"Cartel destabilization effect of leniency programs"

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Abstract

This paper investigates the theoretically and empirically unsettled question of the effect of the leniency programs on cartel duration, cartel fines and the length of the investigation. The fact that leniency programs were implemented in two different jurisdictions (EU and Spain) at different moments of time, and the exogeneity of the date of introduction, allow us to identify and quantify the effect of the programs on the outcomes using difference-in-difference program evaluation techniques. We empirically show that leniency programs destabilize existing cartels in the short run as expected from theory and previous empirical papers, and then dissuade the creation of new cartels in the long run. Deterrence effects dominate empirically in the long run, although theoretically they might not dominate, and previous empirical findings were inconclusive. Fines per firm increase substantially after the introduction of the leniency policy, despite whistleblowing firms are partially or totally exempted from fines. The duration of the investigation increases with the introduction of the leniency programs. Leniency programs have sharp and clear short-run cartel destabilization and long-run cartel dissuasion effects.

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1. Introduction

Cartels are considered one of the most harmful anti-competitive practices. The very secretive nature of cartels makes their detection and investigation very difficult. The competition authorities use different instruments to combat these practices, with leniency programs standing out as effective tools. Basically, these programs involve rewarding those firms that participate or have participated in cartel agreements for disclosing their cartels to the competition authorities and contributing to their dismantling. This reward, in general, translates into a reduction or even total exemption from the fines that would otherwise have been imposed on those firms had they not cooperated with the authorities.

The success of these programs to uncover cartels, as well as their potential deterrent effects against the creation of new ones, has promoted their rapid establishment and implementation around the world (Borrell, Jiménez and García, 2014). After the introduction of leniency programs, a clear surge in the number of detected cartels is usually observed in most jurisdictions. Although this increase is also followed by a gradual decline in the detection rate (see, for instance, Miller, 2009; Ordóñez-de-Haro et al., 2018).

The academic literature on leniency programs has been interested in explaining the keys to the leniency programs' success and their potential drawbacks. In fact, there is a wide economic literature on the mechanism that underlies the programs' functioning and the role they play in different fields, including theoretical, empirical, and experimental approaches.[6]

According to the seminal theoretical studies by Motta and Polo (2003) and Spagnolo (2004), leniency programs have, in principle, destabilization effects in the fight against cartels. Many other theoretical contributions by Fees and Walzl (2004), Motchenkova (2004), Chen and Harrington (2007), Harrington and Chang (2009) and Sauvagnat (2015) also yield to the same general conclusion: leniency programs hinder collusion.[7]

Nevertheless, Spagnolo (2004) raises concerns that leniency programs may facilitate collusion if final expected fines turn smaller by applying into the program and obtaining amnesty. These concerns could be more acute where, as Harrington (2008) pointed out, the authorities focus their efforts and limited resources on leniency proceedings whilst reducing the resources available for their ex officio investigations or where, as Chen and Harrington (2007) show, leniency programs only facilitate the discovery of the less stable cartels while make the coordination of the more stable cartels easier.

Harrington and Chang (2009) build a dynamic game-theoretic model that endogenizes both cartel formation and dissolution. Their model provides important theoretical predictions that can be used to evaluate the effectiveness of different types of competition policies, including the leniency policy. More specifically, their model predicts that an antitrust innovation that increases the

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[6] Marvão and Spagnolo (2015, 2018) provide a comprehensive review of the literature in this research area.

[7] Aubert et al. (2006) notice that leniency programs would improve if they would offer not only fine reductions to leniency applicants but also positive rewards to firms and individual informants.

probability of detection and conviction leads the least stable cartels to break up immediately. Thus, the cartels that survive are those which tend to be more stable and therefore more long-lasting. Since this is the group from which discovered cartels are drawn, the average duration of discovered cartels increases in the short run, in response to a more aggressive detection and conviction policy. In the long run, the average duration of discovered cartels decreases because of the overall improvement in deterring these practices.

However, they also point out that the latter result may not apply for the leniency policy since, in the long run, the average duration of detected cartels can go up or down. This is because this policy has perverse effects that promote cartel formation that oppose its destabilizing effects.[8] Thus, an effective policy against cartels should make the latter effects dominate which might require the use of pro-active detection tools.

Experimental studies also find that leniency programs reduce cartel formation (see, among others, Apesteguia et al., 2007; Hinloopen and Soetevent, 2008; Bigoni et al., 2012; and Dijkstra et al., 2020). Some of these studies, however, also warn about the leniency programs' perverse effects on market prices, obtaining evidence that collusive prices turn to be higher, conditional on a cartel forming, when there is a leniency program (Apesteguia et al., 2007; Bigoni et al., 2012; and Dijkstra et al., 2020).

This paper is closely related to the empirical literature on the effects of leniency programs, particularly, to those academic contributions that try to identify and quantify how leniency programs specifically affect the duration and stability of cartels, as well as the fining policy against their members, throughout the period covered by the programs (see, among others, Brenner, 2009; Miller, 2009; De, 2010; Choi and Hahn, 2014; Zhou, 2015; Feinberg et al. 2016; and Jochem et al., 2020). This empirical literature provides mixed and inconclusive evidence on the destabilization and deterrent effects of the leniency program on cartels.

Unlike previous empirical work, we study the leniency program, exploiting the geographic and time differences of this exogenous policy. Our goal is not only to analyze the short run and long run impact of the policy using a difference-in-difference program evaluation approach, but also to take advantage of the explanatory power of considering two differentiated temporal and geographical scopes of the implementation of the leniency program.

More particularly, we examine the impact of leniency on a wide set of cartel cases sanctioned by the European Commission (EC) and the Spanish Competition Authority since 1969 and 1995, respectively, until 2018 inclusive. Leniency programs were introduced in two different moments of time: in 1996 in the EU (and revised later in 2002 and 2006) and in 2008 in Spain. The Spanish leniency program was inspired by the EU leniency program, so this program does not substantially differ from the EU program.

We compare the cartel cases partially treated by the program and those fully treated to the control group, respectively. This approach allows us to identify and quantify more accurately the impact of

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[8] Harrington and Chang (2015) provide an extension of the Harrington and Chang (2009) model by endogenizing non-leniency enforcement.

leniency programs on cartel duration, cartels' final fines, and duration of the investigation. The key identifying assumption in this analysis is that the exact moment at which leniency programs are introduced is largely exogenous as it depends on the political developments at the EU and Spanish level, respectively.

These differences in the timing of the policy adoption allow us to separate out the changes in the mean of cartel duration, cartel fines and investigation duration across jurisdiction (EU versus Spain) and across time (before versus after), and once these effects are controlled for, we estimate the impact of the differences-in-differences effect of the introduction of leniency programs.

Therefore, the contributions of this paper are several. First, we study the leniency program implemented in EU in 1996, together with its revisions in 2002 and 2006; and the one implemented in Spain in 2008. We exploit the geographic and time differences of this exogenous policy. Secondly, we allow for heterogeneous effects of the program in terms of short run and long run impact, distinguishing between the observations partially treated by the program (unexpected change in competition policy) and those fully treated (cartels born under the existence of the program). Finally, we carefully define our control group and our treatment group of interest with respect to those cases uncovered by leniency applications, those that benefited from the program (regardless of how they were discovered), and those that were affected by the policy even if they do not fall in any of the previous categories. In addition, we use program evaluation techniques (difference-in-difference estimator) since we always work with a treatment and a control group, where the latter is not only composed by the old cartel cases in that jurisdiction but also includes those cases of the other jurisdiction considered. We test the parallel trend assumptions that are key to identify causal treatment effects.

Our results show that leniency programs have a clear cut and sharp effect on cartel stability: cartel duration approximately doubles in the short run and halves in the long run. According to the theory (Harrington and Chang, 2009), the positive short run impact on cartel duration and the negative impact in the long run show that the policy was effective in terms of more aggressive detection and conviction, and results into fewer cartels forming due to the program. Leniency has a clear and sharp destabilization short-run, and a sharp and clear long run deterrence effect.

We are not able, however, to tackle the pending question of whether leniency promotes the stability of hard-core cartels which remain still undetected.

With respect to the effect of the leniency programs on cartels fines, we find a very substantial increase in the fines imposed on each cartel member on average, despite the partial or total fine exemption that whistleblowers get from the program. We also find weak evidence that the investigations lasted longer with the introduction of leniency programs.

The paper organizes as follows. After this introduction, section 2 details the review of the related literature; section 3 shows the data collected for this paper on cartel cases sanctioned by the EC and the Spanish Competition Authority. It also details the methods of the diff-in-diff program evaluation techniques used in the paper and defines the groups of control cartels and the leniency treated cartels. Section 4 shows the results of the program evaluation exercise and offers the magnitudes of the impact of leniency programs on cartel duration, the amount of the fines and

investigation duration. Finally, section 5 offers concluding remarks, policy implications, and a discussion of the pending questions for further research.

2. Review of related empirical literature

During recent years there have been a growing interest in empirically investigating the impact of the leniency program on cartels. Many studies have been driven also by recent theoretical contributions, particularly those by Harrington and Chang (2009, 2015) and Harrington and Wei (2017), that provide predictions on the specific cartels' temporal pattern following a policy innovation and conditions to get around the selection bias issue inherent in any of the empirical studies –detected cartels could be a non-representative sample of the total cartel population (detected and undetected cartels)-. As pointed out above, the results of the empirical literature have been very inconclusive so far.

Miller (2009) and Brenner (2009) are the two seminal empirical studies in this specific topic. Miller (2009) uses 207 cartels discovered in US between 1985-2005 to evaluate whether leniency entrance enhances detection and deterrence capabilities. His empirical strategy is based on a Poisson regression model to estimate cartel discoveries as function of some control variables as GDP, budget of the US Department of Justice (US-DoJ), fines, time, and leniency program. He concludes that the number of cartels discoveries peaks after the introduction of US leniency program and it then falls to pre-entrance period. He also exposes some caveats about how cross-sectional variation could provide more robust identification, using data from introduction of leniency programs across the world.

Brenner (2009) studies how the first EU leniency program adopted in 1996 affected (or not) three variables of interest: fines, duration of investigation and the duration of detected cartels. He uses data from 61 European Commission's cartel cases in the period 1990-2003. The critical issue is the potential sample selection bias from only observing detected cartels. To solve this, the author, following the existing literature, checks conditions on short and long-term changes of number and duration of cartels, and examines whether cartels differ in observable dimensions before and after the introduction of the leniency program. He shows that the level of fine per firm is larger in the cartel cases sanctioned under the EU leniency program, and that the duration of the investigation decreases by 1.5 years. However, those effects are not properly identified using program evaluation techniques and the study was not able to show how leniency programs affect cartel stability. Indeed, his findings about how the introduction of leniency program impacts in the short and long-run on cartels' average duration and the number of detected cartels does not appear to consistent with theoretical predictions.[9]

De (2010) focuses on cartel duration on 110 cartels fined by the EC in the period 1990-2008. She employs a Cox-proportional hazard regression to test what factors affect cartel breakdown. Her results expose that the structure of the cartel and the external disturbances play an important role in cartels break up. She finds, however, no significant result for the cartels detected under the

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[9] Another frequent critique is based on his definition of the short run as the period of the first three years after the entry into force of the leniency program, without any solid justification provided.

leniency program. Note that she has no control group so that she is not able to define the leniency program's short run effect properly. Nevertheless, she shows that cartels discovered after the 1996 EU leniency program came into force have a lower chance of survival than those discovered earlier.

Klein (2010) uses the intensity of competition at the industry level of OECD countries to measure the effectiveness of leniency programs in the fight against cartels. Estimating an instrumental variable approach, the results reveal a positive effect of leniency programs on industries' competition intensity, indicating effectiveness in cartel destabilization and effective deterrence.

Levenstein and Suslow (2011), using a sample of 81 international cartels prosecuted by the US-DoJ or the EC between 1990 and 2010, provide descriptive empirical statistics that would support the theoretical predictions by Harrington and Chang (2009), cartels broken up immediately after the introduction of the leniency program are lasting longer than those that have been uncovered since then, although they are not able to test these predictions formally, and they consider the first two to five years after the introduction of the leniency program as the short run.

Choi and Hahn (2014) examine the impact of Korea's leniency program on cartel duration and stability, applying a semi-parametric hazard model to a data set of 619 cartels discovered between 1981 and 2012. They obtain a short run effect of the introduction of the leniency program that reduced the hazard rate, and which resulted in longer cartel duration, while in the long run it increased the rate of cartel dissolution which caused a reduction in cartel duration. Feinberg et al. (2016) also study the impact of Korea's leniency program and apply a hazard model to a data set of 388 cartel cases that formed between 1989 and 2012. Their results regarding the short run effect of the introduction of the leniency program are quite like those provide by Choi and Hahn (2014), although regarding the long-term effect, they find a smaller and mixed impact on cartel stability.

Zhou (2015) considers Harrington and Chang (2009) dynamic model of cartel formation and dissolution to illustrate empirically how changes in antitrust policies and economic conditions might affect cartel duration. Zhou (2015) distinguishes between short-run and long-run impact of the leniency program on cartels the same way we do it in this paper: considering those cartels born before the entry into force of the program and collapsed after (short-run); and those that were formed and broken under the existence of the leniency program (long-run). However, Zhou (2015) does not work with a treatment and a control group, but only with treated cartels, which is one of the main contributions of this paper.

Zhou (2015) uses data on cartel cases discovered and fined by the EC and the US-DoJ to study the impact of the leniency program implemented in 1996 and modified in 2002.[10] In addition, this paper is not able to study the long run effect of the policy on the cartel cases born and dead after 2002 EU leniency program due to a lack of data, and he uses the US-DoJ cases data as a proxy of those EC cartel cases. In line with Harrington and Chang (2009) theoretical results, his findings show that cartels discovered just after the introduction of the leniency program have even larger durations than cartels discovered before the introduction of leniency (short-run stability effect); but gradually, cartels' duration of the discovered cartels turn to be shorter than before the

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[10] It is important to note that he does not consider the impact of the 2006 EU leniency program.

introduction of the leniency program (long-run destabilization effect).[11] Nevertheless, Zhou (2015) also points out that cross-sectional variation could provide more robust identification. Notice that Zhou (2015), like Brenner (2009), De (2010), Choi and Hahn (2014) and Feinberg et al. (2016), uses the Cox proportional hazard model to estimate the impact of leniency program on cartels, but none of them uses a differences-in-differences (diff-in-diff) approach.

Recently, Jochem et al. (2020) use program evaluation techniques considering only one jurisdiction: the EU.[12] They assume that cartels discovered by the EC own initiative and the different EC leniency programs (1996, 2002 and 2006) can be grouped in different control and treatment groups that fulfil the parallel trend assumption. This is not analytically and quantitatively robust, as the number of cartels discovered by the EC own initiative after 1996 reforms is too low, the control and treatment groups do not have parallel trends before the reforms, and there is no way to create suitable control and treatment groups using only the cartel data of the EU jurisdiction before and after the implementation of the policy. They claim to find that "the duration of self-reported cartels decreased on average by about 87 percent, compared to cartels detected directly by the EC." However, we show that including cartels from different jurisdictions and checking for parallel trends is the way to properly apply program evaluation techniques to cartel data, and that their results are not accurate and biased.

