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Breaking Up Is Hard to Do: Determinants of Cartel Duration

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Abstract

We estimate the impact of cartel organizational features, as well as macroeconomic fluctuations and industry structure, on cartel duration using a data set of contemporary international cartels. We estimate a proportional hazards model with competing risks, distinguishing factors that increase the risk of "death by antitrust" from those that affect natural death, including defection, dissension, and entry. Our analysis indicates that the probability of cartel death from any cause increased significantly after 1995, when competition authorities expanded enforcement efforts toward international cartels. We find that fluctuations in firm-specific discount rates have a significant effect on cartel duration, whereas market interest rates do not. Cartels with a compensation scheme—a plan for how the cartel will handle variations in demand—are significantly less likely to break up. In contrast, retaliatory punishments in response to perceived cheating significantly increase the likelihood of natural death. Cartels that have to punish are not stable cartels.

1. Introduction

In the last 15 years, there has been a major transformation in the attitude of competition authorities toward international cartels. In the past, even the most hostile antitrust authorities presumed that international cartels were largely beyond prosecution—either for diplomatic or jurisdictional reasons or simply for lack of evidence. Today, the United States, the European Union, and numerous other countries are willing to prosecute international cartels: "In the last three

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years, over $2 billion in criminal fines and more than 162 years in jail time have been imposed in cases prosecuted" by the U.S. Department of Justice (DOJ) Antitrust Division (Varney 2009, p. 14).[1] This policy change was precipitated by Mark Whitacre's cooperation with the Federal Bureau of Investigation in an investigation into Archer Daniels Midland, resulting in the 1995 breakup of the lysine cartel and subsequent felony convictions of both member firms and key executive personnel.[2] This increased enforcement has permitted the creation of the data set analyzed here: every one of the cartels in our sample was found to have violated competition laws in the United States or Europe after 1990.

The apparent pervasiveness of price-fixing agreements challenges economists' common presumption that cartels are fundamentally unstable or a nineteenth-century relic. Economic theory identifies uncertainty as the primary cause of cartel instability (Stigler 1964; Green and Porter 1984; Abreu, Pearce, and Stacchetti 1986). The lure of collusive profits, however, provides firms with a strong incentive to reduce that uncertainty. The first response of many cartels to imperfect or noisy information is not to punish fellow cartel members but to create new rules, including governance and compensation systems that raise the quality and credibility of information and better align individual firms' incentives with those of the group. Cartels that endure are cartels that manage to do exactly this.

Using a proportional hazard model with competing risks, we estimate the probability of cartel death, distinguishing between those factors that contribute to death by antitrust intervention and those contributing to cartel collapse, which we refer to as "natural death."[3] This allows us to test several hypotheses suggested by cartel theory, including the impact of fluctuations in discount rates, observable and unobservable demand fluctuations, punishments, and cartel governance structures. One-third of the cartels compensate members when realized sales differ from proposed allocations; these cartels are significantly less likely to break up. In contrast, cartels that retaliate in response to deviations are significantly more likely to break up. We find that cartels that rely on trade associations are less likely to die a natural death. Cartels members on the verge of bankruptcy are too impatient to maintain collusion, and fluctuations in market interest rates appear to have no effect on otherwise stable cartels.

[1] For a listing of the individual cases, both international and domestic, with fines over $10 million, see U.S. Department of Justice, Antitrust Division, Sherman Act Violations Yielding a Corporate Fine of $10 Million or More (http://www.justice.gov/atr/public/criminal/sherman10.html). The percentage of foreign defendants increased from 1 percent in 1991 to roughly 50 percent in the 2000s (Adler and Laing 1997, p. 1; Hammond 2005, p. 3). For an overview of European Commission (EC) cartel fines, see European Commission Competition, Cartel Statistics (http://ec.europa.eu/competition/cartels/statistics/statistics.pdf), which reports that fines of €9.76 billion were imposed over 2005–9 (not adjusted for court judgments).

[2] For the full story of the discovery and breakup of the lysine cartel and Whitacre's role, see Eichenwald (2001) and Connor (2007).

[3] Zimmerman and Connor (2005) also estimate a proportional hazard model of cartel breakup, using a single cause of death. They explore the relationship between cartel success, measured as estimated overcharges, and cartel duration.

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While we focus on international cartels, defined as those with member firms from more than one country, national cartels face many of the same challenges and make use of similar organizational devices. There are differences, however, in the strategies employed. For example, rules for geographic market allocation are used more frequently by international cartels, rather than the simple production quotas favored by domestic cartels. In addition, international cartels face unique challenges posed by cultural and linguistic differences, exchange rate fluctuations, and trade preferences. These factors make international collusion especially difficult to maintain. Thus, international markets provide a rich testing ground for explanations of cartel duration.

The basic theory of cartel duration is laid out in the following section. In Section 3 we introduce our empirical model, followed by a discussion of the sample. We describe causes of cartel death and measures of cartel organization, providing illustrations from a variety of contemporary international cartels. Section 4 presents our estimation results, and Section 5 concludes.

2. The Theory of Cartel Duration

In a market with identical price-setting firms, infinitely repeated interaction among these firms, and perfect information, collusion can be sustained if[4]

$$\sum_{t=0}^{\infty} \delta^t \Pi^i(p_{i,t}^{\mathrm{M}},\ p_{-i,t}^{\mathrm{M}}) > \Pi^i(p_{i,0}^{\mathrm{D}},\ p_{-i,0}^{\mathrm{D}}) + \sum_{t=1}^{\infty} \delta^t \Pi^i(p_{i,t}^{\mathrm{C}},\ p_{-i,t}^{\mathrm{C}}),$$

where $p_{i,t}^{\mathrm{M}}$ is the collusive price charged by firm i in period t, $p_{i,0}^{\mathrm{D}}$ is the price that firm i would charge if it were to defect from the collusive agreement, $p_{i,t}^{\mathrm{C}}$ is the price charged by firm i in the continuation equilibrium following a defection by one firm, Π^i is the profit earned by firm i in a single period, $-i$ indicates firms other than firm i, and δ^t is the discount factor in period t, with $\delta^t = \mathrm{e}^{-r\tau}$, where r is the instantaneous rate of interest and τ is the real time between periods.

This participation constraint implies that permanent collusion can be an equilibrium if firms are sufficiently patient and if the difference between the profits earned while colluding and the profits earned after a firm cheats is sufficiently large. A simple interpretation of this model would suggest that we observe two types of markets: those for which the participation constraint is not met and in which competitive conditions necessarily obtain, and those for which this constraint is met and in which collusion may obtain forever.

What can this model tell us about how long an existing cartel will last? One way to answer this question is to consider equilibria in which collusion does last but firm behavior fluctuates. In their classic articles, Green and Porter (1984) and Porter (1983) introduce the notion of price wars as equilibrium punishments.

[4] The notation and presentation of the problem of cartel sustainability rely heavily on Tirole (1988, pp. 245–53).

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They posit that a collusive agreement might appear to collapse but that in fact the cartel has shifted to a punishment phase required to maintain incentive compatibility. These fluctuations in behavior are observationally equivalent to cartel breakup. Harrington and Chang (2009) provide a different approach, in which firms expect this inequality to hold when a cartel is formed but find that the constraint is violated by future, unanticipated shocks. In that case, duration is systematically related to unanticipated shocks that lead to a violation of the participation constraint. Cartels that are able to cope with shocks will last longer than those that are not.

2.1. Firm Patience and Collusive Stability

One of the few broad generalizations that can be made from the repeated-game model of collusion is that collusive stability is inversely related to the discount rate. A collusive equilibrium that can be supported at one discount rate, above some critical level, will be unsustainable at a rate below that critical level. Thus, an unanticipated increase in the market interest rate may destabilize an ongoing collusive equilibrium.[5] Firm-level changes in the discount rate may also affect cartel stability. For example, a firm's rate of time preference may change if its financing shifts to depend more heavily on debt relative to equity. The increased reliance on debt requires fixed payments to lenders, reducing the firm's discretion and increasing its need for cash flow in the short run.[6] Fershtman and Pakes (2000, p. 221) posit two reasons that the presence of a financially marginal firm may destabilize collusion: insufficient punishment and predatory behavior. A firm that is likely to exit has a shorter time horizon and cannot be punished for defection. Stronger firms that expect to stay in the industry would like to speed the exit of the firm that cannot be counted on as a collusive partner and therefore will prefer not to collude but rather will engage in predatory pricing.

2.2. Imperfect Information and Collusive Stability

In the Green and Porter (1984) framework, collusion essentially ends after some specified history of industry interaction because the "punishment" following that history is a permanent or long-term reversion to competitive pricing. Imperfect information makes it impossible for firms to infer with certainty that other firms are cooperating. If, for example, firms observe only their own sales, $x_{i,t}(p_{i,t}, p_{-i,t}, \theta)$, where θ is a random shock to demand, firms may be unable to distinguish between $x_{i,t}(p^{\mathrm{M}}_{i,t}, p^{\mathrm{C}}_{-i,t}, \theta_{\mathrm{H}})$ and $x_{i,t}(p^{\mathrm{M}}_{i,t}, p^{\mathrm{M}}_{-i,t}, \theta_{\mathrm{L}})$, where θ_{H} indicates a high realization of demand and θ_{L} indicates a low realization of demand. In such a market it is possible that we could observe collusive behavior followed

[5] See Harrington (1989a) for a treatment of collusion with asymmetric interest rates. Barsky and Kilian (2004) discuss the impact of fluctuations in the rate of interest on the ability of the Organization of the Petroleum Exporting Countries to collude to raise prices.

[6] For a broader discussion of the relationship between free cash flow and managerial decisions, see Jensen (1986).

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by competitive behavior because a low realization of demand occurs that firms are unable to distinguish from low pricing by a competitor.

The reliance on punishments—or the threat of punishments—to sustain collusion has three primary implications for cartel duration. First, cartels are more likely to survive in industries where information is better and cartel participants can distinguish between cheating and demand fluctuations. Markets with high variability in demand are more likely than relatively stable markets to have a realization of unexpectedly low demand.

Second, firms try to avoid making the mistake of punishing when no firm has cheated. The implementation of an equilibrium punishment of permanent or long-term reversion to competitive pricing is costly to firms in terms of forgone future profits.[7] Cartels know that there will be variation in demand that may cause individual firms' sales or market shares to differ from what the cartel anticipated. Cartels plan for this variation in demand by using agreed-upon compensation schemes.

Third, cartels put substantial effort into monitoring one another's activities in order to increase observability, so that they can distinguish between the events resulting from demand variability and changes in competitors' prices. Many cartels exchange output, sales, and price data with each other or forward data to a third party, such as a trade association or an independent auditor.[8] One of the simplest and most common techniques that cartels use to reduce imperfect information is to assign markets to individual producers. Stigler (1964, p. 46) long ago recognized the appeal of coordinating via market-share rules: "Fixing market shares is probably the most efficient of all methods of combating secret price reductions."

