antitrust policy environment at time *t*. The categories are '96-LEN^t' for the periods between July 18, 1996 and February 18, 2002, '02-LEN^t' for the periods between February 19, 2002 and June 29, 2008, and 'SETTL^t' for the periods after June 30, 2008.

To examine whether the rate of leniency application increases following the 2002 leniency revision, we run the following statistical test. Taking 02-LEN^t as the omitted category, the regression model generates an increase in the rate of leniency application if the 96-LEN^t coefficient is negative. We therefore test the hypothesis:

$$H_0: \beta_{\text{96-LEN}^t} \geq 0 \text{ versus } H_1: \beta_{\text{96-LEN}^t} < 0,$$

where $\beta_{\text{96-LEN}^t}$ denotes the 96-LEN^t coefficient.

[20] Figure 1 is based on all the cartels from the EC decisions 1996-2014 for which the dates of leniency applications are reported, including cartels excluded from our main regression sample; that is cartels contain a firm that engaged in collusion in the United States.

4.2.2 Description of main control variables

A. Leniency applications in the other markets

Leniency application dynamics may be linked across markets[21]. For instance, with cartel profiling the authority increases the probability of investigation in a second market in which the leniency applicants in the first market also operate (Marx, Mezzetti, and Marshall, 2015). Recall that under the EC's 2002 Leniency Notice, the EC only guarantees full immunity to the first applicant from each cartel, provided that an investigation into the applicant's cartel is not already underway. So in fear of losing the guarantee, a conspirator that has applied for leniency in a market may have an incentive also to apply in a second market before the EC opens an investigation there.

Therefore, we include the following covariates: APPL-OTH-MKT1$^{t}_{ij}$ equals one if by time t colluder j applied for leniency in cartel $-i$ ($-i \neq i$) in which one or more of its co-conspirators in cartel i also engaged in collusion; it equals zero otherwise. This variable corresponds to a situation where several *colluders* jointly appear in two or more cartels, one of which is being reported. We distinguish between this situation and a situation where a multi-market colluder reports a cartel in which none of its co-conspirators from the other cartel also engaged in collusion. APPL-OTH-MKT2$^{t}_{ij}$ equals one if by time t *colluder* j self-reports cartel $-i'$ ($-i' \neq i$) in which none of its co-conspirators in cartel i also engaged in collusion; it equals zero otherwise.

For similar reasons discussed above, we include two variables to track the changes in application decisions by one's co-conspirators in the other markets: APPL-OTH-MKT3$^{t}_{ij}$ equals one if by time t a co-conspirator of j in cartel i self-reports cartel $-i''$ ($-i'' \neq i$) in which j is also a member; it equals zero otherwise. APPL-OTH-MKT4$^{t}_{ij}$ equals one if by time t a co-conspirator of j in cartel i denounces cartel $-i'''$ ($-i''' \neq i$) in which j is not a participant; it equals zero otherwise.

B. Factors influencing the calculation of fines

The primary motive behind a leniency application is to escape punishment. The EC determines the level of fines (in absence of a leniency application) based on a number of factors including (see European Commission 1998, p. 3-5; European Commission 2006, p. 2-5), among others, the duration of an infringement (DUR-OFFENSE$^{t}_{ij}$), the geographic scope of the affected market (MARKET SCOPE$_{i}$), the type of infringement (PRICE FIX$_{i}$, MARKET-ALLOC$_{i}$ and BID-RIG$_{i}$), whether a colluder has been an addressee in the EC's previous decision(s) (RECIDIVIST$^{t}_{ij}$), the colluder's market share calculated near the end of an infringement (SHARE$^{t}_{ij}$), and whether the EC finds evidence that the colluder has acted as a ringleader (RINGLEADER$^{t}_{ij}$)[22]. As mentioned in the introduction, some of these factors have been suggested by the literature to affect leniency application decisions. Moreover, notice that the values of DUR-OFFENSE$^{t}_{ij}$ and RECIDIVIST$^{t}_{ij}$ (weakly) increases as time elapses. Therefore, they may reflect, among other things, the accumulation of a colluder's knowledge and experience with antitrust enforcement along the courses of collusion and investigation.

Moreover, EC decisions report information on the 'basic amount' of fines which is calculated by multiplying the *total* duration of the infringement by the sum of a number of other factors included in

[21] See, eg Marx, Mezzetti, and Marshall (2015) for a theoretical analysis.

[22] In calculating the fines, the EC also takes into account whether the alleged firm is in financial distress. Moreover, the total fine imposed may not exceed 10 percent annual turnover of the firm. See European Commission (2006), pp. 2-5. For the EC Guidelines on the methods for setting fines, see European Commission website: http://ec.europa.eu/competition/antitrust/legislation/fines.html.

our analysis (eg MARKET SCOPE $_{i}$ and SHARE $_{ij}$). Information on the 'basic amount' is not used in our analysis because it does not reflect the accumulation of expected penalties as infringement prolongs.

4.3 Description of the colluder-cartel-spell-period data

Table 3 reports the means and standard deviations of the newly created colluder-cartel-spell-period data set. The first three columns correspond to spell periods before the EC investigates a separate market in which one or more colluders in the spell's market also engaged in collusion. The next three columns correspond to spell periods after the EC has started investigating a separate market. The final columns include all the sampled periods. Looking at the rates of leniency application (row 1), the mean rate triples following the initiation of an investigation in a separate market (columns 1 and 4, row 1). This suggests that an investigation in a market may increase leniency applications in subsequent markets.

The table also shows that the other included variables, such as the likelihood that the EC starts investigating the spell's market (RAID $^{t}_{ij}$), the probability that the EC successfully prosecutes a colluder in separate cartels and will penalise the colluder as a recidivist in the spell's cartel (RECIDIVIST $^{t}_{ij}$), and the accumulation of infringement duration (DUR-OFFENSE $^{t}_{ij}$) co- evolve with leniency application rate as we move from the pre-dawn raid periods to the post-dawn raid periods. The regression analysis in the section to follow will isolate these potential confounding influences from the knock-on effect of antitrust investigation.

Tables 4 and 5 reports the sample moments of the colluder-cartel-spell-period data set by antitrust policy regime. We distinguish between spell periods that ended prior to an investigation in the spell's market (Table 4) and periods following the initiation of an investigation (Table 5). Columns (1)-(3) in each table correspond to the periods between July 18, 1996 and February 18, 2002 (ie the period during which the EC's old leniency was in force). Columns (4)-(6) are for the periods between February 19, 2002 (the EC's 2002 leniency revision) and June 29, 2008 (the day before the introduction of the settlement procedure). Columns (7)-(9) correspond to the periods after June 30, 2008. The final columns include all the sampled periods. Our focus here is on the changes in application rate following the 2002 leniency revision. The mean pre-detection application rate increases by five times following the leniency revision (columns 1 and 4, row 1 of Table 4). However, a similar sharp increase is not found in the post-detection sample, where the application rate merely doubles following the new leniency introduction (columns 1 and 4, row 1 of Table 5). These results suggest the EC's 2002 leniency revision probably has increased leniency applications. But the policy impact diminishes somewhat following the opening of an investigation.

4.4 Regression results

Our empirical analysis proceeds in three steps. As a first step, we run regression on all the sampled spell periods. In this step, the impacts of the new leniency programme on the application hazard before and during an investigation are not isolated. In the second step, we use the same set of explanatory variables as in the previous step but restrict the regression to spell periods before an investigation into the spell's market is opened. This restriction isolates the new leniency's per-investigation impact from its impact during an investigation. In the third step, we limit the regression to the spell periods during an investigation and look at the impact of the new leniency programme after the investigation has opened.

Table 6 reports the regression results of the effects of cartel investigations and antitrust policies on the rate of leniency application using all the sample periods. Column 1 includes RAID-OTH-MKT1 $^{t}_{ij}$, RAID-OTH-MKT2$^{t}_{ij}$, RAID-OTH-MKT3$^{t}_{ij}$, RAID $^{t}_{ij}$ and POLICY ^{t}. Columns 2, 3 and 4 alternately include the timing of leniency application in the other markets, the (time-invariant) firm, cartel and market characteristics, and the (time-variant) macroeconomic conditions. We only have 58,335 observations for the macroeconomic variables. Column 5 includes colluders' histories of infringement and their experience with cartel enforcement. Some of these variables also reflect changes in the expected level of fines as collusion continues. Column 6 includes all the control variables. In all the specifications, we include eight duration-interval specific dummies to describe the overall temporal profile of risk. Together, the interval dummies represent the effect of T^{s}_{ij} on the application hazards. Moreover, we include, in each specification, a predictor that is associated with the previous application episode – NUM-EX-APPS$^{s}_{ij}$. It represents the dependency of the hazard rate on the the histories of leniency applications in a cartel and is included to relax the conditional independence assumption inherent in the multi-spell discrete-time hazard model (Allison 1982, p.93).

Starting with the effects of cartel investigations, the estimated RAID-OTH-MKT1$^{t}_{ij}$ coefficients are positive but small and sometimes insignificant in specifications (1), (3) and (4). After controlling for the impacts of leniency applications in separate markets, the estimated RAID-OTH-MKT1$^{t}_{ij}$ coefficient becomes negative and statistically insignificant (specification (2)). But after controlling for infringement history and cartel enforcement experience (specifications (5) to (6)), the RAID-OTH-MKT1$^{t}_{ij}$ coefficients become statistically significant and larger in absolute value than the corresponding estimates in specifications (1) to (4). Similar patterns exist for the estimated RAID-OTH-MKT2$^{t}_{ij}$ and RAID-OTH-MKT2$^{t}_{ij}$ coefficients. These results suggest that investigation in a market displays a positive knock-on effect on the leniency application rates in the other markets in which one or more firms in the market investigated also engaged in collusion. Moreover, the magnitude of the knock-on effects is affected by or associated with the other included variables, especially the time-varying covariates reflecting changes in firms' infringement history and their experience with cartel enforcement.