By contrast, our findings point out that leniency increases the duration of discovered cartels in the short run (average estimate of around 98%) and decreases duration of the cartels discovered in the long run (average estimate of around 57%). Cartel duration approximately doubles first (short-run impact) and then halves (long-run impact). All these results can be found below.

3. Data and Methods

We have collected the detailed information of all cartel decisions taken by the European Commission and Spanish Competition Authority. The database contains cartels sanctioned by EC between 1969 and 2018, and by the Spanish Competition Authority between 1995 and 2018.[13] In total there have been 243 cartel cases (151 cases in EU and 92 cases in Spain), narrowed to 227 if we exclude the 16 cases involving only business associations but not actual firms (8 EU cases, and other 8 Spanish cases). Our analysis will be at each cartel case level, which usually sanctions one cartel.[14]

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[11] The latter conclusion is also found in De (2010).

[12] They claim to use for the first time a diff-in-diff approach to study the impact of the EU 2002 leniency programs on cartel data. However, our paper started to circulate before Jochem et al (2020) presentation in EALE 2019. The research contained in this paper started while the PhD dissertation of Garcia-Galindo (2018) was undertaken, and previous versions of this paper were widely circulated and presented in JEI 2018 and EARIE 2019. They do not cite this early version of our paper.

[13] We will call European or EU cases to the cartels uncovered and sanctioned by the European Commission, and Spanish cases or cases in Spain to refer to the cartel uncovered and sanctioned by the Spanish Competition Authority.

[14] There are a few decisions in which more than one cartel is sanctioned: usually because during the investigation

In our sample, leniency policy spans for approximately 23 years in the EU (between 1996 and 2018) and 11 years in Spain (between 2008 and 2018). There have been 104 European cartel cases that fell within the scope of implementation of the leniency program since its introduction in 1996 (75 cartel cases initiated following a leniency application), and 27 Spanish cartel cases since its introduction in 2008 (23 cases initiated following a leniency application).[15]

Table 1 shows the basic descriptive statistics of the data collected by jurisdiction (EU/Spain), and by the no leniency/leniency split. The figures of the cases under the EU or Spanish leniency programs consider all cartels that benefited from them. A description of the variables can be found in the appendix, and more in detail in Ordóñez-de-Haro, Borrell and Jiménez (2018).

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closely related cartels were found, some of them were alive simultaneously affecting different but close products, or different moments of time also simultaneously or closely sequentially. Cartels are so closely related that we treat the duration of the cartel case as the dates within which any of those interrelated cartels were active, and the sum of fines to all cartels in such case decision, and the duration of the whole investigation to those closely related cartels sanctioned in the same decision.

[15] Cartel cases that fell within the scope of application of the leniency program includes those initiated following a leniency application, made before the competition authority had taken any investigative steps, or following a competition authority's investigation on its own-initiative or on the basis of a complaint.

Variables	EU (1969-2018)		Spain (1995-2018)	
	No Leniency	Leniency programs 1996, 2002 & 2006	No Leniency	Leniency program 2008
Number of cases (all)	47	104	65	27
Number of cases (associations only excluded)	39	104	57	27
Basic amount of fines	125.7 (300.3)	412.4 (794.2)	21.4 (33.8)	26.6 (32.2)
Final fine	74.3 (204.0)	264.7 (459.7)**	17.2 (25.6)	24.4 (31.2)
Average (percentage) of fine reduction by leniency	0.0 (0.0)	0.3 (0.2)***	0.0 (0.0)	0.7 (0.3)***
Final fine per firm	15.7 (65.3)	21.9 (30.2)	2.1 (3.5)	1.6 (1.8)
Final fine per consolidated firm	21.8 (98.1)	43.3 (75.5)	2.5 (4.4)	2.6 (3.3)
Max cartel duration (years)	7.7 (6.2)	7.8 (6.0)	7.5 (6.8)	11.2 (7.8)**
Duration of investigation	3.5 (2.0)	4.5 (1.6)***	2.8 (1.0)	2.5 (0.5)
Average number of firms	10.9 (10.4)	12.6 (9.7)	13.5 (12.1)	17.4 (20.2)
Average number of consolidated firms	10.0 (9.5)	6.4 (3.6)***	11.9 (10.7)	13.0 (16.5)
Average number of countries	4.7 (4.1)	5.1 (2.8)	1.2 (0.5)	2.4 (1.7)***
Average number of countries (parent firms)	4.7 (4.2)	3.9 (2.0)	1.2 (0.5)	2.3 (1.7)***
Cartel Stability	0.1 (0.2)	0.2 (0.1)	0.1 (0.3)	0.0 (0.0)*
Cases stem from a leniency application	0.0 (0.0)	0.72 (0.5)***	0.02 (0.1)	0.81 (0.4)***
Cases stem from the EC's own initiative	0.72 (0.5)	0.21 (0.4)***	0.47 (0.5)	0.15 (0.4)***
Cases stem from a notification	0.05 (0.2)	0.0 (0.0)**	0.0 (0.0)	0.0 (0.0)
Cases stem from a complaint	0.23 (0.4)	0.07 (0.3)***	0.51 (0.5)	0.04 (0.2)***

Note 1: Fines in constant millions of euro 2010 (GDP World Bank deflator). Standard deviation within brackets. Cartel cases with sanctions only to business associations (not individual firm sanctions) excluded: 8 cases out of 151 excluded in the EU, and 8 cases out of 92 excluded in Spain.

Note 2: *, ** and *** indicates that mean t-tests between leniency/no leniency split shows statistical significance at 10%, 5%, 1% respectively.

Source: Authors elaboration from the European Commission and the Spanish Competition Authority publicly available cartel cases.

Table 1 shows that the average reduction in fines by the application of the leniency program is 30% in the EU cases, while it is as large as 70% in the Spanish cases. Moreover, the average of the sum of final fines imposed on all members involved in each cartel case is larger in those cases in which the leniency program was applied than in those it was not. This difference is particularly significant in the EU jurisdiction: average total final fine is 264.7 million under the EU program compared to 74.3 million per case not under that program.

Apparently, there is not a significant difference between EC cartel cases that fell and did not fall within the scope of implementation of the EU leniency program in respect of the average maximum duration of cartels. There also appears to be a longer average duration of Spanish Competition Authority cartel cases in which the leniency program was applied (11.2 years), compared to those cases in which it was not (7.5 years).

The average duration of investigation is significantly lengthier in the EC cartel cases under the EU leniency program than those not under the program: 4.5 years compared to 3.5 years per cartel

case, respectively (at 1% significance level). However, it is apparently shorter in Spanish Competition Authority cartel cases under the leniency program than those not under it: 2.5 in comparison to 2.8 years per cartel case, respectively (although the difference is not statistically significant).

The leniency applications led to the uncovering of cartel cases in 72 per cent of those EC cartel cases that benefited from the EU leniency program, and in 81 per cent of those that benefited from the implementation of the Spanish leniency program.

In the EU jurisdiction, there is also a fewer average number of consolidated firms[16] in cartel cases in which the leniency program was applied than in those in which was not, 6.4 to 10.0 consolidated firms per cartel case, respectively. In the Spanish case, there is a greater average number of different countries from which cartel participants belonged to if cartel cases fell within the scope of application of the leniency program than if they did not fall, 1.2 on average to 2.4 average number of firms, and to 2.3 average number of consolidated firms (discounting the effect of parent and subsidiaries, where they exist).

These changes might stem from changes in the type of sanctioned cartel cases whenever the leniency program was applied, but the leniency program may not have caused those changes. We need an identification strategy that allows us to separate and quantify the causal effect of the leniency program on cartel duration, fines, and the duration of cartel investigations. Previous empirical papers lack completely a clear identification strategy. We propose and apply a strategy based on the staggered adoption of leniency programs in the EU and Spain to obtain causal impacts from the introduction of leniency programs on cartel duration, fines and the length of cartel investigation.

Additionally, the EU leniency program adopted in 1996 has undergone a couple of reforms in 2002 and 2006 in order to improve its transparency, accessibility and effectiveness. We can then look at the mean differences in cartel case profiles using the split of the different versions of the EU leniency programs.

Table 2 shows that the average amount of fines is considerably higher in those cartel cases in which the 2002 or 2006 leniency was applied, this is also observed in terms of final fine per consolidated firm involved in those cases, reaching 52.3 and 55.8 million euros per consolidated firm, respectively. This may be due to the leniency program enforcement combined with the application of the new European Commission fining guidelines.

The average number of firms and the average number of countries per cartel case are also greater in those cases under the last two versions of the EU leniency program and are apparently much more marked in the application of the 2002 leniency program. It is also noteworthy that the number of cartel cases uncovered by leniency applications represent a growing percentage of cartel cases under each of the three versions of the EU leniency program, reaching 94% of those cartel cases in which the 2006 leniency program was applied.

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[16] Those subsidiaries and parent belonging to the same holding. See Annex 1.

Variables	No Leniency		1996 leniency program		2002 leniency program		2006 leniency program	
Number of cases (all)	47		39		29		36	
Number of cases (associations only excluded)	39		39		29		36	
Basic amount of fines	125.7	(300.3)	241.7	(286.6)	456.7	(427.4)**	692.2	(1481.8)
Final fine	74.3	(204.0)	157.1	(189.7)*	342.8	(348.7)***	318.3	(681.5)
Average (percentage) of fine reduction by leniency	0.0	(0.0)	0.3	(0.2)***	0.3	(0.1)	0.5	(0.2)***
Final fine per firm	15.7	(65.3)	20.0	(25.5)	21.3	(21.6)	24.4	(39.9)
Final fine per consolidated firm	21.8	(98.1)	25.2	(27.1)	52.3	(63.5)**	55.8	(110.3)
Max cartel duration (years)	7.7	(6.2)	9.0	(6.3)	8.2	(7.2)	6.3	(4.3)
Duration of investigation	3.5	(2.0)	4.3	(1.7)*	4.7	(1.5)	4.7	(1.5)
Average number of firms	10.9	(10.4)	9.1	(6.0)	17.0	(12.2)***	12.8	(9.3)
Average number of consolidated firms	10.0	(9.5)	6.6	(3.6)**	7.2	(3.9)	5.4	(3.3)*
Average number of countries	4.7	(4.1)	4.2	(2.5)	6.4	(2.6)***	4.9	(2.8)**
Average number of countries (parent firms)	4.7	(4.2)	3.8	(2.0)	4.8	(2.3)*	3.3	(1.5)***
Cartel Stability	0.1	(0.2)	0.0	(0.0)	0.0	(0.0)	0.0	(0.2)
Cases stem from a leniency application	0.0	(0.0)	0.51	(0.5)***	0.72	(0.5)*	0.94	(0.2)**
Cases stem from the EC's own initiative	0.72	(0.5)	0.33	(0.5)***	0.24	(0.4)	0.06	(0.2)**
Cases stem from a notification	0.05	(0.2)	0.0	(0.0)	0.0	(0.0)	0.0	(0.0)
Cases stem from a complaint	0.23	(0.4)	0.15	(0.4)	0.03	(0.2)	0.0	(0.0)

Note 1: Fines in constant millions of euro 2010 (GDP World Bank deflator). Standard deviation within brackets. Cases with sanctions only to firm associations (not individual firm sanctions) excluded: 8 cases out of 151 excluded in the EU, and 8 cases out of 92 excluded in Spain.

Note 2: *, ** and *** indicates that mean t-tests between categories shows statistical significance at 10%, 5%, 1% respectively.

Note 3: Mean t-tests compare cartel cases under the 1996 leniency program with cartel cases not under leniency program, cartel cases under the 2002 leniency program with respect to cartel cases under the 1996 leniency program, and cartel cases under the 2006 leniency program with respect to cartel cases under 2002 leniency program.

Source: Authors elaboration from European Commission and Spanish Competition Authority publicly available cartel cases.

3.1. The identification strategy of the leniency programs' effects

We are interested in studying the effect of the leniency program on cartel duration, fines, and years of investigation. For this purpose, we are going to compare the cartel cases affected by this regulation with the cartel cases not affected by the leniency programs. Our main identification source comes from the fact that the date of implementation of the program is exogenous, and that it has been introduced in two jurisdictions at distinct points of time. We use a difference-in-difference approach in which we compare the cartel cases in the treatment group to those in the control group, both groups being composed of European and Spanish cartel cases.

However, we need to be more specific about our sample of interest given that it is not as simple as having a treated and a control group with treatment allocated randomly. There are three issues that

we tackle which had not been taken into account in previous empirical papers studying the impact of leniency programs. First, cartel members can benefit from the leniency program if they provide the competition authority with evidence which allows it to initiate an investigation and to uncover their cartel. But even if the cartel's discovery would have resulted from the competition authority's ex-officio investigation, cartel members could also benefit from the leniency program if they cooperate under the terms of the program.

Secondly, the previous situations can take place even if the cartel had actually died before the leniency program came into force.

Finally, apart from falling or not within the scope of implementation of the program, an additional distinction needs to be made among cartel cases in our sample: some cartels were alive before the date of the entry into force of the leniency program and died after that date (partial treatment) and some others were born and broken with the program already in force (full treatment).

The figure below summarizes all the possible treatment options (cartel cases potentially affected by leniency), and the control group (cartel cases not potentially affected by the leniency policy).[17]

Figure 1. Sample split EU/Spain. Definition of treated and control group.
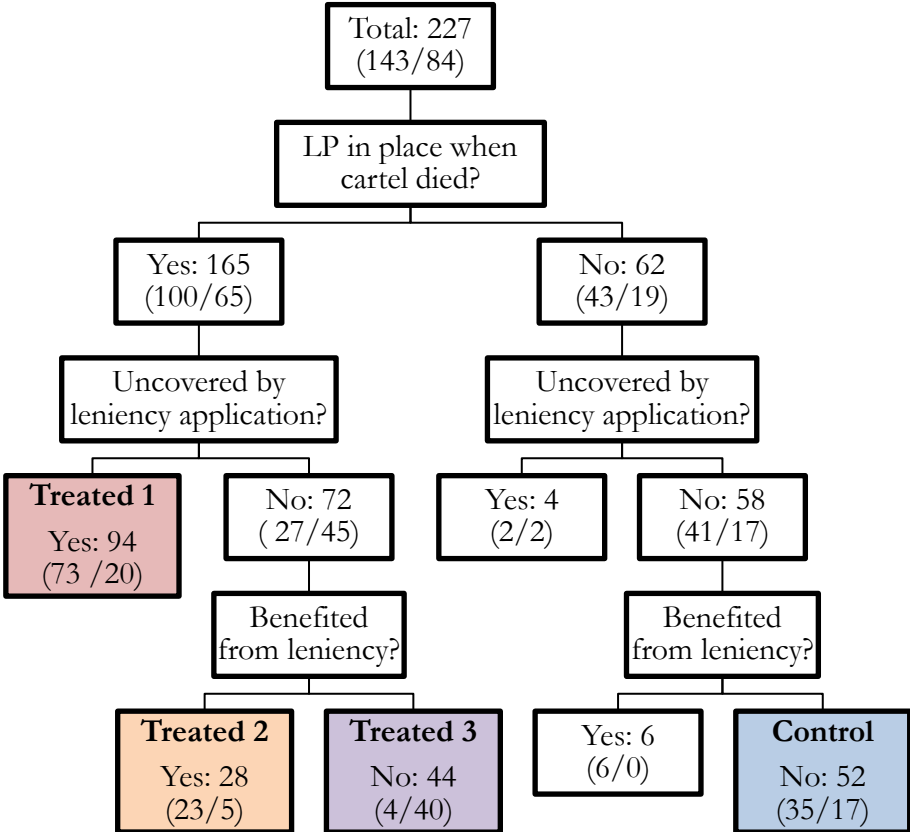
Source: Authors' elaboration from the publicly available case files.

