Membership, Stability and Internal Institutions in European Cartels

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Abstract

The first topic this thesis examines is that of firms which enter and leave cartels without affecting the existence of the cartel. The first chapter predicts which firms in markets will choose to join and leave cartels. The findings align with a group of theoretical models identified in the literature review, indicating that cartel membership is explained by firms' individual preferences for collusion, which are consistent over time. The firms most likely to join and leave cartels are small firms in large cartels.

The second chapter questions what effect this behaviour by firms has on the survivability of cartels. Theory is ambiguous on this, since entry and exit by firms could signal poor discipline among cartelists which prevents the cartel from raising prices substantially due to undercutting by outsiders or it could signal a structurally stable cartel which marginal firms take advantage of in their membership decisions. Cartels which experienced more entry and exit by firms had a lower risk of breakdown in each period than cartels with more static membership, indicating that member firms recognise when cartels are strong and take advantage of this by constantly re-evaluating their membership decisions.

The final chapter discusses a different topic: the types of agreement formed by cartels. All cartels must agree to either fix prices, restrict the output of its members, allocate exclusive territories, allocation customers, or rig bids in order to fulfil their objective of raising member profits. Many cartels engage in more than one of these practices simultaneously. Structural variables are poor at predicting the presence of agreement types in the cartels studied, but distinct strategy profiles where certain agreement types substitute for each other or complement each other are present. These strategy profiles appear to be associated with particular industries and cartels of common geographical scope.

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Introduction

The Citric Acid cartel was founded during a meeting of members of the European Citric Acid Manufacturers Association, a trade association, in Basel on 6 March 1991.[1] *The four largest European producers of citric acid were present at the meeting where they fixed prices and assigned target shares of world output to the four producers present and to one producer which was not present at the meeting: Cerestar Bioproducts. Cerestar was the smallest of the major manufacturers of citric acid, having only recently entered the market and not yet being a member of the trade association. Cerestar was present at the next meeting of the ECAMA, having since joined the trade association, in Brussels on 15 November 1991 but was not informed of the existence of the cartel or of the quota the other producers had assigned to it, though the General Manager of Cerestar was invited to meet with the World Head of Marketing Vitamins and Fine Chemicals of Hoffman-Roche, a ringleader firm of the cartel.*

The meeting took place in Basel on 12 February 1992 and the mechanisms of the cartel were explained to the Cerestar manager: Producers were to charge a uniform price and aim to produce the share of world output they have been assigned. Each producer's output was to be monitored closely by the other firms so that at meetings held every six months any discrepancies between quotas and actual output could be corrected by compensation payments from the overproducers to the underproducers. This set of mechanisms would later become known as the Lysine Strategy Profile, due to its use by the Lysine cartel which was active in parallel with the Citric Acid cartel with which it shared several members. Cerestar attended the next meeting of the cartel in Jerusalem in May 1992 where it formally agreed to the 5% market share which the other members had agreed upon previously. It had produced close enough to 5% of world output in the months preceding its entry to the cartel that no compensation payments were deemed necessary. The cartel agreement continued until 1995, though it suffered from repeated cheating by the relatively small producer Jungbunzlauer. The ringleader producers regarded the agreement as

[1] This information is from the EC's decision document for the Citric Acid cartel, OJ L 239, 06.09.2002, p. 18 - 65. It presents one of the most readable cartel narratives in the sample. Connor [2008] also provides a detailed narrative of the Citric Acid cartel and several related conspiracies.

slowly coming to an end due to cheating and the loss of market share to fringe producers, mostly in China, when the existence of the cartel was revealed when US authorities raided the offices of member Archer Daniels Midland in connection with the Lysine cartel.

Evidence of the Citric Acid cartel was found in records of the Lysine cartel because a representative of Archer Daniels Midland had repeatedly talked of his involvement in the Citric Acid cartel to employees of other Lysine producers in order to convince them to form the cartel. The exact system of price fixing, quota allocation, formal and informal monitoring of output, and compensation payments used in the Citric Acid cartel was adopted by the Lysine cartel at the urging of the Archer Daniels Midland employee.

Narratives of cartels reveal a great amount of detail about cartelists' behaviour which falls outside of simple accounts of collusion between firms. There is a high-quality body of theoretical research into many of these aspects individually: the formation of cartels, incomplete cartels, the loss of cartel market share to fringe firms, the use of different techniques for collusion, the defection of firms from agreements, and the breakdown of cartels, for example. However these topics are difficult for economists to analyse empirically, especially econometrically, because of the difficulty in finding detailed quantitative data on cartels and the complexity of the theoretical models around them. This thesis focuses on investigating such topics empirically.

Firms which join cartels which are already in progress or leave cartels without the cartels breaking down are the first phenomenon considered. Their behaviour and identities may allow theoretical models of cartel behaviour to be tested empirically. Chapter 1 surveys the literature on cartel membership. The cartel membership literature includes research into the choice made by firms to become cartel members. It encompasses the part of the theory of incomplete cartels where the firms are assumed to be heterogeneous, and also the theory of the process of cartel formation. What empirical evidence there is on the nature of firms which collude compared to those which do not is also summarised. Theoretical models of collusion broadly agree that firms with high costs, low capacities or low discount rates compared to other firms in the same market will tend to be cartel outsiders.

Two distinct trends in the theoretical modelling of cartels are also identified, which are termed the marginal firms and the balanced temptations-based approaches. Marginal firms models see each firm as constantly re-evaluating their membership decision in

order to maximise their profits. Cartels will be only as large as is necessary for their continued existence and all firms which may be outsiders will choose to be so. Firms on the margin between being a cartel member and being an outsider may change their membership decision multiple times, joining the cartel when necessary to ensure its survival but then leaving when it has an opportunity. Balanced temptations models see cartel formation in a similar way but differ in their conception of the exit of firms. These models see cartels as allocating profits among members such that each member has an equal incentive to defect from the agreement, in order that the cartel does not have 'weak links' in the form of marginal firms.

The descriptive statistics and details about the collection and background of the data used in the thesis are presented in Chapter 2. This chapter is intended to show the reader the level of detail and quality of data provided by the European Commission's decision documents, and provide an overview of the nature of the cartels and firms in the sample. Where these descriptive statistics have direct relevance to the research questions considered in the substantive chapters, they are discussed in those chapters.

The first topic this thesis examines is that of firms which enter cartels which are already active or which leave cartels without causing their breakdown or discovery. Chapter 3 attempts to predict which firms will choose to join and leave cartels and what this indicates about the success of theoretical models of incomplete collusion. The findings align with many theoretical models, indicating that firms' preferences for colluding are consistent over time and that the firms most likely to leave and join cartels, therefore spending time as outsiders, are small firms in large cartels.

With the motivations of the firms who choose to alter their membership decisions better understood, another question is prompted: What does this indicate about the cartels which these firms are members of? What a large amount of entry and exit by member firms may signal about a cartel is ambiguous. A cartel which experiences entry and exit may be a cartel with weak internal institutions which was unable to encompass all of the firms in its market, and which is unable to prevent its members from defecting. Alternatively it could be a cartel which is structurally robust, meaning its firms are able to switch between the fringe and the cartel in order to achieve the best possible profits.

Chapter 4 approaches this question by testing whether entry and exit by firms is associated with cartels' risk of breakdown. The analysis finds that cartels in the sample

which experienced entry and exit were less likely to break down in each period of operation than those with more static memberships. This lends support to the view that firms in a cartelised market recognise the strength of the cartel and are willing to change membership decisions in order to maximise their profits while preserving the cartel.

Chapter 5 focuses on predicting the strategies of cartels, in particular what aspect of firm behaviour the cartel members choose to coordinate. Five broad agreement types are identified by the European Commission: price fixing, bid rigging, territorial allocation, customer allocation and quota allocation. Many cartels engage in more than one of these practices simultaneously. Data on the number of firms in each cartel, the asymmetry in the market shares of the cartel members, the geographical scope of the cartels, and the industrial sector of the cartel is used to predict the presence of all five agreement types in the sample of cartels. The correlations between the agreement types are also of interest.

Chapter 1.

Literature Review on Cartel Membership

Cartel outsiders are firms which remain outside of a cartel in their market. Many cartels do not comprise all of the firms in their market and so have these fringes. This chapter aims to review the literature on which firms in a market will be in a cartel and which firms will not be. The first two substantive chapters of this thesis are concerned with interpreting the behaviour of firms which choose to join or stay outside of cartels and on considering what this behaviour signals about the strength of a cartel agreement.

This research builds on the theory of incomplete cartels since, if anything is to be learned about cartel membership, situations in which firms face a meaningful membership choice must be examined. A recent and comprehensive survey of the literature on incomplete cartels is provided by Bos [2009]. Because of this, I shall limit my discussion of the theory of symmetric incomplete cartels to a summary, and to the literature published since Bos [2009]. Other strands of economic theory examine collusion among firms which vary by capacity, cost or discount factors, the initial formation of cartels and the reaction of cartels to firms entering their markets. Some work brings together more than one of these strands, such as the model of endogenous cartel formation with heterogeneous firms and differentiated products of Paha [2010].

The heart of this chapter is a review of the literature on incomplete collusion between asymmetric firms. I shall also discuss what empirical work there is about the differences between colluding and non-colluding firms. I argue in this chapter that there are two main methodological approaches to modelling cartel membership: A 'marginal firms' approach which sees firms as having different levels of commitment to the cartel and being able to change their membership decisions on the basis of self interest, and the 'balanced temptations' approach which sees cartels as choosing their allocation rules to eliminate the problem of firms exiting and entering on the margins. The tension

between the predictions made by these two theoretical approaches is the subject of Chapter 3.

1.1. Agreements Among Identical Firms

The simplest models of collusion are those where all firms in the market are assumed to be identical in their costs, capacities and other attributes. The most directly relevant conclusions of theory are drawn from more complex models where firms are heterogeneous but models of firms with identical costs still provide useful stylised facts about the behaviour of colluding and non-colluding firms. That firms will generally prefer to be outsiders rather than insiders, given that a cartel exists, is a stylised fact which is central to the models discussed later since it leads to the conclusion that cartels are likely to be only as large as they need to be to raise prices and remain stable.

Bos [2009] examines several models of oligopoly and provides a survey of the literature around incomplete cartels. The paper identifies the proportion of firms and output controlled by the cartel in each model.

The five models of oligopoly considered by Bos are:

1. Simultaneous Bertrand competition with homogeneous products;
2. Sequential, collusive price leadership;
3. Simultaneous Bertrand competition with product differentiation;
4. Simultaneous Cournot competition with homogeneous products;
5. Collusive quantity leadership.

Incomplete cartels are impossible in the first case, inconclusive in the second and third, require ∼80% market share in the fourth and ∼50% in the fifth case.

In the simultaneous Bertrand game any outsider, or group of outsiders, is capable of completely and perfectly replacing the output reduction by firms attempting to found a cartel. This means that no incomplete cartel is viable because outsider firms will always undercut the cartel and take all of their output.

In models based on sequential price leadership, the cartel is assumed to be the price leader and the fringe firms price takers. Unlike the simultaneous version of the Bertrand game, outsiders may find it profitable to restrict their own output (though not by as much as cartel members) in order to ensure that the cartel is profitable for the member firms. If the outsider firms were not to restrict their output then the members would not maintain the cartel and the outsiders would lose the high profits they gain from the cartel's existence. That firms compete à la Bertrand is an assumption which is appealing to modellers since it makes the existence of a cartel certain with a finite number of firms (as proved by D'Aspremont et al. [1983]) since even a small, weak cartel will make the profits of the firms involved non-zero and so be worthwhile for those firms involved, compared to zero-profit Bertrand equilibrium.

Deneckere and Davidson [1985] model mergers among firms producing differentiated products and competing in price. The paper's findings on mergers may equally be applied to cartels. Here, any cartel able to charge a price higher than the fringe may exist, but the profitability of any given incomplete cartel will depend upon the degree of product differentiation. The more differentiated the products, the smaller the drop in cartel members' market shares when they raise their prices because consumers will be less willing to substitute to the products of the fringe members. This makes relatively small cartels profitable where products are strongly differentiated. Since greater profits are possible as an outsider than as an insider, firms will not choose to join a cartel which is already profitable and stable without their membership. This conclusion, that cartels will tend to be smaller when the market is more amenable to collusion, is perhaps counter-intuitive and it makes an important point which is central to Chapter 4: that structurally strong cartels may be small and comprised of opportunistic, profit-chasing firms.

When firms simultaneously choose quantity, rather than prices, the 'merger paradox' identified by Salant et al. [1983] applies. A cartel among identical firms will only be profitable if it comprises at least 80% of firms in a market. If fewer than 80% of the firms attempt to form a cartel then the remaining outsiders will find it most profitable to expand their output to such a level that the cartel is no longer profitable for its members. Similarly to the reasoning in price-competition games, a reduction in output by a cartel's members will only be profitable if the higher prices outweigh the sales lost to the outsider firms.

Martin [1990] shows that when a cartel is able to act as a Stackelberg quantity leader, a cartel requires only at least half of the firms to be members. The fringe's best response function is very soft due to its strong incentive to keep the cartel in existence. More precisely, the smallest cartel possible is $k = \frac{n+1}{2}$. Taken together, these models show how the size of the smallest viable cartel in a market will depend on the response of the cartel's outsiders to changes in output by the cartel.

1.1.1. Incentive and Participation Constraints

All of these results are true where firms are identical and symmetrical. Bos discusses incomplete cartels among heterogeneous firms briefly, concluding that the critical discount factor necessary to maintain a given cartel is higher where firms are more asymmetric, because the incentive and coordination problems associated with collusion will be more severe.

At the centre of Bos' view of incomplete cartels is that cartels are bound by both an incentive constraint and a participation constraint (in addition to needing to solve a coordination problem). The incentive constraint must be satisfied for all firms and it is familiar from the theory of complete cartels. It requires that the discounted value of future collusive profits exceed the payoff which a firm would receive for secretly cheating on the cartel agreement and suffering whatever punishment the cartel can muster as a result of this. The constraint represents the requirement that cartel membership be individually profitable for every member.

The participation constraint applies to particular potential cartels containing combinations of firms in the market. It requires that no cartel member would prefer to be a member of the fringe in equilibrium and that no fringe firm would prefer to be a member of the cartel. This concept is named cartel stability by D'Aspremont et al. [1983] and is discussed in greater detail in section 1.1.1. That the participation constraint is satisfied means that it is profitable for a particular cartel to be formed. That the incentive constraint is satisfied means that no member will wish to deviate from the agreement.

Models of collusion which assume all firms in a market must be members of a cartel for a cartel to be formed focus on the incentive constraint entirely since it is assumed that the firm which is most marginal about participation may not leave the cartel for

the fringe without destroying the cartel. Where incomplete cartels are assumed to be possible, satisfying the participation constraint becomes important.

Cartel Stability and the Participation Constraint

D'Aspremont et al. [1983] defined the conditions under which a cartel is considered stable. Let k be the number of firms in a cartel, $\pi^c(k)$ the single-period profits of a member of a cartel containing k firms and $\pi^o(k)$ the single-period profits of a cartel outsider in a market containing a cartel with k members. Note that this implies that the fringe of cartel outsiders consists of $n-k$ firms where n is the total number of firms in the market. $\pi^o(k) > \pi^c(k)$, meaning that outsiders earn more profits than insiders for cartel of a given size since they are not obliged to restrict their output as members are.

A cartel may be considered internally stable if no member prefers to be outside the cartel instead. A cartel is internally stable where:

$$\pi^c(k) >= \pi^o(k-1)$$

A cartel may be considered externally stable if no outsider would like to join the cartel.[1] A cartel is externally stable where:

$$\pi^o(k) >= \pi^c(k+1)$$

These constraints illustrate a solution to the apparent paradox of collusion still occurring given the profitability of being an outsider. A firm in a cartel of size k is aware that they could be making greater profits as an outsider to a cartel with k firms but realises that they cannot attain these profits since their leaving will allow only them the profits of an outsider in a market with a cartel of size $k-1$. The intuition of this model is shared by other models in the 'marginal firms' strand of the literature.

While the number of firms in the market is finite there will always exist a stable cartel, though that cartel may consist of only one firm. This follows from the assumption in the model that the profitability of the cartel's members, π_c will always be increasing in the size of the cartel k. This means that a cartel of size $k = 0$ will never be externally stable and a cartel of size $k = 1$ will always be internally stable. If a continuum of firms

[1] An all-inclusive cartel (i.e., where $k = n$) may trivially be considered externally stable.

is assumed rather than a finite number of firms then the internal stability of a cartel of size $k = 1$ cannot be guaranteed to be internally stable, since an individual firm's membership decision will not affect π^o or π_c. This reasoning also applies to markets with a large but finite number of firms, meaning that cartels are more likely to be internally unstable and so stable cartels likely to be smaller, depending on the specific cost assumptions made.

This model, with the additional assumption of quadratic costs, is expanded upon by Donsimoni et al. [1986] who prove that there exists a unique stable cartel where firms are not too cost-efficient relative to market demand, and two stable cartels otherwise[2]. They also show that the incomplete stable cartel is smaller where the size of the market is large relative to the size of the firms in the market. This is true because where firms are small each firm recognises that its own membership decision has a small effect on the market price and will suffer less penalty from choosing to be an outsider. Thoron [1998] makes a further extension to the model by proving that a unique coalition-proof stable cartel exists. This coalition-proof equilibrium is unique even under the circumstances that Donsimoni et al. found there would be multiple equilibria if defection were limited to a single firm.

A flaw in this view of cartel stability is pointed out by Diamantoudi [2005]: that it assumes firms are myopic with respect to the membership decisions of the other firms in the market. In these models, a firm will anticipate the new price which will be reached in equilibrium once it has changed its membership status. What firms do not consider in these models is the effect that their membership decisions will have on the membership decisions of other firms. For example, a firm may consider it advantageous to join a cartel assuming that the cartel will be of size $k + 1$ after its entry. However its entry may prompt a firm which was already a member firm to leave, meaning the entrant firm faces a cartel of the same size as before but is now earns the lower profits of an insider. Similarly a firm may choose to leave a cartel to become an outsider without considering that this may prompt further exit by member firms, eroding the profits the firm gained by exiting. They show that a unique stable equilibrium exists with farsighted firms.

[2]One complete cartel, and one incomplete cartel.

1.1.2. Supergame-Based Models of Collusion

D'Aspremont et al. [1983] forms the basis for a large amount of literature on collusion. This group of models sees the cartel as acting as a leader and the fringe as followers. This approach is tractable because it allows the cartel and market to be modelled statically. The alternative is modelling cartels where both the cartel members and fringe firms strategically choose their membership and production choices simultaneously.

Friedman [1971] and Friedman [1974] launched another strand of literature. These models see collusion as a game-theoretic supergame which must be solved for all players. This makes the model less tractable but avoids treating the cartel firms as fundamentally different kinds of entity to the fringe firms through the structure of the model. Eaton and Eswaran [1998] contrast a leadership model with a supergame model in order to illustrate the differences and show that in leadership models fringe firms will choose a higher output and fewer firms will be cartel members than in supergame models.

Friedman and the Balanced Temptations Equilbrium

Friedman [1971] noted that non-cooperative supergames may have a very large number of equilibria [3]. In the specific case of an oligopoly this represents there being a large set of prices and distributions of output among firms which would be preferred by all firms to the static Cournot price and output. In a situation of repeated interaction, the static Cournot equilibrium is not pareto-efficient in that all firms could increase their profits through collusion. The set of agreements which are stable is limited only by the patience of the firms involved (that they would not prefer to undercut the other firms for an immediate large payoff) and the need for all firms to earn more than they would under static Cournot.

Friedman sees this abundance of feasible equilibria as the key reason why static Cournot remains the most tractable model of oligopoly, despite all firms being able to increase their profits in a repeated game. He proposes an equilibrium which he believes is a focal point for tacit coordination, being both Pareto-optimal and non-cooperative (in the game-theoretic sense). This is the Balanced Temptations Equilibrium, elaborated upon in Friedman [1974].

[3] This is the well-known 'folk theorem' result.

In standard models of incentive-compatibility, a given cartel is viable where all firms are patient enough that their discount factors exceed their critical discount factor, δ^*. Firm i's discount factor is

$$\delta_i* = \frac{\pi_i^{'} - \pi_i^*}{\pi_i^{'} - \pi_i^c}$$

where π_i^* is the payoff to firm i from colluding, $\pi_i^{'}$ the payoff to firm i from defecting from the agreement and π_i^c the payoff following defection (often assumed to be the competitive level of profits, following the breakdown of the cartel). The Balanced Temptations Equilibrium equalises the critical discount rates for all firms assuming a grim trigger strategy is used to punish defectors.

Outsiders in Supergame Models

Martin [1993] provides a model of incomplete collusion as a supergame. He calculates the common critical discounts factor necessary to maintain a given incomplete cartel, making that cartel a subgame-perfect equilibrium, given various market sizes where the cartel uses either a grim trigger strategy or an optimum punishment strategy. Martin shows that for both of the cartel strategies considered, a smaller fringe requires a lower industry-wide discount rate in order to be stable.

Allowing the common assumption of a grim trigger punishment strategy to be relaxed, Eaton and Eswaran [1998] instead allows firms to leave the cartel and join the fringe without the cartel necessarily breaking down as a result. The only punishment firms face for defection in the model is ejection from the cartel. The cartel is assumed to continue after the ejection has taken place, subject to it still being profitable for the remaining member firms to continue colluding. This model exemplifies the phenomenon of opportunistic exit from cartels by marginal members. The result of such a punishment strategy is that the largest possible stable cartels tend to be relatively small since where cartels contain a relatively large number of firms, each firm faces a large incentive to defect due to the high prices and output possible as an outsider.

1.2. Asymmetry and Cartel Agreements

Questions of membership are almost entirely arbitrary when identical firms are considered and questions of agreement types or collusive technologies mostly trivial. Since firms lack individual identity in such models, equilibria of incomplete cartel models are non-unique with respect to the identities of the firms involved. It is in the study and modelling of collusion in markets with asymmetric firms that stylised facts about which firms are more likely to be cartel members and which firms outsiders may be obtained. The main axes of differentiation which have been studied are where firms vary by capacity or by cost. Firms with varying discount factors have also been considered.

1.2.1. Capacity Asymmetry

Models in which firms have asymmetric capacities are considerably more tractable than those in which firms' costs are asymmetric. Where firms have different costs: allocation has implications for productive efficiency, and therefore joint profits; also, colluding firms will each desire a different price to be set by the cartel, with more efficient firms desiring a lower price. These effects also have the implication that a cartel's members may reject the addition of a new member under certain conditions.

By contrast, in models of capacity asymmetry: the allocation rule does not affect joint profits given a particular cartel; all members of a cartel wish the price charged to be the same. The cartel's price is strictly increasing with its size so the addition of a new firm to the cartel is always desirable to the members. Bos and Harrington [2010] provide a model of cartel formation with capacity asymmetry. Their model is one in which a cartel sets a price and the competitive fringe undercuts it by a negligible amount. Cartels which are stable in a static setting are assumed to be stable over time.

The model relies upon a crucial piece of reasoning. The members of a cartel must be making a profit in order for their cartel to exist, and they must be charging a price above the Bertrand competitive level of $P = MC$. This implies that the combined capacities of the fringe firms is less than the quantity demanded at the price set by the cartel. Fringe output is therefore equal to fringe capacity. Given this, cartel may be considered to be a follower, setting both price and quantity to maximise profits given the residual demand left after the fringe's output. A proportional allocation rule is used, meaning that each member firm receives the same share of their capacity in output quota.

Of interest in this model is each firm's incentive to join the cartel. A cartel will consist of the largest firms in an industry under the equilibrium proposed. The reasoning behind this is that a firm, joining the cartel, will lose profits from the reduction in output it must suffer but gain profits from the increase in price this causes (note that all other firms in the cartel will also reduce their output when a new firm enters). A proportional allocation rule is assumed to hold in all cartels, meaning that all members of the cartel will produce the same proportion of their capacity. Since firms of any size have to reduce their output by the same proportion in order to join the cartel but larger firms will have a greater effect on price from the same proportional reduction, this implies that larger firms will gain more from joining a cartel.

1.2.2. Cost Asymmetry

Cost asymmetry is unlike capacity asymmetry since the allocation of output between the firms affects the average efficiency of production and therefore the cartel price. Models of asymmetric costs are therefore less tractable than models of asymmetric capacity since it is not possible to calculate an optimal price for the cartel and then proceed to allocation - the two are interdependent.

Donsimoni [1985] models cartel stability (as defined by D'Aspremont et al. [1983]) where firms have varying increasing marginal costs. She finds that more efficient firms join the cartel while less efficient firms will remain outsiders. The cartel will contain a greater proportion of the firms in the market where firms are more cost efficient overall relative to market demand, where consumers are more willing to pay for the product, where there are many firms in the market and where demand is relatively price elastic.

The paper's model sees the outsiders choose their level of production first and leave a residual demand curve facing the cartel. This is a similar technique to that which Bos and Harrington [2010], above, use to find the levels of output for the cartel and the fringe. Small outsiders will leave a large amount of residual demand for the cartel, causing the cartel to choose a higher price and make more profits than if they were left with a smaller amount of residual demand from a larger fringe. For a given cartel size, it may be seen that both small and large firms benefit from the larger firms joining the cartel and the smaller firms staying out, rather than the other way around. Total

industry profits increase with the size of the cartel but its size is limited by the incentives of the marginal firms. This logic may be examined in simple terms in a two-firm model where one may choose to become the leader: both firms earn higher profits where the high-cost firm is the leader (analogous to being the outsider in the cartel model).

1.2.3. Discount Rate Asymmetry

Asymmetry between firms' discount rates may be seen as representing differences in firms inherent preferences for collusion derived from characteristics which are unobservable or idiosyncratic. A firm with a low discount rate is modelled as being one which is relatively impatient and prefers short-term to longer-term profits, and so is more likely to defect from an agreement for a short-term payoff. This could either be considered as reflecting directly the culture among decision makers at the firm in question or it could be seen as representing a more abstract distaste for collusive behaviour at the firm.

Harrington [1989a] shows that firms with lower discount factors (meaning they are more impatient) have a stronger bargaining position and so are likely to receive a larger share of cartel output than firms with higher discount factors should they be members. This result differs from the above results on capacity and cost asymmetry because it assumes that the cartel will be all-inclusive if it exists, and that firms will use the Nash Bargaining Solution in allocating production within the cartel[4]. Firms with lower discount factors require greater shares in order to prevent them from deviating from the agreement than firms with high discount factors do. Low discount factor firms may be seen as threatening the existence of the agreement in the negotiation stage of the game in order to extract profits from the high discount factor firms. Note, however, that firms with low discount factors do reduce the likelihood of a cartel forming at all, harming the expected profits of all firms in the market.

1.2.4. Asymmetry and Allocation Rules

When asymmetric firms are modelled, it is necessary to consider how the output produced and profit gained by the cartel is allocated among the member firms. Such concerns are frequently de-emphasised by papers which wish to focus on different aspects of collusion

[4]This is because the set of stable allocations may be large. The Nash Bargaining Solution means a unique equilibrium will be selected.

and sometimes other assumptions determine allocation within the model. For example, models which assume Balanced Temptations Equilibrium necessarily imply that the cartel will distribute profits among its members to ensure each faces an equal incentive to defect. Fulfilling this objective implies a specific allocation for any given cartel and leaves no space for other allocation considerations.

