Discussion Paper No. 17-002

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Centre for European Economic Research

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WHEN DO FIRMS LEAVE CARTELS?
DETERMINANTS AND THE IMPACT ON CARTEL SURVIVAL

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January 2017

Abstract

We use a dataset of 615 firms which participated in 114 illegal cartels – convicted by the European Commission between 1999 and 2016 – to investigate the determinants of the duration of a firm's participation in a cartel. Applying a Weibull proportional hazard model with a particular focus on the impact of internal and external time-varying determinants, we find that firms show an increased probability to leave a cartel if prior exits occurred as well as in periods of high demand growth. However, we find a reduced exit probability in situations of prior entries to the cartel or in periods of high interest rates. Additional estimations on the cartel level further suggest that firm exits increase the probability of a cartel breakdown substantially.

JEL Classification: C41, K21, L41

Keywords: Survival Analysis, Cartels, Duration, European Union

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1 Introduction

The last few decades have not only experienced a remarkable strengthening of the enforcement of anti-cartel laws – reflected, e.g., in the introduction of leniency programs, a substantial broadening of fine spectrums or a general increase in international cooperation between competition authorities – but also showed an equally impressive increase in theoretical, empirical and experimental research on the economic behavior of cartels. Although the various contributions shed light on the rise and fall of illegal cartel agreements from many different angles, they often relate to the question of "*What determines cartel success*?" (Levenstein and Suslow (2006)).

Although answers to this pivotal question are certainly multifaceted – and must consider insights on, e.g., the degree of price increases implemented by cartels – the duration of cartel agreements certainly is a key measure of cartel success. Consequently, several studies aimed at identifying the determinants of cartel duration – guided by the construction of hypotheses derived out of the existing theories of cartel formation and breakdown – by applying survival estimation techniques to various datasets of mostly illegal and international cartel agreements. Prominent examples include Dick (1996), Suslow (2005), De (2010), Levenstein and Suslow (2011) and Abrantes-Metz et al. (2013).

In this paper, we contribute to this empirical literature by applying a Weibull proportional hazard model with competing risks to a dataset of 114 cartels – consisting of 615 firms – which were convicted by the European Commission for cartelization between 1999 and 2016. In contrast to existing research, we are primarily not interested in explaining cartel duration as such but focus on the duration of a firm's participation in a cartel. Such an approach appears not only generally desirable – as cartels are rather loose agreements of legally independent firms which might at any time decide to end their involvement – but it especially allows the methodologically sound inclusion of several time-varying determinants of the duration of a firm's participation in a cartel. Potentially important variables to be considered are interest rate and demand growth fluctuations as external drivers and entry and exit of cartel members as internal drivers of cartel stability and thus duration.

However, despite this primary focus on the determinants of the duration of a firm's participation in a cartel, the broader question of the determinants of cartel duration certainly stays relevant. In our empirical setting, this is especially the case as it allows investigating the subsequent research question whether the exit of a cartel member has a negative impact on

cartel survival. In other words, in addition to answers to our primary research question *'when do firms leave cartels?'*, we are also able to provide evidence on the secondary research question *'whether a firm's break up spurs the cartel's breakdown?'*.

The remainder of the paper is structured as follows. In Section 2, we initially provide definitions of cartel duration in general and the duration of a firm's participation in a cartel in particular (Section 2.1). Subsequent to a brief review of the related literature on the determinants of cartel duration in Section 2.2, we develop seven sets of testable hypotheses on the determinants of the duration of a firm's participation in a cartel in Section 2.3. Section 3 is then devoted to our empirical analysis. While Section 3.1 introduces into the dataset and discusses the descriptive statistics, Section 3.2 carefully develops our empirical strategy based on survival analysis. Subsequently, Section 3.3 presents our estimation results and interpretation. Section 4 concludes the paper with a review of its main insights and a discussion of avenues for future research.

2 Cartel Duration and the Duration of Firm Participation

In this section, we start with an introduction of the definitions of cartels and cartel duration in general and our definition of the duration of an individual firm's participation in a cartel in particular (Section 2.1). Subsequent to a brief review of the related literature on the determinants of cartel duration (Section 2.2), we develop seven sets of testable hypotheses on the determinants of the duration of a firm's participation in a cartel (Section 2.3).

2.1 Initial Definitions and General Relevance

A cartel is typically defined as "… group of [legally independent] firms who have agreed explicitly among themselves to coordinate their activities in order to raise market price …" (Pepall et al. (1999), p. 345). From a welfare perspective, a (horizontal) cartel is expected to create both static and dynamic losses in consumer and (net) overall welfare due to elevated prices and reduced incentives for product or process innovations. Cartels are therefore a prime example for a per se prohibition reflected in many antitrust legislations around the world.

From a firm perspective, illegal cartel agreements aim at increasing profits – technically by internalizing the external effect the respective firms' separate business decisions impose on the profits of their competitors. However, although the general incentive of firms to reduce competitive pressures through cartelization is omnipresent, the respective costs and benefits of forming and stabilizing such agreements lead to different cartelization possibilities and

probabilities across markets. On the cartelization benefit side, the profit differential between the cartel profit and the competitive profit depends on the specifics of the market and market interaction. On the cartelization cost side, the costs of operating a cartel – e.g., for reaching and monitoring cartel agreements as well as antitrust fines and damages in case of detection – might become prohibitive for certain market/firm constellations.

The subsequent question after market and firm constellations with such a 'higher cartelization probability' has been addressed theoretically and empirically as part of research on so-called 'facilitating factors'. Rey (2006) – in accordance with many other commentators on the topic – subdivides these factors into structural, supply-related and demand-related factors. Structural factors that ease collusion include a low number of competitors, high entry barriers, frequent interaction between firms and market transparency. Demand-related factors include market growth, absence of significant demand fluctuations or business cycles, low demand elasticity, buying power and the absence of club and network effects. Finally, supply-related factors that ease collusive agreements include mature industries (with stable technologies), symmetric costs, symmetric capacities, product homogeneity, multi-market contact, structural links and cooperation and other contractual agreements.

Cartel duration and the duration of firm participation

In principle, the presence of sufficient (and permanent) net benefits of cartelization would suggest that cartels could last forever. However, in reality, many facilitating factors – and thus the incentives to stick to the agreement – frequently change over time thus challenging the stability and existence of the cartel. Significant changes of internal stability factors include the entry of additional firms into the cartel or capacity extensions of existing cartel members while possibly influential changes of external stability factors are interest rate or demand fluctuations. The implications of all these changes on the individual cartel member's profits are constantly evaluated by the members and might either lead to the exit of a cartel member (while the other members stay in the cartel) or to the complete breakdown of the cartel (thus the end of any coordination efforts among the firms in the market and the return to competition).

The instability of cartel agreements as such as well the individual firms' participation in a cartel suggests a separation of the analysis into 'duration on the cartel level' and 'duration on the cartel firm level'. Figure 1 below shows the entry and exit dynamics of a hypothetical

cartel that is subsequently being used to disentangle and further characterize the two main definitions.

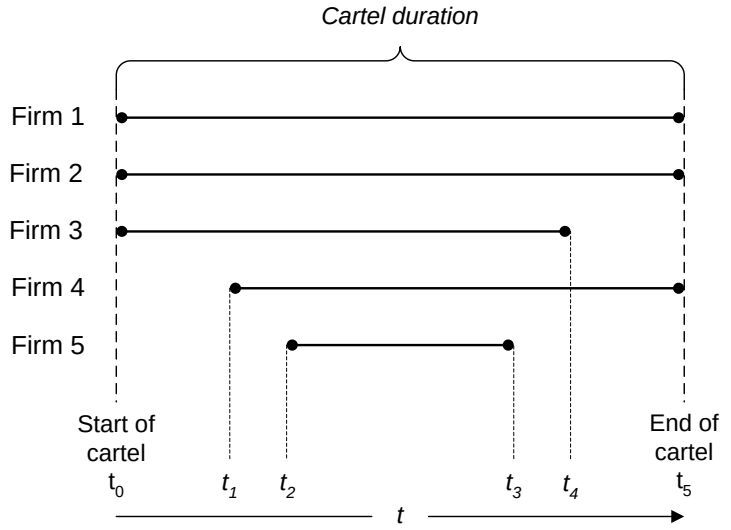

Figure 1: Cartel duration and duration of firm participation
Source: own illustration

In Figure 1, cartel duration is straightforward to calculate by subtracting the cartel end date from the cartel start date; i.e., $t_5 - t_0$.[1] However, as further shown in Figure 1, the duration of individual firm participation diverges partly substantially. While there is no difference with respect to firms 1 and 2 – as they were both founding members of the cartel in t_0 and stuck to the agreement up to its end in t_5 – firm 3 decides to leave the cartel earlier (in t_4) thus showing a shorter cartel duration. The same conclusion is true for firm 4 which entered the cartel in t_1; i.e., at a point in time at which it was already operating (but then decided to stay until the end of the cartel in t_5). Finally yet importantly, firm 5 is characterized by a late cartel entry in t_2 and an early cartel exit in t_3 thus showing the shortest duration of all cartel members.

Cartel entry and exit dynamics can be complex and can only be studied sensibly on the firm level. As suggested by the hypothetical example above, cartels may survive both entry and exit of members; i.e., complementary to the well-researched question of cartel duration as such (and the factors that might affect it), the broader research question after the determinants

[1] Although not the primary focus of our paper, Figure 1 also reminds us of the challenges of identifying clear cartel start and (particularly) end dates. In this respect, a recent paper by Boswijk et al. (2016) discusses in great detail why the official cartel end dates published by the competition authority need not necessarily be congruent with the duration of the actual infringement (which could endure beyond the formal breakdown due to, e.g., long-term supply contracts).

of cartel firm exits is likely to generate additional insights on the inner workings of cartels. In particular, following such an approach also allows answers to the question whether the entry or exit of a cartel member has an impact on both the participation duration of other firms in the cartel ('domino effect') and the duration of the cartel generally.

Actual duration of firms' participation in the European Commission's cartel cases

Before we turn to a description of the existing literature on cartel duration in general and the development of testable hypotheses for the duration of an individual firm's cartel participation in particular, it adds value to complement our discussion of the hypothetical cartel case above with real data from the European Commission's cartel cases. If we find that the majority of detected cartels did not experience firm entries and/or exits during their lifetime, the research questions sketched above would stay theoretical without any practical relevance. Figure 2 therefore plots the duration of firms' cartel participation – sorted by the start date of the cartel – on a cartel-by-cartel basis.

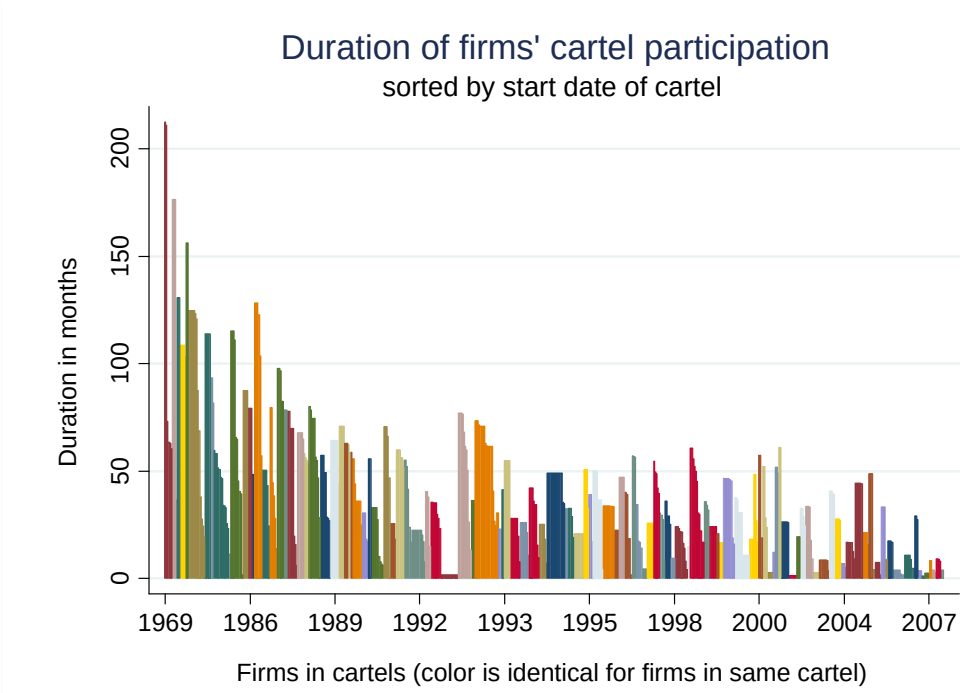

Figure 2: Duration of firms' cartel participation
Source: own figure based on ZEW cartel database

Figure 2 indicates that there is indeed substantial variation in duration among members of the same cartel.[2] Out of the 114 cartels shown in Figure 2, only 39 cartels show identical start and

[2] Additionally, Figure 2 also shows that the recently started 'younger' cartels have a lower average duration than the 'older' cartels. See Hellwig and Hüschelrath (2016) for a detailed discussion.

end dates for all of its members. Out of the majority of 75 remaining cartel cases with changes due to firm entry and/or exit, 23 percent experienced one such event, compared to 26 percent with two events and 51 percent with three or more entry/exit events (thus leading to different durations of firm participations in a cartel).[3] In other words, our simple descriptive evidence suggests substantial heterogeneity in individual firms' duration of cartel participation and thus makes an empirical assessment of the underlying determinants a highly relevant research question.