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[17] The division of European and Spanish cases is specified in brackets. The first figure corresponds to EU and the second one to Spain.

Our control group are those cartels that were born and died before 1996 for the European cases, and before 2008 for the Spanish cases. The control group is not affected by the treatment in any sense[18]: cartel members could not apply to any leniency program while they were alive, and they did neither benefit from it afterwards (depicted at the right bottom of previous Figure 1 and named Control).

Our treatment group will be different, depending on the outcome of interest. When studying the effect of the leniency programs on cartel duration, our first treatment group will be formed by those cartel cases that were uncovered as a result of the leniency applications from some of their members (treated 1: ***cartels uncovered by leniency application***).

The second treatment group will consider all the cartel cases for which the leniency program was available while they were active, regardless of whether they fell or not within the scope of application of the program: cartels alive while the leniency program was into force (treated 1, treated 2 and treated 3: ***all treated cartels***).

The reason for this distinction is the following: when studying cartel duration, we are firstly interested in those cases that internally broke up because some cartel member applied for leniency disclosing the existence of the cartel to the competent authority, that is, those in which some member applied for leniency and then the cartel got uncovered as a result of its application. This will give us the comparison between those cartel cases in which their members made direct use of the program and broke up (treated 1) and the control group (control).

Additionally, we are also interested in studying the effect of the existence of the program on the duration of all cartel cases discovered. Regardless of whether the members of the cartel did or did not apply for a lenient treatment, the entry in force of the program could have had some deterrence effect on existing and future cartels (maybe new cartels formed are shorter-lived), and in that case the treatment group of interest are all the cartel cases that coexisted with the leniency program already in force during some period of their lifespan, that is, all cartels treated by the policy (treated 1, treated 2 and treated 3).

However, when analyzing the effect of the policy on fines and on the duration of the investigation, our treatment group is composed by those cartel cases for which the leniency program was available while cartels were still alive, and that additionally applied for leniency and obtained some benefit from the program (treated 1 and treated 2 in the previous figure). Those are all the cartels coexisting with the leniency program to which the program was implemented and that obtained some fine reduction (treated 1 and treated 2: ***benefited from leniency***).

This group excludes also dead cartels in which some of their members obtained immunity or fine reductions under the leniency program although these cartels were no longer alive when the program came into force. In those cases, leniency applicants revealed the existence, or cooperate

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[18] Note that, in this case, in which cartel cases died before the leniency programs were implemented, the cartels uncovered by leniency application (4 cases in total) or that benefited from leniency (6 cases in total) are excluded from our sample of interest, since they are not an appropriate control nor a properly treated case (died before LP).

if cartels were already uncovered, of a dead cartel that was active before the leniency program came into force, cartels whose lifespan was prior to the entry into force of the leniency program.

As mentioned above, there is a second distinction we make in our treatment group among those cartel cases that died after the corresponding leniency program entered into force in each jurisdiction: EU or Spain. The classification comes from the date of formation: if the cartel was born before the date of the entry in force of the leniency program (and died after), we consider this observation had a *partial* treatment. On the other hand, if the cartel both was formed and died after the program had entered into force then it had *full* treatment.

Table 3. Classification of Partial and Full Treatment

	Control		Partial Treatment		Full Treatment	
	Born (Before)	**Died** (Before)	**Born** (Before)	**Died** (In/After)	**Born** (In/After)	**Died** (In/After)
1996 EU Leniency	1996	1996	1996	1996	1996	1996
2002 EU Leniency	1996	1996	2002	2002	2002	2002
2006 EU Leniency	1996	1996	2006	2006	2006	2006
2008 Spanish Leniency	2008	2008	2008	2008	2008	2008

It should be clarified that these treatment variables corresponding to EU overlap. The reason is that, since 1996 EU Leniency considers all those cartel cases born and dead after 1996 (full treatment), it also includes those cases affected by the versions of the program implemented afterwards.

With respect to partial treatment, we could also have a similar case: for instance, two different cartel cases may have been formed in 1994 but one could have died in 1999 (partial treatment under 1996 EU Leniency) and the other one in 2004 (partial leniency under 2002 EU Leniency). We assign partial treatment status in both stories. Thus, the effects obtained refer to the total effect of the leniency program from that moment onwards, and not to the effect of the version of the program implemented in any given year.

However, a cartel formed in 2000 which died in 2004 would be a cartel fully treated under the 1996 EU Leniency Program, but also partially treated under the 2002 EU Leniency Program.

In the estimations we include both treatments simultaneously in the regressions. So, the estimated parameter of treatment dummy offers the marginal effect of each type of treatment (full or partial), given that in a few cases both treatments may have had an impact on the studied outcomes (cartel duration, fines, and years of investigation).

In so doing, we are then obtaining conditional effects taking into account that a few cartels had the impact of full treatment under the previous leniency program, but also the impact of the partial treatment under the subsequent EU leniency program. We also run separated regressions for each type of treatment (full or partial) and the results were very similar to those including both treatments simultaneously.

In the non-parametric matching estimations, the effect of each type of treatment has to be estimated separately by construction. So, in this case, we cannot obtain the conditional estimates given the impact of the previous and subsequent EU leniency programs. Finally, for rendering unbiased and consistent estimates of the impact of the treatment, difference-in-difference estimation requires that the outcomes under study should follow parallel trends before any treatment in the two jurisdictions under study.

Annex 2 test the parallel trend assumption: it holds when analyzing the impact of leniency programs on cartel duration, basic amount of fines and final fines. However, it does not hold when studying the number of years of investigation.

3.2. Estimation models and procedures

3.2.1. Survival Analysis

Our first effect of interest is the impact of the leniency programs on cartel duration. We compare the duration of the cartels in the treatment group against those in the control group. A limitation of working with cartel cases is that we can only work with discovered cartels, and results may not be inferred to the whole population.

However, Harrington and Chang (2009) develop a model of cartel creation and dissolution that allows inferring the impact of the competition policy on the population of cartels by measuring the impact on the duration of discovered cartels.

According to Harrington and Chang (2009) model, if the probability of discovering and convicting cartel members increases due to a change in the policy, then the least stable cartels collapse immediately. Thus, the surviving cartels have longer durations, and this turns into a rise in average duration of discovered cartels in the short run. In the long run, average duration of observed cartels could go up or down, since less stable cartels do not form in first place (rise in duration) but the formerly stable cartels break up earlier (decrease in duration).[19]

We distinguish between the short run and long run impact of the leniency program on cartel duration in the sense of those cartels that were formed before the date of the entry into force of the program and died after (partial treatment or short run effect) versus those cases that were formed when the leniency program was already in force (full treatment or long run effect).

For our purpose, we estimate the Cox proportional hazard model for survival analysis[20]. The purpose of the model is to examine how specified factors influence the rate of an event happening. In this case, the event is cartel death.

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[19] Harrington and Wei (2017) give the conditions under which the duration of detected cartel would be an unbiased measure of the duration of the cartel population.

[20] Brenner (2009), De (2010) and Zhou (2015) also use this methodology, with the main difference that we study the cases of EU and Spain, which allows for a diff-in-diff approach. This gives us the opportunity to improve the comparison group by not only using the previous cases of the corresponding jurisdiction but also the ones in the other

The Cox proportional hazard model assumes that the effects of the predictor variables upon survival are constant over time and are additive. If the coefficient is positive, or equivalently the hazard ratio is greater than one (exponential of the coefficient), it indicates that, as the value of the covariate increases, the event hazard increases and thus the length of survival decreases. In other words, a hazard ratio above one indicates that it is positively associated with the event probability, and thus, negatively associated with the length of survival.

The regression estimated is the following one:

$$h_i(t) = h_0(t)\exp(b_1 treatment_i + b_2 spain_i + b_3 lncountry_i + b_4 lnfirm_i + b_5 stability_i + e_t + h_s + u_i) \quad [1]$$

where: $treatment_i$ is a binary variable that either denotes partial treatment or full treatment and takes value 1 if the cartel case was affected by any leniency program; $spain_i$ is a binary variable that takes value 1 for Spanish cases; $lncountry_i$ is the logarithm of the number of countries to which belong the firms involved in the cartel case; $lnfirm_i$ is the logarithm of the number of firms involved in the cartel case; $stability_i$ is a binary variable that takes value 1 if all firms entered and exited the cartel at the same time; ε denotes time fixed effects; η denotes industry fixed effects; and u_i is the error term.

The time fixed effects correspond to two dummy variables: one of them takes value 1 if the year of the decision is between 1996 and 2007 (both inclusive) and the other one takes value 1 if the year of the decision is after 2007. An alternative specification considers investigation year, instead of decision year, as time fixed effects. These variables control for any possible changes in average cartel duration not related to the leniency enforcement that happened simultaneous either in Spain or in the European Union in three periods: before the entry into force of the leniency program in the EU (1995 and before), in the period in which the only leniency program enforced was the one in the EU (1996-2007), and in the period in which both programs were enforced (2008 and after).[21] The industry fixed effects are captured with inclusion of NACE Rev.2 classification sector dummies.[22]

3.2.2. OLS estimations

We also estimate an OLS approximation to the impact of the leniency program on the log of duration to check whether the functional form of the Cox proportional hazard model for survival analysis has any impact of the results. We will see that results of both the Cox model and the OLS approximation are very similar.

Additionally, we are interested in studying the effect of the leniency program on the basic amount of fines and final fines imposed to the discovered cartels, and on the duration of the investigation.

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jurisdiction, and the treated group receives the treatment in different periods of time.

[21] A binary variable for each year which would control all average changes orthogonal to the leniency program that simultaneously affect the EU and Spain cannot be used because the number of observations is not big enough.

[22] NACE is the French acronym for the European Classification of Economic Activity.

Following Brenner (2009), if more information is disclosed due to the cooperation with the authority, then the basic amount of fines per case (fine prior to the application of the leniency scheme) should be larger than the basic amount of fines per case imposed before the introduction of the leniency program. The effect on the final fines of the treated group could be either positive or negative, depending on the reduction. However, Brenner (2009) finds that the fine reductions do not fully compensate for the increase of basic amount of fines. With respect to the duration of the investigation, it should decrease given that the costs of obtaining relevant information are lower. We should also consider that the information disclosed could make the analysis of the case more complex. The latter could be also explained by the greater body of evidence that must be assessed before a decision is taken by the competition authority.

The regression estimated, by OLS, is the following one:

$$y_i = \beta_0 + \beta_1 \cdot treatment_i + \beta_2 \cdot Spain_i + \beta_3 \cdot lnCountry_i + \beta_4 \cdot lnFirm_i + \beta_5 \cdot lnDuration_i + \varepsilon_t + \eta_s + u_i \qquad [2]$$

where: y_i is the logarithm of the outcome of interest (basic amount of fines, final fine or years of investigation); $lnDuration_i$ is the logarithm of the maximum duration of the cartel case; and the rest of the variables are defined as above.

An important methodological issue arises at this point. To study cartel fines, we have to control for cartel duration, since it is relevant to determine the fine imposed by the authority. However, leniency program may have an impact on cartel duration. Therefore, we also estimate a reduced form equation without duration as explanatory variable to see the impact of leniency on fines via both channels altogether: the direct effect of leniency on fines, and the indirect effect of leniency on fines through changes in cartel duration.

3.2.3. Matching estimator

Finally, matching techniques are used to overcome the potential problem of cartels comparability (Bos et al., 2018). The methodology used in this case is the non-parametric nearest neighbor matching method. Following Imbens and Wooldridge (2009), let Y_i denote the outcome of interest, let X_i be the observable characteristics on which we are matching and let C_i be the treatment variable. Given a sample $\{Y_i, X_i, C_i\}_{i=1}^{N}$, let $\ell_1 (i)$ be the nearest neighbor to i, that is:

$$\ell_1(i) = j, \ for \ j \in \{1, ..., N\}, \ if \ C_j \neq C_i, \ and \ ||X_j - X_i|| = \min_{k:C_k \neq C_i} ||X_k - X_i|| \qquad [3]$$

where the metric used is the Mahalanobis metric, which is based on the inverse of the full sample variance-covariance matrix and is the most common in the literature. The observable characteristics used for the matching are the control variables used in the OLS specification.

We exploit the variation across groups of units that receive treatment at different times. Goodman-Bacon (2018, 2019) show that the difference-in-difference estimation of the effect of the treatment

applied to different units at different times is "a weighted average of all possible 2x2 DD estimators that compare timing groups to each other".[23]

In our case, we compare the cases treated by leniency at the EU jurisdiction with the control cases both in the EU and Spain for which cartels were alive only before the introduction of the leniency policy. We also compare the cases treated by the leniency policy at two different times, using the later-treated group (Spain) as a control before its treatment begins, and then the earlier-treated group (EU) as a control after its treatment begins.

According to Goodman-Bacon (2018, 2019) when treatment effects do not change over time, the difference-in-difference estimator yields a variance-weighted average of cross-group treatment effects and all weights are positive. We find no heterogeneity of treatment effects over time (similar average effects in the staggered effect of the treatment first in the EU and then, later on, in Spain).

Słoczynski (2020) shows that difference-in-difference regression model is expected to provide a reasonable approximation to Average Treatment Effect (ATE) in which we are interested if both groups, treated and control, are of similar size even when treatment on the treated (ATT) differs from the effect of treatment on the untreated (ATU). In our dataset, we have a quite similar number of control cartels cases with respect to the number of cartels cases treated in each treatment: partial or full treatment. So diff-in-diff is offering non-biased estimates of ATE, the average treatment on the treated (ATT) and the untreated (ATU).

3.3. Data

Table 4 shows the descriptive statistics of the data we are going to use to identify and quantify the impact of the leniency policy on cartel duration: the **control group** and the group of **all treated cartels** (treated 1, treated 2 and treated 3 in Figure 1) that were alive while the program was available whether their members had applied or benefited from it or not.[24]

There are 52 cartels in the control group, 67% corresponding to the EU and 33% to Spain, with a mean maximum duration of 7 years, mean basic amount of fines of 26 million Euros, mean final fine of 29.9 million Euros, and mean duration of the investigation of 3.5 years.