Models of cost asymmetry face a further methodological problem in their treatment of allocation that models of capacity and discount rate asymmetry do not. In models where the allocation of profits within a given cartel does not affect the joint profits of the cartel it is possible to calculate first the joint profit-maximising level of overall cartel output, and then to consider how these profits are distributed. Where costs are asymmetric, the allocation of output will affect the joint profits of the cartel so allocation and total cartel output may not be considered separately. Patinkin [1947] proposed that a cartel which contained members with varying though increasing costs should allocate output such that the marginal cost faced by each firm be equalised, thus maximising joint profits.[5] A similar assumption of joint profit maximisation by colluding firms with heterogeneous and increasing costs is made by Donsimoni [1985].

It is still possible for models of cost-asymmetric cartels to assume allocation rules which are not based purely on joint profit maximisation. Schmalensee [1987] is concerned with cost asymmetries between firms and the implications this has for the agreement types possible. However, it concerned itself only with complete cartels and the 'baseline case' used in the allocation rules was the competitive equilibrium. Take the example of the Nash Bargaining Rule, which maximises the products of the gains of all firms within the constraints imposed (in this case by the collusive technology). Let Π_i^* and Π_i^c be firm i's profits under collusion and Cournot competition, respectively. The relevant expression to be maximised when only complete cartels are viable is then:

$$(\Pi_1^* - \Pi_1^c)(\Pi_2^* - \Pi_2^c) \ldots (\Pi_N^* - \Pi_N^c) \text{ for } i = 1, \ldots, N$$

Other cooperative solution concepts, such as Kalai-Smorodinsky or Equal Gains, also rely upon this comparison between collusion and competitive profits. If incomplete cartels are possible these problems become much more complex. A firm's 'gains' from membership of a particular cartel must be calculated by comparing the profits from a

[5] Bain [1948] pointed out that in many circumstances, the resulting cartel may not be incentive-compatible for the member firms without side payments to encourage the participation of some firms.

particular cartel and those from any potential subcartel which a firm could otherwise be involved in. The full range of possible agreement types considered by Schmalensee are detailed in Section 5.2.1.

Berg [2012] considers this in his model of three firms, two efficient and one inefficient, which may form complete or incomplete cartels and use the Nash Bargaining Theory to decide allocation. A cartel will consist either of the two efficient firms or of all three firms. Given the grand coalition, any firm has the choice to deviate unilaterally or in coordination with another firm (the only possible coordinated deviation is where the two efficient firms form a subcartel, ejecting the inefficient firm). Both unilateral and coordinated deviation are represented by incentive constraints in terms of firms' discount factors. Whether the grand coalition is bound by the possibility of unilateral deviation (and reversion to competition) or coordinated deviation (and the creation of a subcartel plus an outsider) will determine the allocation.

1.2.5. Balanced Temptations and Asymmetry

Some models of collusion between asymmetric firms use the balanced temptations equilibrium. In addition to the argument that this equilibrium is a focal point which tacitly colluding firms may use, some authors argue that it is a logical allocation rule for an explicit cartel to follow in order to maximise the stability of the agreement.

Bae [1987] uses the balanced temptations equilibrium in the process of showing that improvements in technology can decrease social welfare if it leads to greater collusion. He emphasises the attractiveness of the balanced temptations equilibrium as a focal point at which firms may arrive with a minimum of negotiation or no negotiation at all, and suggests that actual cartels are likely to follow or approximate such a rule in practice. This choice of equilibrium is criticised by Harrington [1991]. Harrington argues that the balanced temptations equilibrium places such great constraints on the price and output quotas chosen by the cartel that models which use it are limited in the results they can produce on firm behaviour. He suggests that models use more basic assumptions, such as negotiation according to the Nash bargaining solution. This assumption does not require assuming that the cartelists choose to maximise joint profits, as Bae does, or to use ad-hoc assumptions where a joint profit-maximising balanced temptations equilibrium does not exist, as it is not guaranteed to exist.

The argument that the balanced temptations equilibrium is a likely outcome of explicit collusion is made by Verboven [1997], who shows that such an equilibrium is Pareto-efficient within his framework of repeated duopoly and constant marginal costs, and may be the only Pareto-efficient equilibrium. The balanced temptations equilibrium is a possible outcome of bargaining between cost-heterogeneous firms in this framework according to the Nash bargaining solution. Verboven also emphasises the tractable nature of the equilibrium, since it is possible to perform comparative statics in costs with heterogeneous firms.

Correia-da Silva and Pinho [2016] also argue that cartels are likely to arrive at the balanced temptations equilibrium. They identify the critical discount rate of the firms in the collusive agreement as representing the stability of the cartel to defection caused by external shocks. They argue that in a heterogeneous cartel there will be a single firm which has the strongest propensity to defect from the agreement and that the stability of the cartel in its present structure will depend solely on the decision of this firm. The cartel may always be made more stable by allocating more profits to this firm, until all firms face the same propensity to defect from the agreement and the balanced temptations equilibrium is reached. Where cost asymmetry between members prevents the balanced temptations equilibrium from being reached by the allocate of output, side payments between members may be necessary.

1.2.6. Side Payments

Simple lump-sum payments made between cartel members solve many of the problems associated with collusion among heterogeneous firms. Firms whose participation constraints mean they do not wish to be members of a cartel may be paid a sufficient amount so the reward for being a cartel member is greater than the reward for being an outsider.

The potentially important role of side payments in cartels was first pointed out by Bain [1948] in his response to Patinkin [1947]. Patinkin models a cartel with heterogeneous and increasing costs as a single firm with multiple plants of varying efficiency. He shows that the best strategy for such a cartel is to minimise costs by dividing production among the firms such that all firms face equal marginal cost. This implies that low-cost

firms should produce a disproportionately large amount of the industry's output. Bain points out that, unlike a multi-plant firm, a cartel must be privately profitable for each of its members and the disproportionate share of output allocated to the low-cost firms is detrimental to this. The practical difficulties in implementing a 'perfect cartel' such as the illegality of such transfers in most circumstances and the need for firms to commit credibly to levels of output in order for a system of side payments to work make it unlikely that any cartelised industry would be able to minimise its joint costs.

It is important that side payments, which are very rarely observed in real cartels, are not confused with compensation payments, which are frequently seen. A side payment is a payment made ex ante to a firm which would not otherwise participate in a cartel. A compensation payment is made after levels of revenue are known in order to correct an unintended misallocation of profits between firms which are willing to participate in a cartel. The direction and amount of compensation payments may not be known before firms' profits are realised, unlike side payments which must be agreed in advance.

1.3. Changes in Cartel Membership Structure

The theoretical models previously discussed may hint at the mechanism by which a cartel forms but they do not allow for changes in market structure over time or provide an account of how a cartel can form in a market which was previously competitive. Given that any incomplete cartel structure must have been reached through either the formation of an incomplete cartel or the defection of a cartel member from a complete cartel, these theories are crucial to understanding incomplete cartels.

1.3.1. Members' Attitude to Cartel Size

The profits of firms in a market containing a cartel will depend on the size and composition of the cartel. In the majority of theoretical models of collusion, the profits of cartel members and outsiders are increasing in the size of the cartel. However, it is often observed that cartels will not permit an outsider to join the cartel. This implies that the member firms believe that the outsider firm becoming a cartel member will harm their expected profits. One explanation for this is that the members are concerned that accommodating entry will induce further entry to the market, but even in a static

context it is possible for an increase in the size of the cartel to decrease members' profits.

Where symmetrical firms compete according to Bertrand competition, the profits of cartel members are increasing in cartel size. This is shown numerically by Bloch [2002]. However when firms compete according to Cournot competition the profits of cartel members are U-shaped with respect to cartel size, initially declining as the cartel increases in size before increasing. This is because when firms which choose quantities collude they must decrease their output in order to raise prices. This cost is proportionally greater when the cartel is small, and outweighs the gains from higher prices initially.

Where firms are asymmetric in their costs there is an additional complication to collusion in that firms will prefer the cartel set different prices. More efficient member firms will desire a lower price than less efficient member firms and the increase in cartel price necessary to induce a less efficient firm to join a cartel may harm the profits of the more efficient members sufficiently that the less efficient firm will not be accommodated in the cartel.

This argument is developed by Cave and Salant [1995] who model the internal decision-making system of cartels. They observe that a commonly seen system in legal and export cartels is for the cartel to operate on a quota system where member firms produce a fixed proportion of their capacity, and vote democratically on the proportion they choose. Larger-capacity firms will prefer that the proportion chosen by the cartel is smaller. Given weak assumptions about the preferences of firms, the proportion preferred by the median member will be chosen by a majority of the members. These results hold in the presence of outsider firms.

The model may also be extended to situations where the cartel's members have differing marginal costs. More efficient firms will then prefer a lower cartel price than less efficient firms. Because of the this, the price set by the cartel could exceed the monopoly price which the efficient firms would prefer, as the price implied by the quotas set by the majority including the median firm would bind the efficient firms. Donsimoni et al. [1986] also make this point in their model of collusion between heterogeneous firms.

This model gives new depth to the matter of preference for entry. In addition to directly changing the incentives faced by the cartel in deciding on a quota, the entry of

a new firm could affect the majority decision reached by the cartel. The possibility of gaining a vote in the cartel's decision-making is an incentive to entry, and the possibility that a new entrant could change the quota chosen by the cartel could cause cartel members to oppose the entry of a new member.

Cartels' Reaction to Market Entry

The possibility of firms entering a market greatly affects the ease of collusion and the behaviour of colluding firms. Broadly speaking, the possibility of market entry will make collusion difficult to sustain and will affect the cartel's optimal treatment of cartel outsiders. If a policy of permitting outsiders to enter the cartel will induce further entry, then cartels may choose to not permit the membership of an outsider even when it would immediately increase the profits of the cartel members.

Harrington [1989b] models a cartel in a market where barriers to entry are arbitrarily small. He considers a cartel which is able to commit to various reactions to entry and potential entrants consider the implications of the reaction to their entry when making their entry decision. The three broad strategies are to discontinue collusion upon entry, to accommodate entrants or predation against entrants. The problem the cartel members face is that accommodating entrants in order to preserve the cartel and their own profits will trigger further entry and ultimately erode cartel profits. On the other hand, predation or the discontinuation of collusion may deter entry but is directly costly to the incumbent cartel members. Harrington concludes the best strategy is to predate at first and then accommodate entrants in order to deter entry but sustain collusion and profits in the long run.

Scott-Morton [1997] empirically examines British shipping cartels and their reactions to new entrants. Both accommodation and predation were practised against different entrants. Entrants which had less funds, were active in fewer markets, had less experience, and which entered at times of weaker demand were more likely to be predated against by the incumbent cartel than stronger entrants. This suggests that predation was the preferred strategy for this cartel, attempted unless incumbents believed it would not be effective in forcing the outsider to exit. Podolny and Scott Morton [1999] examined the same group of cartels but considered also the social class of the new entrants. They discovered that this was a better predictor of the

reaction of the cartel than the economic characteristics of the entrant. The (largely upper class British) cartel was far more likely to accommodate entry by firms led by other upper class British people and far more likely to predate against lower class or foreign-owned entrants. The authors speculate this is because the incumbents trusted those of a similar background to them to abide by the 'gentlemen's agreement' the cartel relied upon. Contrary to the former finding, this seems to indicate that the driving force behind the accommodation/predation choice was the defence of the agreement from cheating and that they were not loathe to accept new, well-behaved cartel members.

1.3.2. Cartel Formation

Models of cartel formation consider the means by which a stable cartel, of the kind modelled in D'Aspremont et al. [1983] might actually come about. The difficulty in formation in such models is that small cartels are unlikely to be stable to defection so the cartel must consist of a large portion of the market immediately upon its creation. Where cartels must be complete to be stable this problem is relatively simple. However if the cartel is able to support outsiders then each firm in the market will wish to be an outsider, greatly reducing the probability of a stable cartel being formed if communication or precommitment is impossible. Where pre-commitment is possible the cartel will form at its smallest stable size, with the firms able to pre-commit to non-cooperation being outsiders.

Simultaneous Cartel Formation Games

Selten [1973] was the first to consider the means by which a cooperative equilibrium in a market might arise from a competitive starting point. Starting with the intuition that small groups of firms will find coordination easier than larger groups, Selten aims to find the point at which a group of firms becomes 'large' and cooperation becomes untenable. Within his model, where symmetric firms in a Cournot market with linear demand and costs simultaneously choose to join a coalition which will set binding output quotas, complete cartels are certain to be formed in markets with four or fewer firms and suddenly become very improbable with five or more firms.[6] Interestingly, it is the desire

[6] More precisely, with five firms each firm has a probability of 0.5263 of choosing to join a cartel (firms play mixed strategies in these cases) leading to a probability of 0.0404 of a complete cartel being formed and of 0.1817 of a cartel with four members being formed (note that under Cournot competition such a cartel is stable, see Salant et al. [1983]). With six firms the probability of any

of each firm to become an outsider when $n > 4$ which drives this sudden unwillingness to cooperate. Selten concludes it is credible that similar sudden dividing lines exist even under relaxed assumptions about the nature of demand, costs and symmetry.

Prokop [1999] considers both simultaneous and sequential games in which firms commit to join a cartel or not. He develops the simultaneous treatment by considering the case where firms have quadratic costs. Collusion is easier in such a situation because the sharply increasing costs which accompany increased production both restrict the extent of chiselling at members' profits by outsiders and restrict the profits of outsiders. Like Selton, the probability of cartel formation is certain for low n before dropping suddenly (the exact figure at which this happens depends on the precise cost and demand functions used). Unlike Selton, the probability of stable cartel formation decreases slowly with n after this point. In the numerical example Prokop gives the probability of stable cartel formation is 1 when $n = 5$, 0.2936 when $n = 6$ and 0.1405 when $n = 300$.

Sequential Cartel Formation Games

Prokop's sequential move game has players commit to join or not join a cartel in sequence before price and quotas are decided upon for the cartel which results. The result of this game is simple given that firms know the decisions of firms who moved before them and the unique cartel size, k, which is both internally and externally stable. That no more than k firms will choose to join a cartel is clear from the stability constraints. By backwards induction, the subgame perfect equilibrium is that the first $n - k$ firms will choose not to join the cartels and the last k firms will have no choice but to do so if they wish for a stable cartel to be formed (and all firms do).

This result is mirrored by Bloch [1996] which examines the sequential formation of coalitions where payoffs to members are dependent on the structure of the coalitions. Cartels of firms are an examples of such coalitions. In Bloch's model of sequential bargaining, firms propose cartels to the other firms in the market in turn and these propositions are either rejected or accepted. Acceptance of the proposed coalition must be unanimous among the prospective members, and if a proposition is rejected by a single prospective member then that member becomes the next proposer. Once the cartel has been agreed and formed, members are committed to their membership and

stable cartel drops to 0.013. For ten or more firms, the probability is below 0.0001.

non-members to non-membership. Bloch shows that when firms are identical the size of the cartel, k, will be the first integer following: $(2n + 3 - \sqrt{4n + 5})/2$[7].

These models of sequential cartel formation are informative about real life cartels because they emphasise pre-commitment. A firm which is capable of signalling and committing to non-participation earlier than other firms stands a greater chance of becoming an outsider. A firm which enters a market containing a cartel or is for some other reason excluded from the cartel upon its formation will have the same advantage. This has implications for many aspects of an outsider's strategy: they may be unwilling to communicate with member firms at all, or to acknowledge that the existence of a cartel benefits them.

1.3.3. Cartel Breakdown

Collusion may stop for a variety of reasons and it is not always clear when cooperation between firms has ceased, even when the behaviour of firms is more consistent with cooperation than collusion. Collusion is frequently observed to occur in 'episodes' punctuated by periods of higher output and lower prices than would be expected in collusion. There has been considerable debate on whether these 'price wars' should be regarded as a breakdown in collusion, and therefore each episode of collusion as a separate cartel within the same industry, or as a continuation of collusion by different means, so the full span of episodes should be regarded as a single cartel.

Leniency programmes allow firms who are cartel members to avoid punishment by revealing the existence of the cartel to the authorities. Firms who cooperate extensively with the authorities during the ensuing investigation are also eligible for fine reductions but only the first firm to reveal the existence of the cartel receives full immunity from punishment. The decision of whether to cooperate with the authorities is made after the discovery of the cartel rather than while the cartel is in progress. Zhou and Gärtner [2012] note that applications for leniency frequently are made after a cartel has ended. That a cartel was detected through leniency therefore cannot be taken as an indication that the cartel was ended because of a leniency claim.

[7] Note that where $n = 4$ this expression equals 3.21, meaning the cartel will contain all four firms in the market, and where $n = 5$ this expression equals 4. This is mirrors the result of Salant et al. [1983].

Some leniency programmes, such as that of the USA and the EU before 2002, exclude cartel 'ringleaders' from leniency programmes, preventing them from receiving such immunity. Ringleaders are defined as firms which founded cartels or brought other firms into the cartel. The conduct of such firms is seen as particularly heinous and there are concerns that the leniency system could be abused by firms, thus causing increased cartel conduct.

1.3.4. Endogenous Formation with Heterogeneous Firms

Paha [2010] combines many of the concepts discussed above in a single model and uses a methodology of simulation followed by regression analysis in order to examine endogenous cartel formation with cost-heterogeneous firms and differentiated products. The model of cartel formation used assumes that a mixed strategy Nash equilibrium is used, with each firm choosing a probability of participation. Paha finds that inefficient firms chose a higher probability of participation than more efficient firms. While this may seem contrary to the above results, it is precisely because efficient firms derive a greater benefit from the cartel that this result is reached. Efficient firms prefer the cartel to be larger than inefficient firms, who will prefer the fringe if the cartel is already relatively large. In order to prevent the inefficient firms using a pure strategy of staying out of the cartel and letting the efficient firms form a cartel of sufficient size to be profitable for the inefficient firms, the efficient firms will lower their participation probabilities in order to induce the inefficient firms to play a mixed strategy. This may be seen as another way of approaching the balanced temptations equilibrium view of cartel formation described above. It also emphasises the power of pre-commitment to a strategy in determining the eventual composition of the cartel.

A model in which the size of the cartel varies according to the amenability of the market to collusion may be found in Bos and Harrington [2015]. The basic model is that of incomplete collusion among firms which vary by capacity in Bos and Harrington [2010], discussed in section 1.2.1, with an anti-cartel enforcement policy of varying strength. Their model finds that as antitrust penalties become stricter, the most inclusive stable cartel possible becomes smaller. The intuition behind this is simple - antitrust enforcement adds an additional cost to joining a cartel on top of the cost of reducing output. Since lower capacity firms gain less from joining the cartel than higher-capacity firms, they are the first to change their membership decision as enforcement becomes stronger.

This process of a cartel becoming internally unstable until enough of its members leave the fringe that the cartel once again becomes internally and externally stable provides the fundamental intuition of 'marginal firms'-type models of cartel membership, along with the observation that the order in which firms leave the cartel is strictly determined by their capacity. If a firm of a given capacity is a cartel member, along firms with larger capacity will be members. If a firm is not a cartel member, all firms with smaller capacity will also not be members.

1.4. The Marginal Firms and Balanced Temptations Approaches

The marginal firms and balanced temptations approaches described above represent one way to divide the theoretical literature on cartels. The predictions of models using the two approaches are not necessarily contradictory but they lend themselves to different ways of considering cartel membership. In models which use the marginal firms approach the stability of a cartel is constrained only by the firm with the strongest propensity to deviate. This marginal insider firm will limit the decisions of the cartel, for example by preventing it from setting too high a price without defecting. In models which use the balanced temptations equilibrium the cartel is instead constrained by the incentive compatibility constraints of all members. Decisions such as the cartel price will be constrained by all firms simultaneously reaching the limits of their incentive compatibility constraints.

This distinction is a salient one in the context of cartel membership because each approach focuses on a different source of the cartel membership decision. The marginal firms approach centres individual firms as making decisions on cartel membership given the strategy of the cartel, whereas the balanced temptations approach focusses on the role of the cartel's allocation of profits in determining the membership of the cartel.

A similar grouping of papers is identified by Correia-da Silva and Pinho [2016]. They summarise the reasoning underlying the papers which use a marginal firms approach as 'the sustainability of the cartel only depends on the behaviour of the firm with the strongest propensity to deviate.' They point out that in some circumstances a balanced temptations equilibrium may only be achieved through the use of side payments. Such

a scenario is modelled in the paper, where firms are assumed to have heterogeneous and quadratic cost functions and must transfer profits after members have received the profit from their outputs in order to achieve balanced temptations.

1.4.1. Combining the Two Approaches

These approaches are not necessarily opposed to one another, nor are their predictions irreconcilable. It is possible to combine the two approaches, considering the propensity of each firm in a market to join a cartel individually while assuming that that cartel allocates profits between cartel members such that the temptations of each cartel member to deviate once a member are balanced. This approach is taken by Bos and Harrington [2015] in their model of endogenous cartel formation with capacity-asymmetric firms.

As discussed in section 1.2.5, balanced temptations equilibria imply a specific allocation rule must be followed by a cartel. A model which follows the marginal firms approach in centring the constraint placed upon the cartel by the firm with the strongest incentive to deviate may also assume that an allocation rule which implies balanced temptations will be followed. This is the case in Bos and Harrington [2010], who show that when firms are allowed to vary by their capacity a proportional allocation rule, where members' allocation of cartel output is directly proportional to their capacity, has the effect of balancing temptations. The paper argues that a rule which has the effect of balancing temptations will be preferred by members because it will maximise the joint profits of the cartel. This is because the joint profits of the cartel are maximised when the output of each cartel member is minimised to the point where its incentive compatibility constraint just binds. A member's slack incentive compatibility constraint represents a further cut in output, and so increase in price, which is possible.

1.5. Empirical Investigations into Membership

1.5.1. Narrative Studies of Individual Cartels

In-depth studies of cartels frequently describe asymmetry and cartel incompleteness since they are facts of real industries and cartels. Such studies provide a valuable way to witness the behaviour of colluding firms directly and the narrative form of such studies means this view is not blinkered by what a theoretical or empirical model may choose

to focus on. Genesove and Mullin [2001] is among the most influential cartel narrative studies, examining the American Sugar Institute cartel of 1927 to 1936. Central to the narrative is how the cartel chose to react to deviations by its members from the cartel agreement. Suspected cheating was not met with massive retaliation, as some models of collusion assume, but with cautious communication in order to establish that the activity was not accidental followed by threats then limited sanctions. Full-scale price wars were eventually launched in some geographical areas but only when communication between firms had broken down completely. This willingness to engage in massive retaliation to combat complete defection from the cartel sustained collusion. This tolerance of minor deviations and intolerance of defection is an example of the kind of cartel institution which may allow asymmetric cartels to maintain large memberships.

Wang [2008] and Clark and Houde [2013] both studied retail petrol cartels, focusing on price leadership as a test of theoretical models of dynamic oligopoly (such as that of Maskin and Tirole [1988]). The order in which firms are informed of an upcoming price change and the order in which they must do so is highly informative in understanding the importance of commitment to cartel membership. It was necessary for low-cost firms to raise their prices before the high-cost firms would follow and for the ringleader to focus their efforts on convincing the low-cost firms to participate. High-cost firms did not need as much persuasion to raise their prices to the cartel level as the low-cost firms. In the cartel studied by Clark and Houde [2013], a large low-cost firm was able to be a cartel outsider because it invested heavily in marketing a 'lowest price guarantee'. This allowed it to commit credibly to low pricing and to force the cartel firms to take on the burden of raising their own prices.

Johnsen [1991] describes the unusual and controversial Socony-Vacuum case. Petrol refiners were accused of buying fuel from retailers and storing it before reselling it to retailers. The judgement of the Department of Justice at the time, that the purpose of purchases was to drive up prices, was widely criticised by economists at the time. Johnsen suggests that the purpose of the purchases was to allow for the reallocation of cartel rents among members in order to induce cooperation by small firms. For independent refiners to be willing to join the cartel, major refiners needed to reduce their output by a larger proportion. However retailers were unwilling to substitute the branded petrol of the major refiners for the unbranded, possibly lower-quality, petrol of the independents. It was necessary for major refiners to purchase large quantities of the independents' product in order to make this side payment and overcome the participa-

tion constraints of the independents. The prevalence of this strategy of accommodation in cartels is discussed in Havell [2011].

The international Vitamins cartels of the 1990s are described in great detail by Connor [2008], along with the related cartels in Citric Acid and Lysine. Collusion progressed very differently across different markets despite the similar nature of the products and the common firms present in each. Some Vitamins markets contained a fringe of Chinese, Indian and Russian firms which undercut the cartel's price and resisted all attempts by the cartel to moderate their output or include them in cartel negotiations. By the time of the cartels' discovery, Chinese non-cartel firms produced more than a third of the global output of Folic Acid, up from less than 3% just two years before. Similarly sharp increases in fringe production happened in other markets and hampered the ability of the cartel to raise price in these markets. Part of the reason for the non-participation of the fringe firms is that their small sizes and ability to rapidly expand capacity made participation incentive incompatible. However, this does not adequately explain why when the market price began to crash due to their rapidly expanding production they did not chose to moderate their output or join the cartel. It is believed that the managers of the Chinese firms were simply uninterested in colluding.

The actions of Archer Daniels Midland (ADM) in the Vitamin B2 market are also of interest. ADM was a keen cartelist in many markets when they entered into the B2 market, including being a member of several cartels with firms which were already present and colluding in the B2 market at the time. ADM refused to participate in the cartel and was able to seize a very large market share from the incumbent firms, even when they attempted to launch a coordinated price war against ADM. ADM was an extremely cost-efficient and high-capacity producer upon their entry and it is likely that it was more profitable for them to have a high market share in a competitive market than a low market share in a collusive market, despite their willingness to collude if profitable.

1.5.2. Statistical Studies of Colluding Firms

In jurisdictions where collusion between firms is legal more detailed and complete data on cartels is available. Frequently, detailed records of the existence of cartels and their agreements are kept by government departments. Hyytinen et al. [2011] examine

such a dataset of cartels registered with the Finnish government between 1951 and 1990. They use this dataset to estimate the rate of cartel formation in uncartelised industries to be 20%, and the rate of cartel breakdown in cartelised industries to be 10%. Given these figures, and the assumptions underlying the hidden Markov model they use to estimate them, the proportion of Finnish industries containing cartels was roughly 90%. That collusion was so pervasive when it was not prohibited indicates that cartels are incentive-compatible in the vast majority of markets, and that the sanctions of competition authorities likely play a large role in reducing the number of cartelised industries where they are illegal. Fink et al. [2015] examine a similar dataset of registered legal cartels in Austria. Their study focuses on the characteristics of the agreements formed by these cartels, and is discussed in section 5.2.2.