An explanation of these results is that there is a possibility that the competition authority responds to a cartel discovery by increasing the probability that it investigates the other markets of the detected colluders (Marx, Mezzetti, and Marshall 2015). Recall that the EC guarantees complete fine reductions only to the first leniency applicant from each cartel, provided that an investigation into the applicant's cartel is not already underway. If the conspirators expect an investigation in the other markets, then they expect to be prosecuted there, so they would typically have an incentive to outrun the EC's investigation there by promptly submitting an application, hoping to be first in the door and avoid paying a fine. An alternative explanation is that when cartel profits are linked across markets, discovering and desisting a cartel in one market reduces the sustainability of the cartels in the other markets (Choi and Gerlach 2013), thereby inducing leniency applications in those markets.

Looking at the effect of investigation in the market under investigation, the estimated RAID$^{t}_{ij}$ coefficients are negative but small in absolute values and insignificant throughout specifications (1), (2), (3) and (4). Although the coefficient turns significant in specification (5), it becomes insignificant again after we control for the other factors that may affect both application decisions and the timing of an investigation (column 6). This indicates that opening an investigation does not significantly affect the rate of leniency application in the market investigated.

Turning to the effect of 2002 leniency revision, the estimated 96-LEN coefficients in specifications (1) to (5) are negative and significant at conventional levels, suggesting the 2002 leniency introduction may have increased the rate of leniency application. But, after controlling for the effects of all the included covariates (specification (6)), the 96-LEN coefficients become statistically insignificant and smaller in absolute value than the corresponding estimates in specifications (1) to (5). This result suggests that the introduction of leniency programme does not significantly affect leniency application rate. This result deserves scrutiny. One limitation of specifications (1) to (6) is that the new leniency programme, to the extent it has any impact, is constrained to generate time-average shifts in the hazard functions across different spell periods. But the impact of the policy revision prior to an investigation may differ from that during an investigation: whereas following the policy revision fine reductions have become automatic and guaranteed for the first confessor who reports before an investigation into its cartel starts, fine reductions have continued to be provided on a discretionary basis for applications that arrive after the start of an investigation. So deviations in the hazard rate may not be found when the movements are averaged out across different spell periods.

Specification (7) isolates the movements of hazards during an ongoing investigation by restricting to spell periods prior to the start of investigations. Zhou (2013) finds that the introduction of the new leniency programme has enhanced the EC's cartel detection capabilities. The coefficient of LEN-96 in specification (7) is consistent with this finding: the introduction of the new leniency immediately results in a hazard profile with a probability of application that is approximately 1.77 times higher than the pre-leniency levels. The effect is statistically significant and greater in absolute value than the corresponding estimates from specifications (1) to (6).

Specification (8) restricts to spell periods during investigations and isolates the movements of pre-investigation hazards. As expected, the coefficient of LEN-96 becomes statistically insignificant and smaller in absolute value than the corresponding estimate in specification (7). This result suggests that the introduction of the 2002 leniency programme does not affect leniency application timing after the start of an investigation.

A similar pattern exists with the 2008 Settlement Procedure where significant policy impact is found only after we isolate the movement of hazards following the opening of investigations (row 7, specification (7)). The settlement procedure provides late cartel confessors or non-confessors with an opportunity to obtain fine reduction outside leniency. So the procedure reduces the incremental fine reductions that a first-in confessor would obtain vis-à-vis late or non-confessors. The result here suggests that the procedure discourages conspirators from revealing undiscovered cartels. Moreover, the estimated SETTL *t* coefficient becomes negative and statistically insignificant in specification (8) where the regression is restricted to spell periods that follow the start of investigations. This means that the procedure does not affect leniency application rate after an investigation starts.

To summarise briefly the effects of the other covariates (specification (6)), we find little effect of a colluder's status as being a ringleader ($RINGLEADER_{ij}$) or a recidivist ($RECIDIVIST^{t}_{ij}$), the size of cartel membership ($UNDERTAKINGS_{i}$), changes in the interest rate ($INTEREST^{t}$), the expected demand fluctuations (Δ GDP^{t} and $PEAK\text{-}TROUGH^{t}$) and unexpected demand shocks ($POS\text{-}SHOCK^{t}$ and $NEG\text{-}SHOCK^{t}$) or changes in the geographic scope of the cartel ($MARKET\ SCOPE_{i}$), but a significant decreased application rate following increases in the number of prior EC investigations on a colluder ($NUM\text{-}RAIDS\text{-}OTH\text{-}MKT^{t}_{ij}$) and the number of prior applications in the spell's cartel ($NUM\text{-}EX\text{-}APPS^{s}_{ij}$). Moreover, application hazard significantly increases with the duration of infringement ($DUR\text{-}OFFENSE^{t}_{ij}$) and the number of prior applications that a colluder has made in the other markets ($NUM\text{-}APPS\text{-}OTH\text{-}MKTS1^{t}_{ij}$). Application rate is higher in price fixing cartels than in non-price fixing cartels.

Finally, the duration-interval-specific dummies describe the logit-hazard profile for the application spell. The estimates suggest that likelihoods of application do not evolve monotonically over time.

5. Policy implications

Two policy implications emerge from our results.

5.1 Linking leniency across markets may be unnecessary for enhancing detection

A difference between the DOJ's leniency programme and the programmes in many other jurisdictions around the world is that the DOJ links leniency across markets through Amnesty Plus and Penalty Plus. Under the Amnesty Plus, a firm being prosecuted for collusion that has not received leniency can receive reduced penalties if it applies for leniency in a separate market in which it has also engaged in collusion; under the Penalty Plus, the failure to confess collusion in separate markets can put firms at risk for increased fines should they later be discovered for collusion in those markets[23]. In 2001, the Organisation for Economic Cooperation and Development recommended the inclusion of Amnesty Plus as part of the EC's 2002 leniency reform. But the recommendation was not followed. Similar to that in the EU, many other jurisdictions around the world do not have Amnesty Plus and Penalty Plus provisions[24]. The data analysed here suggest that without linking leniency across markets, antitrust enforcement in one market appears to have already increased leniency applications and hence volunteered information and evidence contributing to conviction in the other markets.

5.2 Transparency in enforcement agendas facilitates pro-competitive knock-on effects

Another difference between the DOJ's and the EC's practices is that within days following its surprise inspections, the EC openly announces, in its press release, that the inspections have been carried out and reveal the product market under investigation. But the DOJ maintains strict confidentially regarding its investigation schedule. The data analysed here suggest that transparency and immediate announcement of law enforcer's investigation agenda may be an important element of successful cartel enforcement: they may decoy conspirators in separate, undiscovered cartels, including those not have engaged in the investigated offense (who would otherwise be uninformed about the opening of the investigations at the time that they happen), towards confession.

6. Conclusion

Cartels often involve firms that collude in more than one market. The majority (82 percent) of leniency applications that the EC received in the past 19 years are from markets in which one or more cartel members also engaged in collusion in other markets. Many of these leniency applications closely followed the opening of cartel investigations in related markets. Using a novel application of multi-spell discrete-time survival analysis for a sample of cartels prosecuted by the EC between 1996 and 2014, we show that antitrust investigation in a market increases leniency applications in related markets.

The foregoing discussions have focused primarily on cartels. But the results and insights we derived in this paper may apply more generally to anti-crime policies of a broader interest. Cartels and other forms of organised crimes such as narcotics violations, terrorism, large-scale fraud, long-term corruption, and arm and human trafficking share in common an important characteristic: conspirators may resort to long-term relationships to sustain cooperation due to a lack of enforceable contracts. Such relationships may leave evidence that one or more conspirators can sell to the law enforcement

[23] See Lefouili and Roux (2012) for a discussion and theoretical analysis of Amnesty Plus. See Marx, Mezzetti, and Marshall 2015 for a discussion and theoretical analysis of Penalty Plus. See also Wils (2008, Chapter 5.4.4).

[24] To our knowledge, programs such as Amnesty Plus or Penalty Plus only exist in the United States, Canada, Brazil and Poland.

in exchange for amnesty[25]. The results presented here suggest that enforcement externalities boost the marginal benefits of enforcement measures when detections are publicly observable. The sizable impact found in our data indicates that it is crucial to consider these knock-on effects in a cost-benefit analysis on the optimal level of law enforcement.

Several issues are left for future research. Our regression sample is a single time series. Cross-sectional variation from other jurisdictions could provide more robust identification. Cartel discoveries in individual European member states and jurisdictions outside of the EU (eg Asia) may provide this variation in future research. The second issue is that due to their illegal nature, cartels conceal their activities and one observes only discovered cartels. Because the discovered cartels might be a small and characteristically unrepresentative sample of the population of cartels, one cannot infer the impact of cartel investigation on the population of cartels based on information gleaned from the discovered cartels without additional assumptions being made that may or may not be correct. Future research should explicitly address the potential sample selection bias.

[25] The similarities between cartel offenses and other forms of conspiracy have also been discussed by, among others, Spagnolo (2000, 2004), Buccirossi and Spagnolo (2006), Miller (2009), Bigoni *et al* (2012) and Zhou (2012).