2.3. Buyer and Seller Concentration

If there are n symmetric firms and they use a symmetric sharing rule, such as $\Pi^i = 1/n \sum_{i=1}^{n} \Pi^{\mathrm{M}}$, then the returns to collusion for any individual firm will be decreasing in the number of firms. On the other hand, the returns to defection are unlikely to be affected by the number of firms in the market. Thus, the collusive participation constraint is more likely to be binding in industries with more firms and lower concentration. Shocks that affect industry profitability are more likely to disrupt collusion in unconcentrated industries than in concentrated ones. It is also likely that the observability of cheating (distinguishing between $p_{i,t}^{\mathrm{M}}[\theta_{\mathrm{L}}]$ and $p_{-i,t}^{\mathrm{C}}[\theta_{\mathrm{H}}]$) is more difficult with a large number of firms.

[7] This issue has been discussed at length in the literature on renegotiation, but the focus there is on whether the possibility of renegotiation after a "bad" realization will eliminate collusive equilibria (Pearce 1984; Bernheim 1984).

[8] It is interesting to note that this list does not include cost data. The exchange of cost information could, in principle, increase cartel efficiency. As noted in Athey and Bagwell (2001), exchange of such information entails costs as well as benefits to the cartel. Cartel members recognize this and therefore rarely share such information. See Levenstein and Suslow (2006a) and Harrington (2006) for further discussion of the content of cartel communications.

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Thus, for a variety of reasons we expect cartel duration to be positively related to concentration in the cartelized industry and negatively related to the number of participants in the cartel.

With regard to the buyer side of the market, Stigler (1964) argues that the temptation to cheat will be greater if customers are large relative to the size of the market. Each firm will find it easier to "steal" a large proportion of the market from other firms. In this case, the short-term profits from deviating from the collusive equilibrium, $\Pi^i(p^{\mathrm{D}}_{i,t},\ p^{\mathrm{M}}_{-i,t})$, may be close to the entire monopoly profit for the industry (for one period). The larger the cartel's customers are relative to the size of the market, the easier it will be for a single firm that offers its customers $p^{\mathrm{D}}_{i,t} = p^{\mathrm{M}}_{i,t} - \varepsilon$ to capture the entire market. Large customers understand this temptation and may take actions to disrupt a cartel. For example, during a 2002 conference Michael Dell noted that "we saw cartel-like behavior by a couple of DRAM suppliers" and "announced that [Dell] would widen its network of suppliers to try to defeat the anti-competitive conspiracy."[9]

Alternatively, consider the case where the customers are producers and the downstream industry consists of a few large firms and a competitive fringe. In this case, the incentive for the large customers to break up the cartel may be reduced if they are able to negotiate a price lower than that charged to the fringe. In the electrical and mechanical carbon products cartel, for example, large customers did not always accept the announced cartel price (see, for example, Commission Decision of December 3, 2003 [Case C.38.359: Electrical and Mechanical Carbon and Graphite Products], pars. 76, 106). In the sorbates cartel, producers explicitly set a separate target price for the largest, or "ultrabig," purchasers.[10] Large customers may even find an upstream cartel advantageous if they are in a position to bargain for lower prices while their smaller competitors are not.[11] This price differential on a purchased input may give them a strategic advantage that outweighs any incentive to undermine the cartel. For example, in the bitumen cartel, the five largest customers colluded with producers to limit rebates to smaller customers. The European Commission (EC) wrote in its report,

> For a period lasting at least between 1 April 1994 and 15 April 2002, collusion existed between and within a group of bitumen suppliers, consisting of Kuwait Petroleum, Shell, Klöckner, Wintershall, BP, Esha, Total and Nynäs, and a group of large Dutch road builders,

[9] Quoted in the dynamic random access memory (DRAM) antitrust litigation, Third Amended Class Action Complaint, par. 195, *Petro Computer Systems, Inc., v. Micron Technology, Inc.,* No. 08-16478 (N.D. Cal., February 27, 2008), MDL No. 1486.

[10] See Indictment, *United States of America v. Yuji Komatsu, Yoshihiko Katsuyama, Wakao Shinoda, and Hitoshi Hayashi*, No. CR 01-0019 PJH (N.D. Cal., January 23, 2001) (http://www.usdoj.gov/atr/cases/f7300/7366.htm). The rubber chemicals cartel also regularly gave discounts to its largest customers. The EC reports, for example, that Flexsys assured Bayer of its "support for Crompton/Uniroyal's price increase initiative, other than at Goodyear" (Commission Decision of December 21, 2005 [Case COMP/F/38.443: Rubber Chemicals], par. 149).

[11] See Han, Schinkel, and Tuinstra (2009) for a discussion of the impact of cartel damages along a vertical production chain.

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consisting of KWS, Heijmans, BAM NBM, HBG, Ballast Nedam and Dura Vermeer, to regularly fix for sales and purchases of road pavement bitumen in the Netherlands as to the following: (1) the gross price; (2) a uniform (minimum) rebate on the gross price for that group of road builders; (3) a smaller (maximum) rebate on the gross price for other road builders (Commission Decision of September 13, 2006 [Case COMP/F/38.456: Bitumen - NL], par. 48).[12]

These two potential effects were in opposite directions, so there is no a priori prediction of the effect of buyer size or buyer concentration on cartel stability.

3. Empirical Model and Data

3.1. Hazard Model

We estimate a proportional hazard model, specifying the probability of cartel breakdown as a function of variables that influence the stability of collusion. The hazard function $\lambda(x)$ is the ratio of the probability density function $f(x)$ to the survival function $S(x)$, given by

$$\lambda(x) = \frac{f(x)}{S(x)} = \frac{f(x)}{1 - F(x)},$$

where $F(x)$ is the cumulative distribution function. The hazard rate is the probability that an event occurs (that is, the cartel dissolves) at time t, given that it has not already occurred.

A proportional hazard model with a vector of covariates, $\mathbf{x}$, can be written as

$$\lambda(t;\ \mathbf{x}) = k(\mathbf{x})\lambda_0(t),$$

where $\kappa(.) > 0$ is a nonnegative function of x and $\lambda_0(t) > 0$ is the underlying or baseline hazard. The baseline hazard is common to all subjects in the population. It is invariant across cartels but can be any separable function of time. Individual hazard functions differ proportionately on the basis of a function $\kappa(\mathbf{x})$ of observed covariates. Typically, $\kappa(.)$ is parameterized as $\kappa(\mathbf{x}) = \exp(\mathbf{x}\boldsymbol{\beta})$, where $\boldsymbol{\beta}$ is a vector of parameters and $\exp(\mathbf{x}\boldsymbol{\beta})$ is a shift factor that depends on economic variables. Taking logs of both sides yields

$$\log\lambda(t;\ \mathbf{x}) = \mathbf{x}\boldsymbol{\beta} + \log\lambda_0(t),$$

where β_j measures the semielasticity of the hazard with respect to x_j.

In our application we are interested in how the covariates shift the hazard function, in which case the estimation of λ_0 is not necessary. Cox (1972) obtained a partial maximum likelihood estimator for $\boldsymbol{\beta}$ that does not require estimating λ_0.

Let us assume now that

$$\lambda(t;\ \mathbf{x}) = \lambda_0(t)e^{(\beta_1 x_1 + \beta_2 x_2 + \ \ldots\ + \beta_p x_p)},$$

where $\lambda(t; \mathbf{x})$ is the hazard at time t for a cartel with covariate vector $\mathbf{x} = (x_1,$

[12] The EC fined these customers along with the cartel producers.

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$x_2, \ldots, x_p$). The parameter vector $\boldsymbol{\beta}$ is estimated via a maximum likelihood approach.

Note that if we change the measurement of one covariate—say, x_1—by 1 and keep other covariates unchanged, then the relative risk of breakup is

$$\frac{\lambda_0(t)e^{(\beta_1 x_1+\beta_2 x_2+\ \ldots\ +\beta_p x_p)}}{\lambda_0(t)e^{[\beta_1(x_1-1)+\beta_2 x_2+\ \ldots\ +\beta_p x_p]}} = e^{\beta_1(x_1-x_1+1)} = e^{\beta_1}.$$

Thus, the estimated coefficient is the natural logarithm of the hazard rate ratio when x_1 is increased by 1 unit. We estimate the probability that a cartel that has lived to year $t-1$ breaks up in year t as a function of the parameter vector $\boldsymbol{\beta}$ that includes characteristics of the cartel, the market, and the economic environment in year t.

In our data, cartels can break down from one of two causes: exogenous antitrust intervention or natural death. We estimate a competing-risks model that treats all cartels as being at risk of death from either cause.[13] In estimating the covariates of one cause of breakup, cases are treated as censored if the cartel breaks up from the alternative cause. An estimated hazard rate ratio greater (less) than 1 indicates that the covariate is associated with an increased (decreased) hazard of cartel breakup.

3.2. Sample of Contemporary International Cartels and Variable Definitions

We examine the determinants of cartel duration for 81 international cartels found by either the United States or the EC (or both) to have engaged in collusion since 1990.[14] These international cartels—with member firms from more than one country—engaged in price fixing or market division agreements.[15] Although these cartels are international in membership, they may or may not have a global reach. While all the cartels in our sample were active after 1990, some began operations years before. The oldest cartel in our sample, organic peroxides, began in 1971. The latest end date in our sample comes from the marine hose cartel, which broke up in 2007. Overall we have 654 cartel-year pairs in which a cartel is colluding and is at risk for breakup. The number of observations falls slightly when we examine certain characteristics of the market, such as industry concentration, or firm-level financial ratios that are not available for privately held firms.

Most of the cartels in our sample are in intermediate manufactured goods and services. Forty percent are in chemicals, especially food additives. Another

[13] For general discussion of competing-risks models, see Katz and Meyer (1990) and Hill, Axinn, and Thornton (1993).

[14] Of these 81 cases, 21 were prosecuted in both jurisdictions, 19 were U.S.-only cases, and 41 were EU-only cases. We do not include legal cartels in this study. Their objective functions, including their broader political and economic goals, are likely to differ from those of private cartels.

[15] We use the nationality of the parent company to identify a country of origin for each cartel member. For example, if a U.S. subsidiary of a Japanese company is prosecuted for price fixing, we consider it to be a Japanese company.

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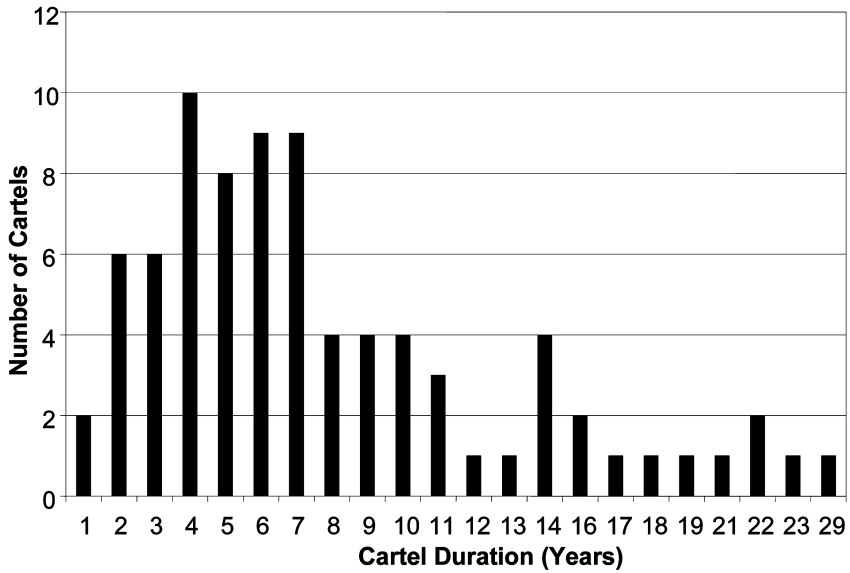

Figure 1. Duration of international cartels

quarter are in a variety of other manufacturing industries, with multiple convicted cartels in steel, carbon and graphite products, plastics, and paper industries. Cartels were also found in specialized services, such as fine arts auctions and specialized tanker shipping. The only major sector that does not appear in the sample is final consumer goods.