Asch and Seneca [1975] study a sample of 51 firms convicted of colluding and compare it to a sample of 50 randomly-chosen non-colluding firms. They observe that colluders tend to have lower profit rates and lower rates of sales growth, tend to be more diversified, are more likely to manufacture homogeneous 'producer' goods rather than differentiated 'consumer' goods, and be situated in more concentrated markets than non-colluding firms. Interestingly, that a firm operates in a market with very few firms only increases the likelihood of that firm colluding if the firm's (and possibly the industry's) profit rate is low. Small firms in very concentrated markets are very unlikely to collude, possibly indicating a tendency for small firms to be cartel outsiders. However, this study is problematic because it studies firms in isolation rather than whole markets and its technique of comparing characteristics of firms across very diverse markets is unreliable.

A contemporaneous study is that of Hay and Kelley [1974] into 65 US cartels and the features of the markets they existed in which economic theory indicates may have facilitated collusion. They note that in the 32 cartels in their sample which were not all-inclusive it tended to be the smallest firms which were not members of the cartel. In some cases these firms were isolated from the other firms in terms of geography or product characteristics, in others "... it might be assumed that they were willing silent accomplices living under the price umbrella provided by the conspirators."(pp. 21) Bos [2009] points out Hay and Kelley provide the CR4 in 14 incomplete cartels for which they knew the total number of firms in the market. The mean CR4 is 75% and the mean number of firms 12: this implies a high degree of asymmetry in market shares in the markets which contained incomplete cartels.

Posner [1970] also notes that a cartel is likely to comprise the "most important" (pp. 410) firms in an industry because otherwise the colluding firms would not be capable of raising prices reliably. This is an observation made of his sample of US antitrust cases since 1890, though he considers this to be a very obvious conclusion.

1.6. Conclusions

The findings of most interest from the literature on asymmetric incomplete cartels are those which relate to which firms will be cartel members and which outsiders. That outsiders tend to be smaller firms is well-supported by the empirical literature but it is difficult to know which firm characteristics in particular are causing this. Theory sheds more light on this, suggesting that the reason that smaller firms become cartel outsiders because they have high costs or low capacities, meaning that they are able to commit to non-membership better than other firms in the market. That firms with low discount rates are likely to become outsiders provides an account of how maverick firms which otherwise would become cartel members can still commit to non-participation. Despite this it should be emphasised that market structures with low-cost or high-capacity cartel outsiders may be stable, even without these firms having any 'maverick' characteristics. Such membership structures may result from firms entering the market after the cartel's formation, the characteristics of the firms changing after formation, or the outsider simply not joining the cartel on formation by chance.

This review has identified two broad theoretical approaches to modelling the membership decisions of firms and cartels. While these two approaches are not mutually exclusive, in that some papers apply a balanced temptation equilibrium to a model where firms have consistent preferences on collusion which determine their membership, this distinction is useful in considering questions of cartel membership. Marginal firms models see the individual firms which choose whether to join the cartel as the primary determinant of the eventual size of the cartel, whereas balanced temptations models see the cartels' collective decision on allocation between members as the primary determinant. It is in changes to membership where the predictions of the approaches can be seen to diverge. Marginal firms models indicate that a firm's preference for collusion is due to its characteristics and that these characteristics are consistent over time. Given this, if the market changes and the stable cartel becomes smaller then the identity of the firm which defects from the agreement and joins the fringe will be the member firm

with the least preference for collusion. The balanced temptations approach predicts that the cartel will choose its allocation rule to make all members equally marginal about their membership, meaning the identity of the defector will be random. Chapter 3 is dedicated to testing these predictions empirically.

Chapter 2.

E.C. Cartel Decisions 2001-2011

The empirics in the three substantive chapters of this thesis are based on the cartel decisions made by the European Commission between 2001 and 2011. This totals 91 cartels and 478 firms[1]. This chapter presents summary statistics on these cartels and firms, details on how the dataset was compiled and limitations which the nature of the data put upon their analysis.

Data on the duration of each firm's involvement with the cartels and their entry and exit behaviour is novel and receives specific attention because of this, and because analysis of this behaviour is an objective of two of the substantive chapters of this thesis.

Section 2.1 details the process of gathering each variable. Section 2.1.1 discusses problems encountered with the data and the limitations they put on the use of the data. Section 2.2 presents descriptive statistics about the durations of cartels and firms' involvement in them. Section 2.3 presents the structural characteristics of the cartels and the firms within them. Characteristics of those firms which entered their cartels late and exited their cartels early are discussed in sections 2.4 and 2.5.

2.1. Source of Data

Information about cartels and firms was obtained from decisions and summary decisions published in the Official Journal of the E.U. Appendix A provides a list of all cartels studied and their references. In some cases a single decision relates to multiple cartels which are treated separately in the analysis. Examples of this include the twelve *Vitamins* cartels, the separate cartels in the production and processing of *Italian* and *Spanish*

[1] Some firms have been members of multiple cartels during the time period. This figure counts recidivists once for each cartel they were involved in.

tobacco and the three *Elevators and Escalators* cartels covering different geographical markets.

This section will describe the nature of the information available from decision documents published by the European Commission and how it was turned into the dataset used for this thesis.

Duration, Entry and Exit

This dataset is unique — to the best of my knowledge — in containing data on the dates of participation of individual firms in cartels fined by the European Commission. Because the fines given to cartelists are based on the exact proven duration of a firms participation in a cartel the published decisions provide the exact dates when each member firm began colluding and ceased colluding. These dates are supported by documentary evidence of cartel meetings and other contact between member firms.

The dataset of legal cartels in Austria from 1973 until 2002 gathered by Fink et al. [2014] also describes changes in the composition of the cartels over time. The legal system governing cartels during the sample period required cartels to submit their agreements to a central registry. If these agreements required updating as a result of firm entry or exit, then the membership change is noted in the dataset. The authors give the caveat that they observe only the number of cartel members in the old and new agreements rather than the identities of the firms, so if entry and exit happened simultaneously then this will not be noted. The data gathered on firm entry and exit is not analysed in the accompanying paper Fink et al. [2015], which focusses on collusive technologies used by the cartels.

Because of how central it is to the E.C.'s fining process, duration of participation and dates of entry and exit are available for every firm and cartel in the sample.

Cartel Share

The primary source of information on each firms' share of the cartel's output is the figures on turnover used by the E.C. in calculating fines. The exact figures are redacted from publicly published decisions because of the commercially sensitive nature of the

information and ranges are reported instead. The midpoint of these ranges is used in calculating each firms' share of total cartel output. Where such information is not provided or reacted to such an extent that it is unusable, data on cartel and market share is missing.

In 16 cartels data on each firms' share of cartel output is unavailable. These cartels are marked by an asterisk $*$ in the list of cartels in Appendix A.

Cartel Coverage

Cartel coverage is reported inconsistently in decision documents. It is sometimes simply given as a part of the decision's narrative description of the cartel. Occasionally, the size of the market is given and the cartel's coverage may be calculated by adding up the turnovers of the cartel's members and dividing.

Coverage data is unavailable for 20 cartels in the sample. These cartels are marked by a dagger † in the list of cartels in Appendix A. Cartels for which turnover data are unavailable are more common in recent decisions. A systematic reason for this reporting practice is not obvious but it could be connected to the adoption of the settlement process for cartels. The settlement process, described in Stephan [2009], was adopted in 2008 and was first used against the DRAM cartel in 2010. Laina and Bogdanov [2014] describe how in 2013-2014 over half of cartel decisions used the settlement process.

Geographical Scope

The countries affected by the cartels are carefully listed by the published decisions. The European Commission concerns itself primarily with cartels spanning multiple European countries but does sanction some agreements which are confined to a single country. This may be because the country lacks a competition authority of its own (for example, Luxembourg and its cartel among brewers), where national subsets of a wider agreement are considered separately (as in the Elevators and Escalators cartels), or when national competition authorities are not willing to pursue a case (as in the French Beef cartel, where the French minister for agriculture was an initiator of the agreement).

The cartels have been divided into four categories of geographical scope:

Global cartels affecting the entire world or multiple major economics other than the European Union;

Europe-wide cartels affecting all or almost all European countries;

Regional cartels affecting a group of European countries such as Scandinavia or Eastern Europe; and

National cartels affecting an individual European country.

Agreement Types and Collusive Technologies

The types of conduct which cartels engaged in is central to their punishment and are well-documented in the published decisions. These activities may be divided into those directly used to raise firm profits and those used to maintain the agreement.

The collusive technologies used to coordinate behaviour in order to raise firm profits I term 'agreement types' and are analysed in detail in chapter 5. The decisions are consistent in their categorising of types of conduct and I follow them in identifying five types of agreement:

Price fixing where a price is set below which member firms may not charge;

Bid Rigging where the firms manipulate the results of an auction;

Customer Allocation where firms agree to sell to particular customers and not to others;

Territorial Allocation where firms agree to confine their activities to set geographical locations; and

Quota Allocation where firms are set fixed limits for the quantities of goods they can sell.

Cartels may use multiple agreement types simultaneously. Detailed descriptive statistics on the use of agreement types in combination are discussed in chapter 5.

2.1.1. Limitations of Data

Duration

It is possible that cartels in fact began before the start of the offence stated by the E.C.; De [2010a] notes that in 20 of the E.C. decisions she analysed (approximated a fifth of her sample) the E.C. noted that they suspected a duration of 2.5 times the prosecuted duration. This is problematic for the analysis of duration since the duration of some cartels will be underestimated. However the E.C. needs to be convinced of a firms' non-attendance at meetings or lack of compliance with a cartel agreement to a high standard of certainty in order to acknowledge that a cartelist was not following a collusive agreement, meaning the data of late entry and early exit by firms are reliable. Also, the leniency programme of the E.C. gives a strong incentive to firms to reveal the true duration of the cartel: firms are not fined for any stretches of collusion which they reveal to the authorities and firm which extend the provable duration of a cartel are eligible for a fine reduction of between 50% and 70%.

This issue has been noted by many users of cartel duration data. Abrantes-Metz et al. [2013] compare the reported durations of the same international cartels in different jurisdictions. They note that the competition authorities of the USA and European Union tend to report the longest durations and earliest start dates for cartels compared to the competition authorities of developing countries. That the competition authorities of wealthier jurisdictions are likely to have greater investigative resources and be able to use a higher quality of evidence is suggested as the reason for this.

The approach of some authors is to make clear that their reported durations represent lower bounds on the total duration of collusion. Combe et al. [2008] take this approach, noting that colluding firms have an incentive to reduce the proven duration of the cartel in order to limit the fines they receive.

Bryant and Eckard [1991] point out this problem in their sample of illegal US cartels. The source documents in some cases state that a cartel has operated since 'at least' a given date. Their data also suffers from a lack of accuracy with the beginning dates of some cartels, with only the month, season or year of establishment being recorded in some cases. The authors deal with the latter problem by calculating two durations for each cartel, equal to the maximum and minimum durations possible for each cartel based

on the information available[2]. This technique depends on treating the information on cartel starting dates as accurate. The authors note this and caveat that their duration estimates should be regarded as lower bounds, though they do not attempt to correct for this problem in their analysis.

Zimmerman and Connor [2005] also note the problem, though contrary to others claim that competition authorities choose to overstate durations most frequently, rather than understate it. They cite Dick [1996] as evidence of this. Dick claims that when competition authorities do not have evidence of collusion for a period of time they will assume that collusion continued unabated. He argues that his own dataset of legal cartels is not susceptible to this issue.

Another possible reason to suspect that duration is overestimated is noted by Levenstein and Suslow [2006b]. They point out that some cartels are believed to have had no noticeable effect on prices for some of their duration. These periods of cartel ineffectiveness could occur immediately after the formal establishment of the cartel, immediately before its measured breakdown, or represent a hiatus in collusion. In the European Union, cartels are treated as a 'single continuous infringement', meaning that cartels are treated as lasting from the time of their first meeting until their breakdown or discovery. Joshua [2009] criticises the EC for treating cartels as having the longest duration provable on this basis, despite the gaps in collusion which may exist. If periods of cartel ineffectiveness should not considered part of their duration, or if multiple episodes of collusion should be considered separate cartels for the purposes of measuring duration, then the measured durations of the EC may be argued to be too long.

While these issues with data on cartel duration are widely noted, no author has attempted to account for this uncertainty in their empirical modelling.

Entry and Exit

While the duration of each firms' participation in the cartel is documented to the day as described above, what an 'entry' or 'exit' represents is potentially problematic. A merger in the industry may mean that a given firm's participation in the cartel is listed as having ended at a specific date when in fact all of that firm's assets in the market now

[2]For example, if a cartel is noted as beginning in 1973 then one measure will treat it as beginning on 1 January 1973 and the other measure as beginning on 31 December 1973.

belong to another firm whose participation in the cartel continues. The criteria used for dealing with this problem is that a cartel entry or exit should represent a strategic decision on the part of that firm to begin or cease collusion. Detailed descriptions of the contact between the cartel members are given by many of the published decisions and these were examined to ensure that the entries and exits observed were genuine.

Additional research in corporate websites and histories was useful in establishing when a firm's legal exit or entry constituted an actual strategic decision rather than representing a merger, change of name or divestiture. The focus of the analysis is firms' decisions of entry and exit into and from cartels so in such cases care was taken to ensure that each incident of entry or exit represents a strategic decision by the firm, rather than being an artefact of a change in name or ownership.

Market Share

Due to limitations on the availability of market share data it is necessary to exclude some cartels for which this information cannot be found from model specifications where these variables are used and to amalgamate certain groups of cartels which involve a common set of firms and the same set of agreements.[3] These amalgamated cartels represent cartels which the E.C. sanctioned in single decision documents and so reported turnovers for the groups of cartels.

The data on shares give a static snapshot of the size of each firms market share at a given point of time. The actual shares of firms likely fluctuated over time though the figures used were taken as representative by the E.C. when they were calculating fines for the firms. The most common approach is to use the firms' turnovers in the relevant market for the last full year of the infringement. Sometimes, the total turnovers of the cartels members in the cartelised market are summed over the duration of the cartel. The 1998 Fining Guidelines[4] specify only that the 'best available figures' (paragraph 16, 1998) should be used for calculating the basic amount of the fine. The 2006 Fining Guidelines do not update this point.

[3] These amalgamations are of the Hard Haberdashery cartels, the Isostatic and Extruded Speciality Graphite cartels, the Elevators and Escalators Cartels, and the Industrial and Automotive Thread Cartels

[4] Readable online at http://ec.europa.eu/competition/antitrust/legislation/fines.html

Size of Fringe

Chapters 3 and 4 are concerned with the movement of firms between the fringe of non-members and the cartel. While the entry and exit of firms to and from the cartels is observable, the entry and exit of firms to and from the market is not. The size of the cartel fringe at any given time is not reported by the European Commission. Outsider firms are very occasionally mentioned in published decisions, for example when they are targeted for coordinated exclusion by the cartel, but not consistently enough to be useful in analysis.

This is also a problem when interpreting firms' actions. If a firm were to fail — perhaps due to factors unrelated to the cartelised market — and leave the market then the published decision would consider the duration of that firm's participation in the cartel over. This appears identical to a firm deciding to defect from the cartel to the fringe. Information on whether an exit is to the fringe or out of the market entirely is not consistently available from the decisions and could not be ascertained from external sources.

Sample Selection Bias

A problem associated with all empirical studies of cartels is that the sample is limited to cartels which were detected by the authorities. Detected cartels may well be systematically different in their characteristics to undetected cartels, meaning that the findings of studies which use datasets of detected cartels may not be generalisable to all cartels. Ormosi [2014] estimates that 10% to 20% of active European cartels are discovered by the European Commission each year.

The cartels which are under-represented in the sample are likely to be those which are the most successful at avoiding detection. There is no way of telling which types of cartels these might be.

Market Definition

This dataset follows the market definitions adopted by the EC in their decisions. These market definitions could be flawed, either in geographical or product terms. For example, a cartel may be seen to control only a fraction of the European market for a product,

Table 2.1.: Cartel and firm involvement duration in days

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Cartel duration	91	8 yrs	5.9 yrs	6.5 yrs	0	34.9 yrs
Firm duration	478	7.5 yrs	5.9 yrs	5.6 yrs	0	34.9 yrs
Late Entrants	478	0.28	0	0.45	0	1
Early Exiters	478	0.2	0	0.4	0	1

Table 2.2.: Industry type of cartels

Industry	Frequency
Chemicals	37
Food and agriculture	11
Manufacturing	30
Metals	7
Other	6

but may in fact control a group of countries completely. Similarly, a cartel may appear to control a small proportion of the output of a certain product category, but in fact may control entirely a narrower set of products. Taken to an extreme, it could be argued that the incomplete cartels identified in this dataset and in other empirical literature in fact represent cases where the market has been defined too widely and the identified cartels are in fact complete.

That firms leave and join cartels while still producing the same products and being active in the same geographical areas as when they were cartel members suggest that incomplete cartels do indeed exist, however. That many of the incomplete cartels produced homogeneous products, for example in the chemical and pharmaceutical industries, shows that incompleteness is possible in cases where there is little possibility of the product market being defined too broadly.

2.2. Cartel and Firm Duration

Table 2.1 gives data on the durations of the cartels in the sample and the durations of the firms' participation in those cartels. Cartels lasted for a mean of 8 years, with the longest-lasting cartel enduring for 35 years. The longest-lasting cartel was the Animal

Feed Phosphates cartel, founded in March 1969 and ended by the E.C. in February 2004. The participants in the French Beer cartel were fined by the E.C. before their agreement could be implemented, meaning the duration of the cartel was zero.

Mean firm duration is 7.5 years. This is necessarily lower than the mean cartel duration since the duration of a firm's involvement in a cartel cannot exceed the duration of that cartel, but will be less if the firm is an late entrant or early exiter.

133 firms entered the cartels they were members of after the founding of the cartel and 97 firms left the cartels they were members of before the end of the cartel. 186 firms, 39% of the total, either entered late or exited early. Characteristics of these firms are presented in sections 2.4 and 2.5.

Table 2.2 lists the industrial sectors which the cartels occurred in. Particularly notable is the large number of cartels in the chemicals sector. A large number of such cartels were detected in the Vitamins industry (which accounts for 14 of the chemicals cartels) and other chemicals industries which the same firms were active in. The industries of the cartels included in 'Other' are finance, energy, auction services, foreign exchange, removals services, and airlines. The apparent overrepresentation of certain industries could represent a real phenomena, where those industries with many detected cartels have more collusion than those industries which are less represented, due to those industries tending to be structurally amenable to collusion, or through a spate of cartels spreading through markets in an industry through contagion. Alternately, it could represent a bias in the sample due to programmes such as the USA's Amnesty Plus, or particular attention paid by regulators to industries with recently detected cartels, leading to cartels being detected in groups within the same industry.

2.3. Structural characteristics of cartels and firms

Table 2.3 gives data on structural characteristics of the firms. Share data is only available for 75 of the cartels (comprising 379 firms) and coverage data is available for 75 cartels. The share quoted is each member's share of the total cartel output.

Cartels tend to have between 3 and 6 members. Very large cartels are rare. Six cartels have more than ten members, and the largest cartels are Bathroom Fittings and

Table 2.3.: Structural characteristics of cartels and firms

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
For firms:						
Cartel share	379	0.2	0.15	.17	.915	0.0022
For cartels:						
Number of members	91	5.3	4	3.2	2	17
Coverage	71	0.86	0.9	0.15	.15	.39
Range of cartel shares	75	0.32	0.31	0.15	0.83	0
Cartel HHI	75	0.37	0.31	0.14	0.84	0.076

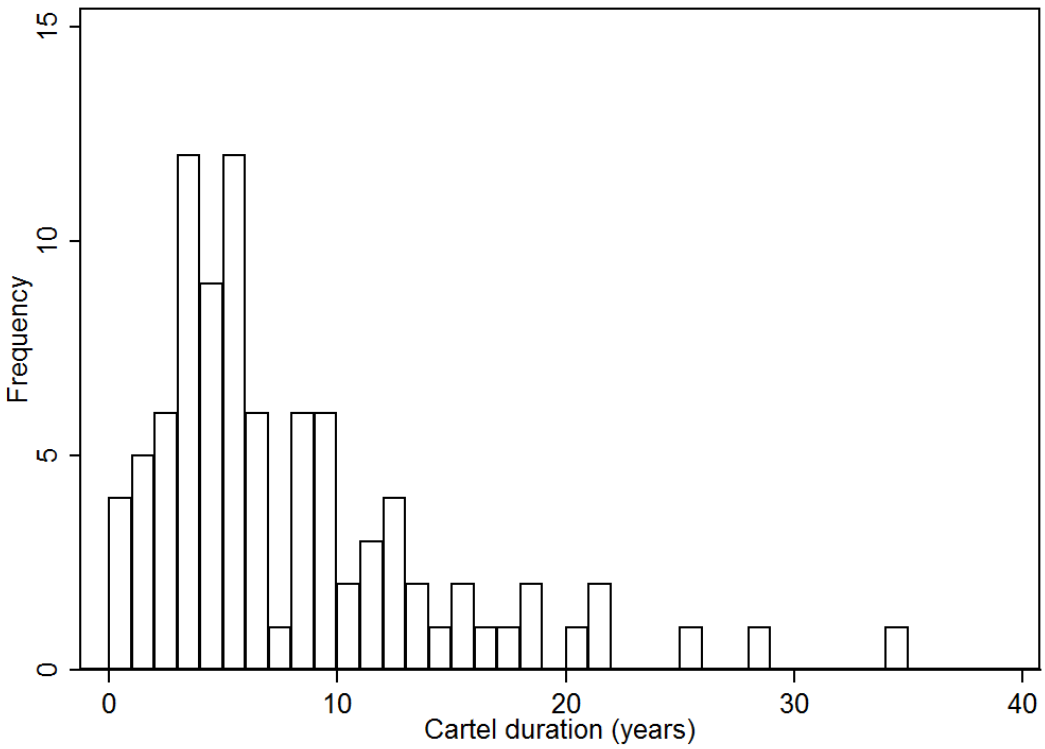

Figure 2.1.: Duration of cartels

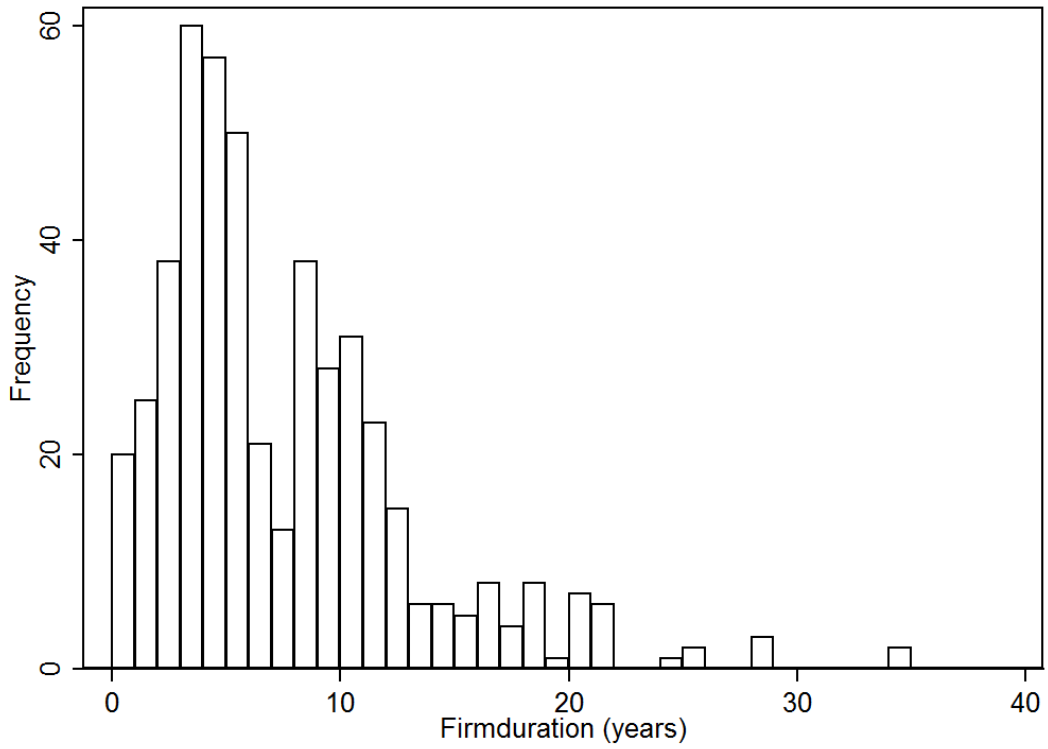

Figure 2.2.: Duration of firms' participation in cartels

Table 2.4.: Geographical scopes of cartels

Geographical scope	Frequency
Global	30
Europe-wide	31
Regional	10
National	20

Fixtures and Prestressing Steel, both with 17 members.

Cartel coverage is high, with 16 cartels have complete coverage of their markets. The lowest cartel coverage in the sample is the German Bank Exchange Rates cartel, which controlled only 39% of its market.

The concentration of cartels is moderately high, with a mean Herfindahl Index of 0.37. Note that because many cartels are incomplete the HHI of the cartel is an upper bound on the HHI of the market containing the cartel. The European Commission's Merger Guidelines (2004) define a threshold at an HHI of 0.2 above which they consider a market to be highly concentrated. Only 10 of the 75 cartels with known HHIs (13%) had an HHI of less than 0.2, indicating that cartels tend to occur in relatively concentrated markets.

2.3.1. Organisational features of cartels

Table 2.4 shows the distribution of cartels across geographical scopes. Global and Europe-wide cartels are most abundant in the sample but smaller cartels make up a substantial amount of the dataset. The 20 national cartels are particularly worth noting because of the relatively strange nature of these cartel compared to the international cartels which led the European Commission to sanction them.

Table 2.5 shows the frequency of use of different agreement types. Note that 64 out of 91 cartels (70%) used multiple agreement types. Price fixing is present in the vast majority of cartel agreements. Bid rigging and especially territorial allocation are far less common in this sample of detected cartels.

Table 2.5.: Agreement types used by cartels

Agreement type	Frequency
Price fixing	78
Bid rigging	19
Customer allocation	35
Territorial allocation	14
Quota allocation	33

Table 2.6.: Characteristics of late entrant firms

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Lateness of entry	133	5 yrs	2.6 yrs	5.5 yrs	7 days	24.6 yrs
Firm duration	133	6.2 yrs	5.6 yrs	4 yrs	95 days	24 yrs
Cartel share	94	0.09	0.06	0.08	0.0022	0.4
Early exiters	133	0.33	0	0.47	0	1

2.4. Characteristics of late entrant firms

Table 2.6 shows statistics about the 133 firms which joined cartels which were already active. The mean lateness of entry is five years and the mean duration of collusion for a firm which entered a cartel late is lower than the mean duration of all firms. Late entrants tend to be small, with a mean cartel share of 9%, and a third of them end up exiting a cartel early.