2.2 Review of the Literature on Cartel Duration

Although to the best of our knowledge, no prior research on the determinants of the duration of a firm's participation in a cartel exists, the more general literature on the determinants of cartel duration is closely related and relevant. Without wanting to provide a full-fledged review of this literature, it adds value to summarize the contents and methodological approaches of the seminal contributions.

From a *content perspective*, several academics have investigated the determinants of the duration of legal and/or illegal cartels for various geographic scopes. While Posner (1970) and Dick (1996) apply datasets of US cartels, De (2010) and Zhou (2012) use detailed data on the European Commission's cartel cases. The majority of studies, however, applies (partly different) datasets of international cartels to study the determinants of cartel duration (see Marquez (1994), Suslow (2005), Levenstein and Suslow (2011) and Abrantes-Metz et al. (2013)).

In addition to their geographical scope, the respective studies partly also differ with respect to the types of variables they identify as potential determinants of cartel duration. While literally all studies include the number of cartel members as basic variable, especially the later studies also consider further potential drivers such as the type of cartel agreement or the affected industries. Additionally, the later studies are able to include enforcement-related variables such as particularly the introduction of the leniency program. Furthermore, while the majority of studies also consider interest rates and demand growth as macroeconomic factors that might influence external cartel stability and thus duration, only De (2010) includes entry and exit activity as possible driver of cartel duration.

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[3] In sum, our sample of 114 cartels shows 154 entries and 116 exits of cartel members.

When it comes to the obtained results of the various empirical studies, partly large differences can be observed. In fact, we were unable to identify one single variable that consistently returned the same results – in terms of the signs of the respective coefficients – across all studies. While the partly different geographical scopes of the used datasets, the different mixes or legal and illegal cartels or the partly different definitions and constructions of the respective variables certainly explain part of this divergence, methodological issues must also be taken into account.

From a *methodological perspective*, it is important to note initially that the existing studies have only employed data with monthly resolution (see Abrantes-Metz et al. (2013), Suslow (2005), Zhou (2011, 2012)) or even relied on yearly data (see De (2010), Dick (1996), Levenstein and Suslow (2011)). This can be problematic as many actually different cartels are treated as sharing the same duration and thus cannot be distinguished. Furthermore, only a few studies have accounted for the competing risk of a cartel's non-natural death, i.e., being stopped by an agency instead of dying of natural causes (see De (2010), Levenstein and Suslow (2011), Zhou (2011, 2012)).

In terms of the chosen econometric approach, only two studies resorted to model duration using a Weibull parametrization (Dick (1996), Zhou (2011)) while the clear majority of studies relied on semi-parametric modeling. While not a disadvantage per se, we will argue below that – when focusing on time-dependent variables – a Weibull model turns out to be more efficient. Last but not least, only a few studies considered time-varying variables (see Levenstein and Suslow (2011), Suslow (2005))[4] and only one study accounted for unobserved heterogeneity (see Abrantes-Metz et al. (2013)).

In this context, we will employ a carefully motivated survival analysis on the cartel firm level using data on a day resolution while simultaneously exploiting time-varying covariates in a parametric model and accounting for the competing risk of collusion being stopped by an agency (instead of a natural death). We will also consider unobserved frailty. However, before we continue with a detailed description of our empirical approach in Section 3, the subsequent

[4] Although De (2010) also aims at including time-dependent variables in her analysis, the fact that she only focuses on yearly data questions the benefit of employing, e.g., demand growth data. Additionally, she aims at capturing cartel entries and exits by computing respective means over cartel duration. However, such a variable violates the assumption of predictability of covariates as this would imply that the number of entries or exits per year would be known already at the start of the cartel. See Section 3.2 below for a detailed discussion.

section develops seven sets of hypotheses for the determinants of the duration of a firm's participation in a cartel which can subsequently be tested.

2.3 Development of Testable Hypotheses

Aiming at investigating the determinants of the duration of firm's participation in a cartel requires the development of hypotheses that can subsequently be tested as part of our empirical analysis. Although the literature on cartel duration – sketched in the previous section – follows a partly different research question, theoretical research on cartel formation, stability and breakdown does not differ fundamentally between the cartel- and the firm-based analysis.

Without wanting to disregard any theoretical contributions on the topic of cartel stability (see, e.g., Motta (2004) or Rey (2006) for overviews), we will concentrate in the following on the development of hypotheses that we are able to subsequently test in our empirical analysis. Particularly, we will subdivide our discussions in the following seven categories: (1) cartel members, (2) types of agreement, (3) affected industry, (4) geographical scope, (5) cartel enforcement, (6) time-varying external factors, and (7) time-varying internal factors.

(1) Cartel members

The probably most straightforward (and least controversial) driver of cartel stability and duration is the number of cartel members. Ceteris paribus, a cartel with three members is easier to form and maintain than a cartel consisting of ten members. Furthermore, a larger number of cartel members increases the probability that at least one member turns unsatisfied with its profit share at some point and decides to realize the (greater) short-run gains from cheating. Finally yet importantly, with an increasing number of firms in the market, the incentives for one or more firms to become (a) cartel outsider(s) increase (thus reducing the size of the cartel's profit pie further).

H1a: The larger the number of other firms in the cartel, the higher the probability of a firm to leave the cartel.

In addition to the pure number of cartel members, it is reasonable to assume that the founding members of the cartel feel more connected to the agreement than firms that joined the agreement at a later point in time (and likely had less influence on the design of the agreement

thus increasing the probability for both intentional and accidental deviations from the agreement).

H1b: Founding members have a reduced probability to leave the cartel.

(2) Types of agreement

Although cartelization is often referred to as 'price-fixing agreement', in reality, cartel agreements regularly make use of a much broader menu of different types of agreements including quantity fixing or market sharing (aiming at preventing cheating more effectively, see, e.g., Posner (1970)). It can therefore be argued that cartels that only use simple price fixing as sole collusion strategy are expected to face stability issues earlier compared to agreements that make use of multiple types of agreement.

H2: Firms operating in cartels that only use price fixing as collusion strategy have an increased probability to leave the cartel.

(3) Affected industry

Although on the surface, the affected industry appears as rather diffuse driver of a firm's decision to leave the cartel, one argument in favor of an inclusion of the respective variable(s) is their relation to the degree of differentiation of the respective products. Ceteris paribus, it is more difficult to form and maintain a cartel agreement in a differentiated products industry compared to an industry with rather homogeneous and standardized products.

H3: Firms operating in industries with differentiated products have an increased probability to leave the cartel.

(4) Geographical scope

From at least two angles, the geographical scope of the cartel should be considered as a potentially important driver of cartel stability and the duration of a firm's cartel participation. First, ceteris paribus, it appears more complicated to monitor a worldwide cartel compared to an agreement that only focuses on several (ideally similar and geographically close) countries.[5] Second, cartels with a rather limited geographical scope increase the likelihood

[5] Furthermore, a worldwide cartel is likely to face an increased probability to be detected by a competition authority. Due to the recently intensified cooperation between competition authorities worldwide, e.g., the European Commission is likely to be informed of a (potentially worldwide) cartel that was detected in the United States.

that the respective members follow comparable business attitudes thus reducing the probability for both intentional and accidental deviations from the agreement.[6]

H4: Firms operating in worldwide or EU-wide cartels have an increased probability to leave the cartel.

(5) Cartel enforcement

In recent years, many competition authorities – including the European Commission – have strengthened cartel enforcement through the introduction of leniency programs.[7] As the first reporting firm is typically granted immunity from fines, it has an obvious advantage over the other cartel members thus suggesting that the introduction of the leniency program in the European Union in 1996 led to an increased probability for firms to leave the cartel. This can particularly be expected for marginal cartels that were at the border to unprofitability anyway.

H5: The introduction of the EU corporate leniency program in 1996 led to an increased probability for firms to leave the cartel.

(6) Time-varying external factors

As time-varying external factors that might affect cartel stability and the duration of a firm's cartel participation, we include interest rates and demand changes. Interest rates – as proxy for the discount factor – become relevant as cartel agreements aim at generating an (excessive) profit stream over an indefinite time horizon. In this context, it can be shown theoretically (see, e.g., Pepall et al. (1999)) that a cartel is more likely to be stable the greater the probability that the market will continue and the lower is the interest rate (basically because higher deviation profits have a smaller value in such a scenario).

H6a: The higher the interest rate, the higher the probability for firms to leave the cartel.

The second time-varying external factor we are able to include are demand changes. Ceteris paribus, it could be expected that cartels in growing markets are less stable than in saturated markets – e.g., either because the additional demand has to be allocated somehow to the

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[6] In this respect, it is important to remark that, by definition, our dataset on European cartel cases solely includes cases in which at least two separate countries are involved (as purely national cartels are enforced by the respective national competition authorities of the EU member states).

[7] A leniency program adopted in cartel cases promises the first cartel member that reports its involvement in the cartel to the competition authority immunity from fines. Further cartel members reporting their involvement to the authority might receive fine reductions of up to 50 percent depending on, e.g., the order of reporting and the additional value of the information provided.

respective cartel members thus creating potentials for conflict or because it is simply more difficult to detect attempts of cheating. Furthermore, following Rotemberg and Saloner (1986), cheating in the form of price wars may be more likely during substantial demand increases ('booms'), as in such a period, the incentives for firms to deviate from the cartel to attract additional consumers might outweigh the decrease in profits resulting from leaving the cartel.

However, a counterargument suggests that managers have reduced incentives to deviate from cartel agreements in growing markets, as they are able to reach their respective performance goals through general growth (and thus see no need to increase short-term revenues and profits by deviating from the cartel agreement). Furthermore, as shown in Ivaldi et al. (2007) collusion is easier to sustain in growing markets as today's profits are small compared to tomorrow's profits. However, as admitted by the authors themselves, this result only holds for a fixed number of firms in the market – an assumption that appears difficult to hold in growing markets. In particular, as market growth is expected to induce entry by new firms into the market/cartel, its presence may in fact complicate collusion. For our empirical analysis below, we therefore expect a positive relationship between demand growth and the probability of firms leaving the cartel.[8]

H6b: A growing (shrinking) demand leads to an increasing (decreasing) probability for firms to leave the cartel.

(7) Time-varying internal factors

As time-varying internal factors that might affect cartel stability and the duration of a firm's cartel participation, we include the entry or exit of firms as well internal restructuring activities within cartel members. Generally, it is reasonable to assume that every cartel must aim at increasing entry barriers in the industry, simply because excessive profits would attract further firms and sharing the cartel profit pie with these additional members is expected[9] to reduce the cartel member's individual shares. Furthermore, entry of a new and unexperienced

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[8] For shrinking demand, there are also competing hypotheses discussed in the literature (see, e.g., Schulz (2003)). On the one hand, shrinking demand could put additional pressures on the cartel members to increase short-run revenues and profits by exiting from the agreement. Furthermore, as argued in Green and Porter (1984), shrinking demand might be misinterpreted by cartel members as cheating attempt (thus triggering a punishment phase). On the other hand, cartel members might have elevated incentives to maintain their illegal agreements in times of shrinking demand (e.g., aiming at improving the revenue and profit situations of the suffering cartel members compared to the alternative of fierce competition).

[9] One exception could be the presence of a strongly growing market in which demand growth allows the entry of (a) further cartel member(s) without reducing the quotas/profits of the old cartel members.

cartel member is likely to create further stability issues (particularly if the entrant behaves aggressively and has a strong financial background, see, e.g., Motta (2004)).

H7a: The entry of a firm into the cartel leads to an increased probability for firms to leave the cartel.