The distribution of cartel duration in this sample is skewed with a long right-hand tail (Figure 1). The average duration of cartels in our sample is approximately 8.1 years, with a standard deviation of 5.8 years (Table 1). The median life span is 7 years. The probability of a cartel's surviving past time t is shown in Figure 2, using a nonparametric estimate of the Kaplan-Meier (KM) survivor function. The estimated probability of survival declines quite sharply in the first several years of a cartel's life and then flattens out. One-third of cartels that survive beyond 5 years survive beyond 10 years. At the other extreme, just under 10 percent of the cartels in our sample lasted 2 years or less.[16]

Average cartel duration does not appear to have changed substantially over the past century. Cross-sectional studies of international cartels covering the late nineteenth and twentieth centuries give duration estimates of between 5.3 and

[16] Because our sampling procedure relies on antitrust prosecutions, it is less likely to capture very short lived cartels. These may form and disappear without ever attracting the attention of the authorities. Thus, as with most other samples of cartels, our estimates of cartel duration may be biased upward relative to the universe of all cartels ever attempted.

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Table 1
Cartel Duration: Comparison to Other Cartel Samples

Duration	Contemporary International Cartels	Other International Studies			U.S. Studies	
		Eckbo (1976) 1800–1970	Griffin (1989) 1888–1984	Suslow (2005) 1920–39	Posner (1970) 1950–69	Gallo et al. (2000) 1955–97
Mean (years)	8.1	5.3	7.3	8.3	7.5	5.4
SD	5.8	2.4	6.3	6.2		
Range	1–29	1–18	1–29	1–13		
% < 5 Years	30			40		
% > 10 Years	23			37		

Source. Drawn from Levenstein and Suslow (2006b, table 1).

8.3 years (Table 1). The U.S. studies are similar, with Posner (1970) and Gallo et al. (2000) finding, respectively, that the average duration of cartels prosecuted by the U.S. government is 7.5 and 5.4 years. In studies including a measure of variance, the variance in cartel duration is high. As Stigler (1964) observed, there are cartels that dissolve quickly: each of these national and international samples includes cartels that barely lasted 1 year. There are other cartels that endure nonetheless.

Measuring cartel breakup is not unambiguous. In particular, we do not have the information necessary to distinguish between cartels that have continued to meet with little effect on price and those that are functioning effectively. In some cases, the cartels themselves are not sure whether their collusion has ended, as the following passage from the EC decision on the organic peroxides cartel illustrates: "The parties confirm that around 1992, tensions between the companies were rising, but their views vary and differ as to the timing, intensity and duration of the tensions. In particular they disagree as to whether the agreement was terminated and later replaced or only certain contacts at high level [*sic*] were suspended. PC and Akzo consider the period of tensions to mark the end of one cartel and the beginning of another. Atochem, in contrast, sees the period of tensions not as the end of the agreement but as a period when the agreement did not work well" (Commission Decision of December 10, 2003 [Case COMP/E-2/37.857: Organic Peroxides], par. 131).

As we turn to the empirical analysis of cartel duration, it is important to keep in mind that we are measuring the formal breakup of an informal institution. In general, we date the end of a cartel to when the cartel members give up trying to sustain collusion, as that is what is observable to us. As long as they are negotiating, it is clear that some members believe that there is a mutually beneficial collusive outcome. What is less clear is whether they have located a set of equilibrium strategies that will support such an outcome.

3.2.1. Causes of Cartel Death

The number of antitrust prosecutions has increased dramatically since 1993, when the DOJ revised and expanded its amnesty policy, offering automatic

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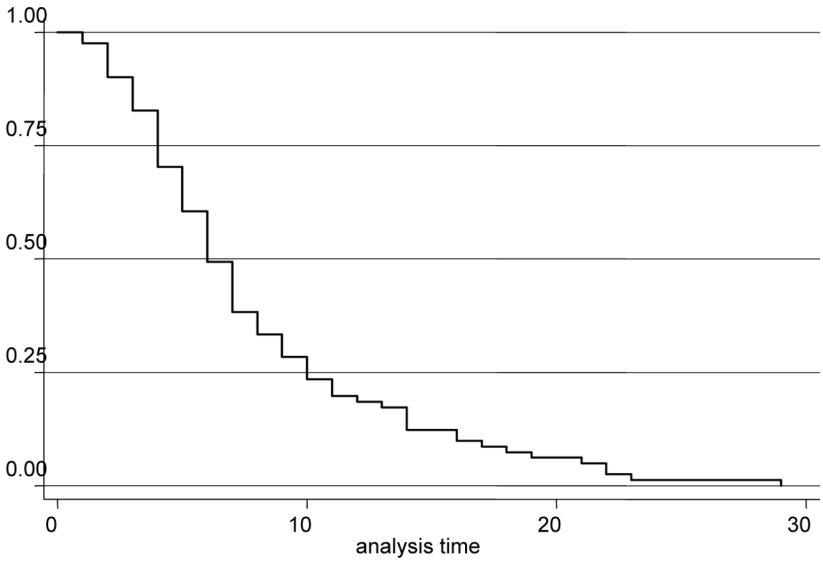

Figure 2. Kaplan-Meier probability of survival, entire sample

amnesty from fines and jail terms to the first cartel member who comes forward voluntarily and prior to the commencement of an antitrust investigation.[17] The EC also has an amnesty policy, first implemented in 1996 and then revised and strengthened in 2002. The EC grants full immunity to the first company to submit sufficient evidence to allow the commission "to launch an inspection at the premises of the companies allegedly involved in the cartel."[18] Some companies simultaneously apply to multiple jurisdictions for amnesty, as Christie's art auction house did in 2000.[19]

This has several implications for our measure of cartel duration. First, the start date for a cartel as coded in our data set reflects the information available

[17] The U.S. Department of Justice (DOJ) has had a corporate amnesty program since 1978, but the earlier program was ambiguous and ineffective. See Department of Justice, Antitrust Division, Leniency Policies (http://www.justice.gov/atr/public/criminal/leniency.htm), which links to the current corporate and individual amnesty policies of the DOJ. Hammond (2005, p. 11) states, "The revised Corporate Leniency Program has resulted in a surge in amnesty applications. Under the old policy, the Division obtained roughly one amnesty application per year. Under the new policy, the application rate has jumped to roughly two per month."

[18] See European Commission Competition, Leniency Policy (http://ec.europa.eu/competition/cartels/leniency/leniency.html). There are other conditions required for full immunity, such as immediately ending the infringement and not serving as the cartel ringleader. See also European Commission (2003).

[19] According to Osborn (2002, p. 7), "Christie's approached regulators on both sides of the Atlantic in 2000 and owned up to wrongdoing in exchange for leniency which could take the form of a reduced fine."

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to the enforcement authorities. In many cases the authorities (or customers) suspect that the cartel began earlier, but there is insufficient evidence to document this. Different firms may join a cartel at different dates, and sometimes cartels begin in one region and expand to other areas. In order to capture these nuances, we take the birth of the cartel to be the first known agreement between any two members of the cartel. We do not estimate the determinants of cartel birth, but a cartel is at risk of dying only after it has been born.

About 80 percent of the cartels in the sample ended with antitrust intervention. This might suggest that the determinants of cartel breakup are legal, not economic, factors. That inference would be wrong. First, consider the case in which the antitrust authorities offer complete amnesty. Any firm that chooses to leave the cartel—knowing that its defection would induce a reversion to competition in the industry—will simultaneously apply for amnesty.[20] In this case, the decision to defect or cooperate is correctly represented by the participation constraint above.

Alternatively, consider the case in which the authorities offer only a fractional reduction in liability: the European Union, for example, often grants a percentage reduction in fines, and in the United States amnesty from criminal liability does not spare firms from potential civil liability. The participation constraint would then include expected liability in the case of defection:

$$\sum_{t=0}^{\infty} \delta^t \Pi^i(p_{i,t}^{\mathrm{M}},\ p_{-i,t}^{\mathrm{M}}) > \Pi^i(p_{i,0}^{\mathrm{D}},\ p_{-i,0}^{\mathrm{M}}) + \sum_{t=1}^{\infty} \delta^t \Pi^i(p_{i,t}^{\mathrm{C}},\ p_{-i,t}^{\mathrm{C}}) - E(L),$$

where $E(L)$ is the expected liability associated with a leniency application. In this case, the economic determinants of duration are still relevant, but the critical discount level will differ. A firm considering defection must consider the additional cost associated with the remaining potential legal liability and weigh it against the expected profit from continuing to collude.[21]

Firms do engage in just such an evaluation before applying for amnesty. Consider, for example, the contrast in Rhône-Poulenc's behavior in the methionine and methylglucamine cartels. Under indictment for its participation in the vitamins cartel, it gave evidence in the methionine case in return for a reduced

[20] One could also consider the possibility that a firm would choose to defect "a little," hoping that this would not undermine the cartel. We do observe small violations of collusive agreements, but these deviations are either tolerated or punished lightly. We do not treat minor defections as cartel breakups in our data, so this possibility does not affect the analysis of duration. This behavior does represent an important theoretical challenge to cartel modeling, as it is not consistent with equilibrium behavior in most models.

[21] For a provocative and insightful discussion of the incentive effects of leniency policies, see Spagnolo (2000, 2007). He shows that partial amnesty can increase the set of collusive equilibria and the potential collusive profits available to a cartel, making collusion easier and therefore presumably more durable. Thus, it is possible that leniency policies that reduce liability but do not entirely eliminate it decrease the likelihood of cartel breakup. See Aubert, Rey, and Kovacic (2006) for a discussion of alternative designs of leniency programs and their impact on both cartel stability and firm performance.