Table 4 shows that the average duration of partially treated cartels is larger, 12.4 years, than the control group. The average basic amount of fines and average final fines are much larger than in the control cartel cases: 213.9 and 136.1 million Euros, respectively. And average duration of the investigation is very similar, 3.3 years, to that of the control cartel cases.

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[23] Other papers that also point to this issue are the following: De Chaisemartin and D'Haultfoeuille (2020), Sun and Abraham (2020), Borusyak and Haravel (2017), and Athey and Imbens (2018).

[24] In annex 1, we show the descriptive statistics for the control group, the group of cartel cases uncovered by leniency application (treated 1 in Figure 1), and for the group of cartel cases that benefited from leniency and that were alive when the program was available (treated 1 and 2 in Figure 1).

For the fully treated cartels, mean duration is smaller than the duration of the cartels in the control group, 4.4 years. The mean basic amount of fines and final fines are much larger than in the control cartel cases: 392.5 and 225.2 million Euros, respectively. And average duration of the investigation is larger, 4 years, than that of the control cartel cases.

<h1 style="text-align: center;">Table 4. Descriptive Statistics</h1>

Variable	CONTROL GROUP					PARTIAL TREATMENT GROUP (All treated cartels)					FULL TREATMENT GROUP (All treated cartels)				
	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
Max cartel duration (years)	52	7.0	5.9	0.0	26.0	89	12.4	7.0	2.2	34.9	76	4.4	3.1	0.3	14.0
Basic amount of fines	28	26.0	67.6	0.0	352.0	72	213.9	315.5	0.0	1575.5	51	392.5	986.7	0.5	6568.3
Final fine	45	29.9	63.8	0.0	352.0	89	136.1	230.0	0.0	1117.2	76	225.2	516.7	0.5	3812.0
Duration of investigation	52	3.5	1.8	0.7	10.7	89	3.3	1.3	1.7	8.5	76	4.0	1.7	1.8	7.8
Spain	52	0.3	0.5	0.0	1.0	89	0.5	0.5	0.0	1.0	76	0.3	0.4	0.0	1.0
Average number of firms	52	11.8	11.7	2.0	49.0	89	15.6	14.7	2.0	109.0	76	11.7	9.0	2.0	48.0
Average number of consolidated firms	52	11.1	11.1	2.0	49.0	89	10.4	10.6	2.0	86.0	76	6.7	6.0	2.0	40.0
Average number of countries	52	3.8	3.9	1.0	18.0	89	3.4	2.8	1.0	11.0	76	3.8	2.9	1.0	13.0
Average number of countries (parent firms)	52	3.8	4.0	1.0	18.0	89	3.0	2.1	1.0	8.0	76	2.8	1.9	1.0	12.0

Note on sample: *All treated cartels* refer to cartel cases subject to treatment 1, 2 and 3 in Figure 1.

4. Results

In this section we present the results of the Cox regression for cartel duration, the OLS results for cartel duration, basic amount of fines, final fines, and number of years of investigation, and the ATT results for fines and the duration of the investigation, after applying matching techniques.

Figure 2 shows the mean statistics of cartel duration by jurisdiction across time. It is clear that cartel mean duration per cartel case increases for the cartel cases created before the leniency program entered into effect and were broken up after it (partial treatment), and that mean cartel duration per cartel case decreases for cartel cases created after the leniency program entered into effect (full treatment). Regression analysis will show whether these mean differences are statistically significant.

Figure 2. Cartel duration by jurisdiction.
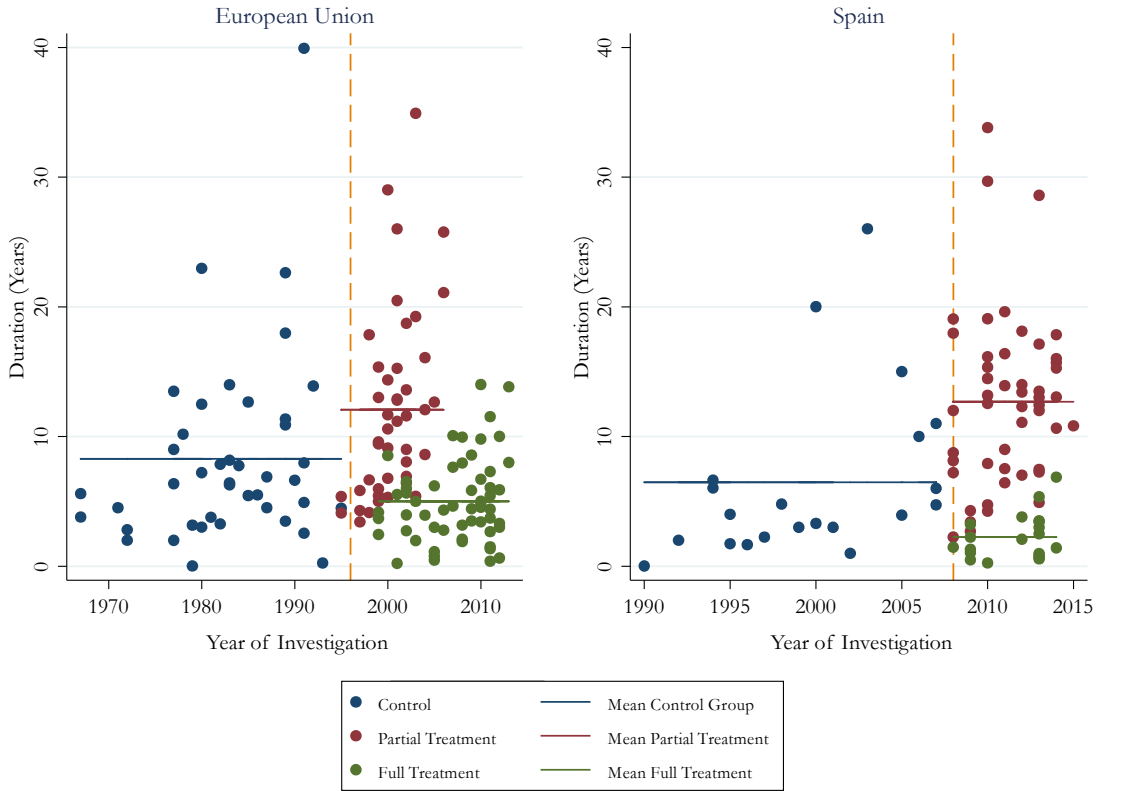
Source: Authors' elaboration from the publicly available case files.

4.1. Survival Analysis

Table 5a presents the results (expressed as hazard ratio) for the Cox regression estimation. Results show that those cartel cases that were partially treated by the leniency program and were uncovered by the leniency program enforcement (treated 1), experiment a 69% decrease in the hazard of

21

failure (short run effect in column 2: estimated coefficient minus 1). This means that the duration of these cartel cases is significantly higher than those in the control group.

When all cartels partially treated are considered (treated 1, treated 2 and treated 3), meaning all the cartel cases affected by the existence of the program, had they applied for the program or not, the decrease in the probability of dying is 67% (short run effect in column 5: estimate coefficient of 0.33 minus 1.00).

Table 5a. Cartel Duration (Cox regression)
Hazard Ratio. All leniency programs (EU96, EU02, EU06 & SP08)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment	0.44***	0.31***	0.25***	0.39***	0.33***	0.27***
	(0.09)	(0.06)	(0.04)	(0.06)	(0.02)	(0.04)
Full Treatment	3.64***	4.05***	3.46***	4.61***	4.90***	4.28***
	(0.63)	(0.42)	(0.61)	(0.60)	(0.68)	(0.71)
Log N. Countries	0.82*	0.74***	0.75***	0.91	0.88*	0.90*
	(0.08)	(0.08)	(0.07)	(0.06)	(0.06)	(0.06)
Log N. Firms	1.19**	1.18	1.21*	1.08	1.05	1.06
	(0.09)	(0.15)	(0.13)	(0.11)	(0.12)	(0.1)
Stability	1.43	1.13	1.15	1.49**	1.35*	1.33*
	(0.42)	(0.35)	(0.32)	(0.26)	(0.23)	(0.20)
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	143	143	143	210	210	210
Pseudo R²	0.043	0.063	0.065	0.059	0.074	0.076
Sample	Uncovered by leniency	Uncovered by leniency	Uncovered by leniency	All treated cartels	All treated cartels	All treated cartels

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.
Note on sample: *Uncovered by leniency* refers to cartel cases subject to treated 1 in Figure 1, while *all treated cartels* refer to cartel cases subject to treated 1, 2 and 3 in Figure 1.

Thus, results show a short-run effect (partial treatment) of leniency program: the detected cartel cases have longer duration than the ones in the control group (hazard ratio lower than one).

This result is consistent with the one outlined theoretically by Harrington and Chang (2009), and also found empirically by Zhou (2015). These authors conclude that the average duration of discovered cartels rises in the short run, in response to a more effective competition policy. The reason is that if the policy is efficacious, then its adoption will immediately cause the marginally stable cartels to collapse and they will exit the cartel population.

Table 5a also shows that those cartel cases that were fully treated by the leniency program and were uncovered by the program, experiment a 305% (column 2, estimated coefficient of 4.05 minus 1.00) and a 390% (column 5, estimated coefficient of 4.90 minus 1) increase in the hazard of failure (baseline hazard is when coefficient equals 1). This means that the duration of these cartel cases is significantly shorter than those in the control group.

The hazard ratio can be interpreted as follows: the probability of dying of those cartel cases that were born and died under the leniency program is around four times higher (4.05, column 2, to 4.90, column 5) than the one of the cartel cases in the control group. Therefore, the duration of the treated cases is lower than the duration of the cartel cases that were born and died before the leniency program came into force and did not benefit from that program afterwards.

Following the previous discussion regarding Goodman-Bacon (2018, 2019), we have also estimated the treatment effect separately for the EU and Spain, although they should be carefully interpreted, given that the number of observations in each group is low, especially in the case of full treatment in Spain. Results are presented in Table 5b, which show no heterogeneity of treatment effects over time nor across jurisdiction (similar average effects in the staggered effect of the treatment first in the EU and then, later on, in Spain).

Table 5b. Cartel Duration (Cox regression)
Hazard Ratio. All leniency programs in EU (EU96, EU02 & EU06) and in Spain (SP08)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment EU	0.42***	0.30***	0.23***	0.46***	0.38***	0.28***
	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.03)
Full Treatment EU	3.72***	4.19***	3.36***	3.67***	4.35***	3.64***
	(0.63)	(0.31)	(0.65)	(0.40)	(0.51)	(0.60)
Partial Treatment SP	0.51	0.36**	0.32***	0.45	0.33***	0.30***
	(0.29)	(0.14)	(0.12)	(0.24)	(0.10)	(0.13)
Full Treatment SP	3.86**	4.18***	3.95***	9.47***	7.32***	7.26***
	(2.15)	(1.72)	(1.97)	(3.97)	(1.30)	(1.48)
Log N. Countries	0.81***	0.73***	0.73***	0.87**	0.85**	0.87*
	(0.06)	(0.07)	(0.04)	(0.05)	(0.07)	(0.07)
Log N. Firms	1.19**	1.18	1.23*	1.07	1.05	1.06
	(0.09)	(0.15)	(0.15)	(0.10)	(0.11)	(0.11)
Stability	1.42	1.14	1.18	1.59**	1.38*	1.40**
	(0.31)	(0.35)	(0.33)	(0.30)	(0.25)	(0.23)
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	143	143	143	210	210	210
Pseudo R²	0.043	0.064	0.066	0.062	0.075	0.077
Sample	Uncovered by leniency	Uncovered by leniency	Uncovered by leniency	All treated cartels	All treated cartels	All treated cartels

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.
Note on sample: *Uncovered by leniency* refers to cartel cases subject to treated 1 in Figure 1, while *all treated cartels* refer to cartel cases subject to treated 1, 2 and 3 in Figure 1.

Going back to the case in which EU and Spain are treated jointly, Figure 3 shows the survival probabilities of cartels at different duration time, at the average value of the other covariates, and for the three groups of cartel cases: partially treated and fully treated cartel groups that got uncovered by leniency (treated 1), and the control group.

The figure shows the survival rates for the cartel cases that were partially treated (leniency introduced after the cartel was born and was in force when the cartel died) is always larger than the control group and, both are larger than the ones in the fully treated group (leniency introduced before the cartel was born), and the control cases.

At the duration of 4 years, survival is around 70% for the control group. For the partially treated cartel cases survival increases up to around 95% (those cartels were very stable while at year 4 of their live, most likely reaching that age before the leniency program came into force, and those cartels broke down once the program entered into force), and for the full treated cartels survival goes down to around 20% (those cartels are less stable at year 4 of their life which occurs while the leniency program had already entered into force).

Figure 3. Survival estimations. Cox proportional hazards regression.
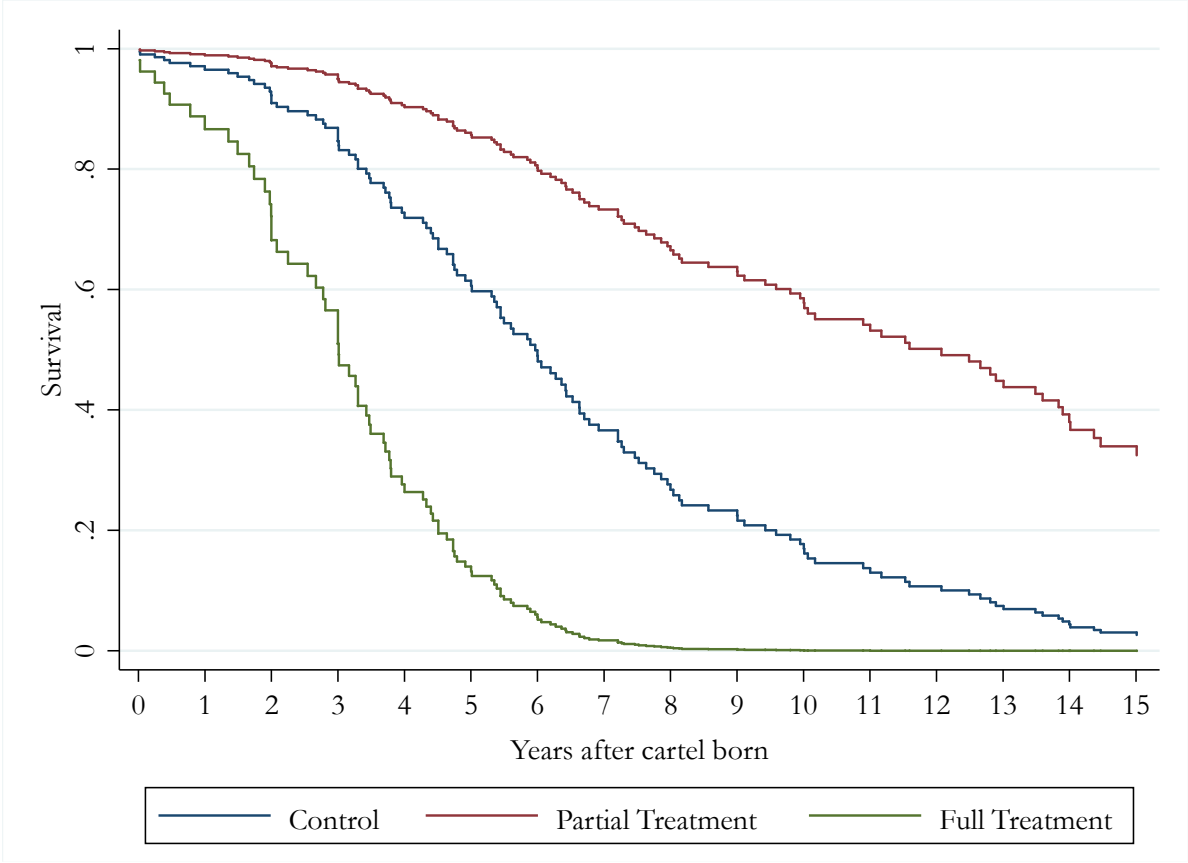
Source: Authors' elaboration from estimations included in Table 5a.