Table 2.7.: Characteristics of early exiter firms

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Earliness of exit	97	387 days	257 days	405 days	1	4.6 yrs
Firm duration	97	7.9 yrs	8.1 yrs	5.4 yrs	95 days	34.7 yrs
Cartel share	76	0.12	0.09	0.12	0.0022	0.5
Late entrants	97	0.45	0	0.5	0	1

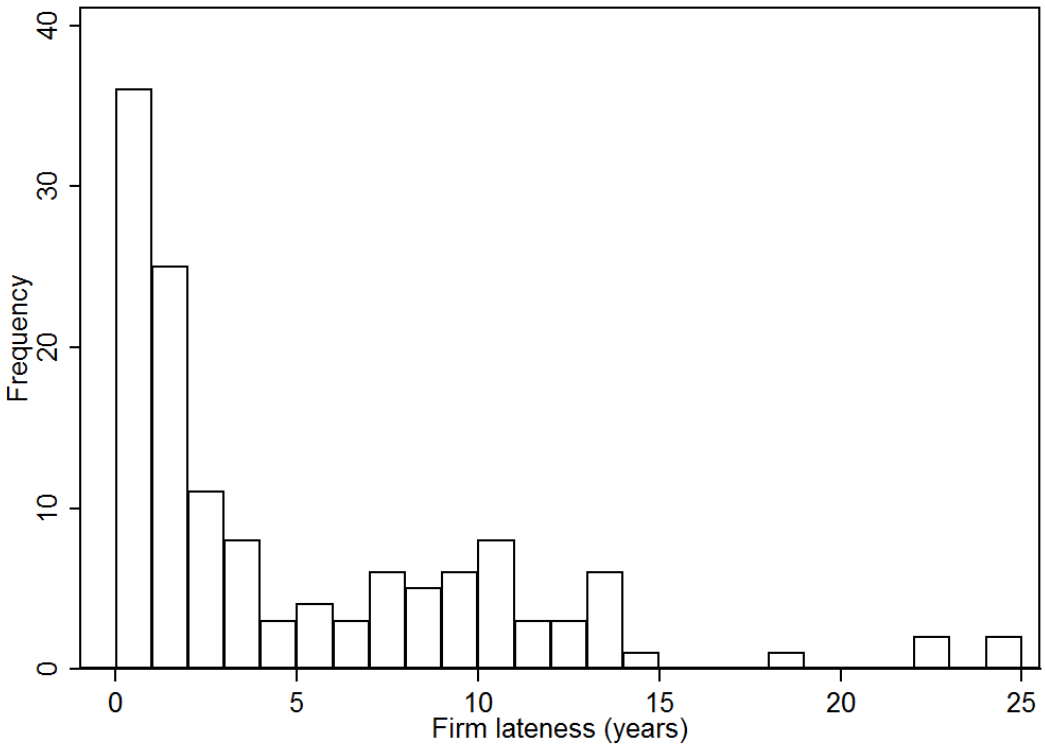

Figure 2.3.: Lateness of entry for late entrants

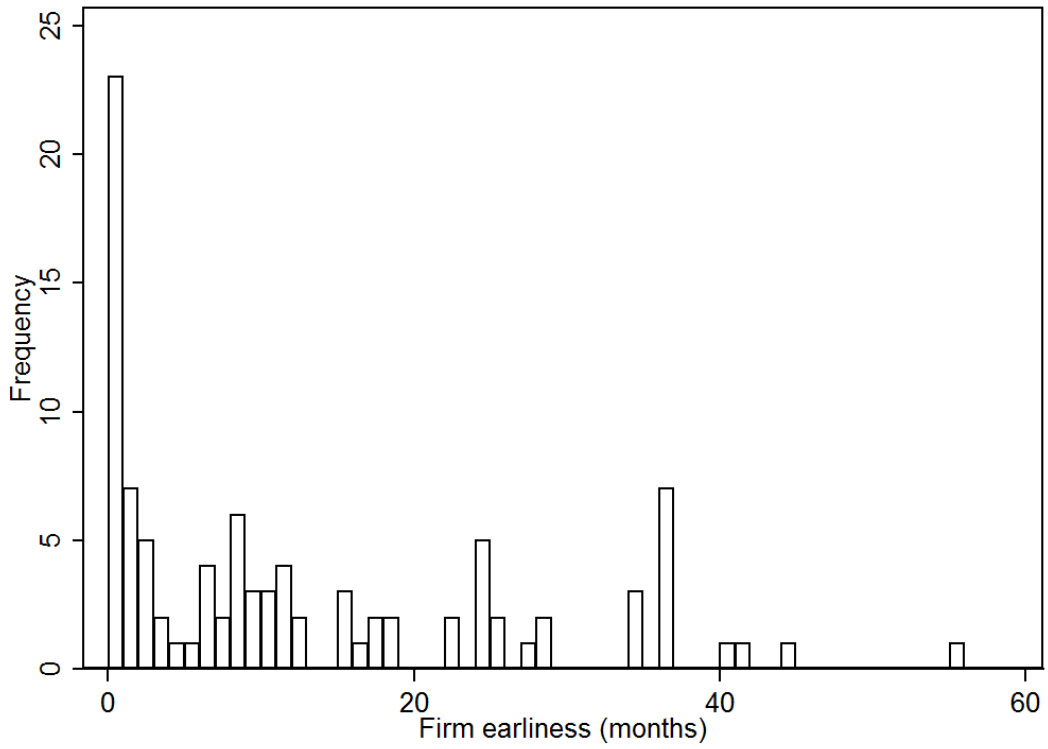

Figure 2.4.: Earliness of exit for early exiters

2.5. Characteristics of early exiter firms

Table 2.7 shows statistics about the 97 firms which left cartels without the cartel breaking down. Mean earliness of exit is only 387 days, with many firms leaving only weeks before the end of a cartel. Early exiters are also relatively small, with an average cartel share of 12%. 45% of early exiters had entered the cartel after its start.

2.6. Conclusion

The first stylised fact which may be drawn from the sample is that entry and exit to and from cartels by firms is relatively common. 39% of all firms in the sample were not in their cartels for that cartel's full duration. 57% of all cartels in the sample experienced one of its member firms joining late or leaving early. That the phenomenons of cartel entry and exit are so common and yet do not play a significant part in other empirical research into cartels is notable. That entry and exit is prevalent also indicates that many cartels do indeed cover only a proportion of firms in their markets and that observed incompleteness is not a result of mistaken market definition: a firm which has been a member of a cartel is certainly a part of the same market as the cartel.

Care should be taken in applying conclusions drawn from this sample to other groups of cartels, but the cartels in this sample are not dissimilar in duration to samples of cartels used in other research. De [2010a] reviews the literature on cartel duration and reviews several samples used in cartel research. Mean duration of cartels is found to be 6.3 years in the sample of international cartels discovered between 1990 and 2004 used by Zimmerman and Connor [2005], 7.5 years in the varied sample of cartels used by Levenstein and Suslow [2006b], 7.5 years in the sample of American cartels discovered between 1890 and 1969 used by Posner [1970], and 7.6 years in the sample of European cartel between 1969 and 2007 (which partially overlaps with my own sample but over a longer time span) used by Combe et al. [2008]. The average duration of 8 years in this sample is similar in size to these other, very varied, samples indicating that my sample is not unusual in this respect.

Chapter 3.

Predicting the Exit of Marginal Firms from Cartels

The existence and prevalence of incomplete cartels are well-understood theoretically and well-documented empirically. A question this prompts is which firms in a market will be members of the cartel and which firms 'outsiders.' Theoretical models of collusive markets with heterogeneous firms, discussed in Chapter 1, address this question. Those models in the 'marginal firms' paradigm hold that firms with high capacity, low marginal costs and high discount factors will be members of the cartel and those firms with low capacity, high marginal cost and impatient firms will choose to be outsiders. These models share a basic paradigm about cartel behaviour which sees firms leaving and joining cartels in order of their individual preferences for collusion. This contrasts with a popular game-theoretic approach to modelling cartels where the cartel chooses an agreement such that the temptations of each firm to defect from the cartel agreements are balanced.

These two models of collusion see cartels as functioning in very different ways, and the choice of which approach to use in creating a theoretical model of collusion is largely arbitrary on the part of the author. The marginal firms model suggests firms join the cartel sequentially and that the cartel follows an allocation rule where the allocation of output within the cartel follows a similar ranking to the allocation of output which would exist if the market were competitive. The balanced temptations model, however, sees cartels as using their allocation rule to minimise the probability of any firm defecting from the cartel by equalising the critical discount factor of all firms.

If the balanced temptations model is correct, then any defections from cartel agreements must be unpredictable, otherwise the cartel did not equalise the temptations of members to defect. If defection is predictable then cartels must follow some other rule.

Testing whether a firm's late entry predicts its early exit from its cartel tests the most general form of the marginal firms model. If firms which join cartels after they start are more likely to defect later then this indicates that some latent variable is driving the firms' preference for collusion, and that this preference is persistent over time. No claim may be made about what this latent variable may be from this simple test since only the behaviour of the firms with respect to their membership decision is considered, rather than their characteristics.

The introduction of market shares to the model specification sheds a little more light onto the mechanisms involved. Market share is again a consequence of the cartels' own decisions and of the firms' behaviour within the cartel and cannot directly be taken to infer directly any attribute of a firm, such as its discount rate, capacity or marginal cost. However, if firms with large market shares are tending to defect then this would indicate that the cartel is practising a policy of accommodation in order to convince firms to join who would not under other circumstances, but not to a sufficient extent that temptations become balanced. If firms with smaller market shares tend to defect then that would indicate that allocation rules where cartel shares are proportional to competitive shares are being followed.

This chapter analyses a group of 478 firms who were members of 91 cartels fined by the European Commission between 2001 and 2011. Data on the dates on which colluding firms left and joined the agreements are available and analysed in all 91 cartels, data on colluding firms' share of cartel output are available and analysed in 75 cartels. This is the dataset described in Chapter 2. Probit models predicting exit and entry from cartels are estimated and matrices showing the order of entry and exit in cartels are constructed.

The marginal firms and balanced temptations approaches are expressed in a form which is tractable for empirical modelling in section 3.1. The determinants of firm early exit are analysed in section 3.2, using descriptive statistics in section 3.2.2 and using probit analysis in section 3.2.3. Determinants of late entry by firms are examined in section 3.2.5. The order of entry, exit and firm size are presented in matrix form in section 3.2.6 as a complement to the other analysis performed. Section 3.3 concludes and considers the policy implications of the findings.

3.1. Models of Cartel Membership

A firm's cartel membership decision may be modelled as a binary choice by firms: to be a cartel member or non-member. Theoretical models of cartel membership assume that the individual firm will choose whichever option maximises their future discounted profit stream given the present size of the cartel and the structure of the market. Should the individual circumstances of the firm or the characteristics of the market change over time, the firm may have cause to switch their membership decision.

The theory of binary choice is outlined in Greene [2011] and is frequently applied to models of consumer behaviour where consumers assess the utility of a consumption choice, switching to an alternative product should it offer greater utility. The intuition of a binary choice model of cartel membership is similar to that of D'Aspremont et al. [1983], with firms choosing cartel membership or non-membership on the basis of which offers higher profits.

When a cartel j exists in a market, a firm i knows its discounted profit stream associated with being a cartel member, π_{ij}^c, and with being an outsider to the cartel, π_{ij}^n. These profit streams are determined by a set of explanatory variables specific to the individual firm such as their cost and capacity, $\mathbf{x}_i$, according to a set of coefficients on these variables, β; a set of explanatory variables common to all firms in the cartel and market such as the nature of the industry and geographical scope of the cartel, $\mathbf{z}$, according to a set of coefficients on these variables, γ; and a random error term, ϵ_{ij}, reflecting idiosyncratic shocks affecting a firms' wish to participate in a particular cartel. The characteristics of the cartel and both vectors of coefficients are allowed to change depending on whether the firm is a member or non-member of the cartel.

$$\pi_{ij}^c = \beta^c \mathbf{x}_i + \gamma^c \mathbf{z}_j^c + \epsilon_{ij}^c \tag{3.1}$$

$$\pi_{ij}^n = \beta^n \mathbf{x}_i + \gamma^n \mathbf{z}_j^n + \epsilon_{ij}^n \tag{3.2}$$

A firm will choose to be a cartel member if its expected profits from being a cartel member are greater than those from being an outsider, taking into account the effect of its own membership decision on the profitability of the cartel[1]. Similarly, a firm will

[1] The membership structure of the cartel is a variable specific to the market, rather than the firm, and so is included in $\mathbf{z}$

choose to be a non-member if its net profit from membership is negative.

$$\text{Net profit from membership}_{ij} = \pi^c_{ij} - \pi^n_{ij} \tag{3.3}$$

Given this, a member firm's probability of exiting the cartel is:

$$\Pr(\text{Firm exit}_i) = \Pr(\pi^n_{ij} > \pi^c_{ij}) \tag{3.4}$$

A non-member firm's probability of entering the cartel is:

$$\Pr(\text{Firm entry}_i) = \Pr(\pi^c_{ij} > \pi^n_{ij}) \tag{3.5}$$

Substituting the (3.1) and (3.2) equations into (3.4):

$$\begin{aligned}
\Pr(\text{Firm exit}_i) &= \Pr(\beta^c \mathbf{x}_i + \gamma^c \mathbf{z}^c_j + \epsilon^c_{ij} > \beta^n \mathbf{x}_i + \gamma^n \mathbf{z}^n_j + \epsilon^n_{ij}) && (3.6)\\
&= \Pr((\beta^c - \beta^n)\mathbf{x}_i + \gamma^c \mathbf{z}_j - \gamma^n \mathbf{z}^n_j + \epsilon^c_{ij} - \epsilon^n_{ij} > 0) \\
&= \Pr(\beta^* \mathbf{x}_i + \gamma^* \mathbf{z}^*_j + \epsilon^*_{ij} > 0) && (3.7)
\end{aligned}$$

Where the vector of coefficients γ^* represents the vectors γ^c and $-\gamma^n$ appended, and the matrix of variables $\mathbf{z}^*_j$ represents the variables γ^c_j and γ^n_j appended. The vector of coefficients β^* represents the net effect of the β^c and β^n coefficients on the $\mathbf{x}_i$ firm-specific variables, $\beta^c - \beta^n$.

And substituting (3.1) and (3.2) equations into (3.5):

$$\begin{aligned}
\Pr(\text{Firm entry}_i) &= \Pr(\beta^n \mathbf{x}_i + \gamma^n \mathbf{z}^n_j + \epsilon^n_{ij} > \beta^c \mathbf{x}_i + \gamma^c \mathbf{z}^c_j + \epsilon^c_{ij}) && (3.8)\\
&= \Pr((\beta^n - \beta^c)\mathbf{x}_i + \gamma^n \mathbf{z}^n_j - \gamma^c \mathbf{z}^c_j + \epsilon^n_{ij} - \epsilon^c_{ij} > 0) \\
&= \Pr(\beta^\dagger \mathbf{x}_i + \gamma^\dagger \mathbf{z}^\dagger_j + \epsilon^\dagger_{ij} > 0) && (3.9)
\end{aligned}$$

Where the variables denoted by † similarly represent appended vectors of coefficients and matrices of variables: $\gamma^\dagger$ represents γ^n and $-\gamma^c$ appended, $\mathbf{z}^\dagger_j$ represents $\mathbf{z}^n$ and $\mathbf{z}^c$ appended, and $\beta^\dagger$ the net effect of β^n and β^c on $\mathbf{x}_i$.

This process may be modelled empirically as a probit model, as I do in section 3.2.3. The two views of firm entry and exit which I have identified may be considered in terms of binary choices.

3.1.1. Marginal Firms and Binary Choice

The literature review chapter argued that theoretical models of incomplete cartels could be categorised into two broad approaches: marginal firms and balanced temptations. If the distinction between these classes of models is to be investigated empirically, it is useful to write down a broad version of each of those so the theoretical version may be operationalised into a model to which data may be fitted. Broadly, I characterise the marginal firms models as claiming that the behaviour of firms may be predicted through covariates reflecting their characteristics and the balanced temptations models as claiming that the behaviour of firms appears non-determinated.

According to marginal firms models, there will be a member firm which is closest to exiting the cartel and an outsider firm (if the cartel is incomplete) which is closest to joining the cartel. Any entry or exit to or from the cartel will involve one of these two firms.. These two firms may be called the 'marginal firms'. Entry could be prompted by a change in market demand or in the circumstances of any of the firms in the market which makes being an outsider more appealing to the insider marginal firm or cartel membership more appealing to the outsider marginal firm.

This proposition, that entry must come from the largest outsider firm which will then become the smallest insider and is most likely to be involved in any subsequent exit, is testable. If this is the case, a firm's entry into a cartel after the formation of that cartel should be a good predictor of its exit before the cartel's demise. This relationship need not be perfect since firms' circumstances and preferences may change during their membership and because many cartels either lack entry or lack exit. The number of firms in a market will also play a role in determining the possibility and extent of entry and exit. Whether or not the behaviour of firms is consistent with this theory is investigated in Section 3.2.

3.1.2. Balanced Temptations and Binary Choice

An alternative group of models of cartels sees them adjusting the allocation profits among firms in order to ensure that all firms have an equal incentive to defect from the agreement. Friedman [1971] suggests this as a possible non-cooperative equilibrium in repeated games and Friedman [1983] applies it to the case of a cartel, suggesting it as a point on the profit frontier which could be arrived at by firms with a min-

imum of communication. In supergame models this involves equalising the critical discount rate among all member firms. In the binary choice framework outlined above, firms' discount rates are included in the terms representing discounted future profit flows.

In the binary choice framework I have outlined balanced temptation models do not make any specific claims about the pattern of entry. A firm's decision to join a cartel could be determined by a set of covariates similar or identical to those in a marginal firms model of entry. It is therefore impossible to falsify either model using the probability of cartel entry as a test. For the probability of cartel exit, however, balanced temptations models do make a prediction: that the allocation within the cartel be such that all firms have equal incentive to leave and become an outsider. This prediction is testable using the data on cartel membership in European Commission-sanctioned cartels 2001-2011.

3.2. Analysis

The theory of marginal firms outlined above suggests that the most recent firm to join a cartel will be the first to leave it, excepting when changes in costs, capacity discount rates or other firm characteristics cause a different firm to be the most marginal about participation. It also indicates that cartels with more member firms are likely to experience more entry and exit.

The predictions of models of cost and capacity asymmetry are not directly testable, since these attributes are not directly observed. Firms' shares of cartel output are observed for many cartels but these could reflect many attributes of the firms involved. More importantly, they could also represent the allocation rule chosen by the cartel.

3.2.1. Predicting Firms' Early Exit

That a firm entered late should be a strong indicator that it has a relatively weak preference for collusion and so is likely to leave the cartel. It is a very direct observation of a firm's conduct and so is unlike the other variables, which relate to the conduct of the cartel as a whole and the structure of the marketplace. If late entry is a strong predictor of early exit then this is a confirmation of the most general form of the marginal firms hypothesis: that firms' preferences for collusion determine cartel membership and are

persistent over time.

The theory of incomplete collusion among asymmetric firms discussed in Section 1.2 suggests that markets may only contain outsiders where firms are sufficiently numerous. Markets with greater numbers of firms are better able to support both a cartel and a fringe. If the number of firms in the market is too few then it may not be possible for both a cartel which is profitable for all of its members and one or more fringe firms to coexist — in the simple, symmetric Cournot model this boundary is at five firms in the market. The balanced temptations and marginal firms models do not differ in their predictions of the effects of cartel size on the entry and exit of firms to and from cartels.

The theories of incomplete collusion predict that firms with higher costs or lower capacities will be less inclined to join a cartel but the links between these attributes and market shares are not firm. In a competitive market, firms with higher costs and lower capacities will tend to have lower market shares and cartel allocation rules are commonly assumed to reflect competitive market shares. Firms' share of cartel output is used rather than their market shares because of the limited data on cartel coverage. Whether this variable is able to predict entry or exit should be considered a test of a more specific form of the marginal firms hypothesis: that firms' preferences for collusion are based on economic, profit-maximising concerns.

The role of cartel coverage in predicting exit is clear: a cartel must be less than all-inclusive in order to support a fringe. However, coverage data is not available for all cartels, and there is a possible endogeneity problem associated with the variable. The possible endogeneity problem is that the cartel may have incomplete coverage because of the exit of the firm under observation. A cartel which already supports a fringe is less likely to require the participation of all firms

The relationship between a firm receiving full leniency from punishment by the European Commission and early exit is unclear. It is a legal requirement that firms cease collusion immediately following a leniency application to the Commission. This raises the uncomfortable possibility that leniency-claiming firms classified as early exiters may be identical in their behaviour to other firms besides the fact of the leniency claim.

The geographical scope of the cartel and the broad industrial sector in which the cartel operated may affect the tendency of firms to leave and join cartels. Theory

makes no predictions as to the direction of strength of such effects. Still, there may be systematic differences in the characteristics of a group of cartels which spans different industries and geographical scopes which may affect their structural strength or the behaviour of the member firms.

3.2.2. Descriptive Overview

While general descriptive statistics for the sample of cartels and firms were given in Chapter 3, it is useful to address some of the points listed above by directly questioning the data.

The mean size of a cartel with static membership is 3.3 firms. The mean size of a cartel with membership which is at all variable is 6.9 firms. The smallest cartel to experience a change in membership during its lifespan has 3 members (the largest, 17 members). The largest cartel to have a static membership has 8 members (the smallest, 2 members). These figures differ from those given in Table 3.1 because the figures given in the table are the sizes of the cartels of which the firms are members, meaning larger cartels are overrepresented.

Firms which enter cartels late or leave them early are, on average, smaller than firms which do not. The mean cartel share of a late entrant is 8.8% and mean cartel share for an early exiter is 12%, compared to a mean of 24.3% for firms which are members of cartels for their full duration.

44 firms both entered their cartels late and exited them early. The Spearman correlation coefficient between them is 0.1975, a positive and significant correlation.

The variability of membership stasis found in different industries and levels of geographical scope is not consistent with any particular account. The manufacturing sector has a notably high amount of cartels with varying membership, with 22 out of 30 cartels experiencing a change in membership. Europe-wide cartels also experience a lot of membership variability: 22 out of 31 have variable membership.

Table 3.1.: Descriptive statistics for firms

	All firms	Static firms	Late entrants	Early exiters
Mean size of firm's cartel	7.2	5.9	9.9	8.4
Median size of firm's cartel	6	5	9	8
Mean cartel share	0.2	0.24	0.09	0.12
Median cartel share	0.15	0.21	0.06	0.09

3.2.3. Probit Analysis

The probit model is a suitable model for predicting the probabilities of binary events using parameters. The marginal firms model predicts that an unobserved latent variable explains firms' preferences to participate in cartels so the probit model is preferred over the odds ratio-motivated logit model.

Recall the prediction of the marginal firms model discussed in section 3.1: that firms' cartel membership decisions are determined by a vector of firm-specific covariates, $\mathbf{x}_i$, and cartel-specific covariates, $\mathbf{z}_j$, with a random disturbance, ϵ^{c}_{ij}. These variables, combined with the coefficients in the vectors β and γ, determine the relative profitability of a firm choosing to be a cartel insider or outsider and so its membership decision. With the data which is available to us, the actual underlying profitability of membership and non-membership is not observable.

Equations (3.7) and (3.9) are presented in an ideal form, with all relevant variables assumed to be observable. There are many variables which will affect the relative profitability of a firm's membership decision which are not observed in the dataset, for example the firms' exact costs, capacities and discount rates. Allowing $\mathbf{x}$ and $\mathbf{z}$ to refer to firm- and cartel-specific characteristics which are observed in the data, β and γ to their respective vectors of coefficients, and relaxing the $*$ and $\dagger$ notation, a firm's probability of exiting a cartel may be written as:

$$\Pr(\text{Firm exit}_i) = \Pr(\beta^{*}\mathbf{x}_i + \gamma^{*}\mathbf{z}^{*}_j + \epsilon^{*}_{ij} > 0) \tag{3.10}$$

Assuming that the random disturbance is described by a symmetric normal distribution: $\epsilon^{*}_{ij} \sim N[0,1]$, then the marginal firms account of cartel membership may be tested through estimating probit models:

$$\Pr(\text{Firm exit}) = \int_{-\infty}^{\beta^* \mathbf{x}_i + \gamma^* \mathbf{z}_j^*} \phi(L_i) dL_i = \Phi(\beta^* \mathbf{x}_i + \gamma^* \mathbf{z}_j^*) \tag{3.11}$$

Where ϕ is the standard normal distribution and Φ is the cumulative density function of the standard normal distribution.

Table 3.2 shows the results of five probit model specifications predicting a firm's early exit from a cartel with its late entry and the size of its cartel. Each observation in this estimation is an individual firm. Dummy variables of the geographical scope and industry of the cartels are used as controls and are omitted from these tables. They are included in Table B.1 in Appendix B. Standard errors given in these tables are robust to heteroskedasticity.

Model 1 includes all of the explanatory variables of interest as covariates. The number of observations which may be used to estimate each model specification is limited by the availability of data. Data on cartel coverage is available for only 328 firms in the sample.

Model 2 excludes cartel coverage in order to expand the number of observations used for estimating the model to 379. In order to see if there is a sample selection bias caused by the cartels for which data on coverage are available being different from those without data on coverage (but with market share data), Model 2 is estimated again using only the observations for which coverage data are available. Model 2 (b) therefore uses the same 328 observations which Model 1 was estimated with.

Late entry is peculiar among the variables used to predict early exit because it is purely behavioural. The number of members in a firm's cartel, the cartel's coverage and each firm's share of cartel output are structural variables which are hypothesised to proxy the latent variable which determines a firm's tendency to collude. If this is the case late entry will be collinear with the structural variables, since firms' latent tendencies to collude will also affect their late entry behaviour For this reason, Model 3 is estimated without using firms' late entry as a covariate.

Model 4 excludes the cartel coverage and firm share of cartel output variables. This allows all 478 observations in the dataset to be used to estimate the model specification.

Table 3.2.: Probit models predicting early exit for firms

	Model 1	Model 2	Model 2 (b)	Model 3	Model 4
Late entry	0.637**	0.595**	0.686***		0.508**
	(0.204)	(0.190)	(0.203)		(0.169)
Number of members	0.0771*	-0.0117	0.0637*	0.0855**	0.00518
	(0.0317)	(0.0253)	(0.0304)	(0.0308)	(0.0198)
Cartel coverage	-1.635*			-1.922**	
	(0.706)			(0.698)	
Firm share	-1.074	-1.910**	-1.032	-1.851*	
	(0.708)	(0.687)	(0.660)	(0.740)	
Full leniency	0.287	0.199	0.259	0.241	0.317
	(0.273)	(0.246)	(0.274)	(0.285)	(0.205)
Constant	-0.332	-0.908**	-1.715***	0.0711	-1.133***
	(0.731)	(0.344)	(0.396)	(0.753)	(0.237)
Observations	328	379	328	328	478
Psuedo R^2	0.184	0.124	0.172	0.155	0.0747
log pseudolikelihood	-136.7	-166.5	-138.7	-141.5	-223.1
χ^2	57.87	52.23	60.14	48.78	40.19

Robust standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Geographical scope and Industry controls not reported

The baseline for geographical scope is that the cartel is of national scope, and may be of regional, Europe-wide or global scope. The baseline for industry is that the cartel is in the chemicals sector, and the alternative categories are cartels in the food & agriculture, manufacturing, metals or 'other' sectors. The coefficients for these variables are omitted from the models given in the main body of the text since they are intended merely to serve as controls. For geographical scope, Model 3 finds that firms in Europe-wide cartels are more likely to exit early compared to the baseline of national scope, significant at the 10% level. For industry, firms in cartels in the Metals industry are found to be more likely to exit early in models 1, 2 (b), 3 and 4, all significant at the 5% level.