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sentence in the vitamins case (and amnesty in the methionine case).[22] Its confession did not mention the methylglucamine cartel, for which it was later fined.[23] Why would Rhône-Poulenc turn in one cartel and not the other? One was profitable and the other was not. Monsanto was a large and growing producer of methionine that refused to participate in the cartel.[24] As a result the cartel had ceased to have much effect on price. The methylglucamine cartel, in contrast, was much more successful, with the two cartel members controlling 100 percent of the global market. Similarly, in the wax cartel, Shell applied for leniency from the EC on March 17, 2005, after a February meeting at the "brightly colored four-star Hotel Madison Residenz in Hamburg [at which the cartel] was unable to come to an agreement on prices" (Carvajal and Castle 2008, p. B3).[25] In both of these cases, the immediate, precipitating cause of the cartel breakup was antitrust intervention. Still, the decision to apply for amnesty is an economic one influenced by the expected profitability of the cartel compared to the profits available to a firm when freed from cartel restrictions.[26] The increase in criminal enforcement and the availability of amnesty change the calculus, but, controlling for this one-time change in incentives, the other elements of the decision to participate in a cartel remain the same. To capture this shift in enforcement policy after 1995, we include a dummy variable (Enforcement) in the regression analysis.[27]

[22] F. Hoffmann–La Roche's U.S. subsidiary was issued a U.S. grand jury subpoena in the vitamins case on May 8, 1998 (Commission Decision of November 21, 2001 [Case COMP/E-1/37.512: Vitamins], par. 149). On May 20, 1999, charges were filed against Roche and BASF (Vitamins Decision, par. 150). On May 26, 1999, "Rhône-Poulenc submitted to the Commission a statement admitting its involvement in a [ ]* [*sic*] cartel to fix prices and allocate quotas for methionine and invoking the Notice on the non-imposition or reduction of fines in cartel cases (the 'Leniency Notice')" (Commission Decision of July 2, 2002 [Case C.37.519: Methionine], par. 52).

[23] Merck KgA received leniency in the methylglucamine case (see Commission Decision of November 27, 2002 [Case COMP/E-2/37.978: Methylglucamine], pars. 33, 272). There was a similar occurrence in the gas-insulated switchgear cartel. In 2004 the firm ABB reported the cartel to the EC and received amnesty. At the time, ABB was involved in the power transformer cartel but chose not to reveal its existence to the EC. See the EC press release regarding the power transformer cartel (IP/09/1432, Brussels, October 7, 2009) and Gas Insulated Switchgear decision, European Commission Case COMP/F/38.899 (January 24, 2007).

[24] Monsanto entered the market with a new, liquid methionine formulation that it believed—correctly—would allow it to compete successfully against the incumbent cartel firms (see Commission Decision of July 2, 2002 [Case C.37.519: Methionine], pars. 8, 80–81, 150).

[25] Note that this cartel was undermined by bargaining problems. See Levenstein (1997) and Levenstein and Suslow (2006b) for further discussion of the importance of bargaining to cartel stability. Similarly, in the laminated tubes cartel, a member firm applied for amnesty because it wanted to enter the U.S. market, from which it was excluded under the cartel agreement (U.S. Department of Justice 1996).

[26] For a discussion of strategic responses to amnesty, see Spagnolo (2007), Harrington and Chang (2009), and Miller (2009).

[27] These changes in policy and enforcement did not occur all at once. As discussed above, U.S. amnesty policy was revised in 1993, and the EC's leniency policy was adopted in 1996. This period also saw increased international cooperation in information sharing among competition agencies, but only after some resistance to what was perceived to be extraterritorial enforcement of U.S. competition laws. Considerable publicity was associated with the Archer Daniels Midland lysine case, but there were other cases, such as the thermal fax case, that helped to establish the legal and political

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Table 2
Causes of Cartel Breakup

Cause	Cartels	Average Duration (Years)
Death by antitrust:		
Follow-on investigation	13	8.8
Customer complaint	7	4.0
Other sources (including whistle-blowers)	29	8.2
Natural death:		
Amnesty application	17	10.3
Cheating	6	7.7
Growing fringe	7	6.4
Unknown cause of breakup	2	4.5
All cartels	81	8.1

When we observe in our data that a cartel has been broken up by an amnesty application, it must be the case that a cartel member that had previously found it optimal to cooperate no longer does. This could be the result of this one-time shift in enforcement policy, but it could also be because of a change in one or more of the economic variables that affect the participation constraint. The observation that the antitrust authorities take an action that ultimately puts an end to the cartel does not vitiate the economic analysis; the antitrust authorities become the instrument of the defecting firm.

We code the cause of death for 79 of the 81 cartels in the sample (Table 2). We distinguish between those cartels for which the proximate cause of breakup was government antitrust enforcement and those that dissolved for other reasons, such as cheating or a growing fringe of noncartel producers. We also distinguish these amnesty breakups from follow-on breakups. In order to reduce penalties, many firms—like Rhône-Poulenc, as described above—having been caught colluding in one market, will offer evidence of collusive activity in a different market.[28] There are 13 such follow-on breakups in our sample, and the average duration of those cartels is 8.8 years. We expect that the timing and determinants of offers by cartel members to come clean made under the duress of antitrust prosecution may differ from those offered under a voluntary amnesty plan.

Cartels broken up by amnesty applications were relatively long lasting (with an average duration of 10.3 years). Harrington and Chang (2009) argue that

viability of prosecuting international cartels. We chose the public breakup of the lysine cartel as the defining moment for this shift in cartel enforcement.

[28] The DOJ has an Amnesty Plus program that offers leniency to firms caught in the investigation of a cartel for which they are not eligible for amnesty if they provide information about a second cartel that was previously unknown to the authorities (see Hammond 2004). The EC does not have a formal "amnesty plus" process, but there are cases in which it is clear that the EC discovered a cartel as the result of an earlier cartel investigation. The EC reports details of each firm's cooperation and leniency granted. The DOJ rarely publicizes the identity of firms receiving amnesty, so in some cases we infer whether a cartel investigation followed directly from an earlier investigation on the basis of indictments in other markets.

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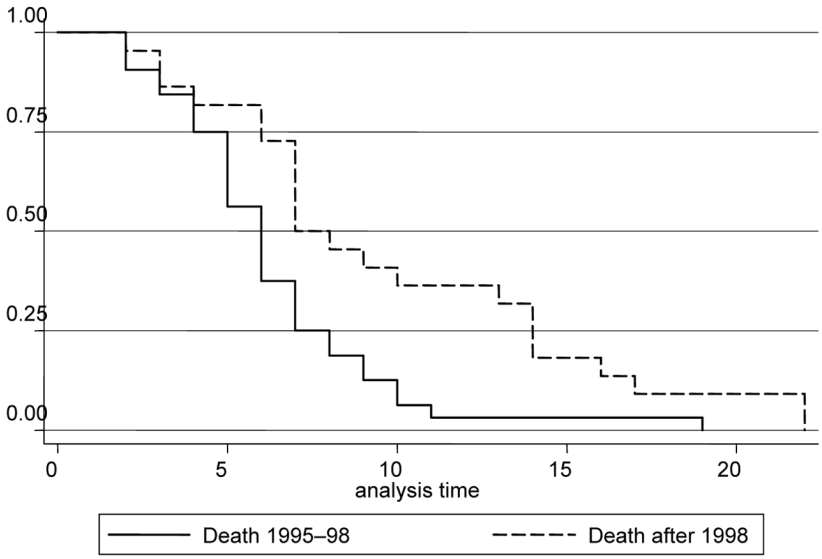

Figure 3. Kaplan-Meier probability of survival, by time of death

changes in antitrust policy will lead to a change in the observed distribution of cartel age and in the distribution of those caught by the government. Their model predicts that "a rise in [detection and conviction] causes the immediate collapse of the least stable cartels. . . . This means the surviving cartels are those [of] . . . longer duration. Because this is the pool from which one draws discovered cartels, the average duration of discovered cartels rises in the short-run in response to a more aggressive detection and conviction policy" (p. 1415). Our descriptive empirical statistics support these theoretical predictions. Although we are not able to test these predictions formally, Figure 3 compares the KM survival function for cartels broken up immediately after the change in enforcement policy and for those that have been caught since then. As predicted by the model, the cartels caught most recently are longer lasting than those first nabbed in the post-Whitacre dragnet.

Despite the attention given to amnesty, an agency investigation may arise from other sources of information. The modal cause of breakup in our sample is antitrust intervention that did not result from an amnesty application, follow-on investigation, or customer complaint: 29 of 81 cartels fall into this category, with average duration of 8.2 years. In the chemical tankers, ferrosilicon, citric acid, and lysine cases, for example, a whistle-blower triggered the investigation.[29]

[29] Note that whistle-blowers sometimes receive amnesty on their own behalf, although their employers (or former employers) do not.

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In the preinsulated pipe cartel, a competitor who had been hounded by the cartel complained to the EC.[30]

Approximately one-sixth of the sample broke up prior to antitrust intervention, because of either cheating or a growing fringe. Cartels that broke up because of a growing fringe lasted on average 6.4 years. The cartels in vitamins B_1, B_2, and B_6, for example, all ended primarily because of growing Chinese exports. In the vitamin B_6 market, the Chinese share grew from 3 percent of the world market in 1991 to 48 percent in 1993.[31] Cheating was also an issue, particularly in the B_2 cartel, but entry of Chinese production was the catalyst for the breakup. For each cartel in our sample, we select the factor that was most significant in the cartel's final breakup. There are six cartels in our sample that we code as breaking up primarily because of cheating; they lasted 7.7 years, on average. Some are quite short-lived, such as the aluminum phosphide cartel, which lasted only 11 months after one producer charged prices substantially lower than the target price set by the cartel (Dauner 1994). There are, however, numerous cartels for which cheating was an issue either intermittently or throughout the life of the cartel. Thus, for many of the cartels cheating was a fact of life—a reality of running the organization—but not a cause of death.

3.2.2. Producer and Customer Concentration

Most of the cartels in our sample had a small number of member firms (MemNum; see Table 3). The mean number of members is 7.4, with a range from two members (12 cartels) to 35 (a shipping cartel). The cartels in our sample occur predominantly in very highly concentrated industries. The mean industry four-firm concentration ratio (C4) is 75 percent:[32] two-thirds of the cartels were in industries with a C4 of 75 percent or more. The existence of some cartels with a large number of participants is not as paradoxical as it may seem: many cartels with a large number of firms rely on the active involvement of a trade association.

Following previous analyses, we include the number of member firms in all

[30] The preinsulated pipe cartel made numerous attempts to eliminate or contain this competitor, Powerpipe. Powerpipe alleged to the Commission that cartel members "had taken concerted steps to damage the business of Powerpipe and/or confine its activities to the Swedish market and/or drive it out of business altogether by (inter alia) systematically luring away key management personnel and unlawfully interfering with its contractual relations with customers and suppliers" (Commission Decision of October 21, 1998 [Case No IV/35.691/E-4: Pre-insulated Pipe Cartel], par. 20).

[31] "Roche says that by the first half of 1994 the parties recognised that the vitamin B6 agreement was no longer viable owing to the Chinese imports and decided to end the agreement" (Commission Decision of November 21, 2001 [Case COMP/E-1/37.512: Vitamins], par. 348).

[32] Our concentration measure is based on a subsample of 57 cartels for which we have market share data, collected from a variety of sources. The vast majority of these concentration ratios are for the global market, but there are a few pertaining only to the U.S. market, in cases where that was the only country in which a given cartel tried to fix prices (see the Appendix for details). Often, empirical studies of international cartels measure the cartel's market share. In almost all cases in our sample, the cartel included all major firms.