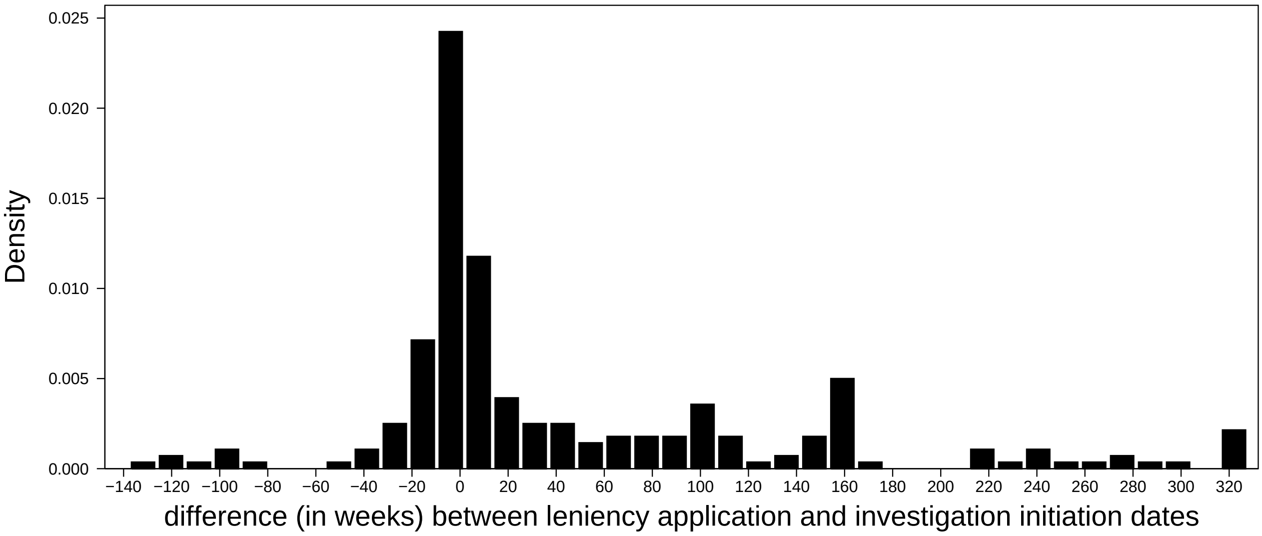


Figure 1. Distribution of Leniency Applications Around Investigation Initiation in A Cartel

Notes: The sample consists of 241 colluder-cartel combinations that the authors constructed using cartel decisions on 96 cartels by the European Commission for the period 1996-2014. The figure plots the distribution of leniency applications around the time that the EC opens an investigation (i.e., dawn raid of cartel members' premises) into the cartel being reported. The observations located to the left (right) of zero on the horizontal axis are applications before (after) the start of an investigation.

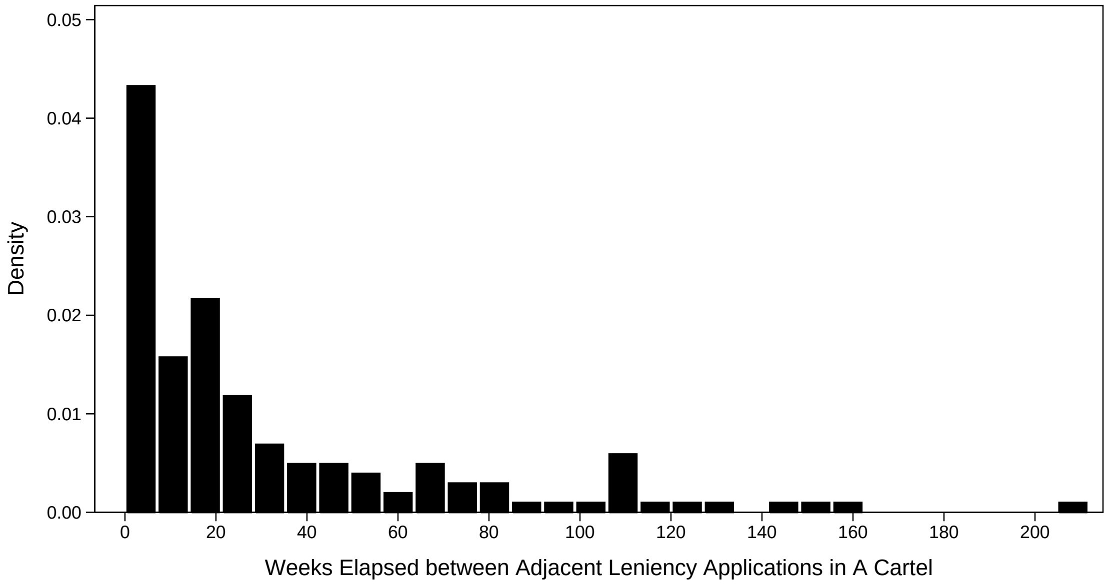


Figure 2. Distribution of Weeks Between Adjacent Leniency Applications in A Cartel

Notes: The sample consists of 156 colluder-cartel combinations the authors constructed using cartel decisions and information on 71 cartels by the European Commission for the period 1996-2014. The figure plots the distribution of the number of weeks between adjacent leniency applications in a cartel.

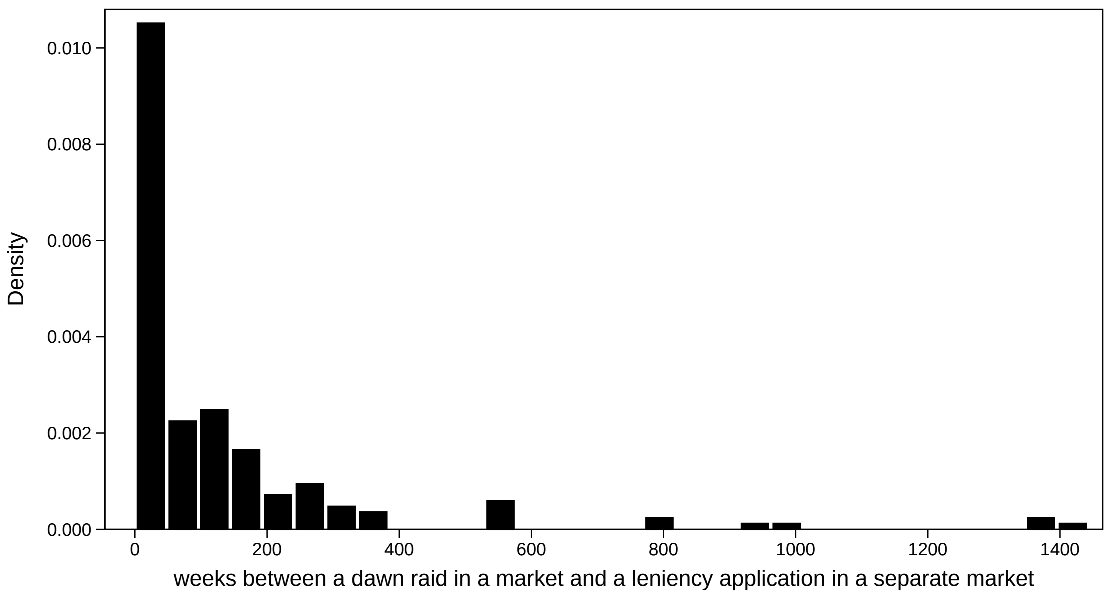


Figure 3. Distribution of The Weeks until A Leniency Application from The Most Recent Dawn Raid in A Separate Market

Notes: The sample consists of 177 colluder-cartel combinations the authors constructed using cartel decisions and information on 69 cartels and 103 colluders by the European Commission for the period 1996-2014. The figure plots the distribution of the number of weeks elapsed until a leniency application from the most recent dawn raid (the EC's surprise inspection at a cartel member's premise) in a separate market in which a conspirator in the cartel being reported also engaged in collusion.

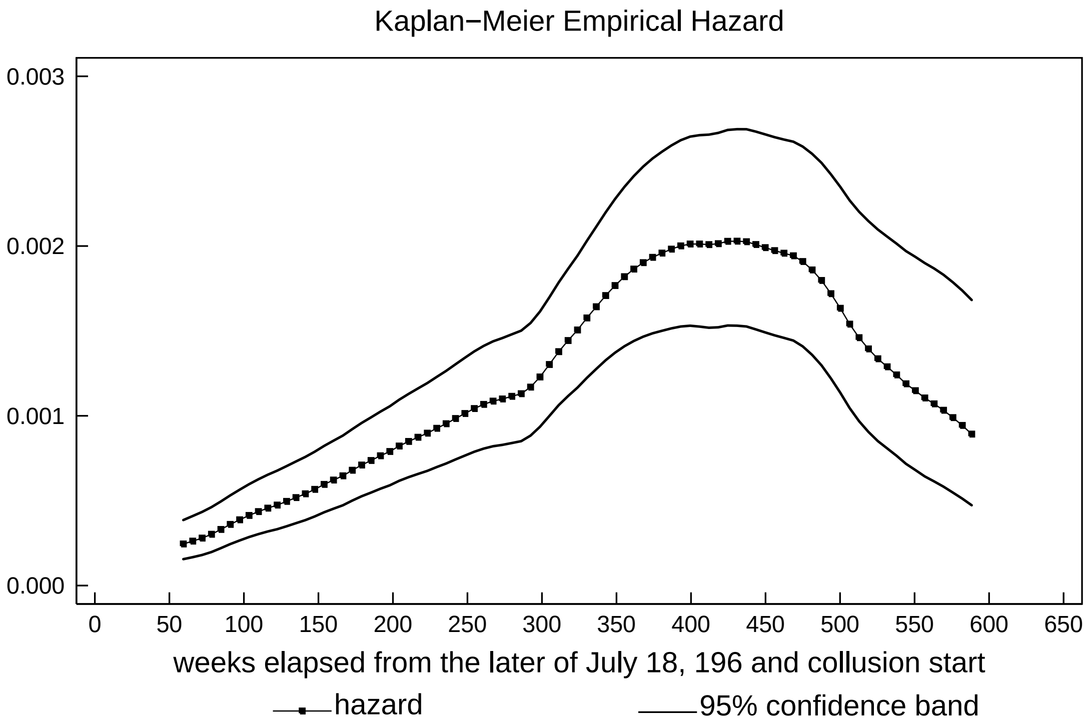


FIGURE 4. KAPLAN-MEIER EMPIRICAL HAZARD OF LENIENCY APPLICATION

Notes: The sample consists of 404 colluder-cartel combinations the authors constructed using cartel decisions and information on 69 cartels and 314 colluders by the European Commission for the period 1996-2014. The sample includes only cartels in which no firm has engaged in collusion in the United States.