The coefficients in these models indicate that firms which entered a cartel late are more likely to leave early than firms that did not and an increase in the number of firms

in a cartel will increase the probability of early exit. Firms which are members of less inclusive cartels are more likely to exit early, as are firms which have small shares of cartel output.

Where coefficients in these three models are significant, they are quite similar in magnitude indicating robustness of results across the specifications. In discussion of the findings of these models I shall use the coefficients of Model 1 for Late Entry, Number of Members and Cartel Coverage and those of Model 2 for Cartel Share. Model 1 is the most inclusive of variables and is the preferred model overall but the larger sample size of Model 2, along with the fact that the coefficient on Cartel Share is significant and similar to that of Model 3, means that Model 1's coefficient on Cartel Share is less useful.

3.2.4. Interpretation of Marginal Effects

The coefficients of a probit model are difficult to interpret directly in more depth due to the non-linear functional form of the model. Still, it is essential to know the relative importance of each of these factors. Marginal effects may be calculated for the covariates used in the model, allowing the effect on the probability of exit from a change in the value of covariate to be seen. Table 3.3 gives Average Marginal Effects for the covariates reported in Table 3.2 for all five estimations.[2] Average Marginal Effects are calculated differently from the more commonly used Marginal Effects at Means. Marginal Effects at Means are calculated for a covariate by setting all other covariates at their mean values and reporting the change in the predicted probability implied by a change in the covariate in question. This is problematic because the means of the other covariates do not represent any individual firm which could exist: No actual firm could be a member of a cartel with 5.3 members, or be 0.28 of an early entrant. The method of Average Marginal Effects avoids this problem.

Calculating Average Marginal Effects utilises the individual observations in the dataset used to estimate the model specification. For every covariate a marginal effect is to be calculated for, estimated probabilities are calculated for each observation in the dataset where the covariate in question is varied and all other covariates retain their actual values. The difference between the probabilities calculated is that observation's marginal effect. The mean of all of the observations' marginal effects is the reported Average

[2]Marginal effects for the Industry and Geographical Scope control variables may be found in the unexpurgated Table in Appendix B

Table 3.3.: Average Marginal Effects for models predicting early exit from cartels

	(1)	(2)	(2 (b))	(3)	(4)
Late entry	0.148**	0.146**	0.161***		0.132**
	(0.0451)	(0.0443)	(0.0451)		(0.0429)
Number of members	0.0179*	-0.00286	0.0149*	0.0206**	0.00134
	(0.00720)	(0.00618)	(0.00704)	(0.00723)	(0.00513)
Cartel coverage	-0.378*			-0.463**	
	(0.159)			(0.163)	
Market share	-0.249	-0.467**	-0.242	-0.446*	
	(0.162)	(0.165)	(0.153)	(0.174)	
Full leniency	0.0664	0.0486	0.0605	0.0580	0.0823
	(0.0630)	(0.0599)	(0.0641)	(0.0688)	(0.0530)
Observations	328	379	328	328	478

Marginal effects; Robust standard errors in parentheses
(d) for discrete change of dummy variable from 0 to 1
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Marginal Effect. The calculation and interpretation of various types of marginal effects are discussed in Williams [2012].

It is also possible to calculate the predictive margins associated with chosen values of covariates in a similar way. A predicted probability is calculated for all of the observations in the dataset with the covariate in question set to the chosen value. The mean of all of these values is then reported, and the process repeated for the next chosen value of the covariate of interest. This technique is used to calculate the predicted probability of exit associated with specific values of dependent variables, rather than to provide a headline marginal effect for a dependent variable.

Late Entry

If firms' cartel membership decisions are motivated by a latent variable then the clearest indication should be a behavioural one. Firms which are on the margins of participating in the cartel may choose to be outside of the cartel initially, then join the cartel later following a change in market circumstances or a small change in individual preference

Table 3.4.: Predictive margins for early exit of firms in cartel sizes from 2 to 10

	(1)	(2)	(2a)	(3)	(4)
2 Firms	0.122	0.217	0.133	0.111	0.194
3 Firms	0.136	0.214	0.146	0.127	0.196
4 Firms	0.151	0.211	0.159	0.143	0.197
5 Firms	0.167	0.209	0.172	0.162	0.198
6 Firms	0.184	0.206	0.187	0.181	0.200
7 Firms	0.203	0.203	0.202	0.202	0.201
8 Firms	0.222	0.200	0.218	0.225	0.202
9 Firms	0.243	0.197	0.235	0.249	0.204
10 Firms	0.264	0.194	0.253	0.274	0.205

for collusion. When market circumstances change to make the optimal cartel larger or the firm's characteristics change to make them less amenable to collusion this late entrant should be the first firm to leave the cartel.

The Average Marginal Effect of a firm being a late entrant on the probability of their early exit is between 13.2% and 16.1%. This is the amount by which the probability of early exit is estimated as increasing by if a firm is a late entrant, as opposed to it joining its cartel at the foundation. Intuitively, the technique of Average Marginal Effect may be thought of as comparing the probabilities of early exit between two populations of firms; one of which is entirely late entrants and the other of which is entirely non-late entrants, but which are otherwise identical.

Number of Cartel Members

The structural characteristics included in the model indicate what the latent variables indicating a firm's preference for collusion may be. It is possible to calculate the predicted probability of early exit for a member of a cartel of any given size, holding other variables at their means. Using Model 1, the probability of a firm in a cartel of size four, the median cartel size, leaving the cartel early is 12%. Due to the members of larger cartel being overrepresented in the dataset the median firm in the sample is in a cartel of size seven. A firm in a seven-firm cartel has a predicted probability of leaving early of 17%.

Table 3.4 shows the predicted probabilities of early exit for a firm in a cartel with two to ten member firms. The probabilities are calculated using the predictive margins technique described above. The largest cartel in the sample has 17 members, with six cartels having more than 10 members, but the range of 2 to 10 firms includes the majority of the sample used to estimate the models. Note that the number of member firms is insignificant in Models 2 and 5. In the models where number of member firms is significant, the predicted probabilities are robust across specifications. A firm in a cartel with the median size of 4 firms is predicted to have a probability of early exit of 14.6% to 15.9%.

Cartel Coverage

The median firm is in a cartel with a coverage of 90%. Using the technique of average marginal effects, a firm in such a cartel has a 15% probability of early exit. This sharply increases as coverage decreases, with a firm in a cartel covering 70% of its market having a 24% probability of early exit.

Firm Share of Cartel Output

For the predictions around firm's shares of cartel output, the coefficients estimated in Model 2 are used. A firm with a cartel share of 10% is predicted to have a 22% probability of early exit, holding other variables at mean values. A firm with a 50% share of cartel output has a predicted probability of 6%. A very small firm, with a cartel share of 1%, has a predicted probability of early exit of 27%. Several firms have such low cartel shares.

Industry and Geographical Scope

None of the coefficients estimated for the geographical scope variables are consistently significant in any of the estimated models. In model 3 there is weak (p value¡0.1) evidence that firms in cartels of Europe-wide scope are more likely to exit early than firms in cartels of national scope by roughly 11%, but no other coefficients in any of the models are found to be significant. Among the industry variables, one coefficient is significant across four of the five specifications. Compared to the baseline of firms in cartels in the chemicals sector, firms in cartels in the metals sector are approximately

17% more likely to exit early.

3.2.5. Predicting Firms' Late Entry

Analysing the entry of firms to cartels which are already in progress is more problematic than analysing early-exiting firms. When a firm leaves a cartel they are making a decision to become a part of the fringe, even if they later exit the market altogether. On the other hand, a firm which is observed as joining a cartel may have been present in the market for an extended period of time or may have entered the market very recently. This entrant problems limits the extent to which the results can be seen to test the models of collusion discussed above: a new entrant which quickly joins a cartel may be a very keen or a reluctant cartelist.

Following the form of the equation predicting firm's early exit from cartels in equation (3.11), a firm's probability of entering a cartel depends on the sets of observable firm-specific characteristics, $\mathbf{x}_i$, observable cartel-specific characteristics, $\mathbf{z}_j^\dagger$, the respective coefficients corresponding to these sets of variables, $\beta^\dagger$ and $\gamma^\dagger$, and the error term $\epsilon_{ij}^\dagger$

$$\Pr(\text{Firm entry}_i) = \Pr(\beta^\dagger \mathbf{x}_i + \gamma^\dagger \mathbf{z}_j^\dagger + \epsilon_{ij}^\dagger > 0) \tag{3.12}$$

Assuming that the random disturbance is described by a symmetric normal distribution: $\epsilon_{ij}^\dagger \sim N[0,1]$, then the probit model estimating firms' probability of entering a cartel late may be written:

$$\Pr(\text{Firm entry}) = \int_{-\infty}^{\beta^\dagger \mathbf{x}_i + \gamma^\dagger \mathbf{z}_j^\dagger} \phi(L_i) dL_i = \Phi(\beta^\dagger \mathbf{x}_i + \gamma^\dagger \mathbf{z}_j^\dagger) \tag{3.13}$$

Where ϕ is the standard normal distribution and Φ is the cumulative density function of the standard normal distribution.

Model 1 is the most inclusive of variables and least of observations. The cartel coverage variable is the limiting one, leading to it being estimated with 328 observations. Model 2 excludes cartel coverage in order to expand the number of variables to 379. Model 3 is estimated with the full sample of 478 observations. Estimated coefficients and other information about the model specifications are given in Table 3.5.

As in the models predicting early exit, the number of observations used by each model

specification is limited by the availability of data for certain variables. The set of market and cartel structure variables used is the same as that used in the earlier models. The full leniency variable is not used because these models do not share the concern that an exit actually represents a leniency claim. Also the decision to join a cartel is made before the action of claiming leniency, so the idea that it may be used to predict entry is faulty. For the same reason, early exit is not used to predict late entry. Industry and geographical scope control variables are included in the models. The coefficients of the geographical scope variables are reported here in the main text because they produce interesting results. The coefficients estimated for the industry variables are given in Table B.3 in Appendix B.

Results and Marginal Effects

Table 3.6 gives the average marginal effects calculated from the estimated coefficients of the models. The method of calculating average marginal effects was discussed in section 3.2.4. The full table, with average marginal effects for the industry control variables, is given in Table B.4 in Appendix B.

The signs on the coefficients are the same as those in the models which predict early exit. Firms which have smaller share are more likely to enter late, as are firms which are members of larger cartels and cartels which cover less of their markets.

The geographical scope variables are consistently significant and the sizes of the marginal effect are large. For example, a firm in a Europe-wide cartel is as much as 91% more likely to have entered its cartel late than a firm in a cartel of national scope. That all of the regional scope variables are significant in some models indicates that the occurrence of late entry in cartels of national scope (the baseline for the other geographical scope variables) is particularly low. That late entry of firms to the cartel is less likely in cartels which cover a smaller geographical area can be ascribed to several reasons. Where firms are more dispersed, both geographically and culturally it may be more difficult for firms to communicate with each other during the process of formation, leading to some firms being excluded from the cartel on its formation but integrated later, once the cartel is more established. It is also likely that broader geographical areas will experience a greater quantity of new firms entering the market, which then go on to join the cartel.

Table 3.5.: Probit models predicting late entry for firms

	(Model 1)	(Model 2)	(Model 3)
Number of members	0.0476	0.0503*	0.134***
	(0.0330)	(0.0254)	(0.0193)
Cartel coverage	-1.991**		
	(0.726)		
Market share	-4.898***	-4.757***	
	(1.088)	(1.039)	
Global	0.594†	0.624*	0.547*
	(0.326)	(0.297)	(0.268)
Europe-wide	0.754**	0.783**	0.911***
	(0.274)	(0.272)	(0.244)
Regional	0.109	0.556†	0.627*
	(0.383)	(0.300)	(0.260)
Constant	0.806	-1.039**	-2.210***
	(0.789)	(0.384)	(0.308)
Observations	328	379	478
Psuedo R^2	0.232	0.247	0.183
log pseudolikelihood	-135.5	-159.8	-230.9
χ^2	47.46	61.51	89.85

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Industry controls not reported

Table 3.6.: Average marginal effects for probit models predicting late entry for firms

	(1)	(2)	(3)
Number of members	0.0112	0.0121*	
	(0.00769)	(0.00605)	
Cartel coverage	-0.467**		
	(0.166)		
Market share	-1.149***	-1.141***	
	(0.221)	(0.220)	
Global	0.131†	0.137*	0.0729
	(0.0704)	(0.0615)	(0.0522)
Europe-wide	0.173**	0.179**	0.228***
	(0.0571)	(0.0557)	(0.0520)
Regional	0.0204	0.119†	0.406***
	(0.0730)	(0.0652)	(0.0760)
National	0	0	0
	(.)	(.)	(.)
Observations	328	379	478

Marginal effects; Robust standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

3.2.6. Matrices of Ranks of Entry and Exit

Probit analysis is an appealing method because it is multivariate but it fails to take into account a potential information dimension of the data: the order of entry and exit. If a firm is the last to enter then it should be the first to exit (providing the characteristics of the firms do not change too much between entry and exit). Matrices are an intuitive way of representing and analysing the presence of this "Last In, First Out" behaviour.

Hart and Prais [1956] conduct a classic analysis of changes in business concentration over time in which they display the change in the sizes of a sample of firms between two years in a matrix. Firms are divided into size classes, each row of the matrix represents firms in a particular size class in the initial year of the study and each column the firms in a size class in the final year: Each element was the number of firms which started and finished in particular classes.

The inverse rank of entry is used. This means that the final firm to join a cartel is denoted '1', the penultimate firm to join '2', and so on. Exiters are ranked in order, so the first exiter of a cartel is denoted '1', the second '2' and so on. This means that a firm which is the last to join and then the first to leave its cartel will be ranked as '1' in both entry and exit. Table 3.7 shows the entry and exit ranks of the 44 firms in the sample which both entered their cartel late and exited their cartel early.

If firms do indeed behave as the marginal firms theory would predict then one would expect firms to be positioned on the diagonal in this matrix. Firms on the diagonal indicate follow last in-first out perfectly. Firms which are just off the diagonal may also be consistent with marginal firms models if the latent preference of the firms have shifted after their entry, meaning the marginal cartel member is a different firm by the time exit occurs. 14 out of 44 firms are on this diagonal (32%) and 25 are within one space of it (56%).

Matrices of Cartel Share

Similar matrices may be constructed ordering a firms' cartel share with its rank of entry and exit. If propensity to collude is associated with a firm's cartel share and the

Table 3.7.: Ranks of Entry and Exit for Fully Fluid Firms

Inverse Rank of	Rank of Exit						
Entry	1	2	3	4	5	6	Total
1	7	5	2	1			15
2	2	4	1	1		1	9
3	4	1		2			7
4	3	1	1	1			6
5	1	2			1	1	5
6	1						1
7							0
8							0
9	1						1
Total	19	13	4	5	1	2	44

marginal firms theory holds then the expectation is to find a tendency for firms to be on the diagonal in these matrices. If the balanced temptations view of cartels is more accurate then no tendency towards the diagonal should be noted. A grouping towards the upper right corner of the matrix should be expected and does not indicate anything of interest, because most cartels have fewer than six members.

The matrix of cartel share rank and exit rank is in figure 3.8 and the matrix of cartel share rank and entry rank is in figure 3.9. Each matrix displays only observations of firms which entered late or exited early, but the ranks of cartel share were calculated including all firms.

In the exit rank and cartel share rank matrix 18 firms fall directly on the diagonal (28% of all early-exiting firms) and 38 firms are within one space of the diagonal (59%). In the entry rank and cartel share rank matrix 27 firms are on the diagonal (36% of all late-entering firms) and 47 are within one space of the diagonal (63%). This indicates that there is a tendency for firms to leave and join cartels in accordance with their relative sizes. The 18 firms which were the smallest firms in their cartels and which entered late are especially notable.

Table 3.8.: Rank of Exit and Cartel share for Early Exiters

Rank of	Rank of Inverse Market Share										
Exit	1	2	3	4	5	6	7	8	9	10	Total
1	12	2	9	7	2		3				35
2	5	3	2			1	1				12
3	1			3					1		5
4	2		2	2							6
5				2							2
6		1						1			2
7								1			1
8								1			1
Total	20	6	13	14	2	1	4	2	1	1	64

Table 3.9.: Rank of Entry and Cartel Share for Late Entrants

Inverse Rank of	Inverse Rank of Market Share															
Entry	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	18	4	2	3	1			1							1		30
2	4	4	2		1			1									12
3	1	1	2	3	1		1										9
4	1		3	1		1		1									7
5	2			2		1		1									6
6	1							1	1								3
7	1						1										2
8					1												1
9				1													1
10							1			1							2
11																	0
12																1	1
13											1						1
Total	28	9	9	10	4	2	2	4	2	1	1	0	1	0	1	1	75

3.3. Conclusions

The analysis supports the conjecture that the last firm to join a cartel is likely to be the first to leave. This suggests that a firm which joined the cartel (and therefore was evidently the marginal outsider) became the marginal insider and was the first to leave. The finding is consistent with the theory of marginal firms driving entry and exit and suggests that cartel membership decisions are made by firms aiming to maximise their

profits through their membership decision.

The findings are consistent with the theory that membership changes are explained by marginal firms. The relationship is not perfect because firms' preferences and circumstances may change during the time the firm is in the cartel, meaning it does not stay the marginal firm. This means that models such as Bos and Harrington [2010] which utilise the assumption that entry and exit will only be by marginal firms are justified. That firms are willing and able to leave and join cartels easily is also consistent with the view of stability endorsed by D'Aspremont et al. [1983]; that firms will choose their cartel membership status based purely upon maximisation of their own profits, rather than membership being dictated by cartel institutions.

3.3.1. Policy Implications

This chapter has not analysed directly any cartel policies. Still, firms which leave and join cartels are encountered by competition authorities which sanction cartels and their treatment has apparently not received any academic discussion. That cartel membership decisions are determined by economic considerations indicates that the way in which sanctions are designed to deter and detect cartels should be designed with marginal firms and outsider firms in mind.

The European Union fines firms which have been in cartels on the basis of the duration of their participation in the cartel[3], multiplied by the estimated cartel overcharge. This means that firms which spent a part of their cartel's duration as outsiders are not fined on the basis of the excess profits they make, even when they are provably aware of the cartel's existence due to their past membership. The fining guidelines do specifically state that a firm having participated in an undertaking for a shorter period of time than the other cartel firms does not constitute a mitigating factor leading to a percentage reduction in the total fine.

A marginal firm which is considering joining a cartel may take into account the fact they may later leave the cartel to become an outsider once more, safe in the knowledge that it will only face the possible confiscation of the excess profits gaining during

[3]The most recent version of the European Commission's methods for setting fines in competition cases was published in 2006. Official Journal C 210, 1.09.2006, p. 2-5. http://ec.europa.eu/competition/antitrust/legislation/fines.html

its participation in the cartel. This reduction in deterrence could lead to a greater probability of participation in cartels by marginal firms, increasing the overall harm to consumers from collusion. An outsider which is aware of the cartel's existence will have less incentive to report the cartel's existence to the authorities because it will gain less from the reduction in fines from leniency. On the other hand, a firm which is a cartel member could be tempted to leave the cartel by the possibility of gains which will not eventually be appropriated by the competition authority. Whether this increased incentive to leave cartels is detrimental to their stability, and therefore the size of their total harm to consumer welfare, is the subject of the next chapter in this thesis.

Chapter 4.

The Effect of Membership Variability on Cartel Survival

Data on the duration of cartels is widely used in analysis of the success and survivability of cartels. Rarely, however, is the duration of individual firms' participation in cartels examined empirically. Firms frequently join cartels after their founding and leave cartels without the cartel breaking down. The main aim of this study is to establish whether firms joining and leaving a cartel is a signal of that cartel's strength or weakness. A high degree of variability in a cartel's membership could be an indication of an institutionally weak or a structurally strong cartel. Conversely, a cartel whose membership is unchanging over time ('static') could be one with a well-developed agreement which discourages its members from deviating or could be a fragile cartel which would not survive any exit nor is attractive enough to outsiders to prompt entry.

There are two aspects of this theory I wish to test: the idea that entry and exit to and from cartels is driven by marginal firms and whether firms leaving and joining a cartel signals that cartel's strength or weakness.

Providing they can maintain a level of overcharge, cartels will aim to be as stable as possible in order to maximise joint profits. The question then is whether firms with changing membership are more or less likely to break down in each period. If cartels with static memberships are more robust then this indicates that institutions which prevent members from defecting from the cartel and which prevent new firms from entering the market are effective in maintaining collusion. If, however, cartels with changing memberships are more stable then this indicates that firms in markets containing strong cartels are free to choose their membership status on the basis of expected profit maximisation.

The previous chapter of this thesis examined the individual choice of a firm to move from the fringe into a cartel or from the cartel to the fringe. The findings indicated that the firms which choose to change their membership status are constrained by the incentive compatibility of their decision and motivated by the economic concerns of the firms, rather than the individual preferences of the managers and salespeople involved in the cartel. This chapter examines the effect this behaviour among firms has on the cartels these firms are members of.

The sample of cartels examined is those prosecuted and fined by the Director General of Competition of the European Commission between 2001 and 2011, comprising 91 cartels and 482 firms (double-counting recidivists) in total. Descriptive statistics and other details of this dataset may be found in Chapter 2.

I use Cox hazard models with and without time-varying coefficients along with three different metrics of cartels' membership variability. This analysis will discover whether firms leaving and joining a cartel are associated with a longer duration. I find that cartels with varying memberships tend to last longer than cartels with static membership. Controlling for time-related biases, cartels with static memberships are roughly 25% more likely to break down at any given time than cartels with varying memberships.

These findings indicate that a structurally robust cartel is recognised as such by firms, who will choose to switch between the cartel and the fringe when it is profitable for them to do so. This indicates that a cartel with institutions which aim to prevent the movement of member firms into the fringe may be less stable than they may appear.

I discuss the previous literature on cartel durations and cartel survival in section 4.1. I outline what predictions theory may make for the link between membership variability and cartel survival in section 4.2. Analysis using survival models is performed in section 4.3. I discuss the results in section 4.4 and conclude in section 4.5.

4.1. Duration in Cartel Literature

Duration is widely used in the empirical literature on cartels. It is used most often as a measure of cartel success. Cartel success may more accurately be measured by the

total amount of abnormal profits gathered by the cartel over its duration. The ideal way of measuring this is duration multiplied by average cartel overcharge. However information on cartel overcharge is frequently unavailable and may change throughout the cartel period. Duration is a useful proxy for cartel success because it is consistently observed for each cartel in the sample whereas overcharge is not.

Connor and Bolotova [2006] gather the estimates of overcharge made by previous studies of individual cartels. These studies range in type from economists' reports to courts for cartel damages cases, to government publications, to academic publications. The methods they use are extremely diverse and some were published over one hundred years ago. They find that cartel overcharge is significantly higher in longer-lasting cartels. The intuition that firms will be more inclined to maintain a cartel which is more profitable is clear. This kind of mechanism implies that the economic profits of the member firms are an important determinant of the duration of a cartel. International cartels also have long durations. This may be because of this increased difficultly of prosecuting a conspiracy spanning multiple jurisdictions, the large resources of multinational corporations allowing for high evasion effort, or simply the greater coverage of the market implied by a global cartel. Of the sample in this study 71 out of 91 cartels are multinational. If this represents a bias in the sample towards international cartels, the cartels studied could be of longer duration and higher overcharge than an average cartel.

4.1.1. Survival Analysis of Duration

De [2010a], Levenstein and Suslow [2011] and Zimmerman and Connor [2005] are just three of the many papers which use survival analysis to model cartel duration. At their most basic, survival estimates provide an overview of the distribution of duration data. Models may also be built allowing the determinants of duration to be estimated. Kiefer [1988] discusses broadly the use of hazard functions in analysing economic duration data and De [2010a] provides a thorough summary of the literature on cartel duration and its analysis.

The Cox proportional hazard model is the most common choice in cartel duration data. This is a semi-parametric technique allowing the estimation of hazard ratios for variables which estimate the effect that the explanatory variables of the model have

on the risk of a cartel breaking down in each period. The model is explained in more detail in section 4.3.3 on page 86.

De [2010a] and Zimmerman and Connor [2005] use a large number of explanatory variables about the structure of the cartel's market and the wider economic situation at the time of the cartel. They both find that cartels are more likely to be successful in more concentrated markets with fewer and more symmetrical firms and are likely to break down in the presence of external shocks. De [2010a] also finds that several kinds of cartel institution are associated with increased survival: market sharing agreements and regular price wars between members aided the survival of cartels; trade association involvement and compensation mechanisms had no effect; and market leadership and price fixing agreements were detrimental to survival.

4.1.2. Limitations of Duration Data

Duration as a Measure of Cartel Success

Frequently cartel duration is used as a measure of cartel success. Cartel success may be more accurately defined as the total excess profits made by the cartels' members, which may be calculated by multiplying the cartel's duration by the mean amount by which it raised prices above the counterfactual, competitive, level. Given that duration is an important component of cartel profitability, and that a cartel's members will be more inclined to maintain a cartel that is profitable, it is a relatively strong proxy for cartel success. However, a number of problems should be noted.

In addition to duration being an incomplete measure of cartel success in the absence of information on overcharge, duration and overcharge may be related to each other in ways which complicate the link between duration and success. Levenstein and Suslow [2006b] point out that cartels which successfully raise prices and profits in their industries may attract new entrants to the market. This may destabilise the cartel, shortening its duration despite its short-term success. There is a similar risk that high overcharge may attract the attention of competition authorities, leading to the breakdown of the cartel through detection and punishment. Cartels may also choose a low overcharge in order to make cheating on the agreement through undercutting less profitable, and so the cartel more stable. In these cases, there will be a negative relationship between overcharge and duration, though not necessarily between duration and success. Cartels

will, to the best of their abilities, balance overcharge with the risk of breakdown in order to maximise expected total profits.

Quality of Duration Data

In addition to these theoretical issues with the use of cartel data, there are practical issues which arise while using data on cartel duration. A key problem is that the duration of cartels may be longer than is measured by the antitrust authority due to a lack of evidence of communication between firms in the cartels earliest days. Other researchers using cartel duration data also encountered this problem. Their discussion of this problem is detailed in 2.1.1. In light of this fact, it should be noted that the cartel durations used in this chapter may represent lower bounds on duration, rather than true durations. No statistical technique exists which allows this problem to be solved, since it represents uncertainty around the true durations.

However, the institutional background in which this data was collected provides a robustness check. Under the EC's cartel leniency system, firms which provide information extending the provable duration of the cartel are eligible for a reduction in fines between 50% and 70%, in addition to full immunity for the time period which the firm extended the duration of the cartel for. Also, firms receiving full immunity from the EC for revealing the existence of a cartel must cooperate fully with the investigation of the cartel in order to receive the reduction in fines. Satisfying the suspicions of the investigators of the competition authority while maintaining cooperate to their satisfaction will make concealing periods of collusion more difficult and less likely, especially given that the leniency claimant firm has immunity from fines anyway.