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Table 3
Variable Definitions and Descriptive Statistics

Variable Name	Definition	Min	Max	Mean	SD
Producer and consumer concentration:					
MemNum	Number of cartel members	2	35	7.44	6.83
MinC4 (57 cartels)	Minimum four-firm concentration ratio for cartel industry	24	100	74.78	18.40
CustConcHigh (76 cartels)	One if industry of cartel's customers is highly concentrated	0	1	.06	.24
Organizational variables:					
Compensation	One if members agreed to a compensation scheme	0	1	.33	.47
Exclusion	One if cartel took exclusionary action against nonmembers	0	1	.36	.48
MarketAlloc	One if shares, regions, or customers were explicitly assigned to cartel members	0	1	.80	.40
Monitor	One if sales information exchanged for monitoring purposes	0	1	.79	.41
Punishment	One if retaliatory action was taken following cheating	0	1	.19	.39
TradeAssoc	One if trade association was involved	0	1	.31	.47
Firm impatience and macroeconomic fluctuations:					
Enforcement	One if after 1995	0	1	.41	.49
Global_GDP_Growth (37 annual observations)	Annual global growth rate of gross domestic product (GDP)	.43	6.18	2.89	.95
Global_GDP_Resid	Deviations from an AR(1) trend of annual global GDP	−501.65	379.53	−52.03	224.94
HP_Gap (37 annual observations)	Difference between global GDP and trend (using the Hodrick-Prescott filter) ($ billions)	−319.41	407.31	−.82	155.93
IntCoverage (73 cartels)	Interest coverage ratio for cartel member firms	−28.76	69.75	4.42	4.51
IntCoverage < 1 (73 cartels)	One if IntCoverage is less than 1	0	1	.04	.21
LevRatio (73 cartels)	Financial leverage ratio for cartel member firms	.19	1.65	0.76	.16
NBER	Annual dummy variable indicating whether there was a recession in U.S. that year	0	1	.19	.39
T-Bill (37 annual observations)	Annual average rate on U.S. Treasury bills, 3-month maturity	1.01	14.04	5.31	2.04
XchRateChange (37 annual observations)	Absolute value of the difference between current and lagged exchange rate index value	.13	9.71	3.24	2.56

Note. $N = 81$ cartels unless otherwise stated. AR(1) - first-order autoregressive process.

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specifications.[33] We also include a measure of industry concentration, MinC4, the minimum C4 of the industry in which the cartel was active. Concentration ratios are drawn from both industry and government sources. Because of data availability, in some cases we estimate MinC4 using market-share data from the largest two or three firms. For example, the bromine industry consisted of three major producers with a global three-firm concentration ratio of 83 percent in 1998 (Chang 1999, p. 3). The C4 would certainly have been higher, but without an estimate of the market share of the fourth-largest firm, our best estimate of the minimum C4 is 83 percent. We do not have time-series measures of global concentration. In general, concentration ratios do not in fact vary dramatically from year to year.[34]

New entry into the industry, even if the entrant is welcomed into the cartel, will reduce the profitability of collusion and possibly undermine cartel stability. Thirty-six percent of the cartels in our sample engaged in strategic activities designed to exclude entry (Exclusion), including refusal to license technology, strategic acquisition of entrants, and targeted price wars.[35] For example, both the steel beam and graphite electrode cartels were accused of restricting the flow of technical information to outsiders.[36] In 1992, members of the electrical carbon cartel refused to supply any graphite to an East German competitor that had entered the international market after unification, "systematically undercutting it with all customers, so that it would not be able to sell anywhere" (Commission Decision of December 3, 2003 [Case C.38.359: Electrical and Mechanical Carbon and Graphite Products], par. 157). In actions reminiscent of John D. Rockefeller and Standard Oil, the organic peroxide producers "agreed that each of them would purchase [a] competitor. Akzo agreed to acquire . . . Nobel and Enichem. Laporte would purchase Aztec" (Commission Decision of December 10, 2003 [Case COMP/E-2/37.857: Organic Peroxides], par. 271).[37] Thus, existing concentration ratios may reflect actions that cartels have taken to limit entry into their markets. On the other hand, cartels may reduce concentration if their profits allow more firms to remain in the industry than would be sustainable in a more competitive environment (Sutton 1991, 1998; Symeonidis 2002).

[33] We also tested a dummy variable indicating whether there was at least some critical number of firms in the cartel. This was motivated by Selten's (1973, p. 142) classic article on cartel formation, in which the dividing line between "small" and "large" is five firms. The intuition for his result is the "fact that the position of an outsider becomes relatively more attractive as the number of competitors is increased." This variable was not significant, and other results were robust to this change in specification.

[34] In order to consider the possibility that changes in concentration affect cartel stability, we tested a specification using U.S. concentration measures, which are reported at 5-year intervals. This variable was not significant.

[35] For example, Harrington (1989b) shows that cartels able to engage in predatory behavior in response to entry may sustain collusion without additional barriers to entry.

[36] For the steel beam cartel, see Goldsmith and du Bois (1994, p. 3). For graphite electrodes, see U.S. Department of Justice (1998), where one of the charges listed is that the conspirators "agreed to restrict non-conspirator companies' access to certain graphite electrode manufacturing technology."

[37] See Tarbell (1904, 1:66–68) for a detailed description of Standard Oil's acquisitions of its competitors.

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One might expect that explicit conspiracies to fix prices would be redundant for firms in highly concentrated industries. The high concentration ratios in our sample may reflect our selection criteria: we sample cartels that were caught. Firms in highly concentrated industries with keener leadership may be able to find ways to avoid competition without resorting to explicit collusion—and the attendant threat of prosecution. On the other hand, because these are all intermediate goods and services, prices are generally private. This may make tacit collusion much more difficult.[38]

Following Dick (1996), we define a customer concentration variable as the Herfindahl-Hirschman Index (HHI) of the primary downstream consuming industry (defined at the 4-digit Standard Industrial Classification [SIC] or 6-digit North American Industry Classification System [NAICS] level) for each cartel.[39] We obtain HHI estimates from the quinquennial U.S. Census of Manufacturing, 1982–2002.[40] We then create a dummy variable, CustConcHigh, equal to one if the cartel's customers are highly concentrated (either C4 > 50 or HHI > 625 at any time during the cartel's life span; see the Appendix).[41] Although this measure is at best a proxy for downstream concentration and the bargaining power of customers in international markets, it does allow us to begin to address an issue that has been frequently discussed but infrequently studied empirically.

3.2.3. Preventing Cheating

Cartels have developed a variety of mechanisms to address the challenge of cheating: (1) enhancing the information that firms have about one another and the market, (2) compensating one another when firms' sales vary from assigned quotas because of factors outside of their control, such as random fluctuations in demand, and (3) punishing firms when violations do occur. We address each of these mechanisms in turn.

[38] See Harrington and Skrzypacz (2007, 2011) for discussions of private prices, sales, and the feasibility of explicit and tacit collusion.

[39] In his study of legal Webb-Pomerene export cartels, Dick (1996) proxies customer concentration with the market share of the four largest consuming countries of each Webb-Pomerene association's exports. He finds that Webb-Pomerene cartels selling into relatively more concentrated consuming markets tended to be less stable (p. 261).

[40] Further details on the construction of this variable are given in the Appendix. This measure varies from our ideal measure in two ways. First, we must choose one primary downstream industry. Since the primary consuming industry represents only a portion of cartel sales, our measure overestimates downstream concentration. However, if the portion of sales to the primary consuming industry is roughly uniform across cartels, then the variation in our measure of concentration will correctly capture the variation in customer concentration faced by the different cartels in our sample. To the extent that the diversification of sales across consuming industries varies across cartels, we have unmeasured variation that our customer concentration variable misses. Second, our measure of concentration is based on the concentration of U.S. consuming industries. While the U.S. Census Bureau data give us a consistent measure that spans our sample period, it is possible that consuming-industry concentration varies across the national markets in which these international cartels operated, again giving rise to unmeasured variation.

[41] We also created a measure equal to the U.S. four-firm concentration ratio of the industry for the cartel's largest consuming sector. The results from using this variable, not reported here, were similar to those from using the dummy variable defined above.

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Eighty percent of the cartels in our sample exchanged information on sales, production, and price in order to monitor individual firm behavior and market trends (Monitor in Table 3). In some cases, cartel members monitored one another directly. For example, the industrial copper tubes cartel fixed target prices at meetings each autumn. Then, "[i]n the spring meeting they monitored compliance with the agreed targets by analyzing the general market information and the development of their market shares. . . . [Cartel members appointed] market leaders who monitored customer visits and informed the other cartel members of the evolution of the contract situation within their respective territories" (Commission Decision of December 16, 2003 [Case COMP/E-1/38.240: Industrial Tubes], pars. 85, 198.).

Similarly, Samsung encouraged its DRAM sales representatives to "collect customer & competitive information and share them on a timely basis (As You Give, So Shall You Receive)." Customers in a civil suit against members of the DRAM cartels claimed that "in the last month before the DOJ subpoenaed some Defendants, the Defendants found it too bothersome to email and call each other, and so set up a 'listserv' where everyone could share information with the whole group. . . . The email sender states that the 'point of this group is to get the supplier to share information rather than rely on [what] the customer tell[s] us'" (Third Amended Class Action Complaint, pars. 157, 161, *Petro Computer Systems,* No. 08-16478 [N.D. Cal., February 27, 2008]).

In other cases, cartels turned to third parties to collect, review, and sometimes aggregate data for use by individual cartel members.[42] Members of the pre-insulated pipe cartel had their auditors certify "the total sales of pipes during the year, and the certificates were then exchanged among the cartel participants" (Commission Decision of October 21, 1998 [Case No IV/35.691/E-4: Pre-insulated Pipe Cartel], par. 33). Some European cartels, such as the cartonboard cartel, took this one step further: "Fides is a fiduciary company located in Zurich which (amongst other activities) manages information exchange systems for various industries. . . . In the context of the successful implementation of price initiatives, it was considered essential to develop a comprehensive system for the reporting and monitoring of production, sales volumes and capacity utilization. Most of the members of the PG Paperboard contributed periodic (weekly, monthly, six-monthly, annual) reports on orders, production, sales and capacity utilization to Fides. . . . Under the Fides system the individual reports were collated centrally and the aggregated (and supposedly anonymized) data then sent to the participants" (Commission Decision of July 13, 1994 [Case IV/C/

[42] Aoyagi (2005) provides an interesting discussion of the role of third parties in facilitating collusion. He posits that they receive private reports from cartel members to verify that they have implemented agreed-upon actions and use that private information to coordinate firm behavior by giving "secret instructions to players" (p. 456). The third parties discussed here engage in the first action—collecting private information—but do not play the role of coordinator. It is more useful to think of their role as reducing uncertainty or private information than as coordinating the activities of cartel members.

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33.833: Cartonboard], pars. 27, 61–62). Fides provided these services to several international cartels.[43]

Thirty-one percent of the cartels in our sample actively used trade associations to facilitate collusion (TradeAssoc). This is comparable to earlier studies, but a closer examination suggests that this similarity obscures a significant change.[44] Of the 26 cartels in our sample with trade association involvement, not one involved a U.S. trade association. The majority of cases involve preexisting European trade associations whose activities in facilitating collusion probably predate recent changes in EU law and enforcement policies that have made the legal environment much more hostile to price fixing than in years past. Thus, it appears that American trade associations have learned to refrain from involvement in such conspiracies.