Turning to the exit of a firm from the cartel, on the surface, one might argue that such an event decreases the probability of the remaining firms to leave the cartel as the cartel profit pie is now shared among fewer members. However, an observed exit might not only be a signal for a generally reduced efficiency of the cartel agreement but also the size of the post-exit cartel profit pie depends on the behavior of the exited firm (and possible further cartel outsiders). Additionally, the danger that the exited member will report the infringement to the competition authority is also likely to increase thus suggesting a further increase in the probability of further cartel firm exits. In sum, we therefore assume that the negative implications of a firm's exit from a cartel overcompensate the positive implications (from the perspective of the remaining cartel members).

H7b: The exit of a cartel member leads to an increased probability for further firms to leave the cartel.

Finally yet importantly, we are able to include internal restructuring activities within cartel members by observing changes (i.e., entries or exits) in the composition of jointly liable firms which are treated as cartel members as part of our analysis. Ceteris paribus, we expect that cartel members that have recently faced an internal restructuring have an increased probability to leave the cartel (e.g., as the management of the new company is not willing to participate in the illegal cartel agreement anymore).

H7c: Internal restructuring activities referring to changes in the composition of cartel members lead to an increased probability for firms to leave the cartel.

Before we turn to the description of our empirical approach in Section 3, it is important to close with a brief discussion of several data-driven limitations of our analysis. Although we have collected detailed information on a substantial number of possible drivers of the duration of a firm's cartel participation, several possibly influential variables turned out to be either unobservable or only available for (small) sub-sets of all European Commission's cartel cases. This is true for large parts of the internal cartel organization (e.g., the involvement of industry associations, implementation of detection, balancing or punishment measures etc.), the

presence and dimension of heterogeneities between cartel members (e.g., in terms of costs, capacity utilization, financial conditions or market shares), the existence and size of cartel outsiders, or the types and consequences of firm exits (e.g., bankruptcies or mergers, simple exits for unprofitability reasons, price wars following firm exits). Despite these limitations – which are faced (to different degrees) by all cartel duration studies reviewed in Section 2.2 above – we are confident to have collected a comprehensive dataset that allows studying the determinants of the duration of a firm's participation in a cartel in an innovative and meaningful way.

3 Empirical Analysis

In this section, we present our empirical analysis. While Section 3.1 introduces into the dataset and discusses the descriptive statistics – subdivided further into the cartel level, the firm level and our time-varying variables – Section 3.2 carefully develops our empirical strategy based on survival analysis. Subsequently, Section 3.3 presents our estimation results and interpretation.

3.1 Dataset and Descriptive Statistics

The dataset used in this paper comprises detailed information on 114 cartels convicted by the European Commission (EC) between 1999 and 2016.[10] The data were collected from decisions and press releases published on the EC's online platform[11] in the course of its investigations. The dataset generally combines case-related, cartel-related, firm group-related and firm-related information. For our empirical analysis, we use the data on the firm group level – defined as firms within one group that are linked through ownership and are jointly liable for cartel fines. However, for reasons of readability, we will simply speak of 'firms' rather than 'firm groups' in the remainder of the paper.

Before we turn to a brief discussion of our three forms of descriptive statistics, two general limitations of any study on the duration of cartel agreements or firm's cartel participation must be stated clearly. First, for obvious reasons, our sample can only consist of detected cartels; as a consequence, inference of our findings to the universe of all cartels might be

[10] In sum, 5 cases – decided in the period from 1999 to 2016 – had to be excluded from the analysis due to insufficient data on cartel duration and/or the duration of firm's participation in the cartel. The cases are Optical Disc Drives (Case COMP/39.639), Yen interest rate derivatives (Case COMP/39.861), Euro interest rate derivatives (Case COMP/39.914), Trucks (Case COMP/39.824) and Smart card chips (Case COMP/39.574).

[11] See http://ec.europa.eu/competition/antitrust/cases/index.html (last accessed on 6 January 2017).

problematic[12] even though we account for the competing risk of an agency death (implying that these cartels would still be active) in our empirical analysis.

Second, in defining duration, we follow the available legal information and use the cartel's and the respective firm's start and end dates stated in the EC decision documents. Although these dates are certainly the most reliable publicly available information – as they are the result of the EC's investigation work and are also used in the calculation of the basic fines – they need not necessarily be congruent with the actual infringement period (which could have started earlier and/or endured beyond the cartel breakdown due to, e.g., long-term supply contracts with customers, see Boswijk et al. (2016)).

Descriptive statistics on the cartel level

In the following, we provide some general descriptive statistics on the European Commission's cartels included into our dataset.[13] A detailed list of variable definitions is provided in Table A.1 in the Annex.

Starting with an initial general overview, the included cartels were mainly located in the European Union where they impaired the trade between member states; however, a significant fraction also had a worldwide scope. The cartels lasted at least two months with an average value of 90 months. The first cartel started in March 1969 and had the longest duration of about 35 years before it was terminated following a leniency application of the Finnish firm Kemira (Animal Feed Phosphates, Case COMP/38.866). The cartel with the most recent start date (June 2011) lasted about seven months before it was proactively detected by the EC (Power exchanges, Case COMP/39.952).

Table 1 presents the descriptive statistics on the cartel level and shows – in addition to the usual information on mean, standard deviation and minimum and maximum values – also the average duration in months for the respective cartels with the minimum or maximum values of the respective variable. Taking the 'Max. number of firms' variable as an example, Table 1 reveals that the cartels in our dataset had on average about 5 simultaneously active members over their lifetime (with a standard deviation of about 3). Those cartels having only 2

[12] Interestingly, recent theoretical research by Harrington and Wei (2016) suggests that a sample of detected cartels may tell us something about the latent universe of cartels.

[13] For a more detailed overview of European cartel cases and the cartel enforcement process, see Hellwig and Hüschelrath (2016).

members over their lifetime lasted on average 78 months, whereas the cartels with up to 17 members lasted about 147 months.[14]

Table 1 further reveals that the cartels experienced on average 1.35 entries – with a maximum number of 11 entries[15] – and on average one exit over their whole lifetime. Entries and exits of members are defined by the firms' legal start and end dates of participation in the respective cartel.

Table 1: Descriptive statistics – cartel level

Variable	Mean	St.D.	Min	Max	Average duration in months	
					for min value	*for max value*
Duration in months	89.48	74.17	2	422		
Cartel members						
Max. number of firms	5.34	3.10	2	17	78	147
Number of entries during lifetime	1.35	2.00	0	11	73	228
Number of exits during lifetime	1.02	1.36	0	8	72	231
Infringement						
Price fixing	0.22	0.42	0	1	102	48
Market sharing	0.06	0.24	0	1	87	136
Multiple	0.72	0.45	0	1	67	99
Industry						
Agriculture, forestry and fishing	0.03	0.16	0	1	92	21
Manufacturing	0.80	0.40	0	1	58	98
Wholesale and retail trade	0.03	0.16	0	1	91	62
Transport and storage	0.08	0.27	0	1	93	54
Financial and insurance activities	0.04	0.18	0	1	93	29
Other	0.04	0.18	0	1	89	121
Geographical scope						
Worldwide	0.12	0.33	0	1	94	65
EU-wide	0.57	0.50	0	1	89	91
Some countries	0.31	0.46	0	1	87	99
Enforcement related						
Natural death	0.24	0.43	0	1	99	59
N = 114 cartels						

As further shown in Table 1, almost three out of four cartels engaged in multiple infringements (i.e., some combination of price or quantity fixing, information/market sharing, or bid rigging) whereas only 22 percent were exclusive price-fixing cartels and 6 percent had only market-sharing agreements. Four out of five cartels were active in the manufacturing sector. The transport and storage sector is the second most important reaching a share of 8

[14] This actually only concerns the Bathroom fittings & fixtures (Case COMP/39.092) cartel that lasted about 12 years.

[15] This applies to the Prestressing steel cartel (Case COMP/38.344) that lasted about 18 years and had up to 16 simultaneously active members.

percent. Furthermore, there were also cartels detected in three other sectors with correspondingly even lower overall shares below 4 percent. Additionally, as already mentioned above, there is only a rather small share of worldwide cartels (12 percent) in our dataset; however, it is worth noting that these cartels lasted on average rather short showing an average duration of only 65 months.

Finally yet importantly, Table 1 reveals that only roughly a quarter of cartels died of a natural cause – and that these cartels had an on average shorter duration than those ending due to an agency intervention. In defining natural death, we question the usual approach that simply assumes a natural death if the investigation started after the official cartel end date. The start date of an investigation is usually the EC's raid or the date of the first official leniency program (LP) application. However, when firms file a written LP application, they have usually contacted the Commission beforehand. If the official application is just a few months after the cartel's end, it remains uncertain whether the other cartel member learnt about the initial (informal) application and immediately stopped the cartel.[16] The start of the investigation is then just a matter of time; however, the cause of death is not natural in the common sense. We therefore decided to ascribe a non-natural death to all cartels being detected because of a LP-application but for which the investigation already started within one year after the official end of the cartel. Since this is a rather conservative approach, we will conduct robustness checks for shorter transition periods as part of our empirical analysis below.[17]

Descriptive statistics on the firm level

Although the cartel level descriptive statistics provided some valuable first insights, our main interest in this paper is the level of the individual cartel members. We therefore reproduce large parts of Table 1 in Table 2; however, now from a firm level perspective. As already defined above, a firm – or synonymously a cartel member – is defined as a group of firms that are linked through ownership and are jointly liable for cartel fines. In sum, 615 firms have been involved in the 114 cartels of our sample and we will highlight a few important insights revealed in Table 2.

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[16] The case information provided by the EC is often hardly conclusive on this issue as many pieces of information in the publicly available decisions are classified.

[17] When applying the usual definition of a non-natural death (i.e., the start of the investigation lies before the cartel end date), the share of cartels with natural deaths increases to about 40 percent; a number comparable to the results reported in Hellwig and Hüschelrath (2016) who use a slightly different sample.

Table 2: Descriptive statistics – firm level

Variable	Mean	St.D.	Min	Max	Average duration in months	
					for min value	*for max value*
Duration in months	78.05	63.16	2	422		
Cartel members						
Founding member	0.70	0.46	0	1	66	83
Repeat offender	0.08	0.27	0	1	76	102
Member with greatest market share	0.20	0.40	0	1	75	92
Infringement						
Price fixing	0.27	0.44	0	1	90	45
Market sharing	0.04	0.19	0	1	77	112
Multiple	0.70	0.46	0	1	53	89
Industry						
Agriculture, forestry and fishing	0.01	0.12	0	1	79	21
Manufacturing	0.80	0.40	0	1	42	87
Wholesale and retail trade	0.02	0.14	0	1	79	40
Transport and storage	0.12	0.32	0	1	83	38
Financial and insurance activities	0.03	0.17	0	1	79	34
Other	0.02	0.13	0	1	77	112
Geographical scope						
Worldwide	0.13	0.34	0	1	82	52
EU-wide	0.55	0.50	0	1	76	80
Some countries	0.32	0.47	0	1	74	86
Enforcement related						
Natural exit	0.47	0.50	0	1	87	68
Applicability of leniency program						
- at start dates	0.45	0.50	0	1	107	44
- at end dates	0.90	0.30	0	1	46	82
N = 615 firms						

As revealed by Table 2, the average duration of a firm in a cartel is 78 months (which is clearly below the cartel level average identified above). Table 2 further shows that 70 percent of the firms were founding members implying that the cartels were subject to a non-negligible number of entrants which, by definition, have a shorter average duration (66 months compared to 83 months). Repeat offenders are 8 percent of the firms, showing an elevated average duration of 102 months. Members with the greatest (cartel) market share also remain on average longer in the cartel than their counterparts with lower market shares.

Table 2 also contains information on an equivalent to the cartel level natural death discussed above: 'natural exit' depicts whether a firm left independently of enforcement actions; i.e., a firm's participation in a cartel was neither stopped by an agency nor due to a LP-induced intervention. The latter is especially necessary to correctly handle competing risks, which implies to (right) censor any firm that would have remained active if it had not been stopped.

Treating all firms whose cartels dissolved a few months before the first official LP application as having 'naturally' exited appears inappropriate.[18] They might have kept on colluding and thus have to be (right) censored whereas only the LP applicant had an autonomous exit. By the same logic, if the date of the LP application lies before the official cartel end date, then this is only marking the natural exit of the applicant – and all other firms must be considered as censored. Therefore, we apply a different definition of natural death on the firm level than on the cartel level. As shown in Table 2, roughly half of the firms left the cartel naturally and these firms are characterized, as expected, by a lower average duration than those which might have otherwise kept on colluding.