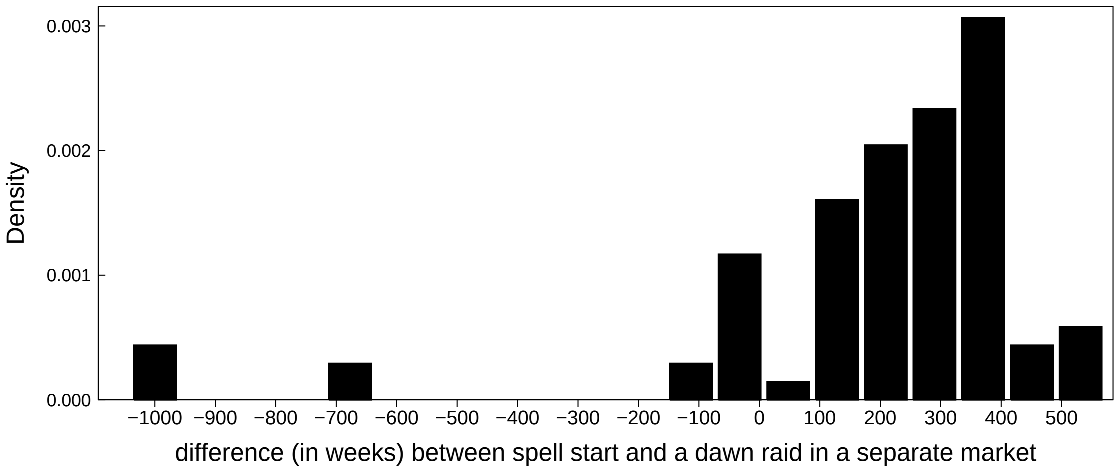
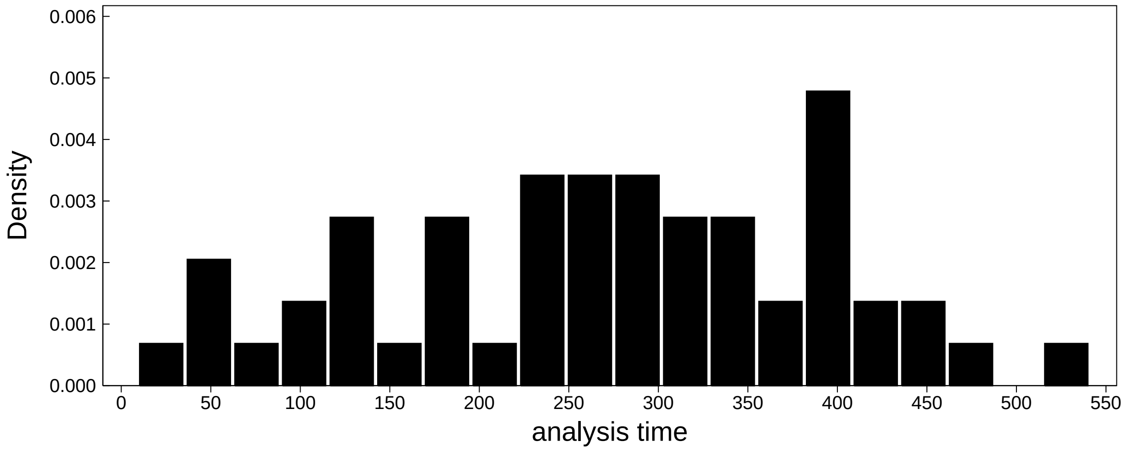


Figure 5. Distribution of Dawn Raids in Separate Markets around Spell Start

Notes: The sample consists of 90 colluder-cartel combinations the authors constructed using decisions and information on 59 cartels and 66 colluders by the European Commission for the period 1996-2014. The figure plots the distribution of dawn raids in a market around the spell start in a separate market in which one or more firms in the raided market also engaged in collusion. The spell starts at the later of July 18, 1996 and the colluder's joining of the cartel. The observations located at zero on the horizontal axis are dawn raids that happen at the same time of the spell start. The observations to the left (right) of zero are dawn raids before (after) the spell start.

Panel A: First Leniency Applications



Panel B: Second Leniency Applications

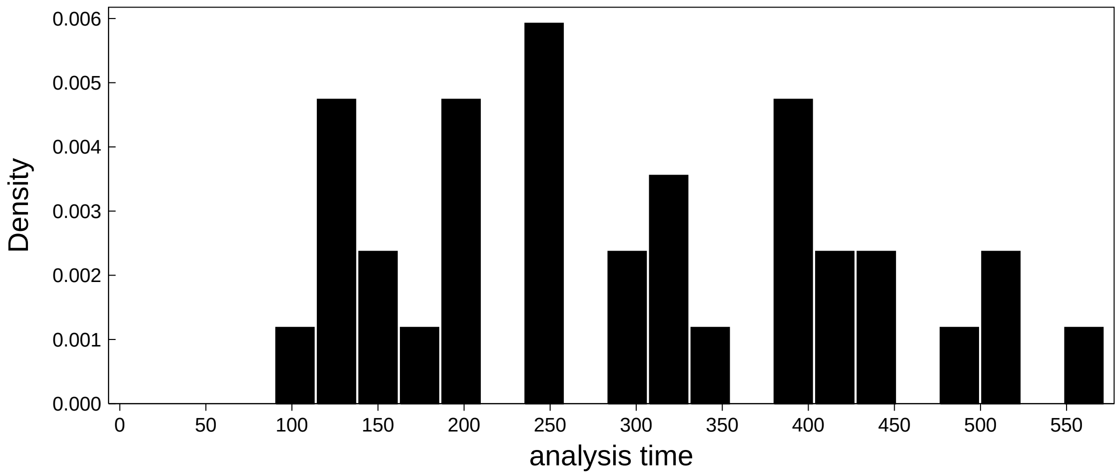


Figure 6. Distribution of Analysis Time of The First and The Second Leniency Applications in A Cartel

Notes: The sample consists of 90 colluder-cartel combinations the authors constructed using cartel decisions and information on 59 cartels and 66 colluders by the European Commission for the period 1996-2014. The figure plots the distribution of analysis time— the time elapsed between the later of July 18, 1996 and a colluder's joining of the cartel until the time of the colluder's leniency application. Panel A plots the distribution of the first cartel confessors' analysis times. Panel B plots the distribution of the second confessors' analysis times.

Table 1. Terms and Definitions

	Definition
Market	An relevant product and geographic market that comprises all those products and/or services which are regarded by the EC as interchangeable or substitutable and comprises the area in which, according to the EC, the conditions of competition are sufficiently homogeneous.
Cartel	An agreement or a series of agreements between competing firms or associations of firms that constitutes a single infringement on a market, according to the EC, of Art. 101 (formerly Art. 81 and Art. 85) of the EC treaty.
Censoring date	= the date of EC investigation closure if a *colluder* did not apply for leniency and was not acquired by a co-conspirator before the closure of investigation; = the date of acquisition if a *colluder* did not apply for leniency and was acquired by a co-conspirator before the closure of EC investigation.
Variables	
DURATION^s_{ij}	= number of weeks elapsed from the later of July 18, 1996 and *colluder* j's joining of cartel i until j experiences event s (i.e., applying for leniency in cartel i or censoring).
T^s_{ij} (spell length)	= number of weeks elapsed from the later of July 18, 1996 and *colluder* j's joining of cartel i until j experiences event s (i.e., applying for leniency in cartel i) if j is the first-in applicant in cartel i; = number of weeks elapsed from the end of the previous spell until j experiences event s (i.e., applying for leniency in i or censoring) if j is not the first-in applicant in i.
APPLY^t_{ij}	A dichotomous indicator of whether during the period (t-7 days, t] *colluder* j applied for leniency for collusion in market i. This is the dependent variable for our regression analysis.
TIME^t_{ij}	Number of weeks since the start of *colluder* j's spell in cartel i.
TIME^t_{ij}-DUMMY	Duration-interval-specific dummies indicating the length of TIME^t_{ij}, one for each spell interval at risk. The dummies are 0-21 weeks, 22-43 weeks, 44-68 weeks, 69-94 weeks, 95-108 weeks, 109-171 weeks, 172-241 weeks, $\geq$ 242 weeks.
RAID^t_{ij}	A dichotomous indicator = 1 if the EC has opened an investigation on *colluder* j in market i by time t, = 0 otherwise.
$\text{RAID-OTH-MKT1}^t_{ij}$	A dichotomous indicator = 1 if by time t the EC has opened an investigation in market $-i$ ($-i \neq i$) in which j and one or more of j's co-conspirators in market i also engaged in collusion; = 0 otherwise.
$\text{RAID-OTH-MKT2}^t_{ij}$	A dichotomous indicator = 1 if by time t the EC has opened an investigation on *colluder* j for collusion related to market $-i'$ ($-i' \neq i$) in which none of j's co-conspirators in market i also engaged in collusion; = 0 otherwise.