Eighty percent of the cartels in our sample allocated geographic markets or assigned specific customers to cartel members (MarketAlloc).[45] Market allocation reduces the need to create monitoring mechanisms.[46] For example, Hoffman-LaRoche, the world's leading producer of vitamin B_2, monitored Japanese government export data knowing that there was only one cartel member, Takeda, producing in that geographic location (Commission Decision of November 21, 2001 [Case COMP/E-1/37.512: Vitamins], par. 289). National boundaries also provide focal points and institutionally supported market divisions (such as those created by differences in language, currency, and distribution networks) that can facilitate collusion. Assigning customers to individual producers limits the opportunity to cheat.

Despite a cartel's best efforts, individual firm sales do not always match assigned quotas. This may occur because of the cartel's inability to predict customer demand perfectly. Or it may occur because cartel participants cheat on the agreement. As a result, many cartels—a third of our sample—adopt formal

[43] See, for example, Commission Decision of January 19, 2005 (Case COMP/E-1/37.773: MCAA), pars. 77–83; Commission Decision of December 10, 2003 (Case COMP/E-2/37.857: Organic Peroxides), pars. 91–93.

[44] Hay and Kelley (1974) find that 29 percent of the cartels in their sample involved trade associations. Fraas and Greer (1977), Posner (1970), and Gallo et al. (2000) report 39, 44, and 23 percent, respectively.

[45] This has been true of international cartels in the past. See Liefmann (1927, pp. 130–31), which describes how international cartels allocate markets geographically. Suslow (2005, table 2, p. 716) reports that 40 percent of her sample of interwar international cartels assigned exclusive territories to cartel participants. Porter (2005, p. 157) notes that a "simple solution to the cartel problem assigns customers or territories to the participants." An efficient solution to the problem of assigning markets or output levels would distribute output quotas on the basis of the comparative advantage of different producers. Athey and Bagwell (2001), for example, describe an equilibrium in which an efficient collusive mechanism is achieved by having high-cost producers reduce output.

[46] Joint distribution agreements are the strongest form of market allocation that cartels use. Historically, cartels often funneled sales through a single central sales organization. For example, Alcoa and the European Aluminum Association essentially eliminated competition between themselves in the interwar Japanese market by agreeing to use a single distributor, a firm controlled by Alcoa's Canadian subsidiary (Bertilorenzi 2009). In today's legal environment, such an obvious mechanism for eliminating competition would quickly attract the attention of antitrust authorities. Not surprisingly, we do not observe the use of joint sales agencies in our sample.

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compensation rules (Compensation). The simplest way to accomplish such compensation is with side payments. However, side payments leave a paper trail that increases the likelihood of antitrust prosecution. The most common compensation procedure requires cartel members who have sold more than their share to purchase output from those who have undersold. This mechanism lessens a cartel member's incentive to cheat and sell more than its quota.[47] It also eliminates the necessity for firms to agree on the profits lost by the firm selling less than its allocated share. For example, in the vitamin A cartel, "if one was seen to be selling more than its allocated quota, it would have to 'slow down' sales to enable the others to catch up. If at the end of the year a producer was substantially ahead of its quota, it had to purchase vitamins from the others in order to compensate them for the corresponding shortfall in their allocation" (Case COMP/E-1/37.512, par. 196).

We distinguish the use of a compensation scheme, agreed upon prior to the realization of market sales, from the use of punishments implemented when the cartel believes that a member has reneged on an agreement (Punishment). Where possible, we have identified the use of disciplinary actions imposed by the cartel in response to violations. While the possibility of punishment—the threat of retaliation—is critical to cartel success and was essentially universal among the cartels studied here, the implementation of punishments is considerably less common than compensation schemes, occurring in only 19 percent of the cartels in our sample.[48] In fact, where punishments did occur, they seem to reflect not just violations of the agreement but disagreements about what the terms of collusion should be. In some cases, the punishment took the form of a price war, as when a preinsulated pipe producer (Løgstør) refused the terms proposed by ABB, the industry leader. This provoked "a strong negative and personal reaction from ABB" and a decrease in prices in major markets by 20 percent. It did not end the cartel: "[T]he producers continued to meet, even if for some time the multilateral meetings were replaced by bilateral and trilateral contacts" (Commission Decision of October 21, 1998 [Case No IV/35.691/E-4: Preinsulated Pipe Cartel], par. 52). In other cases, price wars were not the punishment of choice. For example, Mitsubishi "tried to punish [other thermal fax paper producers] by cutting off their supply when they refused to sell the paper at the recommended prices" (Acharya 1999, p. D3).

[47] Historically, cartels have handled this problem with a variety of mechanisms. For example, bromine cartel members simply provided direct monetary compensation—from one cartel member to another—when actual sales were not allocated as contemplated by the cartel agreement (Levenstein 1997, p. 131). Direct compensation raises the risk of detection by competition authorities and is not observed in our sample.

[48] If we combine Punishment with Exclusion, we can compare our sample to previous studies. Forty-three percent of cartels in our sample use some form of disciplinary or exclusionary tactics, compared to a range of 5–12 percent reported in previous samples (Hay and Kelley 1974; Fraas and Greer 1977; Posner 1970; Gallo et al. 2000). We do not believe that contemporary cartels use punishments and exclusionary tactics more frequently than those in the past. We simply find more documentation of this activity in the elaborate records recently made public by European competition authorities.

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Cartels do their best to use the information-gathering techniques described here to distinguish between cheating and random fluctuations in demand. Cartels do not want to disrupt collusion—reducing profits and undermining trust—by retaliating when a firm has not cheated, and even sometimes when they know that a firm has cheated. On the other hand, they do not want to tolerate excessive deviations from assigned quotas, as that would simply reward cheating and undermine the cartel.

3.2.4. Firm Impatience and Macroeconomic Fluctuations

To measure the impact of fluctuations in firm impatience on the probability of cartel breakup, we include several alternative specifications of the discount rate of cartel member firms. The presumptive measure of the discount rate is the market interest rate. We use the average annual interest rate on 3-month Treasury bills (T-Bill), which represents the short-term market rate of interest generally available to borrowers. Because it is possible that some firms face differential access to credit markets, we also create two firm-specific measures that capture financial distress for individual firms. We follow the approach taken by Busse (2002), who frames this as a question of how close cartel members are to bankruptcy, a condition in which they might well not have access to liquidity at the market interest rate. The leverage ratio and interest coverage, standard measures of firm indebtedness, are defined as follows:

$$\text{LevRatio} = (\text{Total equity} - \text{Net stockholders' equity})/\text{Total equity}$$

and

$$\text{IntCoverage} = (\text{Operating profit} - \text{Nonoperating expense} + \text{Depreciation})/\text{Interest expense}.$$

We construct these ratios at the firm level for each cartel member firm in each year and then calculate a summary statistic in each year.[49] The annual summary statistic is equal to the maximum leverage (or minimum interest coverage) of each cartel member's ratio for each year. Given our focus on changes in the discount rate that might disrupt cartel stability by causing a violation of the participation constraint, we define the annual cartel interest coverage each year as the minimum interest coverage ratio across all member firms. Analogously, we define the annual cartel leverage ratio as the maximum leverage ratio across all member firms in that year. For a given year for cartel j, we use $\max\{\text{LevRatio}_i \mid \text{for all firms } i \text{ in cartel } j\}$ as cartel j's leverage ratio and $\min\{\text{IntCoverage}_i \mid \text{for all firms } i \text{ in cartel } j\}$ as cartel j's interest coverage ratio.

These two variables, IntCoverage and LevRatio, are intended to capture the

[49] Details of the construction of these measures are provided in the Appendix. An alternate, and frequently used, method of assessing whether a firm is financially sound is to construct Altman's Z-score (Altman 1968). The Z-score is calculated as a weighted average of five financial ratios. Although these ratios are generally calculable for U.S. firms from Compustat data, because of the international nature and time span of our sample, the data were not consistently available.

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effect on cartel duration of the most financially vulnerable firm in the cartel, and hence the firm with the greatest incentive to cheat. To identify firms that are in a particularly precarious financial position, without sufficient funds to make required interest payments, we define a dummy variable, IntCoverage < 1, which takes on a value of one if IntCoverage is less than 1.

Another set of variables is intended to capture alternative ways in which cyclical fluctuations may affect cartel duration. In Green and Porter (1984), unexpected negative shocks to demand lead to the appearance of cartel breakup. In contrast, Rotemberg and Saloner (1986) propose a model in which cartels become less effective during macroeconomic booms.[50] Previous cross-sectional studies have found that macroeconomic volatility in demand reduces cartel life spans. Dick (1996, pp. 270–71), for example, defines business cycles using export price indexes and then decomposes export price movements into anticipated and unanticipated components. He finds that Webb-Pomerene export cartels between 1918 and 1965 were more prone to failure during anticipated downturns but that the effect of unanticipated business cycle changes was insignificant. Using Griffin's (1989) sample, Marquez (1994) finds that rapid demand growth increases cartel instability. Suslow (2005, pp. 720–22) uses industrial production data and National Bureau of Economic Research (NBER) reference cycle dates. She finds that economic volatility, either positive or negative, shortens cartel duration. In these studies, macroeconomic instability does destabilize cartels; the Great Depression and World War II dominate all other effects.

We test for the effects of observable business cycle fluctuations with the following variables: the global GDP growth rate (Global_GDP_Growth); a dummy variable indicating that there was a recession in the United States that year, as reported by the NBER's Business Cycle Dating Committee; and deviations from trend in global GDP using a first-order autoregressive process (Global_GDP _Resid). We distinguish between these business cycle measures, which are essentially common knowledge, and potentially unobserved or unexpected shocks to demand. In order to capture the latter, we measure demand fluctuations by estimating a nonlinear trend in global GDP using the Hodrick-Prescott (HP) filter.[51] The HP filter fits a smooth nonlinear trend curve to a time series by decomposing it into a nonstationary trend component and a stationary cyclical component. We then calculate deviations from this nonlinear trend (HP_Gap) so that we can examine the impact of such deviations on cartel survival. This reflects our belief that managers have a sense of market trends that is not limited to a simple linear extrapolation of recent events.

[50] Haltiwanger and Harrington (1991) reverse the cyclicality of prices by introducing autocorrelated shocks to demand. Bagwell and Staiger (1997) provide a further elaboration of this model by distinguishing between the impact of stochastic fluctuations in growth rates (generating a business cycle) and transitory shocks to demand.

[51] The Hodrick-Prescott filter is a weighted moving average, where the researcher must specify the weight, or smoothing parameter, commonly denoted by λ. The choice for λ recommended by Hodrick and Prescott (1997) varies with the frequency of the data. We have annual gross domestic product data, and thus we set λ equal to 6.25 (Ravn and Uhlig 2002).

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Since these are international cartels, fluctuations in exchange rates are also potentially disruptive to collusion.[52] Fluctuations in exchange rates can affect both prices and production costs. Exchange rate fluctuations affect cartel members in different countries asymmetrically, so previously agreed-upon cartel prices and market shares may no longer be sustainable. For example, the specialty graphite cartel had provisions in its agreement that allowed for currency fluctuations and on one occasion decided on an "emergency increase [in particular countries] of 5–10%" because of exchange rate fluctuations (Commission Decision of December 17, 2002 [Case COMP/E-2/37.667: Specialty Graphite], par. 205).[53] In order to capture this effect, we include the absolute value of the change in the exchange rate of the U.S. dollar (XchRateChange).