Finally yet importantly, we have also added a variable indicating whether a leniency program was applicable for the respective firms at the time of their agreement. Since this indicator variable is varying over time – it becomes '1' in July 1996 when the EC's first leniency program went into force – one fraction of the firms in our dataset is never affected (10 percent) whereas another (larger) fraction is already affected from the beginning of their cartel participation (45 percent).

Descriptive statistics for the time-varying variables

Table 3 finally shows the descriptive statistics for our time-varying variables. In sum, our sample consists of more than 1.4 million observations (as we have one observation per day and firm). Focusing on days does not only allow treating duration as continuous but also enables us to distinguish the durations of firms that would otherwise be equal (when only focusing on months or even years). In addition, we can also make use of the interest rates' daily resolution.

Our external time-varying variables are interest rates – as proxy for the discount factor – and demand growth. For the former, we use the daily Bank of England base interest rate[19] (provided by the Bank of England) and for the latter, we calculate the respective values using monthly production data of the Euro area's total industry[20] (provided by the OECD). Figures

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[18] As this is also subject to our previously described 12-month transition period, we will run robustness checks as part of our empirical analysis below.

[19] The Bank of England (BoE) base interest rate is preferred over the Euribor due to its longer availability (as values for the latter are only available since 1994). However, both time series are highly correlated showing a Pearson's correlation coefficient of 0.90. As internationally operating firms can also receive financing rather easily elsewhere, the BoE interest rate can be taken as a reference value for European firms.

[20] See Table A.1 for detailed data description. We abstain from using industry-specific values as they might be flawed by cartel activity (and as they are available for a much shorter period only).

A.1 and A.2 in the Annex present overviews of the development of both time series. In our empirical analysis below, we will not employ actual demand growth but rather a lagged value in order to capture the level of information available at the time; i.e., we do not assume full rationality but presume firms to build their expectations on future demand growth by a more naïve no-change forecast.

Table 3: Descriptive statistics – time-varying factors

Variable	Over whole observation period				At failure times			
	Mean	**St.D.**	**Min**	**Max**	**Mean**	**St.D.**	**Min**	**Max**
Time-varying external factors[21]								
Interest rate (in percent)	7.85	4.18	0.50	17.00	4.97	1.65	0.50	8.88
Demand growth (in percent)	0.13	1.12	-5.01	5.73	0.07	0.91	-4.06	2.34
Time-varying internal factors								
Entry (6 months)	0.65	0.48	0	1	0.03	0.17	0	1
Entry (12 months)	0.65	0.48	0	1	0.07	0.25	0	1
Exit (6 months)	0.57	0.50	0	1	0.14	0.35	0	1
Exit (12 months)	0.57	0.50	0	1	0.30	0.46	0	1
Int. restructuring (6 months)	0.42	0.49	0	1	0.05	0.22	0	1
Int. restructuring (12 months)	0.42	0.49	0	1	0.15	0.36	0	1
N = 1,430,018 firm-day observations								

Notes: For internal factors, the rows in the column 'Over whole observation period' show the percentages of firms ever experienced an entry etc. while the rows in the column 'At failure times' show the experienced entries etc. X months before failure.

Table 3 is subdivided further into two times four columns with the left hand columns summarizing the variables regarding any dates occurring in our dataset and the right hand columns referring only to dates at which failures occurred. This distinction illustrates the difference between parametric and semi-parametric estimations regarding the usage of information. The Cox method only focusses on failure times and thus especially disregards the periods of high interest rates and demand growth (see next section). With maximum values being almost twice as high in non-failure times, this difference is non-negligible.

This feature also applies to the internal factors in our dataset: entry, exit and internal restructuring. For example, we observe many more entries and exits over the whole cartel lifetimes than when only focusing on failure times. In fact, they hardly ever occur at the same failure times (except for rare cases in which the whole cartel experiences a natural death). As we rather expect these factors to trigger exits, we extend their definitions in order to capture

[21] Please note that information on time-varying external factors is available from 1975 onwards only. Although our sample already starts in 1969, the shorter availability is not expected to create any significant problem, as the cartels starting earlier than 1975 did not cease to exit by 1975. They are thus simply treated as delayed entries and the estimations of the variables' impact on hazard are not impaired.

the dynamics; i.e., whenever a cartel experiences an entry or exit, a (respective) binary variable is set to '1' for the other cartel members. However, it is reset to '0' after six months. The construction of such a variable allows capturing whether any cartel member has experienced another firm's exit or entry in the six months before its own exit, and whether this has any impact on the hazard. Besides employing variables that focus on a 6-month period, we will also consider an extended period of one year (12-month period) as robustness check.

Table 3 thus indicates that 65 percent of firms experienced other firms entering the cartel, but only for 3 percent, such entry took place six months before their own exit. For the 12-month period, the respective value increases to 7 percent. With respect to exits, it is obvious that many more firms have experienced other exits in the periods before their own exit (6-month period: 14 percent; 12-month period: 30 percent).

Finally yet importantly, Table 3 also presents valuable insights on the third and final time-varying internal factor: internal restructuring. This variable aims at measuring whether cartel members have experienced internal changes during the cartel lifetime; i.e., it measures whether some form of internal restructuring took place in the months before exiting the cartel. In particular, the information in our dataset not only allows identifying whether a group of jointly liable firms gained or lost an additional member (e.g., through acquisitions or bankruptcies) but also captures whether this lead to a decision to end the cartel involvement. Table 3 reveals that such internal restructuring concerns 5 (15) percent of the firms in the 6 (12) months before their own exit.

3.2 Empirical Strategy

Aiming at investigating the determinants of the duration of a firm's cartel participation, we rely on survival analysis. Although survival analysis is mainly applied in biological and health sciences – where researchers are usually interested in the impact of certain drugs or other features on a patient's survival – it has also become more and more popular in social sciences in general and studies on the duration of cartels in particular (see Section 2.2 above). In the following, we will provide a careful description of our chosen empirical approach and will particularly discuss important assumptions that need to be fulfilled in order to receive meaningful regression results. We will cover the concept of hazard, (semi-)parametric models and their methods of estimation, time-varying covariates, and the definitions of duration while

referring to our cartel setting (see, e.g., Lancaster (1990) or van den Berg (2001) for more detailed technical treatments).

Hazard function

Survival analysis is about modelling the time to the occurrence of an event; i.e., the usual interest is in explaining why a subject leaves a certain state.[22] In the context of cartels, the focus is thus on the factors that trigger a breakdown or – as in our case – a firm's exit from a cartel. Proportional Hazard (PH) models describe the exit rate as a function of explanatory variables and the elapsed duration in the current state. This function is referred to as the hazard function, which is the rate at which the state is left at a certain time given that it has not been left before, as a function of time (van den Berg (2001), p. 3387).[23]

More formally, let T be a continuous non-negative random variable denoting the duration a subject remains in a certain state, and let t be the respective realization. The cumulative distribution function is $F(t) = Pr(T \leq t)$ with $F(0) = 0$. $F(t)$ is also called the failure function and $S(t) = 1 - F(t)$ refers to the survivor function. With $f(t)$ as the probability density function, the hazard function can be defined as $\theta(t) = f(t)/S(t)$. A PH model with a vector of covariates x can then be written as

$$\theta(t|x) = \theta_0(t) \cdot \lambda(x).$$

$\theta_0(t)$ depicts the baseline hazard function, which depends on t (but not on x) and is assumed to be common to all subjects. $\lambda(x)$ is a subject-specific (non-negative) function of x that scales the baseline hazard function. It is commonly modeled as $\lambda(x) = \exp(\beta' x)$ endowing PH models with their central property that absolute differences in x imply proportionate differences in the hazard at each t. The coefficient β depicts the time-independent

[22] This approach motivates Proportional Hazard models described in the following. Another specification concerns Accelerated Failure Time (AFT) models focusing on the effect of covariates on the mean (of the logarithm) of duration. However, they do not give an account of their effect on the individual hazard (see van den Berg (2001), p. 3425). At first glance, they thus appear quite similar to linear regression models. However, if the sole interest lies in the mean duration, AFT models are more suitable as they put different distribution assumptions on the residuals, which ensure the non-negativity of the conditional duration. AFT models can also account for censored duration data in contrast to linear regressions.

[23] Sometimes the hazard function is defined as the *probability* of failure in the next period conditional on having survived up to the present period. However, this only applies to discrete-time settings, in which one relies on interval-censored data. The smaller the intervals compared to duration, the closer one gets to a continuous definition of time (which gives the hazard function the interpretation of a rate). Having data on a daily resolution and cartels that lasted up to 35 years, we can safely employ continuous time methods.

proportional effect on the hazard. A positive value indicates a positive influence on the hazard meaning that an exit from the state is more likely.

PH models thus incorporate the crucial assumption that the subject-specific function acts multiplicatively on the baseline hazard function. Several tests are available and should be conducted since a violation of this assumption renders the model invalid.[24] If necessary, one remedy could be to stratify on the respective variable implying that the baseline hazard is then allowed to differ among subjects with different realizations of this variable. However, identifying any effects of this variable is then precluded. If a variable shows a time-dependent influence on the hazard, it is also possible to directly model the respective time-dependency in order to ensure the PH assumption. PH models allow for time-varying covariates – a property which is pivotal for our analysis and has hardly been exploited with respect to cartels in the existing literature.

The baseline hazard $\theta_0(t)$ describes the nature of duration dependence and can be modeled parametrically if one has information on its shape. Common forms are, e.g., the exponential or the Weibull function. For example, the Weibull model implies that $\theta_0(t) = p \cdot t^{p-1}$. Depending on the shape parameter p – which must be estimated – the hazard rate either falls monotonically with time $(p < 1)$, rises monotonically with time $(p > 1)$, or is constant $(p = 1)$. In the last case, the Weibull model reduces to an exponential model.

Non-parametric analysis, in contrast, is also possible. The Kaplan-Meier estimate of the hazard function, for example, does not condition on any covariates precluding, however, to learn about their impact. Semi-parametric analysis represents a compromise, which allows relaxing the assumption of a certain shape of the baseline hazard while still maintaining the proportional hazard assumption. Cox (1972) illustrates a partial likelihood estimator, which does not impose any restrictions on the baseline hazard. By using the ordering of events, he shows that the baseline hazard contributions cancel out.

The inefficiency of semi-parametric models

What looks appealing at first sight in an application of semi-parametric models comes at a price: the Cox method sacrifices efficiency for more flexibility. To substantiate this point, we

[24] The PH assumption can be checked graphically by examining whether the logarithm of the integrated hazard functions for different groups of subjects move in parallel over time. Alternatively, one can test whether the scaled Schoenfeld residuals (of a Cox regression) have a zero slope when being regressed on a function of time. It is also possible to model and check the time-dependency of a covariate.

introduce the likelihood functions used for the maximum likelihood estimation of the respective models. In parametric models, the sample likelihood function for subjects $i = 1, \dots, n$ with completed durations t_i is given by

$$\mathcal{L} = \prod_{i=1}^{n} f(t_i, x_i) = \theta(t_i, x_i) \cdot S(t_i, x_i) = \theta_0(t_i) \cdot \lambda(x_i) \cdot S(t_i, x_i).$$

The second and third identity are only printed to illustrate that the density function comprises the subject-specific part of the hazard function,[25] which builds the basis for the partial likelihood (PL) function employed by the Cox method. The latter is given by

$$PL = \prod_{j=1}^{D} \frac{\lambda(x_l)}{\sum_{k \in R_j} \lambda(x_k)},$$

where j indexes the ordered failures times t_j, $j = 1, \dots, D$; l is the subject[26] failing at t_j; R_j is the set of subjects k which are at risk at a time just prior to t_j (i.e., including subject l). The ratio depicts the probability that subject l has an event at t_j conditional on being in the risk set at t_j. Focusing only on such instances at which failures occur results in the cancelation of baseline hazards so that only the subject-specific contribution remains. Yet, it is important to point out that this approach does not make use of any information from instances at which no failure occurs. Some crucial information might thus be ignored.