(*continued overleaf*)

Table 1. (*Continued*)

	Definition
RAID-OTH-MKT3$^t_{ij}$	A dichotomous indicator $= 1$ if by time t the EC has opened an investigation in market $-i''$ $(-i'' \neq i)$ in which one or more conspirators in market i except for j also engaged in collusion; $= 0$ otherwise.
POLICY^t	Time-varying categorical variable that indicates the antitrust policy environment at time t. The categories are "96-LEN^t" (for the periods between July 18, 1996 and February 18, 2002), "02-LEN^t" (for the periods between February 19, 2002 and June 29, 2008), and "SETTL^t" (for the periods after June 30, 2008).
NUM-RAIDS-OTH-MKT1$^t_{ij}$	Total number of EC cartel investigations on colluder j by time t in markets other than i.
NUM-RAIDS-OTH-MKT2$^t_{ij}$	Total number of EC cartel investigations on colluder j's co-conspirators in cartel i by time t in markets that are different from i.
APPL-OTH-MKT1$^t_{ij}$	A dichotomous indicator $= 1$ if by time t *colluder* j self-reports cartel $-i$ $(-i \neq i)$ in which one or more co-conspirators of j in cartel i also engaged in collusion; $= 0$ otherwise.
APPL-OTH-MKT2$^t_{ij}$	A dichotomous indicator $= 1$ if by time t *colluder* $-j$ $(-j \neq j)$ self-reports cartel $-i'$ $(-i' \neq i)$ in which j is also a member; $= 0$ otherwise.
APPL-OTH-MKT3$^t_{ij}$	A dichotomous indicator $= 1$ if by time t *colluder* j self-reports cartel $-i''$ $(-i'' \neq i)$ in which none of j's co-conspirators in cartel i also engaged in collusion; $= 0$ otherwise.
APPL-OTH-MKT4$^t_{ij}$	A dichotomous indicator $= 1$ if by time t *colluder* $-j'$ $(-j' \neq j)$ self-reports cartel $-i'''$ $(-i''' \neq i)$ in which j is not a member; $= 0$ otherwise.
NUM-APPLS-OTH-MKT$^t_{ij}$	Total number of leniency applications filed by colluder j by time t in markets other than i.
NUM-APPLS-OTH-MKT2$^t_{ij}$	Total number of leniency applications filed by colluder j's co-conspirators in cartel i by time t in markets other than i.
DUR-OFFENSE$^t_{ij}$	$=$ number of weeks elapsed since j's joining of cartel i until time t if j has not ended its infringement in i by time t; $=$ duration (in weeks) of j's infringement in cartel i if by time t colluder j has ended its infringement in cartel i.
RECIDIVIST^t_j	A dichotomous indicator $= 1$ if by time t colluder j has been an addressee of an EC cartel decision; $= 0$ otherwise.
RINGLEADER$_{ij}$	A dichotomous indicator $= 1$ if colluder j has been identified by the EC as a ringleader in cartel i; $= 0$ otherwise.

(*continued overleaf*)

Table 1. (*Continued*)

	Definition
MARKET SCOPE$_i$	Categorical variable indicating the geographic scope of the cartelized market. The scopes are national, multinational (but less than EU-wide), EEA-wide or EU-wide, and worldwide.
PEAK-TROUGH^t	=1 if at time t the EU is in a peak-to-trough of a business cycle; =0 otherwise.
Δ GDP^t	Annual growth rate of the real domestic product at time t in the EU.
POS-SHOCK^t	Positive deviation of real annual EU GDP from trend line (using the Hodrick-Prescott filter).
NEG-SHOCK^t	Negative deviation of real annual EU GDP from trend line (using the Hodrick-Prescott filter).
INTEREST^t	Annual average (real) short-term interest rates in the Euro area, 3-month maturity.
NUM-EX-APPL$^s_{ij}$	The number of leniency applications in cartel i submitted by colluder j's co-conspirators prior to spell s.

Table 2. Descriptive Statistics of The Colluder-Cartel-Event Data Set

	Full Sample		*Application Sample*	
	Mean (Std. Dev.)	Median	Mean (Std. Dev.)	Median
DURATION (wk.)	339.03 (188.05)	313.93	314.41 (135.66)	317.86
UNDERTAKINGS	9.07 (5.02)	8	6.60 (4.58)	5
NUM-EX-APPLS	1.55 (1.98)	1	1.00 (1.16)	1
PRICE FIXING (1=yes)	0.94 (0.24)	1	0.95 (0.22)	1
MARKET ALLOC (1=yes)	0.60 (0.49)	1	0.85 (0.36)	1
BID RIGGING (1=yes)	0.18 (0.38)	0	0.30 (0.46)	0
RINGLEADER (1=yes)	0.05 (0.23)	0	0.06 (0.23)	0
	N	%	N	%
MARKET SCOPE				
National	116	25.33	30	22.39
Multinational	97	21.18	24	17.91
EU-wide or EEA-wide	224	48.91	68	50.75
Worldwide	21	4.59	12	8.96
Number of Observations	404		114	
Number of Cartels	69		53	
Number of Colluders	314		76	

Source.– Authors' calculations based on decisions and information on 104 European cartels by the European Commission for the period 1996-2014. The sample excludes cartels in which a undertaking (or some firms in the undertaking) has been investigated by the US Department of Justice for collusion in the United States.

Note.– An "observation" corresponds to a Colluder-Cartel-Spell combination.

Table 3. Descriptive Statistics of The Colluder-Cartel-Spell-Period Data Set by Time of Dawn Raids in Separate Markets

	Pre-Dawn Raids in A Separate Market			*Post-Dawn Raids in A Separate Market*			*All*		
	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.
APPLY$^t_{ij\dagger}$ (1=yes)	0.001	(0.033)	31,932	0.003	(0.054)	26,962	0.002	(0.044)	58,894
RAID-OTH-MKT1$^t_{ij\dagger}$ (1=yes)	0.000	(0.000)	31,932	0.454	(0.498)	26,962	0.208	(0.406)	58,894
RAID-OTH-MKT2$^t_{ij\dagger}$ (1=yes)	0.000	(0.000)	31,932	0.164	(0.371)	26,962	0.075	(0.264)	58,894
RAID-OTH-MKT3$^t_{ij\dagger}$ (1=yes)	0.000	(0.000)	31,932	0.882	(0.322)	26,962	0.404	(0.491)	58,894
RAID$^t_{ij\dagger}$ (1=yes)	0.639	(0.480)	31,932	0.820	(0.384)	26,962	0.722	(0.448)	58,894
NUM-APPS-OTH-MKTS2$^t_{ij\dagger}$	0.002	(0.044)	31,932	0.127	(0.543)	26,962	0.059	(0.374)	58,894
NUM-APPS-OTH-MKTS2$^t_{ij\dagger}$	0.011	(0.104)	31,932	2.384	(3.334)	26,962	1.097	(2.548)	58,894
NUM-RAIDS-OTH-MKT1$^t_{ij\dagger}$	0.000	(0.000)	31,932	1.127	(1.364)	26,962	0.516	(1.081)	58,894
NUM-RAIDS-OTH-MKT2$^t_{ij\dagger}$	0.000	(0.000)	31,932	4.824	(3.519)	26,962	2.208	(3.383)	58,894
APPL-OTH-MKT1$^t_{ij\dagger}$ (1=yes)	0.000	(0.008)	31,932	0.041	(0.199)	26,962	0.019	(0.136)	58,894
APPL-OTH-MKT2$^t_{ij\dagger}$ (1=yes)	0.002	(0.043)	31,932	0.052	(0.221)	26,962	0.025	(0.155)	58,894
APPL-OTH-MKT3$^t_{ij\dagger}$ (1=yes)	0.001	(0.024)	31,932	0.165	(0.371)	26,962	0.076	(0.265)	58,894
APPL-OTH-MKT4$^t_{ij\dagger}$ (1=yes)	0.010	(0.101)	31,932	0.521	(0.500)	26,962	0.244	(0.430)	58,894
RECIDIVIST$^t_{ij\dagger}$ (1=yes)	0.000	(0.000)	31,932	0.288	(0.453)	26,962	0.132	(0.338)	58,894
DUR-OFFENSE$^t_{ij\dagger}$ (wk.)	288.243	(251.316)	31,932	312.396	(259.208)	26,962	299.300	(255.241)	58,894
RINGLEADER$_{ij}$ (1=yes)	0.024	(0.152)	31,932	0.016	(0.127)	26,962	0.020	(0.141)	58,894
NUM-EX-APPS$^t_{ij\dagger\dagger}$	1.122	(2.148)	31,932	2.042	(2.285)	26,962	1.543	(2.259)	58,894
UNDERTAKINGS$_i$	7.574	(4.463)	31,932	10.919	(5.451)	26,962	9.105	(5.213)	58,894
PRICE-FIX$_i$ (1=yes)	0.883	(0.322)	31,932	0.944	(0.230)	26,962	0.911	(0.285)	58,894
MARKET-ALLOC$_i$ (1=yes)	0.516	(0.500)	31,932	0.654	(0.476)	26,962	0.579	(0.494)	58,894
BID-RIGGING$_i$ (1=yes)	0.240	(0.427)	31,932	0.044	(0.206)	26,962	0.150	(0.358)	58,894
INTEREST$^t{}_\dagger$	3.322	(1.193)	31,373	3.231	(1.106)	26,962	3.280	(1.155)	58,335
Δ GDP$^t{}_\dagger$ (%)	2.146	(1.551)	31,373	2.019	(1.741)	26,962	2.087	(1.643)	58,335
PEAK-TROUGH$^t{}_\dagger$ (1=yes)	0.428	(0.495)	31,932	0.344	(0.475)	26,962	0.390	(0.488)	58,894
POS-SHOCK$^t{}_\dagger$ (\$tn)	47,445.240	(77, 795.440)	31,373	62,864.540	(99, 549.180)	26,962	54,571.920	(88, 849.240)	58,335
NEG-SHOCK$^t{}_\dagger$ (\$tn)	41,066.680	(67, 989.650)	31,373	50,699.280	(78, 821.500)	26,962	45,518.790	(73, 352.290)	58,335

Table 4. Descriptive Statistics of The Colluder-Cartel-Spell-Period Data Set by Policy Regime (Pre-Detection Sample)