Harrington and Chang (2009) find that the effect of the leniency program on cartel duration in the long run is ambiguous, it could go either up or down. On the one hand, those cartels at the margin that are less stable will not form under this policy, which entails a rise in the observed durations. On the other hand, the formerly stable long-running cartels break up earlier, reducing observed cartels durations. Our results are consistent with the second explanation: the long run effect of the

leniency program is a decrease in cartels duration because formerly stable long-running cartels break up earlier.

Another question is whether the leniency program brings shorter or less stable cartels into light or whether it does really deter collusion by means of the formation of shorter cartels or the formation of fewer cartels. Harrington and Chang (2009) claim that in response to a policy that alters the likelihood of detection and conviction, the effect of the rate of cartels can be inferred by observing the duration of discovered cartels in the short run. If average cartel duration goes up, then the policy has caused the probability that firms are discovered and convicted to rise and thus we can conclude that it will result in fewer cartels forming in the new steady state. Our results prove this last point: fewer cartels are formed in the new steady state.

4.2. OLS estimations[25]

Table 6 shows the results using an OLS regression of log of cartel duration. As shown in the table, results hold. Leniency increases duration of cartels discovered in the short run (average estimate of around 98%) and decreases duration of the cartels discovered in the long run (average estimate of around 57%).[26] Around doubles and halves, respectively. Given the mean duration of cartels in the control group is 7.0 years, duration goes up in 5.5 years up to 12.5 years of mean duration in the partial treatment cases, and goes down by 2.3 years, down to mean 5.3 years of duration in the full treatment cartel cases.

Table 6. Log of Cartel Duration. OLS Regression. All leniency programs (EU96, EU02, EU06 & SP08)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment	0.74***	0.64***	0.81**	0.80***	0.55***	0.71**
	(0.13)	(0.15)	(0.27)	(0.12)	(0.16)	(0.31)
Full Treatment	-0.69***	-0.90***	-0.74**	-0.78***	-0.92***	-0.80***
	(0.12)	(0.11)	(0.30)	(0.10)	(0.09)	(0.19)
Log N. Countries	0.02	-0.01	-0.02	0.03	0.03	0.01
	(0.06)	(0.09)	(0.09)	(0.05)	(0.07)	(0.08)
Log N. Firms	0.13*	0.24*	0.20	0.08	0.13	0.10
	(0.06)	(0.11)	(0.12)	(0.07)	(0.10)	(0.10)
Stability	-0.38*	-0.18	-0.23**	-0.39	-0.27	-0.30
	(0.19)	(0.14)	(0.10)	(0.23)	(0.20)	(0.18)
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year

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[25] Most results presented in this subsection are replicated in Annex 3 considering the implementation of the leniency program separately in EU and in Spain. Results hold, although results are weaker in Spain due to the low number of treated observations. In the case of full treatment, we have not been able to estimate the effect in Spain for most of the outcomes.

[26] Average estimates of columns 2, 3, 5 and 6: estimates including time fixed effects computed using investigation or decision year.

|						
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	146	146	146	217	217	217
R²	0.269	0.365	0.358	0.384	0.443	0.439
Sample	Uncovered by leniency	Uncovered by leniency	Uncovered by leniency	All treated cartels	All treated cartels	All treated cartels

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.
Note on sample: *Uncovered by leniency* refers to cartels treated 1 in Figure 1, while *all treated cartels* refer to cartels treated 1, 2 and 3 in Figure 1.

We also compute all the estimations restricting the sample in the partial treatment group to those cartels with duration of 22 years or less in the EU, and 10 years or less in Spain. These durations are the maximum durations that cartels born and died after leniency (fully treated cartels) can last given that leniency was introduced in the EU in 1996 (2018-1996=22), and in Spain in 2008 (2018-2008=10 years). Results, not shown for the sake of simplicity, hold even under this constraint in the sample. The larger duration of the partially treated cartels is not driven by the left uncensored (uncensored date of birth) potential life span of the discovered cartels before the introduction of leniency.

Table 7 shows that we also find a significant effect of the leniency program on basic amount of fines. Basic amount of fines are the fine before discounting the benefits of cooperation under the leniency program. Both partial and full treatment result in higher fines: by 95% to 99% in the case of cartels under partial treatment that apply for leniency (both uncovered or not by leniency applications) when controlling for cartel duration; by 129% to 200% in the case of cartels under full treatment that apply for leniency or cooperate when controlling for cartel duration.[27]

Table 7. Log of Basic Amount of Fines (Deflated). All leniency programs (EU96, EU02, EU06 & SP08)

Variables	Full Model			Reduced Form		
	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment	1.30**	0.67**	0.69*	1.81***	0.86***	1.10**
	(0.45)	(0.25)	(0.33)	(0.47)	(0.17)	(0.37)
Full Treatment	1.44***	0.83***	1.10***	1.05***	0.36*	0.61**
	(0.25)	(0.10)	(0.11)	(0.28)	(0.19)	(0.27)
Log N. Countries	0.50*	0.39***	0.57***	0.54*	0.42***	0.60***
	(0.27)	(0.10)	(0.13)	(0.26)	(0.06)	(0.08)
Log N. Firms	0.13	0.49***	0.30**	0.21	0.61***	0.39***
	(0.26)	(0.12)	(0.10)	(0.26)	(0.16)	(0.12)
Log Duration	0.63***	0.50**	0.60***			
	(0.14)	(0.17)	(0.10)			
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year

[27] Average estimates of columns 2, 3, 5 and 6: estimates including time fixed effects computed using investigation or decision year.

Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	118	118	118	118	118	118
R²	0.594	0.748	0.754	0.536	0.721	0.714
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to cartel cases subject to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available. This group excludes dead cartels in which some of their members obtained immunity or fine reductions under the leniency program although these cartels were no longer alive when the program came into force. In those cases, leniency applicants revealed the existence, or cooperate if it had been revealed, of a dead cartel that was active before the leniency program came into force, cartels whose lifespan was prior to the entry into force of the leniency program.

When not controlling for cartel duration, the effect of partial treatment is higher due to larger cartel duration of discovered cartels under leniency (136% to 200% in columns 5 and 6 which include time fixed effects) while the effect of full treatment is lower due to shorter cartel duration of discovered cartels under leniency (43% to 84% in columns 5 and 6 which include time fixed effects).

Table 8 shows the results of the effect of the leniency program on final fines. Treatment effects are all positive: leniency drives up not only basic amount of fines but also larger final fines. However, the effect is slightly smaller on final fines with respect to basic amount of fines in the case of partial treatment: 63%-84% increase when controlling for cartel duration (columns 2 and 3 including time fixed effects), and 125%-127% increase without controlling for cartel duration (columns 5 and 6 including time fixed effects).

The effect of leniency on final fines is slightly larger with respect to basic amount of fines in the case of full treatment: 203%-229% when controlling for cartel duration (columns 2 and 3 including time fixed effects), and 120%-139% without controlling for cartel duration (columns 5 and 6 including time fixed effects).

These results may be driven by two effects: (1) competition authorities may access to full detailed information about the cartel activity through the leniency program, helping the authorities to charge a larger fine thanks to the program; (2) it might also be that the leniency program was adopted and at the same time competition authorities adopted a stronger position in the fight against collusion during the whole period, and not necessarily only through the program.

Table 8. Log of Final Fines (Deflated). All leniency programs (EU96, EU02, EU06 & SP08)

Variables	Full Model			Reduced Form		
	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment	1.17***	0.61***	0.49***	1.51***	0.81***	0.82***
	(0.21)	(0.13)	(0.07)	(0.19)	(0.10)	(0.12)
Full Treatment	1.49***	1.19***	1.11***	1.23***	0.87***	0.79**
	(0.21)	(0.07)	(0.15)	(0.17)	(0.19)	(0.29)
Log N. Countries	0.74***	0.65***	0.70***	0.77***	0.66***	0.70***
	(0.18)	(0.14)	(0.15)	(0.17)	(0.13)	(0.15)
Log N. Firms	0.25	0.50***	0.46***	0.34*	0.61***	0.56***
	(0.17)	(0.11)	(0.11)	(0.18)	(0.15)	(0.15)
Log Duration	0.41**	0.35**	0.41***			
	(0.15)	(0.12)	(0.08)			
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	163	163	163	163	163	163
R^2	0.507	0.664	0.668	0.478	0.646	0.643
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * $p<0.10$, ** $p<0.05$, ***$p<0.01$. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available. This group excludes dead cartels in which some of their members obtained immunity or fine reductions under the leniency program although these cartels were no longer alive when the program came into force. In those cases, leniency applicants revealed the existence, or cooperate if it had been revealed, of a dead cartel that was active before the leniency program came into force, cartels whose lifespan was prior to the entry into force of the leniency program.

Finally, we find not so conclusive results with respect to the impact of the leniency policy on the duration of the investigation in the OLS regressions, presented in Table 9. Partial treatment appears to have no impact on the length of the investigation. By contrast, full treatment appears to increase the years of the investigation significantly (by 13% in column 3 and by 29% in column 2 which include time fixed effects). Table 9 offers the results including only the cartel cases that benefited from leniency in the treatment groups (treated 1 and treated 2: **cartels benefiting from leniency**). We obtained very similar results when estimating the OLS regressions including all cartels affected by the leniency policy in the treatment groups (treated 1, treated 2 and treated 3: **all treated cartels**). Reduced form estimations that do not include cartel duration as covariate (which may be affected by the leniency policy) render also very similar results.

Table 9. Log of Years of Investigation. All leniency programs (EU96, EU02, EU06 & SP08)

Variables	(1)	(2)	(3)
Partial Treatment	0.04	-0.02	-0.13
	(0.07)	(0.09)	(0.08)
Full Treatment	**0.28***	**0.29***	**0.13****
	(0.06)	(0.09)	(0.06)
Log N. Countries	0.10**	0.13**	0.12**
	(0.04)	(0.05)	(0.05)
Log N. Firms	0.05	0.04	0.05
	(0.04)	(0.06)	(0.06)
Log Duration	0.01	0.01	0.01
	(0.04)	(0.04)	(0.04)
After fixed effects	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes
Observations	170	170	170
R^2	0.210	0.250	0.258
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

4.3. Matching estimator

We finally double check the robustness of the results of the estimation of the impact of the leniency policy on fines and the duration of the investigation using matching techniques. OLS estimates offer the impact for the cases at the mean of the covariate characteristics of the cartel cases, while local comparisons using matching techniques allow us to estimate the impact comparing cases of similar characteristics locally in the treatments and control groups. So, we can control more accurately for the differences in the characteristics of the cartel cases in the treatments and control groups.

Using local matching comparison techniques, we obtain again a strong and significant positive impact of leniency program (either partial or full treatment) on basic amount of fines and final fines.

Comparing among groups of homogenous cartel cases the impact of partial and full treatment on fines is estimated to be much larger than the estimated using OLS techniques that compare the "average cartel case": basic amount of fines and final fines are between 6 to 15 times larger in the treated cartel cases compared to the control non-treated cartel cases (as the estimates are in logs, we obtain the marginal effects by taking the exponent of the coefficient minus 1). By construction, matching techniques requires to estimate the partial treatment and the full treatment effects separately (see Table 10 and 11).

Table 10. Log of Basic Amount of Fines (Deflated). All leniency programs (EU96, EU02, EU06 & SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	2.55***	2.58***	3.48***	3.09***
	(0.52)	(0.36)	(0.60)	(0.42)
ATT (m=5)	2.41***	2.81***	3.17**	3.11***
	(0.45)	(0.41)	(0.40)	(0.39)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Spain fixed effects	Yes	Yes	Yes	Yes
Observations	109	65	109	65
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.
Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 11. Log of Final Fines (Deflated). All leniency programs (EU96, EU02, EU06 & SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	2.58***	2.73***	2.51***	2.74***
	(0.47)	(0.40)	(0.38)	(0.43)
ATT (m=5)	2.03***	2.38***	2.26***	2.47***
	(0.36)	(0.35)	(0.34)	(0.37)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Spain fixed effects	Yes	Yes	Yes	Yes
Observations	146	101	146	101
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Using local matching techniques, we are also able to identify and quantify the impact of leniency program on the duration of cartel investigations: partial and full treatment make cartel investigation lengthier: around 28% larger in the partial treatment cases and around 57% larger in the full

treatment cases.[28] Given that the average years of investigation is 3.5 years for the observations in the control group, this means an increase of the duration of the investigation or 1 year in the partial treatment cases, and 2 years in the full treatment cases (see Table 12).

Table 12. Log of Years of Investigation. All leniency programs (EU96, EU02, EU06 & SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	0.24 (0.15)	0.58** (0.20)	0.22 (0.14)	0.46*** (0.16)
ATT (m=5)	0.25* (0.14)	0.45*** (0.16)	0.24* (0.13)	0.45*** (0.15)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Spain fixed effects	Yes	Yes	Yes	Yes
Observations	153	108	153	108
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * $p<0.10$, ** $p<0.05$, ***$p<0.01$. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

This result is consistent with the theory that leniency programs offer competition authorities much more details of the cartel conspiracies that allow them to undertake a fully fledge investigation in which more evidence and charges are brought about in the decisions. Including those evidences and charges is time consuming and lengthens the duration of the investigation. At the same time, this leaves less room to the competition authority to investigate other cases by their own initiative as the literature has already highlighted as an undesired effect of leniency policy in the fight against cartels.[29]

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[28] Average Treatment on the Treated (ATT) effect estimates for m=5.

[29] Many authors have alerted competition authorities that they should not make cartel detection's success depend on the results obtained with the leniency program, concentrating their limited resources on this detection method while other methods take up a marginal role. This strategy may end up reducing the effectiveness of the fight against cartels, either by increasing the stability of the cartels, or by generating a sense of security in those cartel operated sectors if the authorities focused only on leniency proceedings, and conversely reducing the *ex officio* investigations (see, among others, Friederiszick and Maier-Rigaud, 2008; Hammond, 2008; Harrington and Chang, 2015; Schinkel et al. 2020).