4. Regression Analysis

We jointly estimate the effects of these variables on the probability of different causes of cartel death in a competing hazard model. To maintain sample size, we group cartel deaths into two overarching categories: natural deaths, which result from violations of the participation constraint, including a member's decision to defect to the antitrust agency, and deaths by antitrust, which result from intervention by antitrust agencies without voluntary action on the part of a cartel member.

We turn first to the determinants of antitrust death (Table 4). Not surprisingly, we find a large, significant increase in the probability of breakup by antitrust enforcement in the post-1995 period (the Enforcement dummy variable). We find that cartels that used market allocation mechanisms were significantly less likely to be broken up by the authorities (the point estimate is less than 1) than those that did not. Similarly, cartels that actively punished members that cheated were significantly less likely to be broken up by antitrust authorities. We suspect that these punishments create the appearance of competition, and presumably fewer complaints from customers, so competition authorities are less likely to devote resources to investigating the industry. On the other hand, the active involvement of trade associations seems to tip off the authorities—and to provide an evidence trail—which increases the likelihood of antitrust death.

One might expect that concentrated industries would draw the attention of authorities. However, we find that neither industry concentration nor the number of cartel members has a systematic impact on the likelihood of antitrust death (models 1 and 2 in Table 4). Half of the cartels in the sample have a C4 of 80

[52] Alexander (2003) provides the only previous empirical test of the effect of exchange rates on cartel stability. Exchange rates are included by de Roos (2006) in his analysis of price wars in the lysine industry, but as an instrument that shifts consumer demand, not for their impact on cartel behavior.

[53] As the decision describes, numerous facets of this cartel agreement were designed to harmonize trading conditions, including an agreement to set up standard exchange rates (Commission Decision of December 17, 2002 [Case COMP/E-2/37.667: Specialty Graphite], par. 100).

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Table 4
Determinants of Cartel Death: Death Caused by Exogenous Antitrust Intervention

Variable	(1)	(2)	(3)
Enforcement	4.36*	6.59*	7.56*
	(3.77)	(2.71)	(2.76)
MemNum	1.03	1.08	1.08
	(1.07)	(1.54)	(1.59)
MarketAlloc	.23*	.20*	.12*
	(−3.72)	(−2.67)	(−3.43)
TradeAssoc	2.52*	2.16*	2.05+
	(2.64)	(1.96)	(1.78)
Punishment	.39*	.41	.58
	(−2.06)	(−1.59)	(−1.00)
MinC4		1.02	1.01
		(1.36)	(.96)
CustConcHigh			1.17
			(.25)
Cartels at risk	81	57	56
Cartel failures	49	33	33
N	654	446	437
Log likelihood	−154.2	−90.3	−88.0
Likelihood ratio χ^2	39.9	29.0	32.4
Degrees of freedom	5	6	7

Note. Values are hazard rates, with *z*-statistics in parentheses.
+ The coefficient is significantly different from 1 for a 10% two-tailed test.
* The coefficient is significantly different from 1 for a 5% two-tailed test.

percent or above. It may be that dispersion in this range is irrelevant to the authorities.

The results also suggest that there is no effect of downstream customer concentration (CustConcHigh) on antitrust breakup. As we discuss below, while large customers are quite happy to collect damages after cartel breakup—as evidenced by the large number of civil suits in the United States and the increasing number elsewhere—they tend not to be proactive in undermining upstream cartels.

We turn now to estimates of the determinants of the probability of natural death for cartels. As with death by antitrust, we see a significant effect of Enforcement on the probability that cartels will collapse on their own (model 4 in Table 5). This effect is smaller than the one for death by antitrust, as might be expected, but reflects the very real effect on incentives that changes in antitrust policy have wrought. Also notable is the result relating to the MemNum variable. As has been the case in every cross-sectional study of cartel duration in every era, we find no effect of the number of cartel members on the probability of

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Table 5
Determinants of Cartel Death: Natural Death

Variable	(4)	(5)	(6)	(7)	(8)	(9)
Enforcement	4.17*	2.06	4.07*	2.86*	2.82*	2.96*
	(3.11)	(1.4)	(3.02)	(2.13)	(2.1)	(2.18)
MemNum	.94	.98	.95	.93	.93	.93
	(−.98)	(−.22)	(−.87)	(−1.09)	(−1.11)	(−1.06)
TradeAssoc	.22*	.20*	.23*	.23*	.23*	.23*
	(−2.30)	(−1.97)	(−2.27)	(−2.15)	(−2.15)	(−2.15)
Punishment	4.11*	2.47	3.21+	3.50+	3.43+	3.52+
	(2.24)	(1.25)	(1.65)	(1.78)	(1.74)	(1.81)
Compensation	.14*	.15*	.17*	.17*	.17*	.18*
	(−2.63)	(−2.42)	(−2.32)	(−2.38)	(−2.38)	(−2.35)
Exclusion	2.24	1.81	2.08	2.31+	2.35+	2.31
	(1.59)	(1.04)	(1.47)	(1.64)	(1.66)	(1.64)
MarketAlloc	.59					
	(−.96)					
MinC4		1.00				
		(.22)				
CustConcHigh			.42			
			(−.86)			
IntCoverage < 1				3.41*	3.30*	3.40*
				(2.26)	(2.14)	(2.26)
T-Bill					.96	
					(−.25)	
XchRateChange						.96
						(−.45)
Cartels at risk	81	57	76	73	73	73
Cartel failures	32	24	28	29	29	29
N	654	446	610	499	499	499
Log likelihood	−93.5	−67.6	−80.7	−76.9	−76.9	−76.8
Likelihood ratio χ^2	31.2	16.0	26.5	25.2	25.3	25.4
Degrees of freedom	6	7	7	7	8	8

Note. Values are hazard rates, with *z*-statistics in parentheses.
+ The coefficient is significantly different from 1 for a 10% two-tailed test.
* The coefficient is significantly different from 1 for a 5% two-tailed test.

cartel breakup (model 4 in Table 5). The degree of industry concentration has a similarly insignificant effect on cartel stability (model 5 in Table 5).[54]

Looking at the effects of downstream industry structure, we find that the point estimate of the coefficient on CustConcHigh is much less than 1 but is not statistically significant. This may reflect the smaller number of observations, which drops from 654 to 437 cartel-years when we introduce this variable (because we are unable to obtain measures of downstream concentration for all industries). However, the other coefficients are robust to this change in the sample. This nonresult is consistent with our general observation that large

[54] See Levenstein and Suslow (2006b, pp. 57–61) for a survey of previous findings on the relationships among industry concentration, the number of cartel members, and cartel duration.

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customers do not increase the incentive of firms to cheat.[55] Although large customers may be able, in principle, to destabilize cartels, in many cases they seem instead to extract concessions that reduce their incentive to do so.

We find the surprising result that market allocation—which was so important in preventing antitrust breakup—has no significant impact on the probability of natural death. Similarly, monitoring has no significant impact on natural death (results not reported here). Both of these practices are pervasive, so their absence in any particular cartel probably says more about the unique information structure of that market than anything else.

Other organizational characteristics do have a significant impact on cartel stability. The active use of a trade organization—which significantly increases the probability of death by antitrust—significantly decreases the probability of the cartel's breaking up on its own (compare model 1 in Table 4 and model 4 in Table 5). Cartels appear to face a trade-off: the involvement of a trade association helps to stabilize the cartel, providing a mechanism for communication and mediation, but it also increases the cartel's visibility and the written record of its conspiratorial activities, which makes it more vulnerable to prosecution.[56] From a policy maker's perspective, this also suggests that scrutinizing the activities of industry associations has a potentially large payoff because it removes from a cartel's arsenal a technique that is particularly helpful for internal stabilization.

Cartels that have a compensation scheme—a plan for how they will handle variations in demand—are significantly less likely to die a natural death (model 4 in Table 5). This undoubtedly reflects the ability of these compensation schemes to align the incentives of cartel members. It also likely reflects the level of organizational trust and cohesion necessary to implement such a scheme. Trust in and of itself, while difficult to measure, is undoubtedly important to cartel stability.[57] This is reflected in the fact that, despite rapid technological change in communications in the late twentieth century, 100 percent of the cartels in this sample had direct, face-to-face meetings. We distinguish compensation schemes from the implementation of retaliatory punishments in response to perceived cheating. Although punishments decrease the likelihood of death by antitrust, they significantly increase the likelihood of natural death (model 4 in Table 5). Cartels that have to punish are not stable cartels.

The one other organizational variable that has a significant impact on cartel

[55] See Levenstein and Suslow (2006b, pp. 61–64), for a review of the empirical literature on the relationship between customer size and cartel stability.

[56] See Genesove and Mullin's (2001) study of the U.S. sugar cartel for an insightful discussion of the importance to cartels of a quasi-judicial framework for mediating disputes. Similarly, Dye and Sicotte (2006) examine the 1931 negotiations of the international sugar cartel and show that cartels function as governance mechanisms to implement and renegotiate incomplete contracts. Taylor (2007) finds that more complex agreements were more successful at reducing output under the National Industrial Recovery Act of 1933. In particular, he finds that agreements with explicit monitoring, quotas, and restrictions on new productive capacity were more successful.

[57] The relationship between cartel stability and trust is discussed in detail in Leslie (2004). Levenstein and Suslow (2006a) give a more detailed discussion of communication among a subsample of the cartels considered here.

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stability in some specifications is Exclusion. Since cartels engage in exclusionary actions only when there is a credible threat of entry, as with punishments, this measure has an ambiguous relationship to cartel stability. Exclusionary actions increase cartel stability, but their implementation implies that a threat exists. While this variable is only marginally significant, the need to rely on exclusionary actions is associated with shorter cartel life. This is consistent with the descriptive results in Table 2 that show that cartels that broke up as a result of a growing fringe were shorter lived than average.

Perhaps the single most robust result of the repeated-game literature on collusion is that as players become more impatient, collusion is harder to sustain (Friedman 1971). In Table 5, model 7, we report results from using the cartel-specific discount rate variable IntCoverage < 1.[58] The coefficient on this variable is significant and much greater than 1, which indicates that the presence of a cartel member with income insufficient to cover interest payments increases the probability of cartel breakup. Consistent with Busse (2002), this suggests that firm-specific discount rates are relevant for cartel stability. In contrast, when we add the variable T-Bill—to reflect the opportunity cost of waiting for most market participants—we find that it has no significant impact on the probability of cartel breakup. Firms that respond to short-term fluctuations in market interest rates may not have sufficient horizon even to attempt collusion. Firm-specific rates capture the impatience of those firms, which constitutes a binding constraint on cartel stability, while market rates do not.

Despite our speculation that exchange rate fluctuations could be a destabilizing force for international cartels, we consistently find that they have no effect on cartel stability. This may reflect the difficulty in capturing the shocks to individual cartels using aggregate data (in this case, a trade-weighted index of the value of the U.S. dollar).[59] But exchange rate fluctuations are common knowledge. While responding to such fluctuations may take the time and attention of cartel members, they do not appear to break up otherwise stable cartels.