	96-Leniency			*02-Leniency*			*Settlement*			*All*		
	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.
APPLY$^t_{ij\dagger}$ (1=yes)	0.001	(0.031)	10,304	0.005	(0.069)	5,612	0.009	(0.093)	457	0.003	(0.050)	16,373
RAID-OTH-MKT1$^t_{ij\dagger}$ (1=yes)	0.075	(0.264)	10,304	0.206	(0.404)	5,612	0.000	(0.000)	457	0.118	(0.322)	16,373
RAID-OTH-MKT2$^t_{ij\dagger}$ (1=yes)	0.002	(0.043)	10,304	0.061	(0.240)	5,612	0.000	(0.000)	457	0.022	(0.147)	16,373
RAID-OTH-MKT3$^t_{ij\dagger}$ (1=yes)	0.178	(0.382)	10,304	0.275	(0.447)	5,612	0.000	(0.000)	457	0.206	(0.404)	16,373
RAID$^t_{ij\dagger}$ (1=yes)	0.000	(0.000)	10,304	0.000	(0.000)	5,612	0.000	(0.000)	457	0.000	(0.000)	16,373
NUM-APPS-OTH-MKTS2$^t_{ij\dagger}$	0.003	(0.078)	10,304	0.177	(0.925)	5,612	0.000	(0.000)	457	0.063	(0.551)	16,373
NUM-APPS-OTH-MKTS2$^t_{ij\dagger}$	0.218	(1.124)	10,304	0.508	(1.664)	5,612	0.000	(0.000)	457	0.312	(1.329)	16,373
NUM-RAIDS-OTH-MKT1$^t_{ij\dagger}$	0.180	(0.675)	10,304	0.614	(1.510)	5,612	0.000	(0.000)	457	0.324	(1.055)	16,373
NUM-RAIDS-OTH-MKT2$^t_{ij\dagger}$	0.503	(1.482)	10,304	1.034	(2.172)	5,612	0.000	(0.000)	457	0.671	(1.753)	16,373
APPL-OTH-MKT1$^t_{ij\dagger}$ (1=yes)	0.000	(0.014)	10,304	0.005	(0.069)	5,612	0.000	(0.000)	457	0.002	(0.042)	16,373
APPL-OTH-MKT2$^t_{ij\dagger}$ (1=yes)	0.002	(0.039)	10,304	0.054	(0.226)	5,612	0.000	(0.000)	457	0.019	(0.138)	16,373
APPL-OTH-MKT3$^t_{ij\dagger}$ (1=yes)	0.002	(0.043)	10,304	0.032	(0.175)	5,612	0.000	(0.000)	457	0.012	(0.109)	16,373
APPL-OTH-MKT4$^t_{ij\dagger}$ (1=yes)	0.054	(0.227)	10,304	0.123	(0.329)	5,612	0.000	(0.000)	457	0.077	(0.266)	16,373
RECIDIVIST$^t_{ij}$ (1=yes)	0.052	(0.222)	10,304	0.180	(0.384)	5,612	0.000	(0.000)	457	0.094	(0.293)	16,373
DUR-OFFENSE$^t_{ij\dagger}$ (wk.)	325.491	(311.567)	10,304	328.361	(329.405)	5,612	197.800	(133.609)	457	322.911	(315.001)	16,373
RINGLEADER$_{ij}$ (1=yes)	0.000	(0.000)	10,304	0.002	(0.040)	5,612	0.000	(0.000)	457	0.001	(0.023)	16,373
NUM-EX-APPS$^t_{ij\ddagger}$	0.068	(0.256)	10,304	0.429	(1.372)	5,612	0.182	(0.386)	457	0.195	(0.848)	16,373
UNDERTAKINGS$_i$	6.678	(4.925)	10,304	6.007	(4.058)	5,612	3.744	(0.988)	457	6.366	(4.608)	16,373
PRICE-FIX$_i$ (1=yes)	0.902	(0.297)	10,304	0.870	(0.336)	5,612	0.860	(0.347)	457	0.890	(0.313)	16,373
MARKET-ALLOC$_i$ (1=yes)	0.818	(0.386)	10,304	0.656	(0.475)	5,612	0.683	(0.466)	457	0.759	(0.428)	16,373
BID-RIGGING$_i$ (1=yes)	0.214	(0.410)	10,304	0.254	(0.435)	5,612	0.683	(0.466)	457	0.241	(0.428)	16,373
INTEREST$^t{}_\dagger$	4.037	(0.599)	10,304	2.781	(0.731)	5,612	1.949	(1.501)	457	3.548	(0.946)	16,373
Δ GDP$^t{}_\dagger$ (%)	2.868	(0.689)	10,304	2.013	(0.764)	5,612	-0.395	(2.525)	457	2.484	(1.038)	16,373
PEAK-TROUGH$^t{}_\dagger$ (1=yes)	0.481	(0.500)	10,304	0.359	(0.480)	5,612	0.635	(0.482)	457	0.444	(0.497)	16,373
POS-SHOCK$^t{}_\dagger$ (\$tn)	36,361.59	(49, 935.97)	10,304	41,476.23	(89, 487.14)	5,612	71,661.05	(97, 060.75)	457	39,099.96	(67, 914.35)	16,373
NEG-SHOCK$^t{}_\dagger$ (\$tn)	14,281.01	(15, 158.77)	10,304	61,445.73	(44, 532.16)	5,612	118,745.50	(143, 791.90)	457	33,362.96	(45, 859.90)	16,373

Table 5. Descriptive Statistics of The Colluder-Cartel-Spell-Period Data Set by Policy Regime (Post-Detection Sample)

	96-Leniency			*02-Leniency*			*Settlement*			*All*		
	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.	Mean	(Std. Dev.)	Obs.
APPLY$^{t}_{ij\dagger}$ (1=yes)	0.001	(0.029)	15,356	0.002	(0.049)	19,295	0.002	(0.042)	7,870	0.002	(0.041)	42,521
RAID-OTH-MKT1$^{t}_{ij\dagger}$ (1=yes)	0.018	(0.133)	15,356	0.088	(0.283)	19,295	0.068	(0.252)	7,870	0.059	(0.235)	42,521
RAID-OTH-MKT2$^{t}_{ij\dagger}$ (1=yes)	0.363	(0.481)	15,356	0.255	(0.436)	19,295	0.175	(0.380)	7,870	0.279	(0.449)	42,521
RAID-OTH-MKT3$^{t}_{ij\dagger}$ (1=yes)	0.419	(0.493)	15,356	0.556	(0.497)	19,295	0.415	(0.493)	7,870	0.480	(0.500)	42,521
RAID$^{t}_{ij\dagger}$ (1=yes)	1.000	(0.000)	15,356	1.000	(0.000)	19,295	1.000	(0.000)	7,870	1.000	(0.000)	42,521
NUM-APPS-OTH-MKTS2$^{t}_{ij\dagger}$	0.015	(0.158)	15,356	0.092	(0.332)	19,295	0.058	(0.298)	7,870	0.058	(0.277)	42,521
NUM-APPS-OTH-MKTS2$^{t}_{ij\dagger}$	0.042	(0.291)	15,356	2.290	(3.258)	19,295	1.867	(3.343)	7,870	1.400	(2.825)	42,521
NUM-RAIDS-OTH-MKT1$^{t}_{ij\dagger}$	0.908	(1.365)	15,356	0.446	(0.861)	19,295	0.323	(0.737)	7,870	0.590	(1.081)	42,521
NUM-RAIDS-OTH-MKT2$^{t}_{ij\dagger}$	2.262	(2.842)	15,356	3.443	(4.091)	19,295	2.275	(3.715)	7,870	2.800	(3.662)	42,521
APPL-OTH-MKT1$^{t}_{ij\dagger}$ (1=yes)	0.001	(0.035)	15,356	0.049	(0.216)	19,295	0.016	(0.124)	7,870	0.026	(0.158)	42,521
APPL-OTH-MKT2$^{t}_{ij\dagger}$ (1=yes)	0.010	(0.099)	15,356	0.041	(0.198)	19,295	0.025	(0.155)	7,870	0.027	(0.161)	42,521
APPL-OTH-MKT3$^{t}_{ij\dagger}$ (1=yes)	0.005	(0.074)	15,356	0.160	(0.366)	19,295	0.140	(0.347)	7,870	0.100	(0.300)	42,521
APPL-OTH-MKT4$^{t}_{ij\dagger}$ (1=yes)	0.020	(0.142)	15,356	0.515	(0.500)	19,295	0.364	(0.481)	7,870	0.309	(0.462)	42,521
RECIDIVIST$^{t}_{ij}$ (1=yes)	0.303	(0.460)	15,356	0.051	(0.219)	19,295	0.074	(0.261)	7,870	0.146	(0.353)	42,521
DUR-OFFENSE$^{t}_{ij\dagger}$ (wk.)	183.540	(137.171)	15,356	358.716	(262.841)	19,295	330.382	(195.175)	7,870	290.209	(227.444)	42,521
RINGLEADER$_{ij}$ (1=yes)	0.049	(0.216)	15,356	0.022	(0.148)	19,295	0.000	(0.000)	7,870	0.028	(0.165)	42,521
NUM-EX-APPS$^{t}_{ij\ddagger}$	0.347	(0.699)	15,356	2.927	(2.502)	19,295	3.290	(2.462)	7,870	2.062	(2.412)	42,521
UNDERTAKINGS$_{i}$	10.830	(4.736)	15,356	10.161	(4.958)	19,295	8.850	(5.566)	7,870	10.160	(5.047)	42,521
PRICE-FIX$_{i}$ (1=yes)	0.976	(0.152)	15,356	0.864	(0.343)	19,295	0.940	(0.238)	7,870	0.919	(0.273)	42,521
MARKET-ALLOC$_{i}$ (1=yes)	0.421	(0.494)	15,356	0.554	(0.497)	19,295	0.576	(0.494)	7,870	0.510	(0.500)	42,521
BID-RIGGING$_{i}$ (1=yes)	0.070	(0.255)	15,356	0.134	(0.341)	19,295	0.159	(0.366)	7,870	0.116	(0.320)	42,521
INTEREST$^{t}{}_{\dagger}$	4.028	(0.549)	15,356	3.029	(0.894)	19,295	1.773	(1.454)	7,311	3.176	(1.210)	41,962
Δ GDP$^{t}_{i\dagger}$ (%)	2.837	(0.627)	15,356	2.237	(0.854)	19,295	-0.771	(2.571)	7,311	1.933	(1.802)	41,962
PEAK-TROUGH$^{t}{}_{\dagger}$ (1=yes)	0.477	(0.499)	15,356	0.211	(0.408)	19,295	0.545	(0.498)	7,870	0.369	(0.483)	42,521
POS-SHOCK$^{t}{}_{\dagger}$ ($tn)	30,862.11	(46, 842.89)	15,356	85,427.00	(115, 029.90)	19,295	57,589.52	(94, 303.73)	7,311	60,608.87	(95, 105.21)	41,962
NEG-SHOCK$^{t}{}_{\dagger}$ ($tn)	15,165.39	(13, 970.07)	15,356	45,399.01	(46, 066.60)	19,295	136,812.10	(147, 015.50)	7,311	50,261.84	(81, 112.84)	41,962