5. Concluding remarks

This paper identifies and quantifies the impact of the leniency programs introduced in competition policy on cartel duration, cartel fines and the duration of the investigation. This was an unsettled theoretical and empirical question. We study the effect of the leniency program implemented in EU in 1996 and modified later on in 2002 and 2006; and the one implemented in Spain in 2008. The exogeneity of the date of introduction and the fact that it was implemented in the two jurisdictions at different moments of time allow us to identify the effect of interest, using a difference-in-difference approach.

Our dataset contains all the cartel cases sanctioned by the European Commission and the Spanish Competition Authority since their beginning (1969 and 1995, respectively), until 2018. There are, in total, 243 cases, out of which 151 belong to the EU and 92 to Spain. We exclude from our analysis those cases that involve only business associations but not actual firms: so the remaining cartel cases analyzed are a total of 228 (144 in the EU and 84 in Spain).

We empirically show that leniency programs destabilize existing cartels in the short run as expected from theory and previous empirical papers, and then dissuade the creation of new cartels in the long run. Deterrence effects dominate empirically in the long run, although theoretically they might not dominate, and previous empirical findings were inconclusive.

To study the impact on the program on cartel duration, we use the Cox proportional hazard model. The treatment groups of interest in this case are two: those **cartel cases uncovered by leniency** applications on the one hand (the discovery is a direct consequence of the program: uncovered cartels); and all of the cases broken after the entry in force of the program (we distinguish between those that were formed before the existence of the program, and those that were born after: **all cases treated**).

To analyze the effect on fines and the duration of the investigation, we estimate an OLS model where the variable of interest is the diff-in-diff. For this second part, the sample of interest is those **cartel cases that benefited** from the leniency program: cartels coexisting with the leniency program to which the program was also applied. We also estimate the effect of leniency policy on fines and duration of the investigation using local matching techniques.

Our results show a short-run effect of the leniency programs: cartels that were partially affected by the policy change have longer duration than the ones in the control group. In the long run, the program decreases cartel duration: the probability of dying of those cartels that were born and died under the existence of the leniency program is much larger than the one of the cartels in the control group.

Using OLS techniques we find that existing cartels discovered after leniency is introduced have a duration that doubles the control cartel cases (98% increase), while new cartels formed and discovered after leniency is introduced have a duration that more than halves the duration of the control cartel cases (57% decrease).

These results are consistent with the theoretical ones proposed by Harrington and Chang (2009). We find evidence in the data of what they show theoretically: in response to a policy that alters the likelihood of detection and conviction, the effect of the rate of cartels can be inferred by observing

the duration of discovered cartels in the short run. As average cartel duration goes up, then the policy has caused the probability that firms are discovered and convicted to rise and thus we can conclude that it resulted in fewer cartels forming in the new steady state.

On the other hand, we find strong and significant effect of the leniency programs on fines. Both basic amount of fines and final fines increase substantially: increase by half, double or even triple using OLS techniques, but increases 6 to 11 times using local matching techniques. Finally, we find that the duration of the investigation increases significantly around 1 to 2 years using local matching techniques, contrary to previous studies in the literature.

In conclusion, our results identify and quantify that leniency programs have sharp and clear short-run cartel destabilization, and also long-run cartel dissuasion effects. So, the way leniency programs have been implemented in the EU and Spain has avoided the theoretically feasible outcome of failure in the deterrence effect. Such a failure in deterring cartels was not rejected from the previous empirical literature. We show that leniency programs have succeeded in destabilizing existing cartels and significantly deterring the formation of new long-lasting cartels.

Further research will be needed to know whether the leniency programs might eventually lose efficacy as suggested by the theoretical literature in case competition authorities rely exclusively in those programs to discover cartels abandoning *ex officio* investigations, and once private claim for damages under the new 2014 Directive becomes finally effective as leniency programs do not hold whistleblower companies harmless from any damage claims. We show that those effects have not yet had any significant impact on leniency programs' effectiveness.

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Annex 1: Description of Variables

From the publicly available case files, we have computed the following information. Monetary values are deflated based on the year 2010 (World Bank prices database):

i) *Basic amount of fines$_i$* (euro): it is the total basic amount of fines of the case *i* before leniency application. This information is not always available in the publicly available case files, which implies we have a smaller number of observations than number of cartel decisions.

ii) *Final fine$_i$*: the sum of fines imposed on all the undertakings involved in the cartel case *i*. It differs from the basic amount of fine because in the final fine it is taken into account aggravating and/or attenuation circumstances that increase or reduce the final fine with respect to the basic amount of fine. The data is offered before and after leniency.

iii) *Average (percentage) of fine reduction by leniency$_i$*: average of the percentage reductions granted to leniency applicants per case in the final fine.

iv) *Final fine per firm$_i$*: the ratio between the final official fine and the total number of firms participating in the cartel *i*.

v) *Final fine per consolidated firm$_i$*: the ratio between the final official fine and the total number of firms participating in the cartel *i*. All the subsidiaries and the parent company belonging to the same consolidated group (*holdings*) are counted only once.

vi) *Maximum duration$_i$*: maximum number of years the cartel *i* was functioning according to the final decision.

vii) *Duration of the investigation$_i$*: the number of years between the starting date of the Commission's investigation and the date of its final decision in each cartel case.

viii) *Average number of firms$_i$*: it is the average number of firms that participate in the cartel during its existence.

ix) *Average number of consolidated firms$_i$*: this is the number of cartel participants but all the subsidiaries and the parent company belonging to the same consolidated group (*holdings*) are counted only once.

x) *Number of countries$_i$*: this is the number of different countries from which cartel participants belonged to. Each company is assigned to the country where it has its registered head office.

xi) *Number of countries (parents)$_i$*: this variable is similar to the previous one but discounting the effect of parent and subsidiaries, where they exist. We account for only one country in which the parent firm has its head office.

xii) *Stability$_i$*: binary variable that takes value 1 when there was no entry or exit of cartel's members throughout the life of the cartel.

xiii) *Case stems from…$_i$*: binary variables which take value 1 for each way a case *i* starts with: a leniency application from one cartelist (post-1996 leniency notice), a notification (in the pre-2004 authorization regime), a Commission's own-initiative investigation (*ex officio*), or a Commission's investigation following a third-party complaint.

Table 13. Descriptive Statistics

Variable	CONTROL GROUP					PARTIAL TREATMENT GROUP (Uncovered by leniency)					FULL TREATMENT GROUP (Uncovered by leniency)				
	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
Max cartel duration (years)	52	7.0	5.9	0.0	26.0	46	12.5	7.1	2.3	34.9	48	5.3	3.3	0.4	14.0
Basic amount of fines	28	26.0	67.6	0.0	352.0	38	263.2	329.7	4.0	1575.5	31	573.4	1219.8	1.9	6568.3
Final fine	45	29.9	63.8	0.0	352.0	46	156.4	220.3	0.5	1027.8	48	300.6	605.4	1.9	3812.0
Duration of investigation	52	3.5	1.8	0.7	10.7	46	3.4	1.4	1.8	7.0	48	4.6	1.6	1.9	7.8
Spain	52	0.3	0.5	0.0	1.0	46	0.4	0.5	0.0	1.0	48	0.1	0.2	0.0	1.0
Average number of firms	52	11.8	11.7	2.0	49.0	46	17.1	17.8	2.0	109.0	48	12.4	8.6	4.0	42.0
Average number of consolidated firms	52	11.1	11.1	2.0	49.0	46	10.6	13.1	2.0	86.0	48	5.7	3.3	2.0	17.0
Average number of countries	52	3.8	3.9	1.0	18.0	46	4.4	2.8	1.0	11.0	48	4.7	3.0	1.0	13.0
Average number of countries (parent firms)	52	3.8	4.0	1.0	18.0	46	3.9	2.1	1.0	8.0	48	3.4	2.0	1.0	12.0

Note on sample: *Uncovered by leniency* refers to cartels treated 1 in Figure 1.

Table 14. Descriptive Statistics

Variable	CONTROL GROUP					PARTIAL TREATMENT GROUP (Benefited from leniency)					FULL TREATMENT GROUP (Benefited from leniency)				
	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max	Obs.	Mean	Std. Dev.	Min	Max
Max cartel duration (years)	52	7.0	5.9	0.0	26.0	65	12.1	7.3	2.3	34.9	56	5.0	3.2	0.4	14.0
Basic amount of fines	28	26.0	67.6	0.0	352.0	55	248.4	323.9	0.0	1575.5	37	534.1	1129.9	0.0	6568.3
Final fine	45	29.9	63.8	0.0	352.0	65	160.5	228.8	0.0	1039.3	56	299.7	585.1	1.9	3812.0
Duration of investigation	52	3.5	1.8	0.7	10.7	65	3.6	1.4	1.8	8.5	56	4.5	1.6	1.9	7.8
Spain	52	0.3	0.5	0.0	1.0	65	0.3	0.5	0.0	1.0	56	0.1	0.2	0.0	1.0
Average number of firms	52	11.8	11.7	2.0	49.0	65	15.9	15.8	2.0	109.0	56	11.9	8.2	2.0	42.0
Average number of consolidated firms	52	11.1	11.1	2.0	49.0	65	9.8	11.2	2.0	86.0	56	5.5	3.2	2.0	17.0
Average number of countries	52	3.8	3.9	1.0	18.0	65	4.3	2.8	1.0	11.0	56	4.8	2.8	1.0	13.0
Average number of countries (parent firms)	52	3.8	4.0	1.0	18.0	65	3.7	2.1	1.0	8.0	56	3.4	1.9	1.0	12.0

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel in which some members obtained immunity or fine reductions under the leniency program and that were alive when the program was in force.

In this annex, we test the parallel trends assumption. Difference-in-difference estimation requires for rendering unbiased and consistent estimates of the impact of the treatment that the outcomes under study should follow parallel trends before any treatment.

Figure 4 shows the linear trend estimation of the duration of the cartels under study before the introduction of the leniency policy in its respective jurisdiction. Cartel duration had an increasing trend both in the EU and in Spain before the introduction of the leniency programs. However, the trends seem parallel in the pre-treatment period. We test the parallel trend assumption in the case of cartel duration in table 15.

Figure 4. Trends before treatment (introduction of leniency policy)
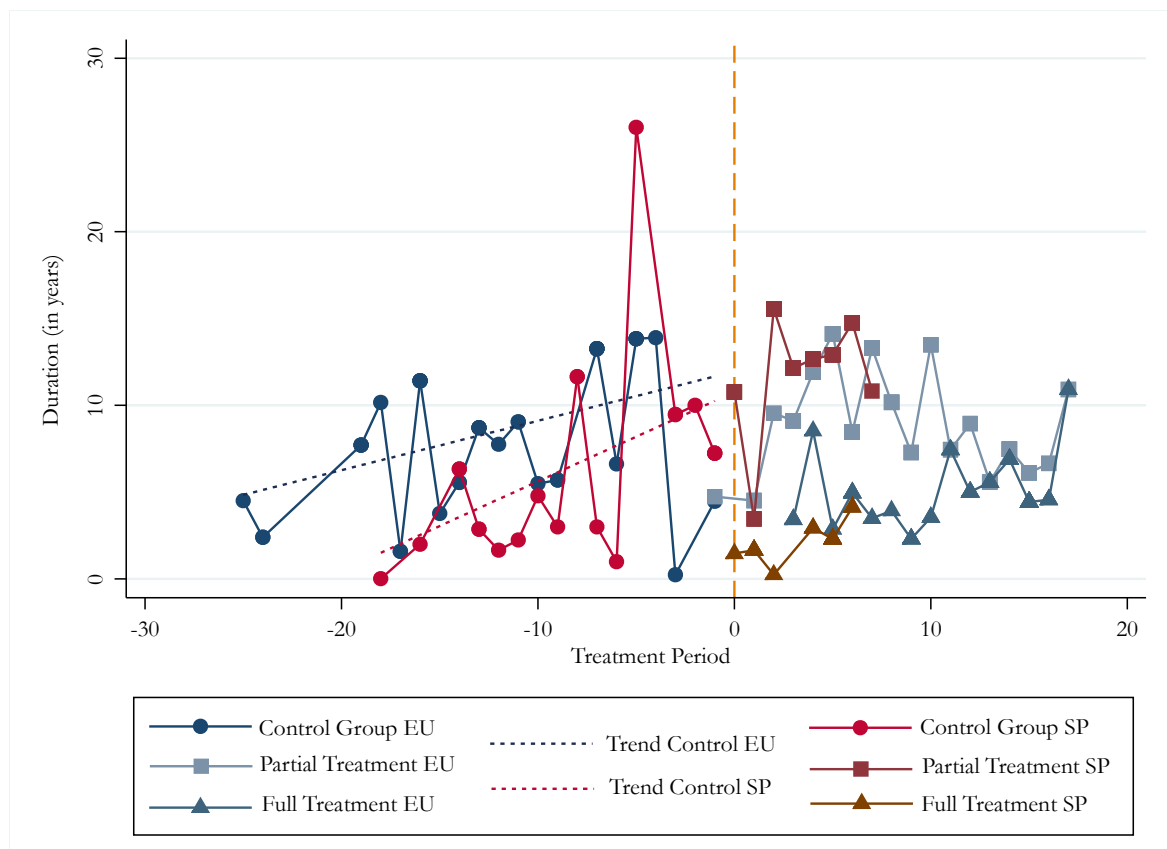
Source: Authors' elaboration from estimations included in Table 15.

Table 15 shows that the assumption of parallel trends is not rejected at the 5% significance level (even at the 10% significance level for most of the estimates) when investigation year or decision year fixed effects are included in the regression, except in model (6). So the parallel test assumption holds, and the diff-in-diff estimation of the impact of the leniency programs on cartel duration is unbiased and consistent when including investigation year fixed effects

Table 15. Log of Cartel Duration. OLS Regression. All leniency programs (EU96, EU02, EU06 & SP08)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Dummy Control EU	0.710	-0.145	-0.039	0.818	0.199	0.344
	(0.465)	(0.627)	(0.992)	(0.500)	(0.701)	(0.860)
Trend Control EU	0.013	0.023	0.018	0.009	0.019	0.011
	(0.034)	(0.032)	(0.027)	(0.032)	(0.030)	(0.033)
Dummy Control SP	-3.189**	-3.230*	-3.902**	-2.895**	-2.457*	-3.385***
	(1.159)	(1.551)	(1.232)	(1.053)	(1.227)	(0.828)
Trend Control SP	0.188***	0.157*	0.181**	0.182***	0.119*	0.17***
	(0.056)	(0.081)	(0.061)	(0.053)	(0.056)	(0.31)
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Control Variables	Yes	Yes	Yes	Yes	Yes	Yes
Observations	144	144	144	215	215	215
R^2	0.821	0.843	0.845	0.836	0.862	0.862
F-test [parallel trends] $\beta_{TrendEU} = \beta_{TrendSP}$	8.355	**2.460**	**3.868**	8.868	**3.196**	**6.792**
p-value [parallel trends assumption]	0.016	**0.147**	**0.078**	0.011	**0.097**	**0.022**
Sample	Uncovered by leniency	Uncovered by leniency	Uncovered by leniency	All treated cartels	All treated cartels	All treated cartels

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses. Dummy variables and trend variables for the different treatment groups were included in the regression, but they are not presented for simplicity. We neither reject the assumption of the parallel trends before the treatment for the duration in levels, not in logs.