4.2. The Theory of Institutional Strength and of Marginal Firms

Spar [1994] analyses international cartels with the methodology of political science. She outlines the Realist and Institutionalist views of cooperation, which were developed to examine relations between nations. Spar claims that the theories may usefully be applied to cartels since they represent scenarios where large organisations communicate without a binding legal system, analogous to the situation of nations. The story of the

Realist view is best summarised as a one-shot Nash Equilibrium game and the story of the Institutionalist view as an iterated prisoners' dilemma.

The Realist view of cooperation holds that individuals follow their immediate incentives when deciding whether to cooperate. If an agreement provides benefits to all of its members then it will be stable. If a member decides it would be better off outside of the agreement they will leave, and if a non-member prefers to be inside of the agreement they will join. According to the Realist view the main way (according to some theorists, such as Keohane and Nye [1977], the only way) that cooperation can arise is if a hegemon, or ringleader, wishes cooperation to take place. In this case, the ringleader will take on any fixed costs associated with cooperation in addition to enforcing the agreement.

The Institutionalist view believes defection is the main threat to cooperation. Factors which facilitate cooperation are therefore the ability of firms to commit credibly to actions, guaranteed repeated interaction and regular punishment for defectors. The best way to achieve these is through an institution.

Spar argues that the Realist account clearly cannot account for the many instances of cooperation where there is not a powerful ringleader, though it is a simple way of explaining those which do. Conversely, the Institutionalist view cannot explain the lack of cooperation in situations where there are opportunities for large profits but cartels failed, such as the markets for uranium and silver despite cartels' great success in the structurally similar diamond and gold markets. Institutionalism is therefore useless if it cannot predict where cooperation will and will not arise. Spar analyses four international cartels and concludes that the internal organisation of the firms involved is most important, with highly-centralised, vertically-integrated firms able to control themselves better and therefore make more credible commitments.

The research question which I test does not quite test the Realist and Institutionalist views. Only 20 out of 91 cartels in the sample has an identified ringleaders so the strict Realist view is immediately discredited. Rather, I hope to discover whether a changing membership signals weakness or strength in a cartel. The most important concepts underlying this are those of cartel stability and of insider, outsider and marginal firms. These models seem to indicate that a firm's recent entry into a cartel makes it the most likely firm to leave the cartel next and that larger cartels are likely to have more entry and exit.

4.2.1. Marginal Firms and Cartel Stability

Marginal firms models of cartel membership, discussed previously in this thesis, hold that firms' cartel membership decisions are based on individual economic incentives. In marginal firms models, firms are willing to change their membership if the alternative membership choice is more profitable and the remaining firms in the cartel are willing to maintain the cartel. A firm will not choose to leave a cartel if they know that they will destroy the cartel by making it unprofitable for the remaining firms and a cartel will not choose to punish a departing firm by destroying the cartel in retaliation. Such means of retaliation are the kind of institution which the institutionalist view of cooperation holds are necessary for successful cooperation.

A cartel is frequently able to support a competitive fringe of outsider firms. The reasons why a firm may choose to leave or join a cartel include changes in market demand, firm costs or preferences, entry or exit of other firms from the market and changes in the internal organisation of the cartel. Changes in the structural characteristics of the market which aid collusion will result in the exit of firms from a cartel to the fringe or the entry into the market of new firms. The entry into a cartel of a fringe member may indicate weakness. Entry or exit may also indicate a failure in a cartel's strategic entry deterrence or enforcement mechanisms.

Organisational tools and institutions used by cartels aim to solve problems such as secret cheating and of allocation. They may also attempt to enforce stability in a cartel's membership in the hope of preventing the loss of cartel production to the competitive fringe and the corresponding loss in cartel profits.

4.2.2. Institutions and Variability of Membership

Osborne [1976] suggests that the deterrence of external production is one of the central problems which cartels must solve. This involves the punishment of any firm which chooses to leave the cartel in favour of being an outsider. Harrington [1989b] finds that accommodating new entrants to a market into the cartel is detrimental to the success of that cartel since it encourages further entry to the market, leading to an over-abundance of firms and diminishing profits for the original cartel members. Both of these accounts

are arguments that a cartel with strong institutions and the means to punish outsiders will have a membership which is unchanging over time.

This is contrary to marginal firms-based theories which suggest that firms decide their cartel membership status and presence in the market based upon their own incentives. Entry and exit to and from a cartel may signal that cartel's structural strength. This is the other question I hope to answer. If a cartel's membership does not vary over time then this could signal either a cartel with strong institutions or it could signal a cartel which is unable to withstand entry and exit without collapsing. On the other hand, a cartel whose membership is highly changeable could signal weak institutions which are unable to deter entry into the market or its members defecting to the fringe. In section 4.3 on page 82 the effect of variability of cartel membership on cartel duration is estimated.

4.3. Survival Analysis

In the following sections I measure how the survival of cartels is affected by the behaviour of their members. I will describe some general features about how likely the cartels in my sample are to break down over time before specifying models with various measures of cartel membership stability. The models specified are Cox hazard models, two with time-varying coefficients and one proportional hazard model.

The more simple survival models give an overview of the nature of cartel failure over time. The more complex models directly test the research question of this chapter by testing the effect of firm entry and exit to and from cartels on the cartels' risk of breakdown. A variety of models are used to address the research question in order to ensure the results are robust to possible time-based biases in the data.

4.3.1. Descriptive Survival Statistics

Kaplan-Meier and Nelson-Aalen plots allow the proportion of cartels which have broken down by any given point in time to be seen. They also indicate whether the rate of breakdown tends to increase or decrease with time. Simple hazard models allow these trends over time to be quantified.

Of the total 482 firms in the data, both firms in the French Beer cartel have durations of zero meaning they are not included in the survival models. The total number of days which firms spent in cartels (the sum of all firm durations) is 1,624,437. The sample consists entirely of cartels which have been detected so all 480 observations ended in failure.

Where each cartel is taken as a single observation the French Beer cartel is also not included in the analysis meaning 90 cartels are included. The total number of cartel-days is 269,158.

Survival and Hazard Functions

The two main kinds of function in survival analysis are survival functions and hazard functions. Let duration be a random variable, T, with distribution function $F(t) = Pr(T \leq t)$ and so density function $f(t) = dF(t)/dt$. A survival function, $S(t)$ aims to predict the likelihood that a random duration, T, will exceed a given value, t; $S(t) = Pr(T \geq t)$. Note that $S(t) = 1 - F(t)$.

Figure 4.1 shows the Kaplan-Meier survival curve for the sample of cartels. This shows the proportion of the sample (on the vertical axis) which survived to any given duration (on the horizontal axis). The median duration of the sample of cartels is six years: this is the point at which the curve crosses the 0.5 point, indicating that half of the cartels in the sample have broken down by this point.

A hazard function, $h(t)$, is the proportion of cartels which end at time t, given that they have lasted until time $t - 1$. $h(t) = f(t)/S(t)$. A cumulative hazard function, $H(t)$, is the total hazard which a subject has experienced by a given point in time. The cumulative hazard function, $H(t)$, is the integral of the hazard function: $H(t) = \int_0^t h_t dt$. The cumulative hazard function may be interpreted as showing the expected number of failures for a single cartel at each point in time. The Nelson-Aalen curve in figure 4.2 shows a cumulative hazard of one at a duration of eight years — the mean duration of a cartel in the sample. Failure is not a repeated event so the rising expected number of failures reflects the diminishing odds of a cartel surviving to longer durations.

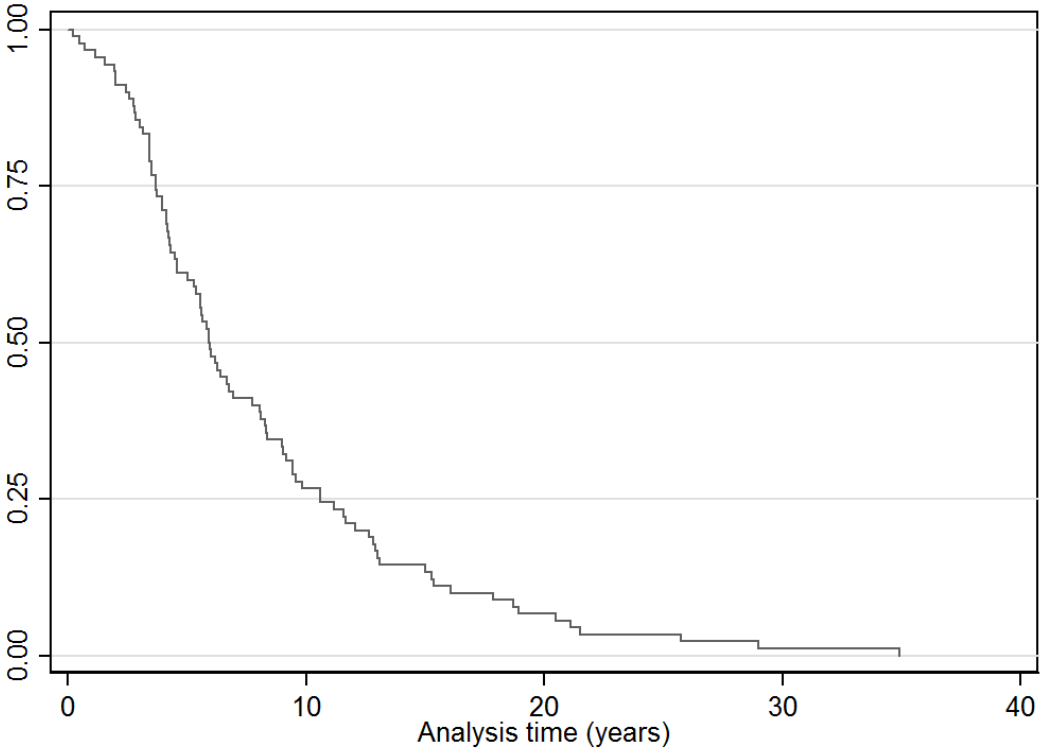

Figure 4.1.: Kaplan-Meier survival curve for all cartels

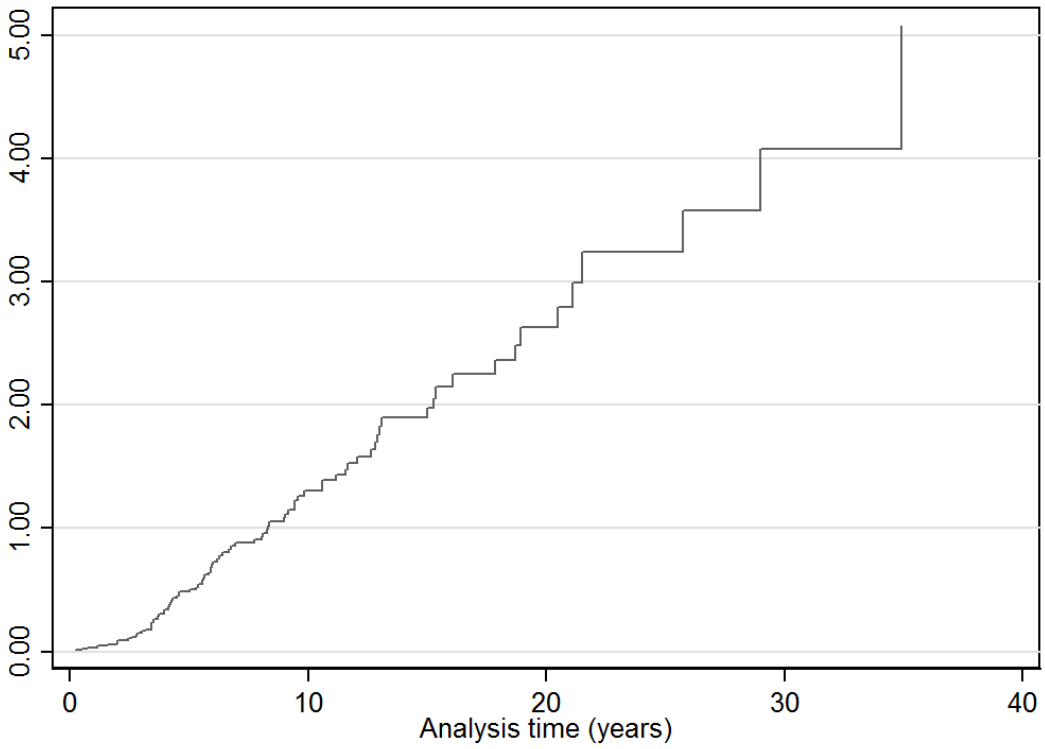

Figure 4.2.: Nelson-Aalen cumulative hazard curve for all cartels

4.3.2. Hazard Models

The nature of the increasing hazard of cartels as their duration increases may be measured by estimated a parametric model of hazard. The Weibull model is ideal for modelling survival where hazard may increase or decrease with time.

The Weibull model assumes hazard to be of the form

$$h(t) = \lambda^p t^{p-1}$$

There are two parameters to be estimated here: the 'scale parameter' λ and the 'shape parameter' p. The relationship between hazard and time is captured by p. When $p > 1$ hazard is increasing with time, when $p = 1$ hazard is constant with time and when $p < 1$ hazard decreases with time.

Estimating the above model with the cartel data gives a value for λ of 0.0517 and a value for p of 1.355. Both estimates are highly significant (with p-values of less than 0.001). λ indicates the baseline probability of breakdown each year for a cartel, independent of the time-varying component of hazard. The estimated Weibull model may be written:

$$h(t) = 0.0517^{1.355} t^{0.355}$$

Since $p > 1$ the indication of the cumulative hazard graph that hazard increases with time is confirmed. To be precise, a cartel in its first year (so $t - 1$) has a predicted hazard of 0.018, meaning it has a 1.8% probability of breaking down in the first period. This probability rises to 2.3% in its second year and 2.6% in its second. A cartel in its 30th year (the longest duration observed in the sample is 34 years) has a 6% chance of breaking down in that year. This increasing hazard produces a convex cumulative hazard curve, as is seen in figure 4.2.

4.3.3. Cox Hazard Models

The Cox [1972] proportional hazard model is the most common choice of model in studies using cartel duration data. A proportional hazard model allows explanatory variables with estimable coefficients to be added to the model alongside a 'baseline' hazard. The baseline hazard is unaffected by the explanatory variable in a proportional

hazard model. The advantage of the Cox model is that it allows the estimation of the coefficients on the explanatory variables without specifying a a baseline hazard function.

A hazard function for an individual, i, in the Cox model takes the form

$$h_i(t, x) = \lambda_0(t)e^{\mathbf{x_i}\beta}$$

where $\lambda_0(t)$ is the baseline hazard function which is common to all individuals and is between 0 and 1 for all values of t, $\mathbf{x_i}$ a vector of explanatory variables specific to the i which may vary across time or individuals, and β a vector a coefficients describing the effect of $\mathbf{x_i}$ on the baseline hazard function. β is also the same for every individual.

A convenient property of the Cox model (and the reason it is known as a 'proportional hazard model') is that two individuals with differences in x_i may be compared directly. Taking two subjects named 1 and 2:

$$\frac{\lambda_0(t)e^{\mathbf{x_1}\beta}}{\lambda_0(t)e^{\mathbf{x_2}\beta}} = \frac{e^{\mathbf{x_1}\beta}}{e^{\mathbf{x_2}\beta}} = e^{(\mathbf{x_1}-\mathbf{x_2})\beta}$$

This is known as the 'hazard ratio' and it is a constant which does not change with t.

The baseline hazard function may take any form and is not non-parametric. Covariates are assumed to affect the baseline hazard proportionally (as opposed to additively, for example). The Cox model is there semi-parametric.

Parametric survival models such as the Weibull, described above, may also incorporate covariates. The baseline hazard is estimated as parametric and the covariates allowed to shift this baseline hazard. The proportional-hazards Weibull model is

$$h_i(t, x) = \lambda^p pt^{p-1}e^{\mathbf{x_i}\beta}$$

Testing the Proportional Hazards Assumption

The Proportional Hazards Cox model is by far the most common model used in survival analysis, and the literature on cartel duration is no exception to this. De [2010b],

Levenstein and Suslow [2006a], Zimmerman and Connor [2005], Suslow [2005] and Dick [1996] all use Cox models in order to reach their conclusions about cartel duration. Brenner [2009] uses a proportional hazards version of the Weibull model.

However, this assumption of proportional hazards may be violated. If this is the case then the simple Cox model is inappropriate and an alternative model must be used. The simplest indicator, for discrete covariates, is to draw the Kaplan-Meier curves for each discrete group of observations on the same axis and check that the curves do not cross. If the curves cross then the proportional effect of the covariate on hazard is not constant with time.

If the change in hazard caused by a covariate is believed to change with time then a Cox model may be estimated with time-varying coefficients. Hastie and Tibshirani [1993] outline Cox models where the explanatory variables are interacted with other variables, including time. Both time-varying and time-invariant coefficients may be present in the same model. The Cox model with time-varying coefficients may be written

$$h_i(t) = \lambda_0(t)e^{\mathbf{x_i}\beta + g(t)\mathbf{z_i}\gamma}$$

where $g(t)$ is a function of time and γ the vector of coefficients for the time-varying explanatory variables, $\mathbf{z_i}$, which may or may not overlap with $\mathbf{x_i}$, the vector of variables interacted with time.

A Cox model may be estimated including a time-varying and non-time-varying version of a covariate. If the time-varying version is found to be insignificant then the assumption of proportional hazards is upheld. This method of assessing the assumption may be used with both continuous and discrete variables.

4.3.4. Static Cartels

The simplest way of examining the effects of the variability of a cartel's membership on its duration is to distinguish between those cartels whose membership was totally static and those which experienced any late entry or early exit at all.

Drawing the Kaplan Meier curves for static and varying-membership cartels on the

Table 4.1.: Cox proportional hazard models predicting cartel breakdown hazard by cartel staticness, cartel completeness, and firm lateness and earliness of entry and exit

	Specification (model) number					
	1		2		3	
Variable	Haz. Ratio	Coeff.	Haz. Ratio	Coeff.	Haz. Ratio	Coeff.
Cartel Static	1.821**	0.6** (0.217)	-	-	-	-
Cartel Completeness	-	-	13.28**	2.586** (0.889)	-	-
Firm Lateness	-	-	-	-	0.833***	-0.182*** (0.022)
Firm Earliness	-	-	-	-	0.661*	-0.413* (0.168)
Firm Lateness*t	-	-	-	-	1.005***	0.0052*** (0.0012)
Firm Earliness*t	-	-	-	-	1.031*	0.0306* (0.0135)
Obs	90		90		476	
Days at risk	266943		269158		264890	
Log (pseudo)likelihood	-314.62		313.33		-2442.2	
LR/Wald χ^2	7.36		9.95		142.82	

Robust standard errors in brackets
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

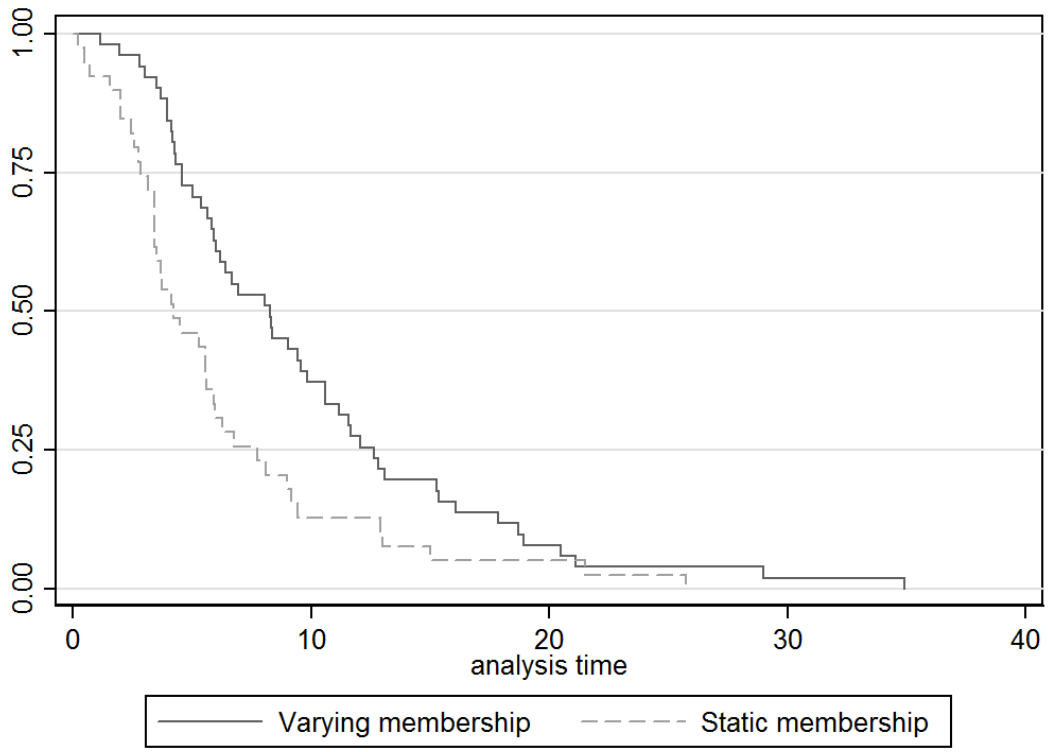

Figure 4.3.: Kaplan-Meier survival curves for static and varying cartels

same axis, as in figure 4.3, finds that the two curves touch each other at high duration, with the static cartels curve briefly peaking over the variable cartels curve. This indicates that a greater proportion of static cartels than variable cartels were still active at that point in their duration. If this had persisted for a longer period of time, then the assumption that the effect of membership stasis on hazard was proportional could not be sustained. Since it only applies to a very small number of cartels (those still active at high duration) this is explainable due to random variation rather than the assumptions about functional form being violated. This quick test of the proportional hazards assumption is therefore inconclusive. There are several tests it is possible to perform once a model has been estimated.

The model may be stated

$$h_i(t) = \lambda_0(t)e^{\text{cartelstatic}_i\beta}$$

This model is estimated using each cartel as a single observation. Since one cartel has zero duration and cannot be included in the survival model, this means there are a total of 90 observations.

The estimated coefficients, hazard ratios and summary statistics of the model are in the first column of Table 4.1 on page 89. Standard errors are robust to heteroscedasticity. The estimated model is

$$h_i(t) = \lambda_0(t)e^{\text{cartelstatic}_i 0.59}$$

The hazard ratio between static and variable cartels implied by this model is 1.82. This indicates that a static cartel is 82% more likely to break down in each time period than a variable cartel. Testing the proportional hazards assumption post-estimation, by analysis of the Schoenfeld residuals, finds that the hypothesis of proportional hazards may not be rejected. Specifying the model with a time-varying version of the *cartelstatic* version finds it to be insignificant, further suggesting that the proportional-hazards Cox model is suitable.

A possible problem with the use of cartel stasis as a basis for a model of survival is that of causation. The model aims to show that the entry and exit of firms experienced by cartels is associated with their durations. However, longer-lasting cartels are, ceteris parabus, likely to have experienced more entry and exit than cartels with shorter durations: a cartel with a short duration may have experienced entry and exit had it continued longer. A cartel which survived a long time with a relatively low propensity for membership instability may have still experienced instability due to the large amount of time in which entry or exit could have occurred. A measure of membership instability which accounts for the duration of the cartel, and more directly measures membership instability over time, is therefore desirable.

4.3.5. Cartel Completeness

An alternative way of quantifying incomplete membership is to calculate the proportion a cartel's duration each firm was a member for, a figure between 0 and 1, and to average these figures for all the firms in a cartel. This variable is known as *cartel completeness*. Descriptive statistics of firm and cartel completeness in the sample are presented in Table 4.2.

Table 4.2.: Completeness of cartels and firms

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Firm completeness	476	0.873	1	0.235	0.128	1
Cartel completeness	90	0.916	0.977	0.119	0.535	1

Rather than focussing on the fact of whether entry or exit has happened in a cartel, as a measure such as cartel staticness does, this measure is concerned with the proportion of time a cartel's member firms spent as members. This more directly reflects the degree of membership instability which a cartel has experienced over time. A firm joining the cartel shortly after the cartel's founding, or leaving shortly before the cartel's breakdown, will not affect the cartel's completeness statistic by a significant amount. A cartel which experiences a large amount of entry and exit over the course of its duration will have lower completeness than one with a smaller amount of entry and exit.

It is not possible to assess the proportional hazards assumption by examining Kaplan-Meier curves since the completeness variable is continuous. Estimation and post-estimation-based techniques must be used. Once the Cox model has been estimated the method of Schoenfeld [1982] may be applied, where partial residuals from the model that may be plotted against model time are taken. If the assumption of proportional hazards is appropriate, these residuals will have zero slope when plotted against time.

The model may be stated

$$h_i(t) = \lambda_0(t)e^{\text{cartelcompleteness}_i\beta}$$

The estimated coefficients, hazard ratios and summary statistics of this model are in the second column in Table 4.1 on page 89. Standard errors are robust to heteroscedasticity. Testing the slope of the Schoenfeld residuals it is found that the null hypothesis of zero slope on time may not be rejected, indicating that the assumption of proportional hazards is appropriate. The estimated model is

$$h_i(t) = \lambda_0(t)e^{\text{cartelcompleteness}_i 2.586}$$

Interpretation of the hazard ratio, 13.28, is here slightly more complicated since *cartelcomplete* varies between 0 and 1 (though the smallest value observed is 0.535). The

quoted hazard ratio is the difference in risk between a cartel with *cartelcomplete* 0 and one with 1. This comparison is not meaningful because a cartel with a completeness of zero is impossible. A comparison between a cartel with the mean value of completeness of 0.913 and a complete cartel with value 1 (of which there are 38) is informative. The ratio of hazards between a cartel with a completeness of 0.913 and a complete cartel is

$$\frac{e^{1\times 2.586}}{e^{0.913\times 2.586}} = 1.252$$

The model therefore indicates that a complete cartel is 25% more likely to break down in each time period than a cartel with mean completeness.

It is possible to compare the results of this model with the above, cartel staticness-based, model in order to examine the effect of using cartel completeness as a variable in order to control for the time bias. The mean completeness of a cartel with non-static membership is 0.852. The hazard ratio between a mean non-static cartel and a static cartel is 1.47, indicating a static cartel is 47% more likely to break down at any given time than a cartel with varying membership. This is substantial but considerably less than the estimate of 82% from the staticness-based model.

4.3.6. Firm Late Entry and Early Exit

Cartel completeness is a detailed measure of membership stability but it is a cartel-level variable. A model which takes into account the entry and exit of individual firms could be a very powerful means of testing the effect of entry and exit on duration. Descriptive statistics and histograms of late entry and early exit are presented in Sections 2.4 and 2.5.

Figure 4.4 shows the Kaplan-Meier survival curve by cartel duration for firms which neither entered late nor exited early, firms which entered late and did not exit early, firms which did not enter late and exited early, and firms which both entered late and exited early. It must be noted that these curves indicate the survival of the cartels which these firms were members of, not the firms themselves. It may be seen that firms which enter late and exit early tend to be members of cartels which last for longer periods of time.