Finally, we test for possible macroeconomic effects with various specifications (Table 6). Neither common-knowledge measures of business cycles nor measures of unexpected shocks to demand appear to have any significant effect on cartel stability. We considered specifications (not reported here) that allowed positive and negative deviations from trend to have different effects, but the results were essentially the same as those reported. The point estimates for all these specifications suggest that deviations from trend in GDP may increase the likelihood

[58] When we include this variable, the number of cartels in the sample drops from 81 to 73 because eight cartels had no members with publicly reported financial data. The number of observations drops from 654 to 499, as there are 22 cartels for which no member firm could be found in at least 1 year.

[59] The relevant fluctuations in the exchange rate depend on the location of production for cartel participants and the regions in which the cartel participants agree to fix prices. The nationality of cartel members as well as the geographic scope of the cartels vary over the sample. Therefore, different pairwise exchange rates may better capture the shocks faced by individual cartels, but adding pairwise exchange rates for each of the countries with cartel participants (and customer markets) in this sample of global cartels would exhaust the degrees of freedom of our sample.

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Table 6
Macroeconomic Determinants of Cartel Death: Natural Death

Variable	(10)	(11)	(12)	(13)
Enforcement	3.01*	2.68*	2.65+	2.24
	(2.19)	(1.95)	(1.93)	(1.56)
MemNum	.92	.93	.93	.91
	(−1.24)	(−1.13)	(−1.15)	(−1.35)
TradeAssoc	.21+	.24*	.24*	.24*
	(−2.30)	(−2.09)	(−2.07)	(−2.09)
Punishment	3.59+	3.42+	3.44+	3.25+
	(1.77)	(1.75)	(1.76)	(1.63)
Compensation	.15*	.17*	.17*	.15*
	(−2.44)	(−2.38)	(−2.38)	(−2.42)
Exclusion	2.29	2.41+	2.43+	2.98*
	(1.59)	(1.69)	(1.70)	(1.97)
IntCoverage < 1	2.94+	3.38*	3.43*	3.07*
	(1.63)	(2.16)	(2.18)	(2.0)
T-Bill	.96	.93	.93	.76
	(−.27)	(−.43)	(−.48)	(−1.36)
NBER	2.23			
	(1.50)			
Global_GDP_Growth		1.14		
		(.45)		
Global_GDP_Resid			1.00	
			(.59)	
HP_Gap				1.00*
				(1.94)
Log likelihood	−75.9	−76.8	−76.7	−75.7
Likelihood ratio χ^2 (df = 9)	27.3	25.5	25.6	29.0

Note. Values are hazard rates, with z-statistics in parentheses. For all models, N = 499, number of cartels at risk = 73, and number of cartel failures = 29.
+ The coefficient is significantly different from 1 for a 10% two-tailed test.
* The coefficient is significantly different from 1 for a 5% two-tailed test.

of breakup by a very small amount, but none are statistically significant. This contrasts with Suslow (2005) and Dick (1996), where macroeconomic shocks are very important.[60] The order of magnitude of the macroeconomic shocks that occurred during the period studied here is not comparable to the shocks of the pre–World War II period. Our result is consistent with many case studies of individual cartels, which rarely report any role for macroeconomic fluctuations in cartel stability (Levenstein and Suslow 2006b, p. 67).

5. Conclusion

What causes cartel death? First and foremost, active antitrust enforcement. The change in antitrust enforcement in the mid-1990s, with additional resources

[60] Note that Domowitz, Hubbard, and Petersen (1987) and Borenstein and Shepard (1996) find empirical support for the Rotemberg and Saloner (1986) prediction in their examination of prices and price-cost margins in industries in which there may be tacit collusion.

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and policy tools directed toward international cartels, resulted in the discovery and breakup of a large number of cartels operating globally across a range of markets. While our analysis suggests that, absent vigorous antitrust enforcement, cartels are relatively stable, there are important lessons from this analysis of what causes cartels to break up on their own. First, cartels break up when a significant producer becomes too financially unstable to wait for high monopoly profits. Firm-specific measures of impatience, such as the firm's ability to handle its debt load, are systematically related to cartel breakup. Firms that are in dire straits do not make good cartel partners. Our empirical analysis is consistent with the theoretical literature's focus on discount rates but suggests that firm-specific measures are more important than market interest rates in determining the relevant discount rate.

Second, cartels that have to punish their members are relatively unstable cartels. Many cartels suffer from a little cheating; this cheating does not result in punishment, let alone cartel death. Cartels use compensation mechanisms to limit the incentive to cheat as well as to respond to variation in demand—which they know will occur. Cartels that use such compensation mechanisms are more likely to endure. Cartels that punish are frequently suffering from fundamental disagreements about how to divide markets or set prices. Pervasive and repeated violations of the terms of a cartel agreement do result in retaliatory punishments, but these punishments do not save the cartel. They undermine trust and lead to cartel breakup.

Similarly, entry destabilizes cartels. Cartels respond creatively to the threat of entry and take a variety of actions to prevent it. While these actions to create barriers to entry may prolong cartel life, their use reflects an active threat and is associated with increased probability of breakup. The threat of entry is an important feature to include in models of cooperative behavior.

Our findings also have implications for the design and implementation of antitrust policy. First, antitrust authorities should look for compensation schemes as a sign of possible collusion. In particular, purchases by competitors, which may have perfectly legitimate motivations, are also a common mechanism used by colluding firms and deserve scrutiny. Second, government policies that facilitate entry are important to effective competition. While such structural policies are less direct than leniency or criminalization of price fixing, they are also an important instrument in the competition policy tool kit.

Appendix

Detailed Data Descriptions

Cartel-Level Data

Variables such as number of cartel members, dates of cartel operation, and cartel organizational characteristics were culled from a variety of publicly avail-

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able sources. These include press releases from the Department of Justice, the European Commission, and the Canadian Competition Bureau, European Commission decisions, and judgments released by the European Court of Justice and the European Court of First Instance. In addition, a variety of industry and business news sources were used, including *American Metal Market*, *Chemical Marketing Reporter*, *European Business Week*, *International Cement Magazine*, the *Oil and Gas Journal*, and the *Wall Street Journal*. Specific sources are available from the authors upon request.

We code the organizational dummy variables as indicated in Table A1. We set each variable equal to one if the cartel engaged in the specified behavior at any point during its life span. Unfortunately, even with the detailed descriptions of cartels that are available, it was not possible to create time-varying measures of these characteristics.

Market Concentration of Producing and Consuming Industries

For each cartel, we identify one primary SIC code and one primary NAICS code. Where available, we obtained HHI and C4 data from the U.S. Bureau of the Census's concentration ratios based on data from the quinquennial U.S. Economic Census.[61] (Some historical observations are available only in hard copy.) We use concentration measures based on the value of shipments because value-added measures are not available prior to 1997. For each year of the cartel's life span, we assign an HHI by linear interpolation of the Census's 5-year observations.

We identify cartel customers, where possible, using lists of plaintiffs in civil damage cases against the cartel members. These plaintiff lists were compiled using docket information available in the Westlaw legal research database and the Public Access to Court Electronic Records (PACER) database of U.S. federal court documents. The primary SIC and NAICS industry codes were obtained for each plaintiff company from Hoover's or Thomson Research. We chose one SIC code and one NAICS code to represent the downstream industry for each cartel. The choice of the representative downstream industry was based on either the majority of customers or the most representative customer, if there was not a clear majority. In those instances without litigation—for example, there are no U.S. civil cases against the European cement cartel—we identified the downstream industry on the basis of other secondary research. For some cartels, we were unable to identify a single predominant customer industry. We obtained HHI estimates from the quinquennial U.S. Census of Manufacturing for the period 1982–2002. The dummy variable, CustConcHigh, is set equal to one if the cartel's customers are highly concentrated, as indicated by a measure of either $C4 > 50$ or $HHI > 625$ at any time during the cartel's life span. Note that if an industry has four equal-sized firms that share half the market and all other firms are infinitesimally small, then the HHI is equal to approximately 625. Our goal

[61] See U.S. Census Bureau, Concentration Ratios (http://www.census.gov/epcd/www/concentration.html).

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Table A1
Coding of Organizational Dummy Variables

Organizational Variable	Criteria to Be Coded Equal to One
Compensation	Cartel agreed upon a scheme that required the voluntary cooperation of any firm that went over quota or otherwise made unauthorized sales to compensate other member firms
Exclusion	Direct evidence that the cartel explicitly and consciously engaged in activities designed to eliminate a competitor or potential competitor; these included agreements to purchase competitors, agreements not to share technology with nonmembers, and targeted price wars against nonmembers
MarketAlloc	Cartel assigned members either specific geographic markets or specific customers
Monitor	Direct evidence that the cartel systematically gathered information about the activities of members; this might include a group decision to self-report as well as arrangements in which a third party was employed to monitor all members
Punishment	Cartel members took retaliatory actions following cheating or deviations from the agreement; such actions are inflicted ex post by those who are injured without the cooperation of the deviating firm
TradeAssoc	A trade association was actively involved in implementing a cartel agreement; we coded this variable as zero if a trade association was simply used as cover for cartel meetings but played no other role

was to have roughly equivalent measures using either the HHI or the C4, so that there would be a consistent measure over time, even as the availability of the two measures changes.

Firm Financial Distress

These ratios draw on firm-level data from Compustat North America (Fundamentals Annual) and Compustat Global (Global Fundamentals Annual). When companies are present in both Compustat North America and Compustat Global, we use the values from Compustat North America. For North America, data are available for publicly traded firms for the full sample period; Compustat Global contains data only from 1987. Following Busse (2002), we calculate the leverage ratio from Compustat variables: Total Liabilities (LT) and Shareholders' Equity (SEQ).[62] The interest coverage variable is calculated from Operating Income (OIADP), Total Non-operating Income Expense (NOPI), Depreciation and Amortization (DP), and Interest and Related Expense (XINT).

For each cartel-year observation, we define the leverage ratio as the maximum of the cartel's member firms' leverage ratios in that year. Analogously, we define the interest coverage ratio for each cartel-year observation as the minimum of

[62] Busse (2002) includes two typographical errors in table 1, where the definitions of these variables are summarized. We use the correct definitions, provided to us by Busse.

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the member firms' interest coverage ratios for that year. For eight cartels, we could not locate members' financial information.[63]

Macroeconomic Data

Annual U.S. Treasury bill, 3-month maturity, secondary market rates are from the Federal Reserve Board.[64] Annual U.S. GDP, in real 2000 U.S. dollars, is from the Bureau of Economic Analysis of the U.S. Department of Commerce.[65] Quarterly exchange rate data from 1970 through 2008 were compiled by Linda Goldberg of the New York Federal Reserve Bank and are available on the bank's Web site.[66] From this Web site, we used the total manufacturing (trade-weighted) exchange rate in the Database on Industry-Specific Exchange Rates.

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[63] These are aluminum phosphide, Adriatic ferry operators, plastic dinnerware, steel beam, tampico fiber, zinc phosphate, freight forwarding, and Luxembourg beer.

[64] See Federal Reserve, Selected Interest Rates (Daily)—H.15 (http://www.federalreserve.gov/releases/h15/data.htm).

[65] U.S. Department of Commerce, Bureau of Economic Analysis, National Economic Accounts (www.bea.gov/national/index.htm#GDP).

[66] See New York Federal Reserve Bank, Industry-Specific Exchange Rates (http://www.newyorkfed.org/research/global_economy/industry_specific_exrates.html).

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