Note on sample: *Uncovered by leniency* refers to cartels treated 1 in Figure 1, while *all treated cartels* refer to cartels treated 1, 2 and 3 in Figure 1.

Table 16 shows that in the case of the log of basic amount of fines, the parallel trend assumption holds for any specification of the regression at any significance level (5% or 10%). So the diff-in-diff estimates are unbiased and consistent estimates of the impact of the leniency programs on basic amount of fines.

Table 16. Log of Basic Amount of Fines (Deflated). Full Model. All leniency programs (EU96, EU02, EU06 & SP08).

Variables	(1)	(2)	(3)
Dummy Control EU	-2.218	0.252	3.363
	(1.775)	(3.034)	(6.750)
Trend Control EU	0.058	-0.016	-0.184
	(0.096)	(0.159)	(0.341)
Dummy Control SP	-1.600	-1.227	-3.554
	(2.540)	(3.197)	(3.081)
Trend Control SP	0.060	0.016	0.070
	(0.130)	(0.148)	(0.15)
After fixed effects	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes
Control Variables	Yes	Yes	Yes
Observations	118	118	118
R^2	0.916	0.945	0.943
F-test [equal coefficients in the trend controls == parallel trends]	**0.000**	**0.011**	**0.299**
p-value of the parallel trends assumption	**0.993**	**0.918**	**0.596**
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * $p<0.10$, ** $p<0.05$, ***$p<0.01$. Standard errors in parentheses. Dummy variables and trend variables for the different treatment groups were included in the regression, but they are not presented for simplicity. We neither reject the assumption of the parallel trends before the treatment for in the reduced form regression excluding duration as covariate.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartels for which some firms got fine reductions and that were alive when leniency was available.

Table 17 shows that in the case of the log of final fines, the parallel trend assumption also holds for any specification of the regression at any significance level (5% or 10%). So the diff-in-diff estimates are also unbiased and consistent estimates of the impact of the leniency programs on final fines.

Table 17. Log of Final Fines (Deflated). Full Model. All leniency programs (EU96, EU02, EU06 & SP08).

Variables	(1)	(2)	(3)
Dummy Control EU	-2.196	-3.421**	-3.026*
	(1.583)	(1.310)	(1.607)
Trend Control EU	0.097	0.125	0.108
	(0.110)	(0.104)	(0.119)
Dummy Control SP	-2.984	-3.100	-4.309**
	(2.219)	(2.067)	(1.711)
Trend Control SP	0.121	0.069	0.118
	(0.101)	(0.099)	(0.080)
After fixed effects	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes
Control Variables	Yes	Yes	Yes
Observations	163	163	163
R^2	0.886	0.918	0.919
F-test [equal coefficients in the trend controls == parallel trends]	**0.016**	**0.084**	**0.003**
p-value of the parallel trends assumption	**0.902**	**0.777**	**0.959**
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses. Dummy variables and trend variables for the different treatment groups were included in the regression, but they are not presented for simplicity.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel in which some members obtained immunity or fine reductions under the leniency program and that were alive when the program was in force.

Table 18 by contrast show that the parallel trend assumption does not hold for the diff-in-diff estimation of the impact of the leniency programs on the length of the investigation. The equal trends assumption is rejected at the 1% or 5% significance level. This rejection may be causing part of the bias that lead to the inconclusive results we found when trying to estimate such impact.

Table 18. Log of Years of Investigation. Full Model. All leniency programs (EU96, EU02, EU06 & SP08).

Variables	(1)	(2)	(3)
Dummy Control EU	0.63***	0.511**	0.393*
	(0.95)	(0.221)	(0.206)
Trend Control EU	0.005	0.007	0.005
	(0.009)	(0.008)	(0.006)
Dummy Control SP	1.718***	1.590***	1.409***
	(0.489)	(0.461)	(0.420)
Trend Control SP	-0.042*	-0.054**	-0.054***
	(0.020)	(0.20)	(0.016)
After fixed effects	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes
Control Variables	Yes	Yes	Yes
Observations	168	168	168
R^2	0.923	0.932	0.934
F-test [equal coefficients in the trend controls == parallel trends]	5.980	11.545	12.780
p-value of the parallel trends assumption	0.033	0.006	0.004
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses. Dummy variables and trend variables for the different treatment groups were included in the regression, but they are not presented for simplicity.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartels in which some members obtained immunity or fine reductions under the leniency program and that were alive when the program was in force.

Finally, Table 19 double checks whether our controls variables in most regressions are clean controls: do have common pre-trends in one and the other jurisdiction. This is clearly the case for the number of countries and the number of firms. The coefficients of the pre-trends cannot be distinguished statistically. However, this is not the case for cartel stability. There are differences. This is why, we do not use stability as a control in the regressions analyzing basic amount of fines, final fines nor the years of investigation. Results regarding cartel duration hold when we exclude stability as a control from the equations.

Table 19. Pre-trends of covariates. All leniency programs (EU96, EU02, EU06 & SP08)

Variables	Log of N Countries	Log of N Firms	Stability
Dummy Control EU	0.663***	1.950***	0.601***
	(0.187)	(0.154)	(0.091)
Trend Control EU	0.041**	0.002	-0.002
	(0.018)	(0.014)	(0.008)
Dummy Control SP	-0.247	2.568**	1.477***
	(0.262)	(0.888)	(0.221)
Trend Control SP	0.021	-0.029	-0.036**
	(0.016)	(0.041)	(0.015)
After fixed effects	No	No	No
Industry fixed effects	No	No	No
Observations	168	168	144
R^2	0.746	0.870	0.520
F-test [equal coefficients in the trend controls == parallel trends]	**1.161**	**0.505**	**2.769**
p-value of the parallel trends assumption	**0.304**	**0.492**	**0.127**
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Uncovered by leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses. Dummy variables and trend variables for the different treatment groups were included in the regression, but they are not presented for simplicity.
Note on sample: *Uncovered by leniency* refers to treated 1 in Figure 1. *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel in which some members obtained immunity or fine reductions under the leniency program and that were alive when the program was in force.

Annex 3: Heterogenous treatment effects

In this annex, we replicate the results of section 4 considering the implementation of the leniency program separately in EU and in Spain, this is, considering potential heterogenous effects. As commented above, results are weaker in Spain due to the low number of treated observations, especially in the case of full treatment – we have not been able to estimate this effect for most of the outcomes. However, in the case of partial treatment we find no heterogenous effects across jurisdictions in the case of cartel duration, basic fines or final fines, while some differences are found the in years of investigation.

Table 6b. Log of Cartel Duration. OLS Regression. All leniency programs in EU (EU96, EU02 & EU06) and in Spain (SP08)

Variables	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment EU	0.78***	0.68***	0.80*	0.67***	0.49***	0.65
	(0.07)	(0.12)	(0.41)	(0.08)	(0.14)	(0.37)
Full Treatment EU	-0.74***	-0.94***	-0.78**	-0.68***	-0.85***	-0.77**
	(0.14)	(0.10)	(0.28)	(0.11)	(0.10)	(0.26)
Partial Treatment SP	0.81	0.66	0.94**	0.90**	0.64**	0.76**
	(0.48)	(0.38)	(0.37)	(0.39)	(0.25)	(0.34)
Full Treatment SP	-0.19	-0.58**	-0.35	-0.92**	-0.94**	-0.81*
	(0.39)	(0.23)	(0.27)	(0.36)	(0.35)	(0.39)
Log N. Countries	0.01	-0.01	-0.03	0.02	0.03	0.01
	(0.05)	(0.10)	(0.10)	(0.05)	(0.08)	(0.08)
Log N. Firms	0.13*	0.24*	0.21	0.07	0.13	0.10
	(0.07)	(0.11)	(0.12)	(0.07)	(0.10)	(0.10)
Stability	-0.35	-0.15	-0.20	-0.41	-0.28	-0.31
	(0.20)	(0.14)	(0.10)	(0.24)	(0.19)	(0.18)
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	146	146	146	217	217	217
R²	0.273	0.366	0.360	0.390	0.444	0.440
Sample	Uncovered by leniency	Uncovered by leniency	Uncovered by leniency	All treated cartels	All treated cartels	All treated cartels

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.
Note on sample: *Uncovered by leniency* refers to cartels treated 1 in Figure 1, while *all treated cartels* refer to cartels treated 1, 2 and 3 in Figure 1.

Table 7b. Log of Basic Amount of Fines (Deflated). All leniency programs in EU (EU96, EU02 & EU06) and in Spain (SP08)

Variables	Full Model			Reduced Form		
	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment EU	1.84***	0.92***	0.76***	2.26***	1.08***	1.05**
	(0.57)	(0.18)	(0.18)	(0.63)	(0.13)	(0.42)
Full Treatment EU	1.55***	0.72***	1.11***	1.11***	0.25	0.62**
	(0.22)	(0.07)	(0.12)	(0.29)	(0.22)	(0.27)
Partial Treatment SP	0.07	-0.33	0.57	0.87	0.02	1.18**
	(0.92)	(1.06)	(0.68)	(0.96)	(0.78)	(0.49)
Full Treatment SP						
Log N. Countries	0.74**	0.52**	0.59***	0.73**	0.54***	0.59***
	(0.32)	(0.19)	(0.17)	(0.31)	(0.13)	(0.10)
Log N. Firms	0.02	0.44***	0.29***	0.14	0.57***	0.40**
	(0.27)	(0.10)	(0.10)	(0.30)	(0.16)	(0.15)
Log Duration	0.68***	0.52**	0.61***			
	(0.16)	(0.20)	(0.12)			
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	118	118	118	118	118	118
R²	0.617	0.755	0.754	0.551	0.726	0.714
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * $p<0.10$, ** $p<0.05$, ***$p<0.01$. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to cartel cases subject to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available. This group excludes dead cartels in which some of their members obtained immunity or fine reductions under the leniency program although these cartels were no longer alive when the program came into force. In those cases, leniency applicants revealed the existence, or cooperate if it had been revealed, of a dead cartel that was active before the leniency program came into force, cartels whose lifespan was prior to the entry into force of the leniency program.

Table 8b. Log of Final Fines (Deflated). All leniency programs in EU (EU96, EU02 & EU06) and in Spain (SP08)

Variables	Full Model			Reduced Form		
	(1)	(2)	(3)	(4)	(5)	(6)
Partial Treatment EU	**1.43***	**0.62**	**0.41***	**1.76***	**0.81***	**0.70***
	(0.16)	(0.22)	(0.18)	(0.10)	(0.20)	(0.29)
Full Treatment EU	**1.49***	**1.18***	**1.11***	**1.23***	**0.87***	**0.80**
	(0.20)	(0.10)	(0.14)	(0.17)	(0.15)	(0.27)
Partial Treatment SP	**0.29**	**0.56**	**0.68***	**0.76**	**0.81***	**1.08**
	(0.64)	(0.48)	(0.14)	(0.77)	(0.45)	(0.44)
Full Treatment SP						
Log N. Countries	0.80***	0.65***	0.69***	0.83***	0.66***	0.69***
	(0.22)	(0.16)	(0.15)	(0.21)	(0.15)	(0.15)
Log N. Firms	0.25	0.50***	0.46***	0.34*	0.61***	0.56***
	(0.16)	(0.11)	(0.11)	(0.18)	(0.15)	(0.14)
Log Duration	0.43***	0.35***	0.41***			
	(0.14)	(0.12)	(0.08)			
After fixed effects	No	Investigation Year	Decision Year	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Observations	163	163	163	163	163	163
R^2	0.519	0.664	0.669	0.487	0.646	0.644
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available. This group excludes dead cartels in which some of their members obtained immunity or fine reductions under the leniency program although these cartels were no longer alive when the program came into force. In those cases, leniency applicants revealed the existence, or cooperate if it had been revealed, of a dead cartel that was active before the leniency program came into force, cartels whose lifespan was prior to the entry into force of the leniency program.

Table 9b. Log of Years of Investigation. All leniency programs in EU (EU96, EU02 & EU06) and in Spain (SP08)

Variables	(1)	(2)	(3)
Partial Treatment EU	**0.15****	**0.08**	**0.03**
	(0.06)	(0.08)	(0.09)
Full Treatment EU	**0.27*****	**0.18***	**0.12**
	(0.06)	(0.09)	(0.07)
Partial Treatment SP	**-0.36*****	**-0.52*****	**-0.53*****
	(0.11)	(0.09)	(0.11)
Full Treatment SP			
Log N. Countries	0.13**	0.15**	0.14**
	(0.05)	(0.05)	(0.05)
Log N. Firms	0.05*	0.05	0.04
	(0.03)	(0.04)	(0.04)
Log Duration	0.02	0.01	0.01
	(0.04)	(0.04)	(0.04)
After fixed effects	No	Investigation Year	Decision Year
Industry fixed effects	No	Yes	Yes
Spain fixed effect	Yes	Yes	Yes
Observations	170	170	170
R²	0.271	0.298	0.308
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Table 10b. Log of Basic Amount of Fines (Deflated). All leniency programs in EU (EU96, EU02 & EU06)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	2.38***	2.45***	2.19***	2.24***
	(0.54)	(0.64)	(0.66)	(0.82)
ATT (m=5)	1.99***	1.97***	1.96***	2.10***
	(0.56)	(0.64)	(0.55)	(0.54)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	77	46	77	46
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 10c. Log of Basic Amount of Fines (Deflated). Leniency program in Spain (SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	1.32**		1.23*	
	(0.66)		(0.74)	
ATT (m=5)	1.56**		1.55**	
	(0.67)		(0.65)	
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	32		32	
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 11b. Log of Final Fines (Deflated). All leniency programs in EU (EU96, EU02 & EU06)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	3.04***	2.73***	2.93***	2.53***
	(0.50)	(0.47)	(0.49)	(0.47)
ATT (m=5)	2.30***	2.39***	2.28***	2.29***
	(0.34)	(0.40)	(0.34)	(0.37)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	107	81	107	81
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 11c. Log of Final Fines (Deflated). Leniency program in Spain (SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	1.19*	1.16	1.17*	-0.04
	(0.66)	(1.28)	(0.62)	(1.08)
ATT (m=5)	1.51***		1.40***	
	(0.55)		(0.50)	
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	39	20	39	20
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 12b. Log of Years of Investigation. All leniency programs in EU (EU96, EU02 & EU06)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	**0.41**** (0.18)	**0.51**** (0.21)	0.30 (0.19)	0.42** (0.19)
ATT (m=5)	**0.39**** (0.16)	**0.45**** (0.17)	0.35** (0.15)	0.41** (0.16)
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	114	88	114	88
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Table 12c. Log of Years of Investigation. Leniency program in Spain (SP08)

Estimator	Partial Treatment (1)	Full Treatment (2)	Partial Treatment (3)	Full Treatment (4)
ATT (m=1)	**-0.32***** (0.09)	**-0.37***** (0.08)	-0.40*** (0.11)	-0.14* (0.08)
ATT (m=5)	**-0.30***** (0.08)		-0.30*** (0.08)	
After fixed effects	Investigation Year	Investigation Year	Decision Year	Decision Year
Industry fixed effects	Yes	Yes	Yes	Yes
Observations	39	20	39	20
Sample	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency	Cartels benefiting from leniency

Note: * p<0.10, ** p<0.05, ***p<0.01. Standard errors in parentheses.