However, the Kaplan-Meier curves for firms which entered late, exited early and both late entry and early exit cross over each other in places. This means that the assumption of proportional hazards which underlies the Cox model is violated. The ratios of the

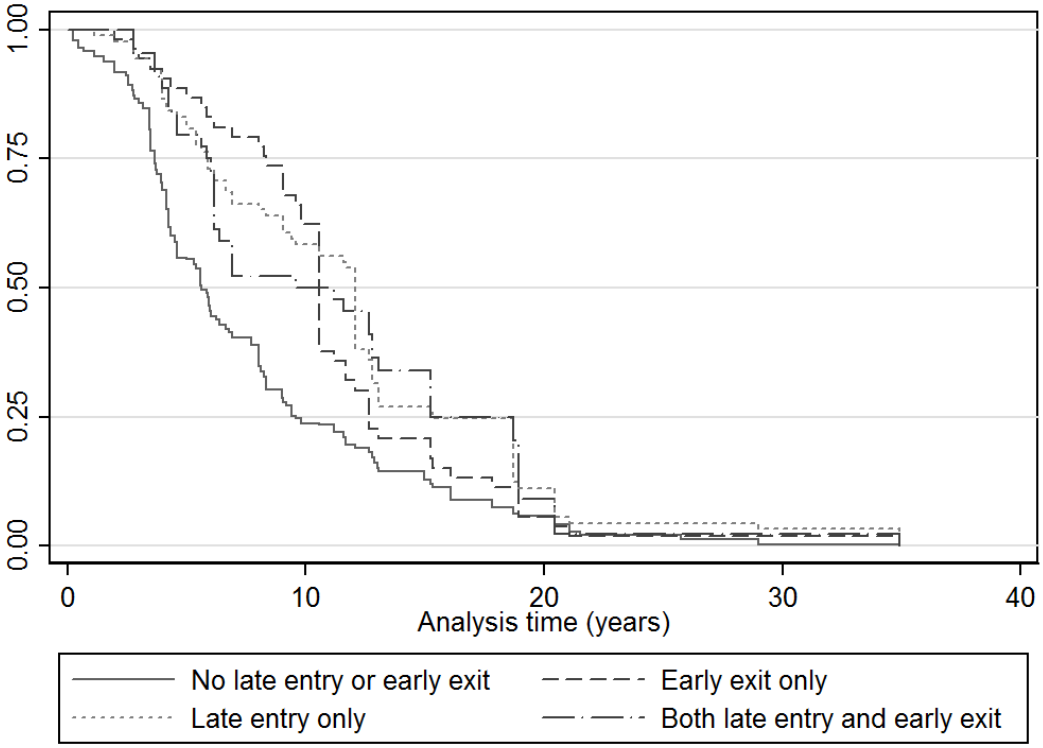

Figure 4.4.: Kaplan-Meier Survival Curve, by late entry and early exit

risks of the different groups are not constant over different durations.

A solution to this problem is to retain the same basic model as before but to discard the assumption of proportonal hazards in favour of one of time-varying coefficients. Using *firmlateness*, the number of days after its founding a firm joined its cartel, and *firmearliness*, the number of days before the end of a cartel. The model is:

$$h_i(t) = \lambda_0(t)e^{firmlateness_i\beta_1 + firmearliness_i\beta_2 + firmlateness_i t\gamma_1 + firmearliness_i t\gamma_2}$$

β_1 and β_2 act just as the β coefficients do in the previous models. Firm lateness and earliness are also interacted with the time period which the cartel is in when the hazard is being assessed. The coefficients for these time-varying explanatory variables are enumerated γ_1 and γ_2. Note that a firm which has static membership has hazard equal to the baseline hazard since both the β and the γ coefficients are multiplied by zero.

Like the completeness measure, this approach is not dependent on the occurrence of the act of entry or exit by firms but the amount of time which each firm spent as a member or non-member. The model assumes that the degree of lateness or earliness of entry or exit is what determines the hazard of breakdown. By being estimated at the level of the firm rather than the cartel, though the hazard is one of cartel breakdown, the model avoids the biases which arise at the level of the cartel. These biases include the possibility of large and longer cartels experiencing a greater number of entry and exit events.

Fisher and Lin [1999] provide guidance on understanding the results of a Cox model estimated with time-varying coefficients. Serious problems with such models occur when a complex interaction between the time-varying covariate and time is specified, where data is censored in a way which is caused by the time-varying covariates or where the time-varying covariate is a direct indicator of the hazard, making the model a self-fulfilling prophecy. The estimated model does not attempt to fit a very complex interaction between time and a covariate and the time-varying covariates, reducing the risk of overfitting the model. The cartels data is not censored so the second concern is not a problem. For the third concern, it is possible that a firm which exits early does so directly because of a leniency claim. This possibility was discussed previously and no major concern was found, partly because the majority of leniency claims are made after the death of a cartel. The final concern is in the use of the model. It is not possible to

draw simple expected-time-to-breakdown curves for individual cartels or firms due to the lack of fixed values for covariates. This does not present a barrier to understanding the results of the model as they relate to the entire sample.

Particular care must be taken since the model attempts to predict the hazard of the cartel each firm was a member of, though the covariates themselves relate to the individual firms.

Estimation of this model is weighted by the number of firms in each cartel so each cartel has equal weight in the calculation of the coefficients. Cartels vary in size between 2 and 17 members so there is a large risk that the results may be distorted by the over representation of larger cartels if this is not done. The standard errors reported are corrected for clusters since the probabilities of cartel survival between firms in the same cartel are clearly related and so the errors correlated. Standard errors are also robust to heteroscedasticity.

Care must be taken in interpreting the results of the model in that the covariates of the model are not confused with the analysis time. This puts limits on the interpretation of the model. It is impossible to consider the hazard of the cartel of a firm which enters after 5 years in that cartel's 2nd year, for example, even though it is possible to put those numbers into the estimated model.

While the data on cartel breakdown and firm entry and exit are daily and the model is estimated with this daily data, the coefficients are scaled to make them yearly. This does not affect the results of the model or their significance but it aids interpretation by stopping the estimated coefficients from being extremely small.

The results of this model are given the third column of Table 4.1 on page 89. The estimated model is

$$h_i(t) = \lambda_0(t)e^{-firmlateness_i 0.182 - firmearliness_i 0.413 + firmlateness_i t 0.0052 + firmearliness_i t 0.0306}$$

The signs on the β coefficients indicate that cartel hazard reduces relative to the baseline as the number of days a firm enters late or exits early. The positive signs on the γ coefficients indicate that, for firms which enter late or exit early, hazard increases

relative to the baseline over the cartel's lifetime.

In order to gain a meaningful hazard ratio, which is comparable to the hazard ratios estimated by the previous models, it is necessary to input some representative numbers in this model. Take a firm of average incompleteness in a cartel of average duration. The mean member firm of a varying cartel enters its cartel 512 days (1.4 years) after its start and exits 78 days (0.21 years) before its end. The mean duration of a cartel is 8 years so let half of this duration be the time at which the hazards of a cartel with a static firm as a member and a representative varying cartel are compared.

The hazard ratio is calculated thus:

$$\frac{e^{0}}{e^{-1.4\times0.182-0.21\times0.413+1.4\times8\times0.0052+0.21\times8\times0.0306}} = 1.263$$

The model therefore estimates that the cartel which a static firm is a member of is 26% more likely to break down in its eighth year than the cartel which an average member of a varying cartel is a member of. This hazard ratio between a mean member of a static cartel (i.e. a static firm) and an average firm may be compared to the hazard ratio estimated between a cartel with completeness of one and a cartel of mean completeness in the cartel completeness model. These hazard ratios represent a comparison between the hazard of cartels which have experienced the same amounts of membership instability, respectively being static and typical. The cartel completeness model estimated this hazard ratio as being 25%, as calculated above in section 4.3.5. That these hazard ratios are very similar in magnitude indicates that the result of entry and exit by firms signalling cartel stability against breakdown is a robust one.

Note that there is a turning point in analysis time where the positive coefficient on the time-varying coefficient exceeds the negative coefficient on the time-invariant covariate. For late entry, this point is at 35 years and for early exit this point is at 13 years. This means that once a cartel has survived 13 years early exit by its members start to increase the probability of cartel breakup. The turning point for late entry is not meaningful because the longest duration in the sample of cartels is 34 years. Due to the estimated hazard ratios being relative to the baseline hazard, Cox models may not be used for out-of-sample predictions.

The negative coefficient on the time-varying covariate suggests an interesting effect

Table 4.3.: Descriptive statistics of leniency-detected cartels

Variable	Obs	Mean	Median	Std. Dev.	Min	Max
Cartel duration	51	9.7 yrs	8.3 yrs	7.1 yrs	0.5 yrs	34.9 yrs
Firm duration	306	8.5 yrs	7.7 yrs	6 yrs	0.5	34.9 yrs
Late entrants	306	0.34	0	0.47	0	1
Early exiters	306	0.2	0	0.4	0	1
Number of members	51	6	5	307	2	17
Coverage	36	0.88	0.93	0.14	0.475	1
Cartel completeness	51	0.889	0.958	0.135	0.535	1

among cartels which have experienced entry or exit in the past. Take a firm which has just entered a cartel which is in its fifth year. The hazard ratio of the cartel of such a firm relative to a static cartel is a very high 2.19. Ten years later, in the same cartel, the cartel's hazard ratio will be 1.68. Note that the gradual increase in hazard for all cartels observed in the Weibull model in section 4.3.2 is accounted for in the baseline hazard function so this change in hazard over time is specific to cartels which have experienced late entry or early exit.

4.3.7. Robustness Check for Uncertain Duration

That the secret nature of cartels may lead to a mistaken identification of the starting date of a cartel and so an underestimation of its total duration was noted in section 4.1.2. This fact may bias the results reported above. As robustness check on these results, it is possible to use the nature of the EC's leniency programme. 51 cartels in the sample were detected by a member firm revealing the cartel to the Commission and receiving full immunity to prosecution and fining. Because full cooperation to the satisfaction of the Commission's officials is a necessary condition of full immunity these cartels are less likely to be susceptible to this source of bias.

Table 4.3 shows descriptive statistics for the group of cartels which were detected by the leniency programme. This may be compared to the tables of duration and structural characteristics for all cartels in tables 2.1 and 2.3. There are 306 firms in the 51 cartels of which 104 entered their cartel late, 62 exited early and 31 did both. 16 out of the 51 cartels experienced no entry or exit of member firms.

Table 4.4.: Cox proportional hazard models predicting cartel breakdown hazard by cartel staticness, cartel completeness, and firm lateness and earliness of entry and exit, containing only cartels detected through leniency

	Specification (model) number					
	1		2		3	
Variable	Haz. Ratio	Coeff.	Haz. Ratio	Coeff.	Haz. Ratio	Coeff.
Cartel Static	1.708†	0.536† (0.308)	-	-	-	-
Cartel Completeness	-	-	8.874**	2.183** (1.037)	-	-
Firm Lateness	-	-	-	-	0.851***	-0.162*** (0.025)
Firm Earliness	-	-	-	-	0.732	-0.312 (0.198)
Firm Lateness*t	-	-	-	-	1.004***	0.0044*** (0.001)
Firm Earliness*t	-	-	-	-	1.025†	0.025† (0.014)
Obs	51		51		306	
Days at risk	180841		180841		179828	
Log (pseudo)likelihood	-151.04		-149.97		-1439.5	
LR/Wald χ^2	2.83		4.98		92.22	

Robust standard errors in brackets † $p < 0.1$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Compared to the full sample of cartels, cartels detected through leniency tend to be longer and larger. The mean duration of cartels which were detected through leniency is 9.7 years, compared to 5.9 years for cartel detected through other means, and 8 years for the full sample of cartels. The median number of members for cartels which were detected through leniency was 5, compared to 4 for cartels discovered through other means and the full sample. In the leniency-detected subset 34% of firms entered their cartels late, with 16% doing so in the non-leniency detected subset, and 28% in the full sample. In both subsets and the full sample 20% of firms exited early.

The results of the three survival models estimated using only the cartels detected through leniency are given in Table 4.4. The significance of the results has declined; notably the cartel static measure is no longer significant at the 5% level in Model 1, and the time-invariant firm earliness variable ceasing to be significant in Model 3. However, the estimated coefficients and hazard ratios are very similar to those estimated using

the full sample. This indicates that the results of the models, in terms of the effect of membership instability on the hazard of cartel breakdown, are robust against the potential for uncertainty in recorded cartel duration.

4.4. Discussion

The findings of Section 4.3 suggest that successful cartels are characterised by firms leaving and joining. This is consistent with the above theory on marginal firms and cartel stability (that firms will leave and join cartels according to their own immediate incentives). In terms of the dichotomy in Spar [1994] between the Realist and Institutionalist views of cooperation this tends towards the Realist view in that cooperation needs to be in the personal interest of all firms in order to be sustainable rather than relying on the commitments of all firms to cooperation. It does not confirm the more extreme interpretation the Realist view that cooperation is only possible in the presence of a hegemon, however.

Osborne [1976] and Harrington [1989b] argue that cartel institutions which aim to control member firms enhance cartel survival. These findings do not suggest that this is necessarily false. Indeed, for any given cartel it is likely the case that the addition of a monitoring or punishment mechanism increases the robustness of the agreement. However, if a cartel rule makes a member firm prefer to break down a cartel when it otherwise would have moved to the fringe without breaking up the cartel then such a rule is harmful.

It must be noted that the sample consists only of detected cartels. If all cartels have an equal chance of being detected then the results of this study may be applied to all cartels without worry. However, it may well be the case that cartels with certain characteristics are more or less likely to be detected by the E.C. or to have a member firm apply for leniency. Unfortunately, neither the true number of cartels in existence is known nor the characteristics of undetected cartels. Care must therefore be taken before too bold a claim is made about the nature of all cartels.

4.5. Conclusions

The models estimated in this paper would seem to further the hypothesis outlined throughout this thesis, that firms' decisions on cartel membership are determined primarily by their economic incentives, rather than by personal characteristics of people involved in collusion or by random chance.. That cartel institutions which restrict firms' entry and exit to and from the cartel may be harmful to the duration of the cartel is a secondary hypothesis. The next chapter of this thesis examines cartel institutions in greater detail in order to find whether their use may be determined by structural characteristics.

The survival models indicate that cartels whose firms enter and exit tend to last for longer than those cartels whose membership is static. Varying membership could indicate a variety of structural characteristics or changes. If information on the existence of outsiders and entry and exit to and from the market housing the cartel were available in the published decisions, which do not give details on the non-colluding firms, then the predictions of marginal firms models could more directly be tested. The problem with the endogeneity of invariability with respect to cartel duration is present in these models despite attempts to alleviate it.

The normative conclusions which can be drawn from this research are limited. If anything, the main advice is aimed at cartelists rather than competition authorities: institutions which aim to maximise the size of a cartel by preventing firms from leaving or which aim to hoard profits by excluding fringe members which wish to join may harm cartels by forcing firms which wish to leave to report the cartel to authorities or firms which wish to join to produce externally to the cartel.

While the conclusion that cartels with variable membership are longer-lasting than those with static or less variable membership may seem to be strange it must be noted that variable membership only signals structural stability. It is highly likely that for any given cartel, defection by members to the fringe is detrimental to the profits of the remaining member firms.

Chapter 5.

On the Use of Collusive Agreement Types

Economists have identified many mechanisms that allow firms to collude in order to increase their profits at the expense of their consumers. Cartels must choose a means by which to agree on the restriction of output in order to cause the rise in price they desire. Price fixing, bid rigging, quota allocation, territorial allocation and customer allocation are common examples of this type of mechanism. Cartels may also attempt to increase the stability of these agreements using strategies such as the monitoring of sales, the exchange of cost information and the imposing of punishment on defectors.

The set of collusive technologies which is dedicated to the setting of price and output which forms the central basis of a cartel agreement, such as price fixing and bid rigging, are known as 'agreement types.' Collusive technologies dedicated to monitoring firms and punishing defection are known as 'enforcement strategies.' This paper focuses on agreement types and the structural characteristics of cartels and markets which give rise to various technologies.

Different agreement types are known to lead to different profit-possibility frontiers and various kinds of conduct by firms. Robust agreements are also recognised as being essential to cartel stability, to ensure that a change in economic circumstances will not break a cartel down. However, beyond descriptive and narrative accounts, there has been no systematic account of what leads a cartel to choose a particular agreement type.

Identifying structural predictors of certain agreement types could not only enhance our understanding of cartel stability and their welfare effects but could also be useful in cartel screening. Different agreement types produce different behavioural collusive markers. A competition authority engaged in screening could find it useful to know

which collusive technologies are likely to be in use in a market, and so on which behavioural markers they should focus their efforts.

The estimated SUR model is moderately effective at predicting the use of price fixing, bid rigging, customer allocation and quota allocation but performs poorly at predicting the use of territorial allocation. The geographical scope of a cartel is found to be one of the best predictors of the agreement type it will choose to use.

5.1. The Importance of Agreement Types

Levenstein and Suslow [2006b] argue that the main cause of cartel breakdown is the failure to adjust cartel agreements following a change in economic conditions. That effective collusive technologies dedicated to monitoring firms for defection from the cartel agreement and enforcing cartel rules will make a cartel viable in a larger set of structural circumstances is clear. Though they do not address the issue directly, it is possible that a cartel's agreement type will partially determine that cartel's adaptability.

Harrington [2006b] details 'collusive markers' which may indicate to competition authorities the use of a particular agreement type. For example, the offering of an identical price to all customers in a market is a collusive marker for price fixing. Extremely stable market shares over time is a collusive marker for output quota allocation. Literature on screening for cartels makes a distinction between these behavioural markers and also structural markers, such as the concentration of markets and the presence of barriers to entry. Harrington [2006a] argues that structural markers are of limited use because of their extremely high risk of false positives, whereas strong behavioural collusive markers are unlikely to accompany legitimate, competitive conduct.

5.2. Comparing Different Agreement Types

5.2.1. Interaction Between Agreement Types and Allocation Rules

Schmalensee [1987] provides a comprehensive look at collusive technologies in the context of firms which have varying costs (specifically, a single low-cost firm and a variable amount of high-cost firms). For various numbers of firms and degrees of cost hetero-

geneity he simulates the equilibrium which results from the combination of each of four agreement types and four solution concepts. In Schmalensee's model, an agreement type provides a contract surface of Pareto-efficient allocations of cartel profits; firms must then bargain over the exact allocation.

The single low-cost firm has costs $C(q_1) = (1 - \theta_1)q_1$ where q_1 is the output produced by the low-cost firm. There are N high-cost firms, each having costs $C(q_2) = (1 - \theta_2)q_2$ where q_2 is each firm's output. Market (inverse) demand is $P = 1 - Q$. The degree of cost asymmetry between the low-cost firm and the high-cost firms may be summarised by the parameter $R = \frac{\theta_1}{\theta_2}$.[1] The market may effectively be described by the two parameters N and R.

The mode of conduct among the firms in the market in the absence of a cartel is assumed to be Cournot competition. Letting S represent the share of market output produced by the low-cost firm in Cournot equilibrium, the parameters of the model may be related to each other thus:

$$R = \frac{N(1 + S)}{(N + 1) - S}$$

A larger S or a larger N (holding the other parameter constant) implies a larger cost advantage for the low-cost firm. A larger share for the low-cost firm with a constant number of high-cost firms requires a larger cost advantage. If there are a greater number of high-cost firms, then the low-cost firm requires a larger cost advantage to maintain the same share of output in equilibrium. The model assumes that a cartel must consist of all firms in the market.

The collusive technologies studied by Schmalensee are side payments, where the efficient firm is able to pay the less-efficient firms to not operate while it acts as a monopolist; Market sharing, where firms are allocated quotas and produce up to those quotas; Market division, where firms are allocated customers or geographical areas and act as a monopolist over their allocation; and Proportional reduction, where firms reduce their competitive level of output by the same amount.

Side payments are almost unheard of in modern cartels due to the impossibility of

[1] In order that the costs of the high-cost firms do not exceed the monopoly price set by the low-cost firm, it is assumed that $\theta_2 > \theta 3 > 2\theta_2$ so $1 < R < 2$.

making a legally binding agreement to not produce and the egregiously illegal and obvious nature of the activity. Compensation mechanisms which mandate transfers between firms when output quotas are exceeded (as found in cartels such as the Lysine cartel Connor [2008]), are not side payments of this type since they are uncertain in their amounts and in their payers and instead may be considered an enforcement mechanism. Still, the monopoly equilibrium provides a benchmark for comparison and illustrates how much profit the cartel loses due to the inefficiency of their agreement type.

The crucial feature of market sharing is that all firms must charge the same price to all customers. This implies an inefficiency since the low-cost firm's profits will be maximised at a lower price to those of the high-cost firm. The model assumes that firms are sufficiently patient that any collusive equilibrium is incentive-compatible. Note that this agreement type may be seen as encompassing price fixing as well as quota allocation, though price fixing alone contains no obvious mechanism by which profits may be allocated among members.

Market division overcomes the basic problem of market sharing by allowing firms to charge which price they choose to their allocated customers or territory. Each firm may then set prices as a monopolist. Because of this, this agreement type is strictly more profitable. Note that this agreement type is still not as profitable as side payments since the high-cost firms are forced to produce to gain profits, rather than this production being performed by the low-cost firm and the resulting profits being transferred. Customer and territorial allocation may be considered types of market division.

The final agreement type modelled by Schmalensee is proportional reduction, where firms all reduce their output by an equal proportion. This is extremely restrictive since the distribution of production is fixed at the same proportions as under Cournot competition. At best, this technology may produce profits as large as those from market sharing, but only for a particular allocation of profits.

The diagram in figure 5.1 illustrates the profit possibility frontiers implied by each of the technologies[2]. The profits of an individual high-cost firm are designated Π_2, on the

[2]Proportional reduction is excluded from this diagram because it is separate from the other technologies in implying an allocation rule in addition to a technology. Its curve on this diagram would describe the set of all possible profit combinations from the collusive technology, rather than a frontier bounding the space of possible profit allocations. The profit curve for proportional reduction would begin at the Cournot point, curve upwards, touch the Market Sharing frontier and then move towards

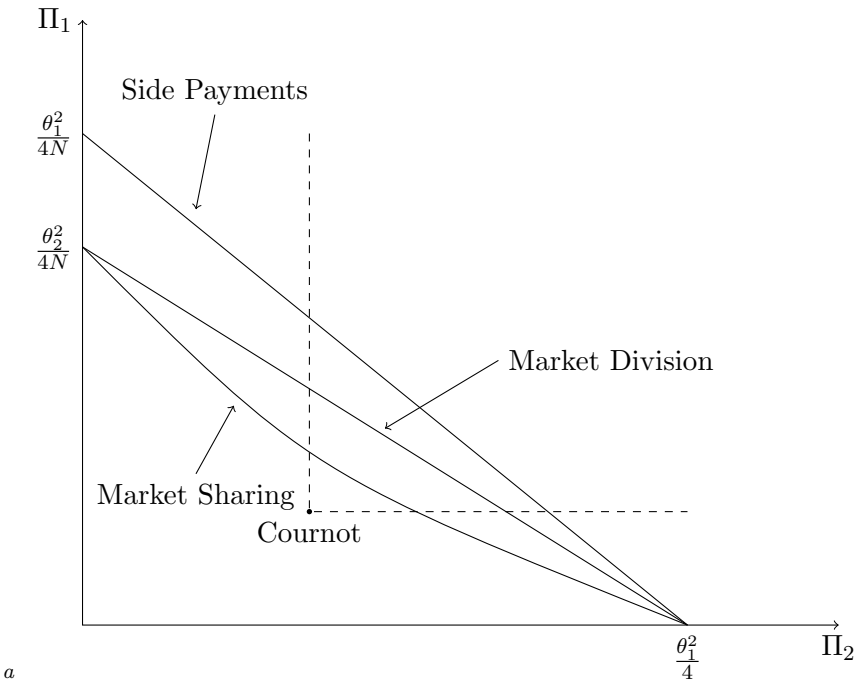

Figure 5.1.: Collusive technologies in profit space

[a] This diagram is a reproduction of that found on page 355 of Schmalensee (1987)

vertical axis, and the profits of the low-cost firm are designated Π_1, on the horizontal axis. The diagram is drawn showing a moderate degree of cost asymmetry between the high and low-cost firms; if costs were completely symmetrical, all of the curves would be identical. In order to be incentive-compatible for all firms their profits must be greater than under competition. The set of allocations of profits for which this is true is enclosed by the dotted lines starting at the Cournot point.

For the incentive-compatible allocations, side payments strictly dominate all other collusive technologies. This represents the low-cost firm producing all of the output in the market and then redistributing a portion of the profits to the high-cost firms in return for them not producing any output.

Market division in turn dominates market sharing across incentive-compatible allocations. This is because of the previously mentioned point that under market division firms may charge which price is optimal for them given market demand whereas under marketing sharing all firms must set the same price. The market sharing price will be some combination of higher than optimal for the high-cost firms and lower-than optimal for the low-cost firm, depending on the agreed allocation. The amount by which the possible joint profits from market division exceed those from market sharing depends on the degree of convexity of the market sharing frontier. The market sharing frontier is strictly convex for any level of cost asymmetry and its convexity increases with greater asymmetry.

The exact allocation of profits that the cartel arrives at depends on the bargaining rule which is assumed. All bargaining rules will produce a pareto-efficient outcome which lies on the profit frontier of the collusive technology used by the cartel. The bargaining rules examined by Schmalensee are

Nash Bargaining Solution where the product of the parties gains from collusion relative to Cournot competition

$$(\Pi_1^* - \Pi_1^c)(\Pi_2^* - \Pi_2^c)$$

is maximised. Π_i^* designates the profits of firm i under collusion and Π_i^c the profits of firm i with collusion.

Kalai-Smorodinsky where each participant receives the same fraction of the maximum

the origin.

possible gains from collusion. Let Π_i^m represent the largest possible gains that firm i could receive from the chosen collusive technology, if all other firms were to be allocated only the profits they would have received under Cournot. Under Kalai-Smorodinsky the cartel then sets Π_1^* and Π_2^* such that

$$\frac{(\Pi_1^* - \Pi_1^c)}{(\Pi_1^m - \Pi_1^c)} = \frac{(\Pi_2^* - \Pi_2^c)}{(\Pi_2^m - \Pi_2^c)}$$

Where the profit frontier of the collusive technology used by the cartel is linear, as it is for side payments and market division, the solutions of the Kalai-Smorodinsky and Nash bargaining rules are identical.

Equal Gains where the absolute gains made by all firms are set to be equal.

$$(\Pi_1^* - \Pi_1^c) = (\Pi_2^* - \Pi_2^c)$$

For side payments the solutions of Nash, Kalai-Smorodinsky and Equal Gains all coincide. For market division, the solution to Equal Gains will be to the left of the solutions to Nash and Kalai-Smorodinsky, reflecting greater profits for the high-cost firms.

$W^* = S$ applies only to the market division technology. It assumes that the firms retain the same share of customers they did in Cournot competition (S) in the cartel equilibrium (W^*), but are able to charge a cartel price to them. This resembles the proportional allocation rule assumed by models such as Bos and Harrington [2010], within the context of market division.