Consider, for example, the impact of the interest rate on the decision to leave a cartel. Suppose that all exits observed in a sample took place when interest rates were rather low. If, at their failure times, the leaving firms were subject to slightly higher interest rates than the firms in the risk pool (which comprises all firms having the same duration as the leaving firm), one would conclude that higher interest rates have a positive impact on the hazard. This information is admittedly not wrong, however, it can greatly overestimate the real effect. Suppose that many firms encountered many periods of very high interest rates but none of these periods were present at a duration time at which another firm left. In the Cox model, this information would thus not be used even though it indicates that many firms managed to deal

[25] Please note that the density function can be easily written in terms of the hazard function due to a one-to-one relationship between these concepts. For the Weibull model, for example, the density function boils down to $f(t, x) = p\lambda t^{p-1} \exp(-\lambda t^p)$ with $\lambda = \exp(\beta' x)$.

[26] In this description, we focus only on one subject failing at a time. However, one might encounter ties, i.e., several subjects failing at a time – especially if one focuses on larger time intervals – what has to properly be accounted for when applying the Cox method.

with these high-interest periods (so that the effect of high interest rates on the hazard is in fact less severe). Parametric methods do not ignore this part of information and are thus more efficient.

Time-varying variables

As time-varying variables are of special interest for our empirical analysis, we accordingly focus on parametric models.[27] We opt for a Weibull model as we expect duration dependence in the form of a monotonically increasing hazard rate.[28] This is motivated by the cartel enforcement feature of how fines are set: they increase with longer participation in a cartel. Even though the clear fine guidelines set by the European Commission were not active from the beginning of the infringement for parts of the analyzed firms, cartel members certainly anticipate being subject to higher fines with longer participation.

Time-varying covariates can be incorporated into our analysis easily. Technically, for each subject, an observation has to be created for every time interval. However, when employing time-varying covariates, one has to ensure that x is a predictable process in order to perform valid econometric inference. This basically means that the values of covariates at t are only influenced by events that have occurred up to t, and these events are observable (van den Berg (2001)). This rules out, for example, interpolations that are computed using future values. Time-invariant variables are obviously predictable; however, the same conclusion is true for stochastic variables that depend on their past and outside variation (which renders, e.g., the use of interest rates valid). One might also include variables that capture the realizations of other durations given that their future realizations cannot be anticipated by the subject. With respect to our setting, all this implies that we have to assume that the cartel members do not know the exact exit dates of other members (which seems reasonable). The amplified number of observations per subject necessitates clustering on the subject-level in order to get robust standard errors.

Modeling duration

Special attention must be paid to the definition of duration. In this respect, all discussions so far assumed that the complete duration has been observed; i.e., start and end dates are known. However, there might be cases where only the subjects' end dates are known; i.e., duration is

[27] However, we will provide Cox regression results as robustness checks since the estimated coefficients should be comparable if we did not misparameterize the underlying baseline hazard (see Cleves et al. (2010)).

[28] This assumption seems to be confirmed as our analysis yields shape parameters p being greater than 1.

then said to be left censored. In contrast, one might observe only the start dates of some subjects as they might still be living at a given time (right censoring). These cases are distinct from cases in which parts of a population of subjects are never observed. Right truncation arises when only subjects failing before a given time are selected into the study. In contrast to such an exclusion of longer-living subjects, left truncation implies the exclusion of subjects with short durations; i.e., the sample only comprises subjects which did not die before a given time but might have died afterwards so that their start and end dates are known. Depending on the case, the likelihood function can be adjusted to account for these anomalies.

We now apply these definitions to our cartel context. Most cartels are presumably never detected. Information on cartel durations is thus mainly – and in this study solely – subject to detection; i.e., the respective samples are usually truncated. On the one hand, many cartels might still be active when a study is conducted. One the other hand, many cartels might possibly have experienced a natural death (but remain undetected). What appears as a problem of simultaneous right and left truncation – which could possibly be handled by adjustments of the likelihood function – is in fact more complicated as we cannot identify the duration of excluded cartels. In most classic survival analyses, the study framework allows to conclude whether the excluded subjects are longer- or shorter-lived. However, when focusing on cartels, a common start point does not exist and if so, we could never tell whether the still living but undetected cartels existed from the start.

Any inference can thus only be based on the population of detected cartels implying at least the advantage of known start and end dates. Still, another complication arises as cartels can end in two different ways: either they experience a natural death or they are detected while ongoing and thus experience an agency death. Survival analysis can account for such competing risks depending on whether the risks are assumed to be independent. Assuming independent risks means that subjects failing due to one risk are treated as if they could later experience the other failure type even though that is impossible (see Cleves et al. (2010)). This assumption seems justifiable in our case as cartels stopped by agency intervention would certainly experience a natural death later; however, an agency death can never be experienced after a natural death.

Our focus is thus only in the cause-specific hazard of a natural death implying that the competing risk of an agency death can simply be treated as (right) censored.[29] [30]

Although we were so far mostly referring to the cartel level, it is important to remark that our lines of thought also apply to the cartel member (firm) level. Their participation in a cartel is either stopped by an agency intervention or they left naturally meaning that either the whole cartel experienced a natural death or the respective firm left autonomously before the whole cartel dissolved at a later point in time.

Model to be estimated

We consequently arrive at estimating the following Weibull model for the duration of a firm's cartel participation by the method of maximum likelihood while accounting for right censoring due to the competing (independent) risk of an agency death:

$$\theta(t|x) = p \cdot t^{p-1} \cdot \exp\left(\beta' x + \gamma' z^i + \delta' z^e\right).$$

x denotes a vector of time-invariant cartel characteristics (such as number of other members, industry, type and geographical scope of infringement; see Section 2.3 above as well as the subsequent section), z^i is a vector of time-varying internal factors comprising other firms' entries into and exits from the cartel, and z^e is a vector of time-varying external factors such as interest rate and expected demand growth.

Although our primary focus in the paper is on the analysis of the duration of the cartel members' participation, it appears likely that individual firm behavior also affects the duration of the entire cartel. We therefore conduct an additional analysis in which we focus on cartel duration and the impact of past entry or exit. However, in contrast to the focus on the

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[29] If the risks were assumed to be dependent, our main interest would no longer lie in the cause-specific hazard but in the cumulative incidence function; i.e., one would presume that the probability of a natural death is not only a function of the hazard for a natural death but also a function of the hazard for an agency death. A medical example (taken from Cleves et al. (2010)) might help illustrating the interdependence: Consider a study aiming at investigating the duration until a breast tumor recurs at the same spot after initial removal. The study, however, only measures the first recurrence regardless of whether it was the local relapse of interest or a distant relapse. As a distant relapse certainly affects the general conditions rendering a local relapse more likely (even though the study is stopped before observing it), its hazard has to be accounted for – making both risks dependent from each other. In the cartel framework, the occurrence of an agency death cannot affect the risk of a natural death for the simple reason that the cartel already ceased to exist.

[30] The adjusted likelihood function is $\mathcal{L} = \prod_{i=1}^{n} [f(t_i, x_i)]^{\delta_i} \cdot [1 - F(C_i, x_i)]^{1-\delta_i}$ with $t_i = \min(T_i, C_i)$ and $\delta_i = \begin{cases} 1 \text{ if } T_i \leq C_i \\ 0 \text{ if } T_i > C_i \end{cases}$ indicating subjects who are not right censored.

individual cartel members described above, we cannot motivate a certain shape of the baseline hazard and therefore opt for a semi-parametric model.

3.3 Estimation Results and Interpretation

Based on the general description of our empirical strategy, we estimate different specifications of a Weibull proportional hazard model for the duration of firms' cartel participation using the method of maximum likelihood while accounting for right censoring due to the competing (independent) risk of an agency death. All specifications incorporate the number of simultaneously active cartel members including information whether the respective firm is a founding member. They further account for the cartels' different types of infringements, industries and geographical scopes as well as for the applicability of the leniency program. Time-varying factors are also included.

Whereas all specifications encompass the external factors interest rate and expected demand growth, they differ with respect to the internal factors. Each specification considers entry, exit, and internal restructuring indicators; however, while Model I focusses on the 6-month period, Model II applies a 12-month period before failure. These two main specifications are decomposed further – as part of sub-models a and b – by the types of entering or leaving firm, respectively.

3.3.1 Main Results on the Firm Level

Table 4 shows our main estimation results. It is important to remark initially that we always find a shape parameter p being statistically significant greater than one. This implies that there is a positive duration dependence. The hazard is increasing with longer duration. As this statement is true – conditioned on the covariates and while accounting for competing risks – we already learn that cartel participation seems to become more and more instable over time (which could be attributed to the firms' expectations of rising antitrust fines).

In discussing and interpreting our estimation results, we use the same structure as applied in Section 2.3 above and will thus refer to the seven categories of variables and the related eleven hypotheses. Furthermore, as all specifications produce comparable results, we concentrate our discussions on Model Ia and will highlight important differences to (or additional results of) the other specifications as they occur.

Table 4: Estimation results for Weibull PH model

Variable	Model Ia		Model Ib		Model IIa		Model IIb	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Cartel members								
Number of other members	-0.15***	[0.02]	-0.15***	[0.02]	-0.14***	[0.02]	-0.13***	[0.03]
Founding member	-0.31**	[0.14]	-0.31**	[0.15]	-0.29**	[0.14]	-0.29**	[0.14]
Infringement (base: multiple)								
Price fixing	0.83***	[0.15]	0.85***	[0.16]	0.79***	[0.15]	0.77***	[0.15]
Market sharing	-0.09	[0.26]	-0.08	[0.26]	0.02	[0.25]	0.02	[0.25]
Industry (base: manufacturing)								
Agriculture, forestry and fishing	1.10***	[0.34]	1.12***	[0.34]	1.25***	[0.32]	1.24***	[0.32]
Wholesale and retail trade	-0.52	[0.45]	-0.50	[0.45]	-0.58	[0.48]	-0.56	[0.48]
Transport and storage	0.32	[0.20]	0.33	[0.20]	0.35*	[0.20]	0.35*	[0.20]
Financial and insurance activities	0.31	[0.50]	0.31	[0.50]	0.41	[0.48]	0.41	[0.48]
Other	-1.43**	[0.70]	-1.44**	[0.71]	-1.26*	[0.70]	-1.24*	[0.70]
Geographical scope (base: EU-wide)								
Worldwide	0.64***	[0.17]	0.66***	[0.18]	0.41**	[0.17]	0.42**	[0.18]
Some countries	-0.33**	[0.14]	-0.32**	[0.15]	-0.34**	[0.14]	-0.34**	[0.15]
Enforcement related								
Leniency program	1.34***	[0.22]	1.35***	[0.22]	1.15***	[0.22]	1.16***	[0.22]
Time-varying external factors								
Interest rate	-0.17***	[0.03]	-0.17***	[0.03]	-0.19***	[0.03]	-0.19***	[0.03]
Expected demand growth	14.24**	[5.87]	14.26**	[5.89]	13.53**	[5.86]	13.37**	[5.89]
Time-varying internal factors		6 months				12 months		
Entry	-0.54**	[0.27]			-0.90***	[0.21]		
- Entry of repeat offender			0.16	[0.68]			-0.65	[0.65]
- Entry of member with greatest market share			(na)				-1.58	[1.03]
- Entry of other firm			-0.53*	[0.29]			-0.88***	[0.23]
Exit	1.02***	[0.16]			1.56***	[0.13]		
- Exit of repeat offender			1.32***	[0.41]			1.05***	[0.38]
- Exit of member with greatest market share			0.87*	[0.51]			1.96***	[0.27]
- Exit of other firm			1.00***	[0.17]			1.53***	[0.14]
Int. restructuring	-0.53**	[0.23]	-0.55**	[0.23]	-0.35**	[0.15]	-0.38**	[0.15]
Constant	-9.58***	[0.55]	-9.67***	[0.55]	-8.62***	[0.54]	-8.61***	[0.54]
Shape parameter *p*	1.21***		1.22***		1.11**		1.10*	
N	1430018		1430018		1430018		1430018	

Notes: Weibull PH model with competing risk of agency death treated as right censored; standard errors (SE) clustered on firm level; na: not applicable[31]; *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

[31] In fact, a hazard ratio of zero is estimated due to a negative collinearity between the covariate and the dead/censor variable meaning that there is never an entry of a firm with the greatest market share observed in the 6-month period before a failure.

(1) Cartel members

Starting with the results for the 'cartel members' category, our estimation results indicate that the number of simultaneously active cartel members has a statistically significant negative effect on firms' hazard; i.e., firms are less likely to leave cartels with more members. In quantitative terms, we can say that the hazard is about 14 percent lower with one additional active member.[32] Although this finding is surprising as it contradicts our expectation specified in *Hypothesis H1a*, a possible explanation is that the long-run losses from cheating increase with the number of firms in the cartel (as post-cartel competition will be fiercer) and thus firms refrain from exiting. A further explanation refers to our sample of detected cartels and argues that cartels with more members are simply breaking down with a higher probability (and are thus overrepresented in our sample).