Table 6. Discrete-Time Hazard Regression Results(All Periods)

	$APPLY_{ij}^{t}$					
	(1)	(2)	(3)	(4)	(5)	(6)
Effects of Investigations						
RAID-OTH-MKT1$_{ij}^{t}$ †	0.642*	−0.812	0.282	0.780**	2.599***	2.842**
	(0.366)	(0.563)	(0.365)	(0.383)	(0.563)	(1.388)
RAID-OTH-MKT2$_{ij}^{t}$ †	0.647*	0.189	0.870**	0.645*	1.875**	4.071***
	(0.386)	(0.412)	(0.368)	(0.390)	(0.873)	(1.248)
RAID-OTH-MKT3$_{ij}^{t}$ †	0.433	0.751**	0.729**	0.538*	1.314**	1.313**
	(0.303)	(0.312)	(0.307)	(0.319)	(0.584)	(0.609)
RAID$_{ij}^{t}$ †	−0.180	−0.435	0.304	−0.210	−0.538**	−0.334
	(0.272)	(0.267)	(0.327)	(0.300)	(0.267)	(0.404)
Effects of Leniency Policy Changes						
96-LEN^{t} (spell periods before Feb 18, 02)	−1.552***	−0.839*	−1.315***	−1.047*	−0.902**	−0.627
	(0.402)	(0.445)	(0.426)	(0.604)	(0.412)	(0.541)
SETTL^{t} (spell periods after July 1, 08)	0.378	0.606*	0.118	−0.498	0.789**	0.153
	(0.291)	(0.311)	(0.344)	(0.668)	(0.312)	(0.573)
Control Variables						
APPL-OTH-MKT1$_{ij}^{t}$ †		2.926***				−0.378
		(0.779)				(1.625)
APPL-OTH-MKT2$_{ij}^{t}$ †		0.458				−3.025*
		(0.762)				(1.684)
APPL-OTH-MKT3$_{ij}^{t}$ †		0.619				0.058
		(0.530)				(0.598)
APPL-OTH-MKT4$_{ij}^{t}$ †		−0.059				−0.359
		(0.385)				(0.549)
Log(UNDERTAKINGS$_i$)			−0.527**			−0.276
			(0.217)			(0.222)
PRICE-FIX$_i$			1.394**			1.827**
			(0.601)			(0.822)
MARKET-ALLOC$_i$			1.031***			0.206
			(0.338)			(0.536)
BID-RIGGING$_i$			0.530			0.633
			(0.332)			(0.467)
MARKET SCOPE$_i$ (ref is national cartels)			No			No
RINGLEADER$_{ij}$			0.410			0.146
			(0.761)			(0.738)
Log(INTEREST$_{i}^{t}$)†				−1.174*		−0.767
				(0.644)		(0.517)
Log(Δ GDP$_{i}^{t}$+5.235)†				0.379		0.618
				(0.497)		(0.539)
PEAK-TROUGH$_{i}^{t}$ (1=yes)				0.285		0.466
				(0.298)		(0.327)
Log(POS-SHOCK$_{i}^{t}$+1)†				0.152		0.065
				(0.246)		(0.215)
Log(NEG-SHOCK$_{i}^{t}$+1)†				0.068		0.016
				(0.244)		(0.219)

(*Continued overleaf*)

Table 6. (*Continued*)

	APPLY_{ij}^{t}					
	(1)	(2)	(3)	(4)	(5)	(6)
Log(NUM-APPS-OTH-MKTS1$_{ij}^{t}$ +1)$_\dagger$					3.659***	5.648***
					(0.702)	(2.198)
Log(NUM-APPS-OTH-MKTS2$_{ij}^{t}$ +1)$_\dagger$					0.544	0.354
					(0.366)	(0.578)
Log(NUM-RAIDS-OTH-MKT1$_{ij}^{t}$+1)$_\dagger$					−3.685***	−4.983***
					(0.890)	(1.754)
Log(NUM-RAIDS-OTH-MKT2$_{ij}^{t}$+1)$_\dagger$					−0.696*	−0.274
					(0.418)	(0.503)
RECIDIVIST$_{ij}^{t}$ (1=yes)$_\dagger$					0.394	0.188
					(0.868)	(0.693)
Log(DUR-OFFENSE$_{ij}^{t}$)$_\dagger$					0.400***	0.434***
					(0.128)	(0.135)
Log(NUM-EX-APPS$_{ij}^{t}$+1)$_\ddagger$	−0.764***	−0.570**	−0.864***	−0.865***	−0.978***	−0.925***
	(0.180)	(0.237)	(0.220)	(0.191)	(0.267)	(0.331)
Duration-Interval-Specific-Dummy$_\dagger$						
[0, 21] weeks	−4.520***	−4.893***	−6.007***	−5.359	−6.685***	−9.723***
	(0.312)	(0.349)	(0.779)	(3.315)	(0.595)	(3.372)
[22, 43]	−6.262***	−6.521***	−7.749***	−6.977**	−8.413***	−11.227***
	(0.517)	(0.536)	(0.815)	(3.329)	(0.720)	(3.414)
[44, 68]	−5.848***	−6.082***	−7.296***	−6.640**	−7.953***	−10.758***
	(0.339)	(0.354)	(0.772)	(3.289)	(0.666)	(3.412)
[69, 94]	−6.726***	−7.003***	−8.161***	−7.569**	−8.773***	−11.698***
	(0.583)	(0.557)	(0.893)	(3.358)	(0.799)	(3.446)
[95, 108]	−6.471***	−6.886***	−7.887***	−7.238**	−8.680***	−11.561***
	(0.432)	(0.431)	(0.774)	(3.321)	(0.677)	(3.442)
[109, 171]	−6.888***	−7.301***	−8.251***	−8.022**	−9.143***	−12.299***
	(0.576)	(0.602)	(0.848)	(3.452)	(0.718)	(3.468)
[172, 241]	−5.871***	−6.147***	−7.262***	−6.759**	−8.168***	−11.084***
	(0.360)	(0.340)	(0.771)	(3.283)	(0.639)	(3.399)
$\geq$ 242 weeks	−5.621***	−5.727***	−7.098***	−6.416*	−8.071***	−10.868***
	(0.279)	(0.321)	(0.758)	(3.294)	(0.689)	(3.458)
Number of Observations	58,894	58,894	58,894	58,335	58,894	58,335
Number of Spells	404	404	404	404	404	404
Number of Cartels	69	69	69	69	69	69
Number of Colluders	314	314	314	314	314	314
Log-pseudo likelihood	-753.359	-709.048	-728.592	-721.540	-697.219	-647.539

Note.– Standard errors are robust to heteroskedasticity, clustered by colluder and are shown in parentheses. The table reports the discrete-time hazard regression results. The dependent variable APPLY_{ij}^{t} is a dichotomous indicator of whether during the period (t-7 days, t] colluder j applied for leniency in cartel i. † indicates a time-varying variable; ‡ indicates a variable that relates to the previous leniency application episode in the spell's market.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 7. Discrete-Time Hazard Regression Results
(Isolating spell periods before and after investigation initiation)

	$APPLY^t_{ij}$	
	(7)	(8)
Effects of Investigations		
$RAID\text{-}OTH\text{-}MKT1^t_{ij}{}_\dagger$	2.519*	3.539***
	(1.464)	(1.286)
$RAID\text{-}OTH\text{-}MKT2^t_{ij}{}_\dagger$	2.695*	6.188***
	(1.518)	(1.656)
$RAID\text{-}OTH\text{-}MKT3^t_{ij}{}_\dagger$	1.153	1.519*
	(1.746)	(0.893)
Effects of Leniency Policy Changes		
$96\text{-}LEN^t$ (spell periods before Feb 18, 2002)	−1.770**	−0.650
	(0.737)	(0.919)
$SETTL^t$ (spell periods after July 1, 2008)	1.735**	−0.660
	(0.741)	(0.906)
Control Variables		
$APPL\text{-}OTH\text{-}MKT1^t_{ij}{}_\dagger$	7.317***	−3.757**
	(1.794)	(1.690)
$APPL\text{-}OTH\text{-}MKT2^t_{ij}{}_\dagger$	6.601***	−5.383***
	(1.957)	(1.742)
$APPL\text{-}OTH\text{-}MKT3^t_{ij}{}_\dagger$	0.014	1.918**
	(1.389)	(0.926)
$APPL\text{-}OTH\text{-}MKT4^t_{ij}{}_\dagger$	−0.665	0.436
	(1.081)	(0.756)
$\text{Log}(UNDERTAKINGS_i)$	0.189	−0.783*
	(0.639)	(0.474)
$PRICE\text{-}FIX_i$	1.552	2.598*
	(1.420)	(1.334)
$MARKET\text{-}ALLOC_i$	−1.267	0.744
	(1.175)	(0.740)
$BID\text{-}RIGGING_i$	0.497	1.308**
	(1.320)	(0.602)
$MARKET\ SCOPE_i$ (ref is national cartels)	No	Yes
$RINGLEADER_{ij}$	-	0.482
	-	(0.783)
$\text{Log}(INTEREST^t_i)_\dagger$	−0.768	−0.704
	(1.470)	(0.797)
$\text{Log}(\Delta\ GDP^t_i{+}5.235)_\dagger$	−0.893	1.389
	(1.297)	(0.872)
$PEAK\text{-}TROUGH^t_i$ (1=yes)$_\dagger$	−0.102	0.689
	(0.535)	(0.500)
$\text{Log}(POS\text{-}SHOCK^t_i{+}1)_\dagger$	−0.622	0.443
	(0.400)	(0.287)
$\text{Log}(NEG\text{-}SHOCK^t_i{+}1)_\dagger$	−0.891**	0.472
	(0.430)	(0.291)