Note on sample: *Cartels benefiting from leniency* refers to treated 1 and treated 2 in Figure 1: cartel cases for which some members got immunity and/or fine reductions under the leniency program and that were alive when the program was available.

Note on controls: Matching cartels according to the number of countries of origin of the firms per cartel, the log of the number firms per cartel, the log of cartel duration, a dummy for Spain, industry fixed effects dummies, and the period after the introduction of leniency fixed effects dummies.

Annex 4: Cases included. European Commission

Decision year	Code	title	Decision year	Code	title	Decision year	Code	title
1969	26623	Intesa internazionale della chinina	2001	36490	Graphite electrodes/PO	2008	39180	Aluminium Fluoride
1969	26267	Materie coloranti	2001	37444 37386	SAS + Maersk Air	2008	39181	Candle waxes
1973	26918	European sugar industry	2001	36756	Sodium Gluconate	2008	39188	Bananas
1974	426	Papiers peints de Belgique	2001	37512	Vitamins	2008	39125	Carglass
1975	27039	Preserved mushrooms	2001	36604	Citric Acid	2009	39406	Marine hoses
1977	29176	Vegetable parchment	2001	37614	Interbrew + Alken Maes	2009	39401	E.ON/GDF
1979	29672	Floral	2001	37800	Luxembourg brewing industry	2009	39396	Calcium carbide and magnesium based reagents
1981	29995	NAVEWA-ANSEAU	2001	37027	Zinc Phosphate	2009	39129	Power Transformers
1982	29525/30000	SSI	2001	37391/37919	Bank charges	2009	38589	Heat stabilisers
1982	29629	Rolled Zinc	2001	36212	Carbonless paper (CLP)	2010	38511	DRAMS
1982	29883	AROW/BNIC	2002	36571	Österreichische Banken	2010	39092	Bathroom fittings & fixtures
1982	30128	Toltecs/Dorcet	2002	37519	Methionine	2010	38344	Pre-stressing steel
1983	30064	Cast Iron and Steel Rolls	2002	36700	PO/industrial and medical gases	2010	38866	Animal Feed Phosphates
1983	29995/30671	IPTC Belgium	2002	37784	Fine art Auction Houses	2010	39258	Airfreight
1984	30988	Benelux Flat Glass	2002	37152	PO/Plasterboard	2010	39309	LCD
1984	30350	Zinc Producer Group	2002	37978	PO/Methylglucamine	2011	39579	Consumer Detergents
1984	30907	Peroxygen products	2002	37667	Speciality graphite	2011	39482	Exotic fruit
1984	29725	Wood pulp	2002	37671	Food flavour enhancers	2011	39605	CRT glass bulbs
1985	30739	Siemens/Fanuc	2002	37956	Ronds à béton	2011	39600	Refrigeration compressors
1986	31149	Polypropylene	2003	38279	French Beef	2012	39452	Mountings for windows and window-doors
1986	31371	Roofing felt	2003	37370	Sorbates	2012	39462	Freight forwarding
1986	31204	MELDOC	2003	38359	Electrical and mechanical carbon and graphite products	2012	39611	Water management products
1986	31128	Fatty Acids	2003	37857	Organic Peroxides	2012	39437	TV and computer monitor tubes
1988	31424	Hudson's Bay-Dansk Pelsdyravlerforening	2003	38240	Tubes industriels en cuivre	2013	39748	Automotive Wire Harnesses
1988	31906	Italian Flat Glass	2004	38069	PO/Copper plumbing tubes	2013	39633	Shrimps
1988	31865	PVC	2004	37750	Brasseries Kronenbourg, Brasseries Heineken	2014	39801	Polyurethane foam
1988	31866	LdPE	2004	38238	Raw Tobacco (ES)	2014	39952	Power Exchanges
1989	31553	Welded steel mesh	2004	38338	Needles	2014	39922	Bearings
1990	33133	Soda-ash - Solvay, CFK	2004	37533	Choline chloride	2014	39610	Power Cables
1990	33133	Soda-ash - Solvay, ICI	2005	37773	MCAA (Monochloroacetic acid)	2014	39574	Smart Card Chips
1992	31572/32571	Buliding and construction industry in the Netherlands	2005	38337	Thread	2014	39924	Swiss Franc Interest Rate Derivatives (CHF LIBOR)
1992	32450	French-West African shipowners committees	2005	38281	Raw Tobacco IT	2014	39924	Swiss Franc Interest Rate Derivatives (Bid Ask Spread Infringement)
1992	30717	Eurocheque_ Helsinki Agreement	2005	38354	Industrial bags	2014	39780	Envelopes
1992	33585	Distribution of railway tickets by travel	2005	38443	Rubber chemicals	2015	39861	Yen Interest Rate Derivatives
1992	32450/32448	CEWAL, COWAC, UKWAL	2006	38620	Hydrogen peroxide (and perborate)	2015	40055	Parking heaters
1994	38907	Steel beams	2006	38645	Methacrylates	2015	39563	Retail Food Packaging
1994	33833	Cartonboard	2006	38456	Bitumen Nederland	2015	40098	Blocktrains
1994	33126/33322	Cement	2006	38121	Fittings	2015	39639	Optical Disc Drives
1994	33218	Far Eastern Freight Conference	2006	38638	Butadiene Rubber/Emulsion Styrene Butadiene Rubber	2016	39914	Euro Interest Rate Derivatives
1995	34202/34179	Stichting Certificatie Kraanverhuurbedrijf and Federatie van Nederlandse	2007	38899	Gas insulated switchgear	2016	39792	Steel Abrasives
1996	34983	Fenex	2007	38823	Elevators and escalators	2016	39965	Mushrooms
1996	34503	Ferry operators — Currency surcharges	2007	37766	Netherlands beer market	2016	40028	Alternators and Starters
1998	35814/39234	Extra d'alliage	2007	39168	Fasteners	2016	39904	Rechargeable Batteries
1998	33708	British Sugar	2007	38710	Bitumen Spain	2017	39824	Trucks
1998	35691	Pre Insulated Pipe Cartel	2007	38432	Professional videotape	2017	40018	Car battery recycling
1998	34466	Greek Ferries	2007	39165	Flat Glass	2017	39960	Thermal systems
1999	33884	Nederlandse Federatieve Vereniging voor de Groothandel op Electrotechn	2007	38629	Chloroprene Rubber	2017	40013	Lighting Systems
1999	35860	Seamless steel tubes	2008	38628	Nitrile Butadiene Rubber	2017	39881	Occupant Safety Systems supplied to Japanese Car Manufacturers
2000	34018	Far East Trade Tariff Charges and Surcharges Agreement	2008	38543	International Removal Services	2018	39920	Braking Systems
2000	36545	PO/Amino acids	2008	38695	Sodium Chlorate	2018	40009	Maritime Car Carriers
						2018	40113	SPARK PLUGS
						2018	40136	Capacitors

Note: The Commission's decisions IV/ 29.995 NAVEWA-ANSEAU and IV/30.671 — IPTC Belgium deal with the same cartel case.

Cartel cases 39792 Steel Abrasives, 39861 Yen Interest Rate Derivatives, 39965 Mushrooms, 39914 Euro Interest Rate Derivatives, 39824 Trucks are settlement hybrid cases which resulted in more than one European Commission's decision, in those cases the table displays the decision year of the the lastest one.

Annex 4: Cases included. Spanish Competition Authority

Decision year	Code	title	Decision year	Code	title
1995	354/94	ELECTRODOMÉSTICOS ALICANTE	2013	S/0385/11	CAMPEZO CONSTRUCCIONES
1996	376/96	CÁRTELES SIDRA	2013	S/0303/10	DISTRIBUIDORES DE SANEAMIENTO
1997	352/94	INDUSTRIAS LÁCTEAS	2013	S/0380/11	Coches de Alquiler
1997	370/96	DESMOTADORAS DE ALGODÓN 0	2013	S/0402/12	ESPUMA ELASTOMÉRICA
1998	395/97	VACUNAS ANTIGRIPALES	2013	S/0397/12	TRANSPORTES MADRID
1998	409/97	ALIMENTOS INFANTILES	2013	S/0314/10	PUERTO DE VALENCIA
1999	426/98	AZÚCAR	2013	S/0378/11	DESMOTADORAS DE ALGODÓN
1999	449/99	REPSOL/ESTACIONES DE SERVICIO	2014	S/0404/12	SERVICIOS COMERCIALES AENA
2001	506/00	TRANSPORTE MERCANCÍA VIZCAYA	2014	S/0445/12	EQUIPOS CONTRA INCENDIOS
2003	543/02	TRASMEDITERRÁNEA/EUROFERRYS/BUQUEBUS	2014	S/0428/12	PALÉS
2003	537/02	Reciclado de Vidrio	2014	S/0430/12	RECOGIDA DE PAPEL
2004	561/03	Líneas Marítimas Estrecho 2	2014	S/0453/12	RODAMIENTOS FERROVIARIOS
2004	555/03	Líneas Marítimas Estrecho	2015	S/0429/12	RESIDUOS
2004	565/03	MATERIALES RADIACTIVOS	2015	S/0473/13	POSTES DE HORMIGÓN
2006	588/05	DISTRIBUIDORES DE CINE	2015	S/0464/13	PUERTO DE SANTANDER
2007	617/06	CAJAS VASCAS Y NAVARRA	2015	S/474/13	PRECIOS COMBUSTIBLES AUTOMOCIÓN
2008	623/07	TRANSPORTES BARCELONA	2015	S/0425/12	INDUSTRIAS LÁCTEAS 2
2009	648/08	HORMIGONES CÁNTABROS	2015	S/0486/13	CONCESIONARIOS TOYOTA
2009	S/0037/08	Compañías de Seguro Decenal	2015	S/0489/13	CONCESIONARIOS OPEL
2009	S/0085/08	Dentífricos	2015	S/0487/13	Concesionarios Land Rover
2010	S/0014/07	Gestión de Residuos Sanitarios	2015	S/0488/13	Concesionarios Hyundai
2010	S/0084/08	FABRICANTES DE GEL	2015	S/0471/13	Concesionarios Audi/Seat/VW
2010	S/0106/08	ALMACENES HIERRO	2015	S/0469/13	FABRICANTES DE PAPEL Y CARTÓN ONDULADO
2010	S/0091/08	VINOS DE JEREZ	2015	S/0454/12	TRANSPORTE FRIGORÍFICO
2010	S/0120/08	TRANSITARIOS	2015	S/0484/13	REDES ABANDERADAS
2010	S/0080/08	NAVIERAS LINEA CABOTAJE CEUTA-ALGECIRAS	2015	S/0482/13	FABRICANTES DE AUTOMÓVILES
2011	S/0086/08	PELUQUERÍA PROFESIONAL	2015	S/0481/13	CONSTRUCCIONES MODULARES
2011	S/0107/08	PLATAFORMA DEL MEJILLÓN	2015	S/DC/0517/14	BODEGAS JOSÉ ESTÉVEZ
2011	S/0159/09	UNESA Y ASOCIADOS	2016	S/DC/0503/14	FABRICANTES DE TURRÓN
2011	S/0185/09	BOMBAS FLUIDOS	2016	S/DC/0505/14	CONCESIONARIOS CHEVROLET
2011	S/0224/10	COLOMER	2016	S/0455/12	GRUPOS DE GESTIÓN
2011	S/0167/09	Productores de Uva y Vinos de Jerez	2016	S/DC/0504/14	AIO
2011	S/0226/10	LICITACIONES DE CARRETERAS	2016	S/0519/14	INFRAESTRUCTURAS FERROVIARIAS
2011	S/0192/09	Asfaltos	2016	S/0506/14	CONCESIONARIOS VOLVO
2011	S/0060/08	SINTRABI	2016	SAMAD/09/2014	CONCESIONARIOS NISSAN
2011	S/0241/10	NAVIERAS CEUTA-2	2016	S/DC/0525/14	CEMENTOS
2011	S/0269/10	TRANSITARIOS 2	2016	S/DC/0544/14	MUDANZAS INTERNACIONALES
2011	S/0251/10	ENVASES HORTOFRUTÍCOLAS	2016	S/0555/15	PROSEGUR-LOOMIS
2012	S/0179/09	HORMIGÓN Y PRODUCTOS RELACIONADOS	2016	S/DC/0538/14	SERVICIOS FOTOGRÁFICOS
2012	S/0280/10	SUZUKI-HONDA	2017	S/0545/15	HORMIGONES DE ASTURIAS
2012	S/0244/10	NAVIERAS BALEARES	2017	S/DC/0512/14	TRANSPORTE BALEAR DE VIAJEROS
2012	S/0287/10	POSTENSADO Y GEOTECNIA	2017	S/DC/0562/15	CABLES BT/MT
2012	S/0318/10	EXPORTACIÓN DE SOBRES	2018	S/DC/0578/16	MENSAJERÍA Y PAQUETERÍA EMPRESARIAL
2012	S/0331/11	NAVIERAS MARRUECOS	2018	S/DC/0584/16	AGENCIA DE MEDIOS
2012	S/0317/10	MATERIAL DE ARCHIVO	2018	S/DC/0569/15	BATERÍAS AUTOMOCIÓN
2013	S/0293/10	TRANSCONT	2018	S/DC/0565/15	LICITACIONES DE APLICACIONES INFORMÁTICAS
2013	S/0343/11	MANIPULADO DE PAPEL			
2013	S/0342/11	ESPUMA DE POLIURETANO			
2013	S/0329/11	ASFALTOS DE CANTABRIA			
2013	S/0316/10	SOBRES DE PAPEL			

Note: For various reasons, the Spanish Competition Authority considered in several decisions the same cartel case, as happened in the following decisions:
S/0084/08 Fabricantes de gel and S/0224/10 Colomer; S/0120/08 Transitarios and S/0269/10 Transitarios 2; S/0226/10 Licitaciones de carreteras and S/0385/11 Campezo Construcciones.

Furthermore, the Spanish Authority adopted a new decision, S/DC/0517/14 Bodegas José Estévez, related to previous decision S/0091/08 Vinos Finos de Jerez.