For *Hypothesis H1b*, we find – as expected – that founding members of the cartel indeed have, at any point in time, a significantly lower hazard (by about 27 percent) than cartel members which joined the cartel at a later point in time.

(2) Types of agreement

With respect to the types of infringement, we find support for our *Hypothesis H2*. Cartels that only use price-fixing as collusion strategy have a significantly higher hazard than cartels using multiple agreements. In contrast, cartels organized by market-sharing agreements only are found to be hardly different from cartels using multiple agreements. In other words, market-sharing agreements appear to be a rather effective way to implement a collusion strategy.

(3) Affected industry

Turning to the estimation results for the affected industries, Table 4 shows that only firms in the agricultural sector have substantially higher hazards (by more than 200 percent) than in the manufacturing sector. Furthermore, we find no significant differences between the manufacturing sector and the wholesale and financial sectors. However, we do find some small indication for higher hazards for firms in the transport sector (reflected in a low statistical significance in Models IIa and IIb, respectively). The results further indicate that firms in the manufacturing sector have a significantly higher hazard than firms in the residual sectors. If we consider the manufacturing sector as being characterized by rather differentiated

[32] The underlying calculation is as follows: $100[exp(-0.15) - 1] = -13.93$.

products – while the agricultural and transport sectors produce rather homogeneous products – we thus find limited support for our *Hypothesis H3*.

(4) Geographical scope

Hypothesis H4 stated that firms operating in worldwide or EU-wide cartels have an increased probability to leave the cartel. As shown in Table 4, we find supporting evidence as not only firms in worldwide cartels have significantly higher hazards than firms in EU-wide cartels, but also that firms in cartels covering only some European countries are found to have the lowest hazards.

(5) Cartel enforcement

Hypothesis H5 referred to the availability of the leniency program as most important contemporary cartel enforcement tool and thus expected that the introduction of the program in July 1996 led to an increased probability for firms to leave the cartel. Across all specifications, we indeed find a clear and highly significant hazard increasing effect thus supporting the introduction of the policy.

(6) Time-varying external factors

Turning to the time-varying external factors, we find a negative influence of the interest rate on firms' hazard. This implies that we observe fewer exits with higher interest rates – a result that contradicts our *Hypothesis 6a*. An immediate reaction to this finding might be that simply more cartels have been detected in recent times (which were characterized by rather low interest rates). However, the detection date is not always equal to cartels' or firms' end dates. Furthermore, although Figure 2 above indicated that the majority of younger cartels have indeed shorter durations, cartel participation ended for nearly 90 percent of firms before 2008 (marking the beginning of the ongoing period of very low interest rates).[33] Finally yet importantly, referring to the more detailed empirical analysis in Levenstein and Suslow (2011), market interest rates might simply be a too broad measure to sufficiently capture the respective cartel member's patience (suggesting the use of firm-specific measures reflecting the individual cartel members financial situation).

[33] See Figure A.1 in the Annex for a graph showing the development of the interest rate. It is revealed that, before 2008, there is sufficient variation in the interest rate rendering our finding plausible.

Turning to our *Hypothesis H6b* – referring to the expected demand growth – we not only find supporting evidence but also a striking magnitude. One additional percentage point of expected demand growth increases firms' hazard million fold.[34] Firms are thus more likely to leave the cartel when they expect a growing market. Our results therefore support the theory of Rotemberg and Saloner (1986) sketched in Section 2.3 above.

(7) Time-varying internal factors

We finally turn to the results for our time-varying internal factors. With respect to entry into the cartel, our *Hypothesis H7a* expects that such an event leads to an increased probability of firms to leave the cartel. However, as revealed by Table 4, our estimation results show the opposite result; i.e., entry of another firm has a positive influence on duration. The variable capturing entry in general is statistically significant in both Models Ia and IIa.

If we investigate closer which kind of firms actually enter the cartel, we learn from Models Ib and IIb that entry by repeat offenders or firms with the greatest market share do not affect the hazard. The effect of entry in general is rather replicated by the entry of other firms since the respective variable exhibits an almost similar coefficient. This seems to be a consequence of the fact that in the months before a failure, only few entries are observed and even less for repeat offenders or firms with the greatest market share. However, it is important to note further that entry also seems to prolong the other firms' participation (i.e., lowering the firms' hazard by 40 to 60 percent) meaning that the cartel might get some kind of positive shock from entry. For example, it appears likely that the old cartel members are fully aware of the possible challenges created by a new and unexperienced cartel member and might thus decide to invest into both the integration of the new firm as well as an intensified monitoring of its behavior.

Turning to our *Hypothesis H7b* – the exit of cartel members – we find supporting evidence: the exit of a cartel member increases a firms' hazard (e.g., in Model Ia by about 175 percent). If the extended 12-month period is considered (Model IIa), this significantly positive effect even increases further to 375 percent. Again, it is possible to decompose the effect by distinguishing between different types of exiting firms. From Model Ib, it is obvious that all

[34] As this result is driven by our assumption that firms do not expect the past demand growth rate to change ('no-change naïve forecast'), we conduct a robustness check by employing the actual values for demand growth. Assuming such full rationality, the respective variable does not exhibit any significant influence on the hazard while the coefficients for all other covariates remain unchanged in terms of both size and significance.

kinds of leaving firms positively affect the hazard, but it is the exit of repeat offenders that affects the hazard the most. However, as this result only holds for the 6-month period – and the period taking into account other exits is just extended in the 12-month period in Model IIb – this result indicates that repeat offenders leave rather late in the respective cartels' lifetime (but if they do, they greatly affect the hazard). Furthermore, members with the greatest market share seem to generally leave earlier than repeat offenders; however, they also trigger further exits.

When interpreting these results, it is important to remind that we only focus on natural exits as part of our empirical analysis; i.e., our results cannot be interpreted in the sense of a forced domino effect as part of subsequent leniency applications. In fact, we identify a different type of 'domino effect' as part of which firms autonomously chose to exit the cartel after having observed that another member left.

Finally yet importantly, as part of *Hypothesis H7c*, we claimed that internal restructuring activities within the composition of cartel members lead to an increased probability for firms to leave the cartel. However, as shown in Table 4, we find the opposite result (across all specifications); i.e., an internal restructuring has a decreasing impact on the firms' hazard. In other words, a change in the composition of the ownership structure does not induce stopping the illegal behavior but these changes prolong a firm's participation in a cartel. Although we are unable to investigate possible explanations for this finding empirically any further, one explanation consistent with the evidence would be that firms actively acquire stakes of fellow colluding firms in an attempt to further reduce deviation incentives.

Robustness Checks

Before we close with an investigation whether firm exits have a measurable impact on total cartel duration, we briefly would like to discuss the results of several robustness checks. First, we relax the assumption of a Weibull shaped baseline hazard by estimating a semi-parametric model – which also accounts for the competing risk of an agency death – using the Cox method. Table A.2 in the Annex provides the respective results. If our assumption of a Weibull shape was not correct, then the estimated coefficients would not be comparable (see Cleves et al. (2010)). However, as this is not found to be the case, our general empirical approach is supported. The obtained results also remain similar in terms of both size and statistical significance. The only remarkable difference is an attenuated effect of expected

demand growth (which is likely to be a consequence of the less efficient estimation technique).

Second, the strong comparability of the parametric and semi-parametric estimation results facilitates checking the proportional hazards (PH) assumption. As elaborated in Section 3.2, the covariates should act multiplicatively on the baseline hazard function at each point in time. One way of checking this assumption is to test whether the scaled Schoenfeld residuals (for each covariate) have a zero slope when being regressed on a function of time. The Cox method facilitates the computation of Schoenfeld residuals, which is why we report the p-values for the global test of the null hypothesis of zero slopes in the last rows of Table A.2 in the Annex. For each specification, the null hypothesis cannot be rejected indicating that our variables do not violate the PH assumption. We have additionally checked whether the covariates exhibit a time-dependency that is not already captured in our model. We could not find opposing results and thus consider our model as robust.

Third, we have also checked robustness with respect to our definition of a cartel's natural death (which also affects the definition of a firm's natural exit and thus censoring). Our main model presented above drew on the classification of a cartel as having experienced an agency death if the investigation started before the cartel's official end date or if the investigation started within 12 months after the end of a cartel that was detected by the leniency program (LP). The latter is helpful for accounting for cartel breakdowns that are presumably caused by a key witness informally approaching the EC before its official (written) LP application (which initially marks the start of an investigation). However, this approach has increased the share of cartels with non-natural deaths in our sample. To check the robustness of our results, we shortened the period to six months and to the original zero months. Table A.3 reports the results for the latter case producing slightly different coefficients, however, without affecting the initially found statistical significance.[35]

Finally yet importantly, we also account for unobserved heterogeneity by extending the Weibull PH model to a mixed PH model, which incorporates an additional time-independent unobservable subject-specific effect ('frailty').[36] Unobserved heterogeneity seems possible

[35] We omit reporting the results for the 6-month case as they fall between the initial 12-month and the reported 0-month case. The results – as well as those for the other robustness checks – are available from the authors upon request.

[36] Mixed Proportional Hazard models (originally developed by Lancaster (1979)) can be described by the hazard function $\theta(t|x,v) = \theta_0(t) \cdot \lambda(x) \cdot v$, where v is the time-independent unobservable subject-specific effect. Assuming that v has a continuous positive distribution with expectation 1 and finite variance θ – a

among firms and among cartels. A mixed PH model with frailty modeled at the firm level, however, does not yield any indication for frailty influencing the firms' hazard (which is why we refrain from reporting these results[37]). In contrast, modeling frailty at the cartel level leads to a significant effect on the firms' hazard. However, we refrain from commenting on the results shown in Table A.4 in the Annex, as the direction of initially found effects remains the same for most variables. The only notable difference is that the time-varying internal factors entry and exit no longer have a significant influence when focusing on the 6-month period; however, they remain significant for the 12-month period.

3.3.2 Additional Results on the Cartel Level

Although the primary focus of our paper is on understanding the determinants of firm exit from cartel agreements, it appears likely that firm entries and exits will also affect cartel duration. We therefore conduct an additional empirical analysis on the cartel level to investigate whether *'a firm's break up spurs the cartel's breakdown'*. In particular, we apply a semi-parametric model as a motivation for a certain baseline hazard shape is not clear.

Furthermore, considering cartels instead of cartel members as subject of study requires a reassessment of the covariates. While controlling for cartel characteristics and including the time-varying internal factors of interest, i.e., entry and exits, remains to be essential, we refrain from disaggregating entries and exits (basically because there are only few cases of entering and leaving repeat offenders – or members with the greatest market shares – and they are hardly observed in the respective periods before a cartel failure).

Additionally, the inclusion of time-varying external factors is problematic from a methodological perspective. We learnt from our previous analysis that interest rate and expected demand growth affect the decision to exit a cartel. If such an exit triggers a lagged

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popular choice is the Gamma distribution – and that v is independent of covariates, they allow integrating out this random effect when deriving the survivor function. Above-average values of v imply that these subjects have higher hazards and leave more quickly. Ignoring this 'weeding out' of subjects can lead to inconsistent estimates (see van den Berg, 2001).

Furthermore, van den Berg and Drepper (2016) point out problems that could additionally arise if the frailty distribution is not independent of (left) truncation points. Biases could result if the likelihood function for delayed entry does not account for the 'weeding out' of truncated subjects. Our setting of detected cartels is originally not subject to left truncation; however, incorporating time-varying variables necessitates the creation of observations of each subject for all time intervals. Every but the first observation is then technically left-truncated. However, fortunately, this kind of truncation is not related to any 'weeding out' so that the correction proposed by van den Berg and Drepper (2016) is not necessary in our setting.

[37] With an estimated frailty variance $\theta = 0$, the coefficients of the initial Weibull PH model remain unchanged. The detailed results are available from the authors upon request.

natural breakdown of a cartel (i.e., the remaining members decide to end the cartel independently from agency intervention), then the realization of external factors might not be decisive and should not affect the hazard. However, if these realizations show a certain pattern at the failure times, their impact could be falsely estimated. Consequently, we disregard the time-varying external factors for our analysis on the cartel level and solely focus on entries and exits.[38] Table 5 shows the estimation results of a respective semi-parametric model, which (as before) accounts for right censoring due to the competing (independent) risk of an agency death.