(*Continued overleaf*)

Table 7. (*Continued*)

	APPLY_{ij}^{t}	
	(7)	(8)
Log(NUM-APPS-OTHER-MKTS1$_{ij}^{t}$ +1)$_{\dagger}$	−2.287	9.695***
	(1.710)	(1.955)
Log(NUM-APPS-OTH-MKTS2$_{ij}^{t}$ +1)$_{\dagger}$	3.309***	−1.760
	(1.184)	(1.182)
Log(NUM-RAIDS-OTH-MKTS1$_{ij}^{t}$+1)$_{\dagger}$	−1.356	−8.163***
	(1.208)	(2.241)
Log(NUM-RAIDS-OTH-MKTS2$_{ij}^{t}$+1)$_{\dagger}$	−1.582	−0.137
	(1.502)	(0.662)
RECIDIVIST$_{ij}^{t}$ (1=yes)$_{\dagger}$	−1.103	−0.752
	(1.406)	(1.226)
Log(DUR-OFFENSE$_{ij}^{t}$)$_{\dagger}$	1.037***	0.894***
	(0.388)	(0.325)
Log(NUM-EX-APPS$_{ij}^{t}$+1)$_{\ddagger}$	−3.751***	−1.244**
	(1.012)	(0.511)
Duration-Interval-Specific-Dummy$_{\dagger}$		
[0, 21] weeks	1.326	−18.761***
	(6.230)	(4.410)
[22, 43]	−0.752	−20.182***
	(6.167)	(4.405)
[44, 68]	−1.034	−19.652***
	(6.297)	(4.500)
[69, 94]	−2.242	−20.661***
	(6.281)	(4.364)
[95, 108]	−0.347	−20.700***
	(6.494)	(4.410)
[109, 171]	−1.841	−21.972***
	(6.261)	(4.559)
[172, 241]	−0.750	−20.489***
	(6.480)	(4.408)
≥ 242 weeks	−1.059	−19.975***
	(6.332)	(4.528)
Number of Observations	16,364	41,962
Number of Spells	404	347
Number of Cartels	69	36
Number of Colluders	314	279
Log-pseudo likelihood	-187.356	-375.939

Note.– Standard errors are robust to heteroskedasticity, clustered by colluder and are shown in parentheses. The table reports the cartel-level discrete-time hazard regression results. The dependent variable APPLY_{ij}^{t} is a dichotomous indicator of whether during the period (t-7 days, t] colluder j applied for leniency in cartel i. † indicates a time-varying variable; ‡ indicates a variable that relates to the previous leniency application episode in the spell's market.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

Table 8. Discrete-Time Hazard Regression Results(All Periods)

	APPLY^t_{ij}		
	(9)	(10)	(11)
Effects of Investigations			
$\text{RAID-OTH-MKT1}^t_{ij\,\dagger}$	2.971*	0.363	
	(1.816)	(0.796)	
$\text{RAID-OTH-MKT2}^t_{ij\,\dagger}$	3.528***	1.663***	
	(1.353)	(0.575)	
$\text{RAID-OTH-MKT3}^t_{ij\,\dagger}$	1.219	0.846**	
	(0.937)	(0.406)	
$\text{RAID-OTH-MKT4}^t_{ij\,\dagger}$			2.839**
			(1.393)
$\text{RAID-OTH-MKT5}^t_{ij\,\dagger}$			4.062***
			(1.256)
$\text{RAID-OTH-MKT6}^t_{ij\,\dagger}$			1.401**
			(0.598)
$\text{RAID}^t_{ij\,\dagger}$	−0.380	0.512*	−0.333
	(0.400)	(0.271)	(0.405)
Interaction			
$\text{RAID-OTH-MKT1}^t_{ij} \times \text{Log}(\text{TIMES}^t_{ij})_\dagger$	0.033		
	(0.226)		
$\text{RAID-OTH-MKT2}^t_{ij} \times \text{Log}(\text{TIMES}^t_{ij})_\dagger$	0.174		
	(0.190)		
$\text{RAID-OTH-MKT3}^t_{ij} \times \text{Log}(\text{TIMES}^t_{ij})_\dagger$	0.038		
	(0.166)		
Effects of Leniency Policy Changes			
96-LEN^t (spell periods before Feb 18, 02)	−0.622	−0.790**	−0.633
	(0.558)	(0.339)	(0.538)
SETTL^t (spell periods after July 1, 08)	0.109	−0.033	0.142
	(0.594)	(0.537)	(0.575)
Control Variables			
$\text{APPL-OTH-MKT1}^t_{ij\,\dagger}$	−0.590	0.233	−0.350
	(1.716)	(0.885)	(1.628)
$\text{APPL-OTH-MKT2}^t_{ij\,\dagger}$	−0.004	0.421	0.041
	(0.645)	(0.544)	(0.598)
$\text{APPL-OTH-MKT3}^t_{ij\,\dagger}$	−3.268*	−2.763***	−2.990*
	(1.781)	(0.950)	(1.681)
$\text{APPL-OTH-MKT4}^t_{ij\,\dagger}$	−0.438	0.360	−0.381
	(0.566)	(0.482)	(0.546)
$\text{Log}(\text{FIRMS}_i)$	−0.287	−0.428**	−0.267
	(0.227)	(0.174)	(0.221)
PRICE-FIX_i	1.767**	1.412**	1.861**
	(0.810)	(0.624)	(0.823)
MARKET-ALLOC_i	0.172	0.558*	0.219
	(0.544)	(0.324)	(0.537)
BID-RIGGING_i	0.684	0.051	0.634
	(0.482)	(0.319)	(0.466)
MARKET SCOPE_i (ref is national cartels)	No	No	No

(*Continued overleaf*)

Table 8. (*Continued*)

	$APPLY_{ij}^{t}$		
	(9)	(10)	(11)
Duration-Interval-Specific-Dummy$_{\dagger}$			
Log($INTEREST_{i}^{t}$)$_{\dagger}$	−0.786	−0.731*	−0.774
	(0.526)	(0.420)	(0.516)
Log(Δ GDP_{i}^{t}+5.235)$_{\dagger}$	0.600	0.346	0.629
	(0.538)	(0.400)	(0.538)
PEAK-TROUGH$_{i}^{t}$ (1=yes)	0.456	0.252	0.476
	(0.329)	(0.203)	(0.329)
Log(POS-SHOCK$_{i}^{t}$+1)$_{\dagger}$	0.061	−0.329**	0.076
	(0.217)	(0.146)	(0.217)
Log(NEG-SHOCK$_{i}^{t}$+1)$_{\dagger}$	0.010	−0.377**	0.029
	(0.222)	(0.152)	(0.221)
Log(NUM-APPS-OTH-MKTS1$_{ij}^{t}$ +1)$_{\dagger}$	6.026***	4.483***	5.614**
	(2.331)	(1.270)	(2.210)
Log(NUM-APPS-OTH-MKTS2$_{ij}^{t}$ +1)$_{\dagger}$	0.383	−0.086	0.365
	(0.580)	(0.468)	(0.574)
Log(NUM-RAIDS-OTH-MKTS1$_{ij}^{t}$+1)$_{\dagger}$	−5.285***	−2.443**	−4.979***
	(1.853)	(0.976)	(1.768)
Log(NUM-RAIDS-OTH-MKTS2$_{ij}^{t}$+1)$_{\dagger}$	−0.290	−0.141	−0.318
	(0.509)	(0.373)	(0.496)
RECIDIVIST$_{ij}^{t}$ (1=yes)$_{\dagger}$	0.164	0.376	0.190
	(0.716)	(0.476)	(0.694)
Log(DUR-OFFENSE$_{ij}^{t}$)$_{\dagger}$	0.438***	0.432***	0.425***
	(0.139)	(0.091)	(0.134)
Log(NUM-EX-APPS$_{ij}^{t}$+1)$_{\ddagger}$	−0.896***	−1.177***	−0.934***
	(0.335)	(0.226)	(0.332)
Duration-Interval-Specific-Dummy$_{\dagger}$			
[0, 21] weeks	−9.409***	−4.334*	−9.890***
	(3.376)	(2.229)	(3.399)
[22, 43]	−10.988***	−5.654**	−11.390***
	(3.398)	(2.213)	(3.440)
[44, 68]	−10.553***	−5.736***	−10.915***
	(3.391)	(2.238)	(3.435)
[69, 94]	−11.515***	−6.243***	−11.853***
	(3.417)	(2.229)	(3.470)
[95, 108]	−11.408***	−6.046***	−11.718***
	(3.417)	(2.280)	(3.467)
[109, 171]	−12.164***	−5.903***	−12.458***
	(3.437)	(2.283)	(3.493)
[172, 241]	−10.960***	−5.821***	−11.246***
	(3.376)	(2.238)	(3.424)
$\geq$ 242 weeks	−10.824***	−5.651*	−11.016***
	(3.427)	(2.261)	(3.482)

(*Continued overleaf*)

Table 8. (*Continued*)

	APPLY_{ij}^{t}		
	(9)	(10)	(11)
Number of Observations	58,335	81,712	58,335
Number of Spells	404	570	404
Number of Cartels	69	113	69
Number of Colluders	314	418	314
Log-pseudo likelihood	-646.805	-1,261.342	-646.912

Note.– Standard errors are robust to heteroskedasticity, clustered by colluder and are shown in parentheses. The table reports the discrete-time hazard regression results. The dependent variable APPLY_{ij}^{t} is a dichotomous indicator of whether during the period (t-7 days, t] colluder j applied for leniency in cartel i. † indicates a time-varying variable; ‡ indicates a variable that relates to the previous leniency application episode in the spell's market.

*** Significant at the 1 percent level.

** Significant at the 5 percent level.

* Significant at the 10 percent level.

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