Table 5: Estimation results for Cox PH model (cartel duration)

Variable	Model Ia		Model IIa	
	Coef.	**SE**	**Coef.**	**SE**
Cartel members				
Number of firms	-0.24**	[0.10]	-0.30***	[0.11]
Infringement (base: multiple)				
Price fixing	1.41***	[0.45]	1.23**	[0.49]
Market sharing	0.12	[0.74]	0.18	[0.65]
Industry				
Manufacturing	-0.27	[0.49]	-0.20	[0.53]
Geographical scope (base: EU-wide)				
Worldwide	0.81*	[0.48]	0.57	[0.54]
Some countries	-0.86	[0.59]	-0.94	[0.61]
Enforcement related				
Leniency program	2.08***	[0.75]	1.82**	[0.75]
Time-varying internal factors	6 months		12 months	
Entry	-0.99	[1.16]	-1.81*	[1.07]
Exit	0.89*	[0.52]	2.04***	[0.45]
p-value for violation of PH assumption	0.813		0.798	
N (cartel-day observations)	306020		306020	

Notes: Cox PH model with competing risk of agency death treated as right censored; standard errors (SE) clustered on cartel level; *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$; PH assumption is checked by testing the null hypothesis of zero slopes of scaled Schoenfeld residuals when regressed on analysis time.

In both specifications, a higher number of firms again implies a lower hazard. Also in line with our previous results, cartels with sole price-fixing agreements have a higher hazard while the presence of a leniency program reduces survival. The remaining variables do no longer show any statistically significant influence on the cartels' hazard (except for worldwide cartels in Model Ia).

[38] Inclusion of these factors result in a significant negative impact of the interest rate on cartels' hazard and in an insignificant influence of demand growth.

Turning to the results of the time-varying internal factors, i.e., entry and exit, we see that they indeed affect cartel duration significantly. While entry into the cartel shows a significant reduction of the cartels' hazard by 84 percent in Model IIa only, firm exit from the cartel is found to increase the hazard for a cartel breakdown between 144 percent (Model Ia) and 669 percent (Model IIa).

4 Conclusion

Rational but unethical firms join cartels if they believe – after a rigorous assessment of the respective costs and benefits – that their individual expected and discounted profit stream is larger than in the counterfactual scenario of normal competition. However, even if we assume that this necessary condition for profitable cartelization is typically met at cartel birth,[39] it would be premature to conclude that cartels typically last forever. Quite the contrary, both anecdotal and empirical research – see, e.g., Harrington (2006), Levenstein and Suslow (2006) or Hellwig and Hüschelrath (2016) – suggest that the life of cartels is constantly at stake due to various and frequent changes in the multitude of factors that influence internal and external cartel stability.

Consequently, cartel members regularly reassess the respective individual costs and benefits possibly leading – if the expected costs of cartelization are likely to dominate the expected benefits in the relevant time horizon – to the decision to leave the cartel. Although in some cases, such an exit of a cartel member will cause the immediate breakdown of the entire agreement; in other cases, the remaining members might be successful in stabilizing the cartel and continue colluding within the smaller group of firms.

In this context, we use a dataset of 615 firms which participated in 114 illegal cartels – convicted by the European Commission between 1999 and 2016 – to investigate the determinants of the duration of a firm's participation in a cartel. Applying a Weibull proportional hazard model with competing risks, we identify six determinants that contribute to an increase in the probability of a firm exit, compared to five determinants that have the opposite effect. In addition to rather fixed general duration determinants, our analysis on the firm level particularly allows investigating the role of internal and external time-varying determinants of cartel stability and thus duration.

[39] An example for a possible exception would be small cartel members which are 'forced' into an illegal agreement by the larger cartel members.

With respect to the rather fixed *general determinants* – already the focus of existing studies on cartel duration – we find that firms operating in worldwide cartels with rather differentiated products which only use simple price-fixing as collusion strategy and face the constant danger of dying through the application of a corporate leniency program show an increased probability to leave a cartel. In contrast, firms operating in cartels with a larger number of members which were also founding members show a significantly reduced probability to leave the cartel.

With respect to the *time-varying determinants* – the primary focus of our empirical analysis – we find that firms have an increased probability to leave the cartel if another cartel member already decided to leave in the 6- or 12-month period before ('domino effect') as well as in periods of high demand growth. However, we find a reduced probability for a cartel member's exit in situations of prior entry to the cartel, a period of high interest rates, and the occurrence of internal restructurings in the firms that constitute a cartel member. Our results remain robust if we relax the assumption of a Weibull shaped baseline hazard function or if we additionally account for unobserved heterogeneity.

In addition to our primary analysis on the firm level, we also investigate the follow-up question whether 'a firm's break up spurs the cartel's breakdown'; i.e., whether the exit of a cartel member has an *impact on cartel survival*. Our estimations on the cartel level indeed confirm that a firm's exit increases the hazard of a cartel breakdown while a firm's entry decreases it significantly. Furthermore, we also find that worldwide cartels which only use simple price-fixing as collusion strategy and operate under the threat of an effective leniency program show an increased breakdown probability.

Our analysis presented in this paper suggests at least two *avenues for future research*. First, although we are confident to have collected a comprehensive dataset that allows studying key determinants of the duration of a firm's participation in a cartel in an innovative and meaningful way, our empirical analysis has to cope with several data-driven limitations. In this respect, detailed cartel- or firm-related information on further determinants such as internal cartel organization, the presence and dimension of heterogeneities between cartel members, the existence and size of cartel outsiders, or the types and consequences of firm exits all bear the potential for valuable extensions of our empirical framework.

Second, it would generally be interesting to apply our methodology to other datasets of illegal cartel agreements in other jurisdictions. Such endeavors are not only likely to generate

additional insights on the inner workings of cartels but they would probably also allow collecting sufficient information on at least some of the additional variables just mentioned – thus contributing to an even richer empirical analysis of the determinants of the duration of a firm's participation in a cartel and their impact on cartel survival.

References

Abrantes-Metz, R., J. Connor and A. Metz (2013), The Determinants of Cartel Duration, Unpublished Working Paper, New York.

Boswijk, P., M. Bun and M.P. Schinkel (2016), Cartel Dating, Amsterdam Center for Law & Economics Working Paper No. 2016-05, Amsterdam.

Cleves, C., W. Gould, R. Gutierrez and Y. Marchenko (2010), An Introduction to Survival Analysis Using Stata, Third Edition, College Station.

Cox, D. (1972), Regression Models and Life-Tables (with Discussion), Journal of the Royal Statistical Society, Series B 34, 187-220.

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

Dick, A. (1996), When Are Cartels Stable Contracts?, Journal of Law and Economics 39, 241-283.

Green, E. and R. Porter (1984), Noncooperative Collusion Under Imperfect Price Information, Econometrica 52, 87-100.

Harrington, J. (2006), How Do Cartels Operate?, Foundations and Trends in Microeconomics 2, 1-105.

Harrington, J. and Y. Wei (2016), What Can the Duration of Discovered Cartels Tell Us About the Duration of All Cartels?, Economic Journal, forthcoming.

Hellwig, M. and K. Hüschelrath (2016), Cartel Cases and the Cartel Enforcement Process in the European Union 2001 – 2015: A Quantitative Assessment, ZEW Discussion Paper No. 16-063, Mannheim.

Ivaldi, M., B. Jullien, P. Rey, P. Seabright and J. Tirole (2007), The Economics of Tacit Collusion: Implications for Merger Control, in: Ghosal, V. and J. Stennek, The Political Economy of Antitrust, Amsterdam, 217-239.

Lancaster, T. (1990), The Econometric Analysis of Transition Data, Cambridge.

Lancaster, T. (1979), Econometric Methods for the Duration of Unemployment, Econometrica 47, 939-956.

Levenstein, M. and V. Suslow (2011), Breaking Up Is Hard to Do: Determinants of Cartel Duration, Journal of Law and Economics 54, 455-492.

Levenstein, M. and V. Suslow (2006), What Determines Cartel Success?, Journal of Economic Literature 44, 43-95.

Marquez, J. (1994), Life Expectancy of International Cartels: An Empirical Analysis, Review of Industrial Organization 9, 331-341.

Motta, M. (2004), Competition Policy: Theory and Practice, Cambridge.

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

Pepall, L., D. Richards and G. Norman (1999), Industrial Organization: Contemporary Theory and Practice, Boston.

Rey, P. (2006), On the Use of Economic Analysis in Cartel Detection, EUI-RSCAS/EU Working Paper, Florence.

Rotemberg, J. and G. Saloner (1986), A Supergame-theoretic Model of Business Cycle and Price Wars during Booms, American Economic Review 76, 390-407.

Schulz, N. (2003), Wettbewerbspolitik: Eine Einführung aus industrieökonomischer Perspektive, Mohr Siebeck, Tübingen.

Suslow, V. (2005), Cartel Contract Duration: Empirical Evidence from Inter-War International Cartels, Industrial and Corporate Change 14, 705-744.

Van den Berg, G. (2001), Chapter 55 – Duration Models: Specification, Identification and Multiple Durations, Handbook of Econometrics, Volume 5, 3381-3460.

Van den Berg, G. and B. Drepper (2016), Inference for Shared-Frailty Survival Models with Left-Truncated Data, Econometric Reviews 35, 1075-1098.

Zhou, J. (2012), Cartel Duration and Endogenous Private Monitoring and Communication: An Instrumental Variables Approach, Discussion Paper Series of SFB/TR 15 Governance and the Efficiency of Economic Systems No. 369, Mannheim.

Zhou, J. (2011), Evaluating Leniency with Missing Information on Undetected Cartels: Exploring Time-Varying Policy Impacts on Cartel Duration, Discussion Paper Series of SFB/TR 15 Governance and the Efficiency of Economic Systems No. 353, Mannheim.

Annex

Table A.1: Variables in the dataset

Variable	Description
Duration	Days from start to end of a firm's legally proved cartel involvement
Cartel members	
Founding member	=1 if firm is active in cartel from the beginning
Repeat offender	=1 if firm is a repeat offender
Member with greatest market share	=1 if firm has the highest market share within the cartel
Infringement	
Price fixing	=1 if cartel solely concerns price-fixing agreements
Market sharing	=1 if cartel solely concerns market-sharing agreements
Multiple	=1 if cartel concerns any combination of price- or quantity-fixing, information- or market-sharing, or bid-rigging
Industry	
Agriculture, forestry and fishing	=1 if cartel is active in industrial sector corresponding to A of NACE Rev. 2 classification
Manufacturing	=1 if cartel is active in industrial sector corresponding to C of NACE Rev. 2 classification
Wholesale and retail trade	=1 if cartel is active in industrial sector corresponding to G of NACE Rev. 2 classification
Transport and storage	=1 if cartel is active in industrial sector corresponding to H of NACE Rev. 2 classification
Financial and insurance activities	=1 if cartel is active in industrial sector corresponding to K of NACE Rev. 2 classification
Other	=1 if cartel is active in industrial sector corresponding to any other NACE Rev. 2 classification (i.e. D: Electricity, gas, steam and air conditioning supply; F: Construction; R: Arts, entertainment and recreation)
Geographical scope	
Worldwide	=1 if cartel market is worldwide
EU-wide	=1 if cartel market is EU-wide
Some countries	=1 if cartel market concerns only some countries in the EU
Enforcement related	
Natural death	=1 if cartel end date lies before the start of EC investigation or if the start of the investigation is at least one year after the cartel end date in case the cartel was detected because of a leniency program application
Natural exit	=1 if the firm left the cartel independent of enforcement reasons; i.e. the exit date is not equal to the non-natural-death cartel end date
Leniency program	=1 after the introduction of the first leniency program on July 18, 1996
Time-varying external factors	
Interest rate (in percent)	Bank of England Official Bank Rate; daily resolution; available since January 1975; Source: Bank of England, series IUDBEDR
Demand growth (in percent)	Production of total industry for Euro area (prior to 1990 this comprises mainly the first 12 Euro area member states plus Denmark, Sweden and the United Kingdom); monthly resolution; available since July 1975; Source: OECD Stat, Production and Sales (MEI)
Expected demand growth	Naïve no-change forecast of demand growth, i.e., actual demand growth lagged by one period
Time-varying internal factors	
Entry (X months)	=1 if firm has experienced an entry of another firm into the cartel in the past X months
Exit (X months)	=1 if firm has experienced an exit of another firm from the cartel in the past X months
Int. restructuring (X months)	=1 if firm has experienced some form of internal restructuring in the past X months (i.e., the composition of jointly liable firms establishing this cartel member has changed)

Table A.2: Estimation results for Cox PH model

Variable	Model Ia		Model Ib		Model IIa		Model IIb	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Cartel members								
Number of other members	-0.14***	[0.02]	-0.14***	[0.02]	-0.13***	[0.03]	-0.13***	[0.03]
Founding member	-0.32**	[0.15]	-0.31**	[0.15]	-0.31**	[0.14]	-0.33**	[0.14]
Infringement (base: multiple)								
Price fixing	0.79***	[0.16]	0.81***	[0.16]	0.73***	[0.16]	0.72***	[0.16]
Market sharing	-0.18	[0.29]	-0.16	[0.29]	-0.13	[0.28]	-0.14	[0.28]
Industry (base: manufacturing)								
Agriculture, forestry and fishing	1.09***	[0.36]	1.12***	[0.36]	1.17***	[0.34]	1.16***	[0.34]
Wholesale and retail trade	-0.45	[0.45]	-0.43	[0.45]	-0.51	[0.49]	-0.51	[0.49]
Transport and storage	0.29	[0.20]	0.30	[0.20]	0.26	[0.20]	0.25	[0.20]
Financial and insurance activities	0.43	[0.50]	0.44	[0.50]	0.50	[0.48]	0.49	[0.48]
Other	-1.49**	[0.71]	-1.50**	[0.71]	-1.41*	[0.72]	-1.39*	[0.72]
Geographical scope (base: EU-wide)								
Worldwide	0.65***	[0.18]	0.68***	[0.18]	0.45***	[0.17]	0.46***	[0.18]
Some countries	-0.36**	[0.15]	-0.35**	[0.15]	-0.34**	[0.15]	-0.35**	[0.15]
Enforcement related								
Leniency program	1.31***	[0.22]	1.31***	[0.22]	1.13***	[0.21]	1.13***	[0.21]
Time-varying external factors								
Interest rate	-0.17***	[0.03]	-0.17***	[0.03]	-0.20***	[0.03]	-0.20***	[0.03]
Expected demand growth	10.40*	[5.60]	10.47*	[5.61]	10.44*	[5.76]	10.49*	[5.79]
Time-varying internal factors	6 months				12 months			
Entry	-0.81***	[0.29]			-1.08***	[0.23]		
- Entry of repeat offender			-0.24	[0.68]			-0.82	[0.64]
- Entry of member with greatest market share			(na)				-1.83*	[1.04]
- Entry of other firm			-0.75**	[0.30]			-1.07***	[0.25]
Exit	0.94***	[0.17]			1.46***	[0.14]		
- Exit of repeat offender			1.34***	[0.46]			0.93**	[0.40]
- Exit of member with greatest market share			0.77	[0.57]			1.84***	[0.31]
- Exit of other firm			0.92***	[0.18]			1.44***	[0.14]
Int. restructuring	-0.48**	[0.23]	-0.51**	[0.23]	-0.28*	[0.17]	-0.31*	[0.17]
p-value for violation of PH assumption	0.629		0.668		0.675		0.905	
N (firm-day observations)	1430018		1430018		1430018		1430018	

Notes: Cox PH model with competing risk of agency death treated as right censored; standard errors (SE) clustered on firm level; na: not applicable; *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$; PH assumption is checked by testing the null hypothesis of zero slopes of scaled Schoenfeld residuals when regressed on analysis time.

Table A.3: Estimation results for Weibull PH model (altered definition of natural death)

Variable	Model Ia		Model Ib		Model IIa		Model IIb	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Cartel members								
Number of other members	-0.18***	[0.02]	-0.18***	[0.02]	-0.18***	[0.03]	-0.17***	[0.03]
Founding member	-0.36***	[0.13]	-0.36***	[0.13]	-0.33***	[0.13]	-0.33***	[0.13]
Infringement (base: multiple)								
Price fixing	0.98***	[0.14]	0.99***	[0.14]	0.94***	[0.14]	0.93***	[0.14]
Market sharing	-0.06	[0.21]	-0.05	[0.21]	0.04	[0.21]	0.05	[0.21]
Industry								
Agriculture, forestry and fishing	0.94***	[0.32]	0.96***	[0.32]	1.06***	[0.31]	1.07***	[0.32]
Wholesale and retail trade	-0.75*	[0.45]	-0.74	[0.45]	-0.84*	[0.48]	-0.82*	[0.48]
Transport and storage	0.29	[0.19]	0.30	[0.19]	0.33*	[0.18]	0.33*	[0.18]
Financial and insurance activities	0.08	[0.50]	0.08	[0.50]	0.21	[0.48]	0.22	[0.48]
Other	-1.65**	[0.71]	-1.66**	[0.72]	-1.48**	[0.71]	-1.48**	[0.71]
Geographical scope (base: EU-wide)								
Worldwide	0.56***	[0.17]	0.57***	[0.17]	0.35**	[0.16]	0.36**	[0.17]
Some countries	-0.30**	[0.12]	-0.29**	[0.12]	-0.31**	[0.12]	-0.32***	[0.12]
Enforcement related								
Leniency program	1.52***	[0.22]	1.52***	[0.22]	1.34***	[0.22]	1.33***	[0.22]
Time-varying external factors								
Interest rate	-0.16***	[0.03]	-0.16***	[0.03]	-0.18***	[0.03]	-0.18***	[0.03]
Expected demand growth	9.74*	[5.46]	9.70*	[5.48]	9.39*	[5.46]	9.17*	[5.48]
Time-varying internal factors		6 months				12 months		
Entry	-0.51**	[0.25]			-0.58***	[0.17]		
- Entry of repeat offender			0.09	[0.68]			-0.76	[0.67]
- Entry of member with greatest market share			(na)				-0.23	[0.51]
- Entry of other firm			-0.48*	[0.27]			-0.62***	[0.18]
Exit	1.18***	[0.15]			1.61***	[0.12]		
- Exit of repeat offender			1.17***	[0.42]			1.01***	[0.38]
- Exit of member with greatest market share			1.23***	[0.37]			1.85***	[0.22]
- Exit of other firm			1.16***	[0.16]			1.60***	[0.12]
Int. restructuring	-0.57***	[0.21]	-0.58***	[0.21]	-0.46***	[0.14]	-0.45***	[0.14]
Constant	-9.75***	[0.52]	-9.83***	[0.52]	-9.00***	[0.50]	-9.01***	[0.51]
Shape parameter *p*	1.24***		1.25***		1.16***		1.16***	
N (firm-day observations)	1430018		1430018		1430018		1430018	

Notes: Weibull PH model with competing risk of agency death treated as right censored; standard errors (SE) clustered on firm level; na: not applicable; *: p < 0.1, **: p < 0.05, ***: p < 0.01

Table A.4: Estimation results for Weibull mixed PH model

Variable	Model Ia		Model Ib		Model IIa		Model IIb	
	Coef.	SE	Coef.	SE	Coef.	SE	Coef.	SE
Cartel members								
Number of other members	-0.24***	[0.06]	-0.24***	[0.06]	-0.17***	[0.05]	-0.18***	[0.05]
Founding member	-0.70***	[0.16]	-0.71***	[0.16]	-0.60***	[0.16]	-0.60***	[0.16]
Infringement (base: multiple)								
Price fixing	1.69***	[0.49]	1.71***	[0.50]	1.47***	[0.41]	1.52***	[0.42]
Market sharing	-1.39**	[0.71]	-1.41**	[0.72]	-0.88	[0.63]	-0.89	[0.63]
Industry (base: manufacturing)								
Agriculture, forestry and fishing	0.72	[1.04]	0.72	[1.05]	0.88	[0.92]	0.85	[0.92]
Wholesale and retail trade	-1.46	[1.24]	-1.47	[1.25]	-1.07	[1.12]	-1.08	[1.12]
Transport and storage	0.50	[0.89]	0.51	[0.90]	0.10	[0.71]	0.07	[0.72]
Financial and insurance activities	1.58	[0.97]	1.61*	[0.98]	1.33	[0.86]	1.29	[0.86]
Other	-2.77**	[1.16]	-2.78**	[1.17]	-2.32**	[1.07]	-2.34**	[1.07]
Geographical scope (base: EU-wide)								
Worldwide	0.91	[0.66]	0.92	[0.67]	0.90	[0.56]	0.90	[0.56]
Some countries	-0.70	[0.44]	-0.68	[0.44]	-0.66*	[0.36]	-0.65*	[0.37]
Enforcement related								
Leniency program	1.87***	[0.29]	1.88***	[0.29]	1.74***	[0.28]	1.75***	[0.28]
Time-varying external factors								
Interest rate	-0.35***	[0.06]	-0.35***	[0.06]	-0.35***	[0.06]	-0.35***	[0.06]
Expected demand growth	12.32*	[6.85]	12.25*	[6.86]	11.97*	[6.85]	11.98*	[6.85]
Time-varying internal factors	6 months				12 months			
Entry	-0.26	[0.28]			-0.89***	[0.24]		
- Entry of repeat offender			0.93	[0.76]			-0.31	[0.77]
- Entry of member with greatest market share			(na)				-1.57	[1.17]
- Entry of other firm			-0.30	[0.30]			-0.90***	[0.25]
Exit	0.09	[0.18]			0.78***	[0.16]		
- Exit of repeat offender			0.68	[0.51]			0.42	[0.46]
- Exit of member with greatest market share			-0.19	[0.62]			1.05***	[0.40]
- Exit of other firm			0.07	[0.19]			1.53***	[0.14]
Int. restructuring	-0.40	[0.25]	-0.44*	[0.25]	-0.42**	[0.21]	-0.45**	[0.22]
Constant	-13.10***	[1.05]	-13.22***	[1.06]	-11.39***	[0.98]	0.75***	[0.17]
Shape parameter p	1.95***		1.97***		1.66***		1.67***	
Frailty variance θ	1.81		1.85		1.36		1.37	
chibar2	159.95		161.44		98.12		96.30	
p-value of Likelihood-ratio test of $\theta=0$	0.000		0.000		0.000		0.000	
N (firm-day observations)	1430018		1430018		1430018		1430018	

Notes: Weibull mixed PH model with competing risk of agency death treated as right censored and cartel-frailty (Gamma distribution); na: not applicable; *: $p < 0.1$, **: $p < 0.05$, ***: $p < 0.01$

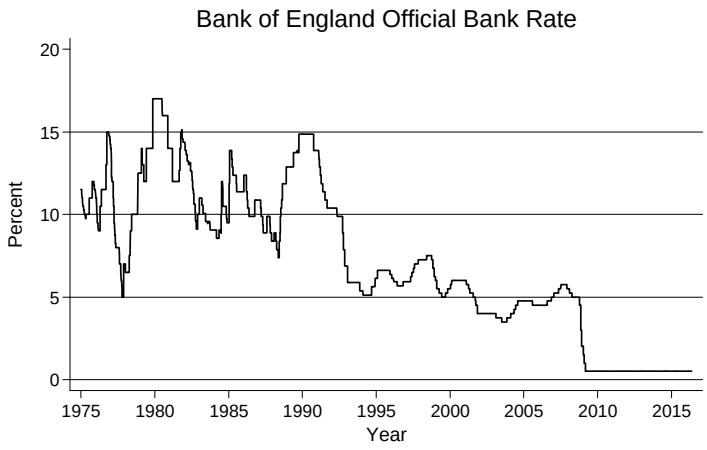

Figure A.1: Bank of England Official Bank Rate

Source: Bank of England, series IUDBEDR

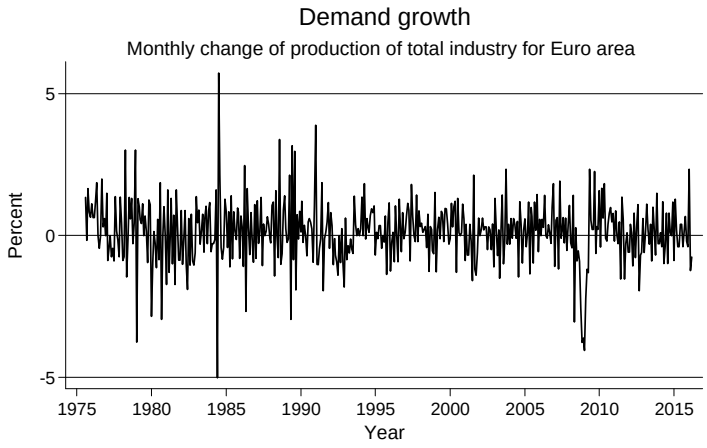

Figure A.2: Actual demand growth

Source: OECD.Stat, Production and Sales (MEI)