Schmalensee takes a numerical simulation approach to examining the effects of changes in R, N and S on the collusive equilibrium. While solutions may be calculated as functions of N and S they are too complex to assess easily the effects of the variables on firm profits, total output and consumer welfare. Consistent patterns may be seen in the simulations, and these are the conclusions of the article.

Where there is cost asymmetry, the profits of the high-cost firms increase by a larger proportion relative to Cournot than the low-cost firm. Collusion always reduces consumer welfare and will reduce total welfare also, unless the asymmetry between firms is extreme and the side payments technology is used. In this case, the rationalisation of all production to the low-cost firm may cause a small increase in total welfare. If side payments are impossible then collusion will necessarily cause decrease in total welfare.

As the number of firms in the market increase, the Cournot equilibrium becomes more competitive so the harm to consumers and gain to firms from collusion increases with N. Increases in N also increase the bargaining power of the high-cost firms relative to the low-cost firm and so decrease the proportion of gains accruing to the low-cost firm. Where asymmetry is large and side payments are impossible, the gains from collusion to the low-cost firm are so low that collusion may be unlikely. Market division allows significantly higher profits for high-cost firms compared to market sharing, especially as the degree of asymmetry increases.

A prediction of the paper which is of particular interest to this chapter is that cartels with greater asymmetry will prefer allocation-based agreement types over price fixing because they firms will be able to choose appropriate prices. That some agreement types dominate others is also important - dominated agreement types such as quota sharing may not be powerful enough mechanisms to be used alone successfully.

5.2.2. Sharing Rules in Practice

A small number of studies have examined the use of agreement types in samples of cartels, rather than as a part of a narrative of a single cartel. Two of these studies use samples of legal cartels. Hyytinen et al. [2012] detail the contracts used by 109 legal cartels in Finland between 1959 and 1988 and Fink et al. [2015] describe the agreements of Austria legal cartels from 1972 to 1995. Both studies are able to examine the actual contracts governing the cartels and so report on their agreement types accurately and in great detail.

In their Austrian sample Fink et al. [2015] identify thirteen different varieties of price fixing, five types of market division, two types of capacity restriction, two types of coordinated vertical exclusion, three various ways of standardising norms, two non-cartel types of cooperation and two methods of entry prevention. They also note the formal structure of the cartels' meetings and management. In total, over 200 fields of data are gathered on each cartel in the sample. Among the 80 distinct horizontal cartels in their sample, they find that 37 used quota fixing, 26 used customer allocation (in the form of 'specialisation' agreements), 41 used price agreements, and 44 fixed the payment conditions members could offer.

Fink et al. [2015] note that over half of the cartels in their sample use multiple agreement types simultaneously. 37 out of the 80 cartels used a single agreement type: 13 fixed payment conditions alone, 10 quotas, 7 fixed prices, and 7 agreed to allocate customers, products or territories. The most common combination of agreement types observed was that of price and payment conditions in 20 cartels, of which 11 also fixed payment conditions.

5.2.3. Sharing Rules as a Constraint to Collusion

The legal Norwegian Cement cartel in the 1950s and 1960s had a rigorous sharing rule, enforced through contracts. Röller and Steen [2006] models structurally the incentives the chosen allocation rule created among the cartel's members and how it led to the cartel's relative ineffectiveness. The allocation rule used was to allocate shares of cartel output to firms proportional to their share of capacity. Total quantity to be sold in Norway was decided by the cartel, but no restrictions were placed on capacity or total production: production above the domestic quota was exported.

After the 1955 founding of the cartel, members invested very strongly in capacity. Total production increased by 150% by 1968 while domestic production increased by only 50%. Norwegian consumers of cement were still being charged a monopoly-level price but each cartel member faced a constant incentive to increase capacity to gain a greater market share. Much of the excess production being exported was sold at a price below the marginal costs of the producers. The additional investment in capacity led to a lower monopoly price set by the cartel so consumers did benefit somewhat from the inefficiency of the allocation rule, but were still harmed considerably compared to competition. The welfare loss to firms from this was so extreme that the paper's model estimates that total welfare was actually increased by the industry's eventual merger to monopoly - that is, the firms' welfare gained through halting cheap exports exceeded the consumer welfare lost through monopoly pricing and production.

The crucial reason why the allocation rule of the cartel led to its failure is that the cartel agreement was incomplete: it did not constrain firms' capacity decisions or the export market. This example shows how semicollusion, where firms collude in some factors under their control but compete in others, can harm the firms engaged in it and explain why they would wish to choose an agreement type appropriate to their industry

or multiple agreement types.

This case illustrates why a cartel which fails to coordinate on multiple aspects of their strategy may collude sub-optimally. A successful strategy profile for the Norwegian Cement cartel may have consisted of a quantity rule which included exports, or a price rule which covered both domestic and export sales. Certain agreement types may complement each other well when used together, whereas other agreement types may act as substitutes for each other.

5.2.4. Multiple Simultaneous Agreement Types

From a simple theoretical viewpoint it may seem that many agreement types are mutually incompatible, or at least redundant when applied together. However, cartels frequently do use agreement types simultaneously. Some agreement types may apply simultaneously to the same transactions, such as price fixing and quota allocation, and some agreement types may be used by the same cartel in different circumstances, such as price fixing in a spot market and bid rigging in an auction market for the same product.

van den Berg and Bos [2017] show that simultaneous price and quantity rules can produce a more profitable outcome for a cartel's members than a cartel which sets price alone. The additional quantity rule allows the cartel to distribute output among members in order to induce the smallest members to stay members, where they might defect under a price agreement alone. Under certain circumstances (where firms produce output in advance of sales, and demand is relatively price inelastic) the cartel is required to set a price lower than the monopoly price. A price-quantity agreement also allows the cartel to prevent overproduction by allocating output shares.

Sometimes different strategies are necessary for different customers. A cartel could fix prices normally but need to rig bids when a customer chooses to buy using a auction. Connor [2008] describes how the Vitamin C cartel functioned by customer allocation for all buyers except Coca-Cola, which bought in such quantities that it was necessary to allocate quotas among producers in order to satisfy Coca-Cola's demand.

De [2010b] studies a similar sample of cartels sanctioned by the E.C., between 1990 and 2007, and discusses descriptively and narratively the use of various collusive technologies

by cartels. She notes that cartels which used enforcement rules, such as compensation payments or the threat of price wars, were likely to use only one such rule. There are multiple explanations for this phenomenon. The use of multiple agreement types may nullify the need for formal mechanisms to prevent or rectify deviation by fixing choices which would normally allow a firm to violate an agreement, intentionally or unintentionally.

Another important finding is that the incidence of certain collusive technologies is very dependent on the existence of other collusive technologies. No cartels use bid rigging or customer allocation as their only collusive technology and their use is strongly correlated with each other, and with price fixing. When a single collusive technology is used, that technology is almost always price fixing or territorial allocation.

5.2.5. The Development of Strategy Profiles

That certain combinations of agreement types are used by multiple cartels is observed by Connor [2008] in his narrative of the global cartels in the markets for citric acid, vitamins and lysine. He notes that all of these cartels used a distinctive system of price fixing and quota allocation, followed by monitoring and corrective compensation payments in order to maintain the quotas. He terms this the 'Lysine strategy profile'.

A part of the reason the Lysine strategy profile was so closely replicated by these cartels is that the structure was developed in the Japanese market for Lysine prior to the entry of Archer Daniels Midland into the Lysine market, and was spread into the other markets by firms which had observed the success of the strategy in other markets. Connor refers to this process as 'contagion'. Cartel contagion is also observed in the dairy market by Balagtas and Sumner [2003] where collusion among milk producers in the USA was observed to gradually spread to states which were geographically adjacent to states which already contained milk cartels.

Levenstein and Suslow [2006b] argue that cartel strategies develop over time to become more robust through a process of trial and error on the part of cartelists. Contagion allows this process to be shortened within a given market by allowing a strategy which is already known to be successful to be implemented, with only small changes necessary for the individual markets such as the addition of another agreement

type in order to cover part of the market. This was observed in the Vitamin C cartel where the sales to the largest customers were divided among cartel members rather than being allocated to a single firm, as in other markets. Zhou [2012] analyses a sample of international cartels and finds that those cartels which use the Lysine strategy profile do indeed have longer duration than those which use other strategies. The spread of cartel strategies via contagion and the development of robust strategies via learning mean that certain combinations of agreement types may be seen to be replicated in multiple cartels.

5.3. The Data and Descriptive Overview

The data set consists of 88 cartels sanctioned by the European Commission between 2001 and 2011. A total of 468 individual firms were members of these cartels. Firms which participated in multiple cartels are counted multiple times in this data. Data on market shares is available for 75 of the cartels studied: this is the set analysed in section 5.4.

The European Commission's decision documents enumerate the types of illegal conduct observed in each cartel. This is the data source for the agreement types. Information on the geographical scope of cartels and the number of member firms is also found this way. Market share data is more complex to gather. Due to the need for secrecy with some details of the firms involved in cartel proceedings, only approximate ranges for firm market shares or output are given. The centre points of these ranges are taken as being the value and the market shares calculated on this basis.

Table 5.2 shows the frequency of use for all five agreement types identified in use by these cartels and the frequencies of all combinations of two agreement types, plus the frequency with which each agreement type is used alone. The final column shows the total number of cartels which used each agreement type, either individually or in combination with others. This table does not capture all possible combinations of agreement types because it is limited to two dimensions. 19 cartels used three agreement types, one cartel, Gas Insulated Switchgear, used four agreement types and the Marine Hoses cartel used all five agreement types. Note that quota allocation is never used alone, indicating that Schmalensee's finding that it is a weak agreement type when used alone may be accurate.

The correlations between the frequency with which agreement types are observed

	Bid rigging	Territorial allocation	Customer allocation	Quota allocation	No other agreements	Total
Price fixing	13	9	27	33	17	75
Bid rigging		2	13	3	0	19
Territorial allocation			4	5	5	14
Customer allocation				7	2	35
Quota allocation					0	33

Figure 5.2.: Frequency of agreement types being used together

Table 5.1.: Correlation between agreement types

	Price fixing	Bid rigging	Territorial allocation	Customer allocation	Quota allocation
Price fixing	1				
Bid rigging	-0.2504	1			
Territorial allocation	-0.2582	-0.0745	1		
Customer allocation	-0.1881	0.3103	-0.0951	1	
Quota allocation	0.3175	-0.2296	-0.0122	-0.2847	1

may be seen in Table 5.1. Positive figures indicate that two agreement types are likely to be observed being used by the same cartel, whereas negative figures indicate that the presence of one agreement type means the likelihood of observing the other is lower. Most of the correlation coefficients are negative, indicating the tendency of most cartels to use only one or two agreement types, rather than many. The two notably positive correlations are between bid rigging and customer allocation and between price fixing and bid rigging. Conclusions about whether these agreement types are complements or substitutes may not be drawn from this matrix, however. These correlations could be caused by agreement types sharing a common set of causal variables. A more detailed analysis allows this problem to be solved.

5.4. Predicting the Use of Agreement Types

The objective of this analysis is to discover whether it is possible to predict which agreement types are likely to be used by a cartel, based on that cartel's structural characteristics. Whether certain agreement types act as complements or substitutes to each other is also of interest.

The correlation between collusive technologies means that the technique of Seemingly Unrelated Regressions (SUR) is likely to provide more efficient estimates than individual OLS regressions. The residuals of the estimated predictors for different agreement types may also be examined to see if they correlate with each other, indicating tendencies for them to be used or not used alongside each other beyond those caused by the covariates included in the model. However, the regressions produced by this technique will be linear probability models which, despite having easily interpretable results, may produce results outside of the interval of $[0, 1]$. A multivariate probit regression, estimating an equation for each agreement type through simulated maximum likelihood, would combine the most attractive attributes of both of these approaches. Unfortunately, the above problem with certain variables predicting the outcomes of some observations perfectly occurs and using a maximum likelihood approach is impossible. The process of estimating SUR does not involve a likelihood function so the presence of some perfect predictors does not prevent estimation using the full number of observations for which there is data available. Large estimated coefficients should be anticipated for those variables which are perfect predictors.

Seemingly Unrelated Regressions models take the form of a set of individual regression equations for different dependent variables combined with each other. A general form is:

$$\begin{bmatrix} \boldsymbol{y}_1 \\ \boldsymbol{y}_2 \\ \vdots \\ \boldsymbol{y}_M \end{bmatrix} = \begin{bmatrix} \boldsymbol{X}_1 & 0 & \cdots & 0 \\ 0 & \boldsymbol{X}_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \boldsymbol{X}_M \end{bmatrix} \begin{bmatrix} \boldsymbol{\beta}_1 \\ \boldsymbol{\beta}_2 \\ \vdots \\ \boldsymbol{\beta}_M \end{bmatrix} + \begin{bmatrix} \boldsymbol{\epsilon}_1 \\ \boldsymbol{\epsilon}_2 \\ \vdots \\ \boldsymbol{\epsilon}_M \end{bmatrix}$$

Where the $\boldsymbol{y}$ terms are dependent variables, the $\boldsymbol{X}$ terms explanatory variables, $\boldsymbol{\beta}$ terms coefficients on the explanatory variables and $\boldsymbol{\epsilon}$ the residuals of the models. M is the number of individual regression equations included in the system. In the particular case where the explanatory variables used in all of the regression equations are identical, the estimated coefficients on those explanatory variables are identical to those calculated by performing Ordinary Least Squares on the individual regressions separately. The residuals produced by the SUR model are of great interest. If the residuals of the individual equations are found to be correlated with other then SUR is a more efficient estimator than separate OLS. Also, the correlations between the residuals may be examined and interpreted in order to reveal correlations between the outcomes of the dependent variables beyond those implied by the common explanatory variables. In the case of agreement types, a positive correlation indicates that the agreement types in question are more likely to be observed together than implied by the explanatory variables and a negative correlation indicates that the agreement types are less likely to be observed together.

This approach does have clear flaws. Aside from the limitations of a linear probability model mentioned earlier, it is very difficult to see how anything other than a reduced-form econometric approach to this question could be attempted. Also, some of the independent variables are likely to be endogenous with respect to the agreement type. This is most clear when it comes to the symmetry in firms' market shares in cartels which use quota allocation: manipulation of market shares is the central point, especially when combined with price fixing. Whether the geographical scope of a cartel is dependent on its agreement is arguable: it may be predetermined by the characteristics of the product or the market or firms may be able to choose whether to compete or collude in various markets.

Table 5.2 contains the results of a Seemingly Unrelated Regression predicting the use

Table 5.2.: SUR model predicting agreement types

	Price fixing	Bid rigging	Territorial allocation	Customer allocation	Quota allocation
Number of members	0.0394**	0.0361*	-0.00791	0.0204	0.00489
	(0.0132)	(0.0153)	(0.0144)	(0.0193)	(0.0158)
Share coefficient of variation	-0.246†	-0.101	0.218	-0.151	0.379*
	(0.132)	(0.153)	(0.144)	(0.193)	(0.158)
Global	0.353***	-0.327**	0.302**	-0.554***	0.535***
	(0.107)	(0.124)	(0.117)	(0.156)	(0.127)
Europe-wide	0.300**	-0.436***	0.146	-0.127	0.0296
	(0.105)	(0.122)	(0.115)	(0.153)	(0.126)
Regional	0.237†	-0.284†	0.0591	-0.227	-0.0502
	(0.137)	(0.159)	(0.149)	(0.200)	(0.164)
Food and agriculture	0.00491	-0.126	0.144	0.0950	-0.214
	(0.137)	(0.159)	(0.150)	(0.200)	(0.164)
Manufacturing	-0.228*	0.322**	0.0955	-0.0653	-0.202†
	(0.0884)	(0.103)	(0.0967)	(0.129)	(0.106)
Metals	-0.280†	-0.0231	0.178	-0.168	0.0383
	(0.150)	(0.174)	(0.164)	(0.220)	(0.180)
Other	-0.304†	0.0150	0.168	-0.232	-0.410*
	(0.164)	(0.191)	(0.180)	(0.240)	(0.197)
Constant	0.678***	0.308*	-0.198	0.691***	-0.00168
	(0.134)	(0.156)	(0.147)	(0.196)	(0.161)
Observations	75	75	75	75	75
r2	0.319	0.345	0.118	0.241	0.461
ll	-113.0	-113.0	-113.0	-113.0	-113.0
chi2	35.11	39.58	9.991	23.84	64.16

Baseline for Geographical Scope is National Scope. Baseline for Industry is Chemicals

Standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5.3.: Correlation matrix of residuals from SUR model

	Price fixing	Bid rigging	Territorial allocation	Customer allocation	Quota allocation
Price fixing	1				
Bid rigging	-0.1704	1			
Territorial allocation	-0.3488	-0.0346	1		
Customer allocation	-0.2170	0.3232	0.0195	1	
Quota allocation	0.0686	-0.1307	-0.0792	-0.2291	1

of the five agreement types identified in the sample with several structural characteristics of the cartels, namely their geographical scope, the number of member firms they had and the coefficient of variation of the members' shares of cartel output. A matrix showing the degree of correlation between the residuals of the SUR model for different agreement types is in Table 5.3. An alternative specification, excluding market share coefficient of variation from the model so that all 91 cartels may be used to estimate the model, is in Table B.6 in Appendix B.

With the exception of the model predicting territorial allocation, the joint significance (as indicated by the chi^2 and p-values) of each of the models is high. The geographical scope variables are the most consistently significant variables across all agreement types.

Logit Models

Logit models may be estimated for each agreement type in order to predict their use individually. A problem with this approach is that some covariates predict the use of certain agreement types perfectly. When a variable perfectly predicts the outcome of some observations within a dataset it is not possible to calculate a likelihood function in order to obtain estimated coefficients. In order to estimate the model under

such circumstances it is necessary to omit the observations for which prediction is perfect. This causes sharp drops in the number of observations which may be used to estimate certain model specifications. Only a single cartel of global scope did not use price fixing, and this cartel does have market share data so is not included in the set of observations used to estimate the main logit model. In the same model, all cartels in the Chemicals sector used price fixing. Taken together, these omissions of observations cause the number of observations able to be used to predict the use of price fixing to only 37. Omissions are also made in the territorial allocation and quota allocation models due to perfect prediction, reducing the number of observations used to 59 and 79 — no cartels of national scope use territorial allocation and no cartel of regional scope or classified as being in the 'other' industrial sector use quota allocation.

The results of the estimated logit models are in Table B.5 in Appendix B. Due to the omitted observations and variables, the results should not be considered authoritative. The results of the models estimated with larger numbers of observations may be considered as robustness checks on the main results. The variables which are perfect predictors of the use of agreement types are informative, however, and will be discussed alongside the results of the SUR model.

5.4.1. Interpretation of Results

The table of observed results has many estimated coefficients. I shall discuss the models' predictions for each agreement type in turn and then examine the importance each set of explanatory variables across all agreement types.

Price Fixing

Price fixing is the most common agreement type in the sample, present in 82% of cartels. That all cartels of global geographical scope in the sample was engaged in price fixing is one indicator of this. Still, all of the coefficients associated with geographical scope variables are significant, positive and large indicating that price fixing is relatively uncommon in cartels of the baseline national scope. Cartels with a relatively large number of firms are more likely to feature price fixing. Compared to agreement types which require each firm being allocated a specific and discrete portion of the market, price fixing may be easily scalable to a large number of cartel members. Cartels in

manufacturing and metals industries are less likely to use price fixing than cartels in the baseline industry of chemicals. Price fixing is also less common in industries which fall into the 'other' category.

Cartels where the member firms have asymmetric market shares are less likely to be observed using price fixing. This could indicate that price fixing is not as robust to large differences in costs and capacities between firms as other agreement types due to the necessity in a price fixing cartel that firms charge the same or similar prices. This finding matches with the theoretical prediction that cartels with heterogeneous firms will face allocation problems with price fixing that they will not with agreement types which allow member firms to charge a price appropriate to their costs.

Bid Rigging

In contrast to price fixing, bid rigging is most common of all in cartels of national scope. This reflects the fact that the most prominent users of auctions in order to purchase products are national governments, so cartels targeting procurement auctions will be limited to the country of the national government in question. Bid rigging is more likely in cartels with more members, indicating that, like price fixing, it is an agreement type which is compatible with a large number of cartelists. Cartels in manufacturing industries are more likely than cartels in the baseline chemicals industry to rig bids.

Territorial Allocation

No cartel of national scope uses the territorial allocation agreement type, and it is relatively likely to occur in cartels of global scope. The possibility of arbitrage between territories or consumers switching where they choose to purchase products make territorial allocation ineffective as a means of restricting competition, whereas large geographical separation between territories makes the localised monopolies or restricted oligopolies created more effective. No other variables are found to be good predictors of territorial allocation being found to be present in cartels' strategies.

Customer Allocation

The occurrence of customer allocation is also difficult to predict using the explanatory variables included in the model. Customer allocation is substantially and significantly less likely to be observed in cartels of global scope than cartels of national scope. No other variables are found to be significant in the regression except the constant term.

Quota Allocation

Quota allocation is likely to to observed as a part of the strategy of global cartels, compared to the baseline of national cartels. It is never observed in the sample in a cartel classified as being in the 'other' industries group and is less likely to be observed in cartels in the manufacturing industries than cartels in the baseline chemicals industries.

There is an observed link between the occurrence of quota allocation and cartel symmetry: the more asymmetric a cartel, the more likely that cartel is observed to have used a quota allocation system. This may seem counter-intuitive, since cartelists with similar costs would seek to make their output shares as symmetrical as possible in order to prevent the defection of the firm with the least profit from the firm. However, if the cartelists have differing costs then a quota system may be necessary to allocation a greater portion of profits to the low cost firms so they do not defect. Lacking a quota system, the fact that all firms charge similar prices may lead to all firms having similar levels of sales because of the indifference of consumers between the firms.

Individual Explanatory Variables

Some individual explanatory variables are consistently successful at predicting the use of agreement types by cartels. Broadly, the geographical scopes of cartels in the sample are the strongest predictors. The number of firms in each agreement and the asymmetry of market shares between firms in the cartels are relatively weak predictors.

Cartels with greater numbers of firms are more likely to be observed using price fixing and bid rigging in their agreements. Each additional firm in a cartel increases the likelihood of price fixing being found in its agreement by 4% and increases the likelihood of the presence of bid rigging by 3.6%.

The coefficient of variation (CoV) of the member firms' shares of cartel output is a rather poor predictor of agreement type. The only significant coefficients are in the price fixing and quota allocation models. These coefficients indicate that there is weak evidence that more asymmetric cartels are less likely to fix prices and that there is moderate evidence that more asymmetrical cartels are likely to use quota allocation. The interquartile range of cartel share CoV for the sample is 0.4, so the marginal effect of a movement from the most symmetrical quartile to the most asymmetrical quartile for a firm is a 9.5% increase in the probability of that cartel using quota allocation.

The geographical scope variables are simple to interpret because the coefficients may be interpreted directly as proportional differences in probability relative to the baseline geographical scope of a national cartel. Global cartels have a strongly predicted set of agreement types. Compared to national cartels, they are likely to use price fixing, territorial allocation and quota allocation. They are unlikely to use bid rigging and customer allocation. Europe-wide cartels are 30% more likely to practice customer allocation and 43% less likely to rig bids. Regional cartels, those affecting a subset of European countries, are 24% less likely to fix prices.

There is some evidence that the industrial sector a cartel is active in predicts the agreement type they will use. Compared to cartels among chemicals companies, cartels among manufacturing firms are less likely to use price fixing and quota allocation and more likely to use bid rigging. Metals cartels and cartels in industries which do not fit into the main categories are also less likely to use price fixing than chemicals cartels. This indicates that price fixing is common among cartels in the chemicals sector.

Note also the large and significant constant terms accompanying price fixing and customer allocation. This indicates that price fixing and customer allocation are common agreement types among cartels.

Multiple Agreement Types

Examining the coefficients on the explanatory variables shows that some of the tendencies for certain agreement types to be used in conjunction by cartels are explained by the explanatory variables. For example, cartels of global scope are more likely to be observed using price fixing, territorial allocation and quota allocation than cartels of

national scope, but less likely to be observed using bid rigging or customer allocation. Large cartels are more likely to use both price fixing and bid rigging than smaller cartels.

The matrix in Table 5.3 showing showing the correlation between the residuals is different from the earlier correlation matrix in Table 5.1 in an important way – the effects of the covariates included in the SUR are accounted for. Correlations between agreement types in this matrix show the agreement types are complements and substitutes for each other for reasons beyond sharing a common correlation with the explanatory variables of the model. The correlation between price fixing and quota allocation is particularly striking here: it is considerably lower in this matrix than in the earlier matrix. This suggests that price fixing and quota sharing are not strong complements in themselves, but rather they are both favoured by global cartels. In contrast, the positive correlation between bid rigging and customer allocation is still present and relatively high. This indicates that these agreement types complement each other for reasons not accounted for in the regressions. Other strongly negative correlations may be seen between price fixing and territorial and customer allocation, and between quota allocation and customer allocation.

5.5. Conclusion

Variables about the structure of the market are found to be poor predictors of whether certain agreement types will be observed in a cartel. Larger cartels are more likely to use price fixing and bid rigging, suggesting these are agreements which may easily be applied to large groups of firms compared to the agreement types which involve making specific allocations to each member firm. Cartels with greater asymmetry among firms are less likely to be using price fixing and more likely to be using quota allocation. This may suggest that allocation-based means of collusion, especially quota allocation, are more robust to asymmetry between cartel members than price fixing: this supports theoretical predictions that cost-asymmetric firms will have difficultly fixing prices because the desired cartel price will differ among firms.

Geographical scope is more consistent in predicting whether certain agreement types are observed in cartels. Every cartel of global scope in the sample used price fixing. No cartel of national scope used territorial allocation and no cartel of regional scope allocated quotas. Other strong predictions from the model are made relative to the

baseline of a cartel of national scope. Global cartels are also likely to use quota allocation and territorial allocation but are less likely to use either bid rigging or customer allocation. This set of strong predictions indicate that many global cartels use similar strategy profiles. Predictions for other scopes are less strong, but both Europe-wide and regional cartels are also less likely to use bid rigging than national scope cartel: indicating that bid rigging is mostly the preserve of these cartels.

These common explanatory variables explain much of the correlation between the appearance of some agreement types. Price fixing and quota allocation are strongly correlated, indicating they are often observed together, but much of this correlation disappears when the correlation between the residuals of the estimated model are examined. This indicates that both price fixing and quota allocation are agreement types favoured by global cartels, but other than this are not strong complements. Bid rigging and customer allocation remain strongly correlated when the residuals are examined, indicating that cartels do favour the use of them both: it is possible to see that both agreement types represent similar behaviour with respect to different types of buyer. Other agreement types are mostly negatively correlated with each other indicating that, outside of certain common strategy profiles, different methods of collusion broadly act as substitutes for each other.

A policy implication of this research relates to the observed presence of distinct strategy profiles. If the existence of these consistent strategy profiles is indeed due to the spread via contagion of successful strategies then halting this spread is extremely important. Policies such as Amnesty Plus in the USA, which encourages detected cartelists to reveal the existence of other cartels they are involving in or have knowledge of, could be an effective means of eradicating tried and tested cartel strategies and eliminating the collective progress of the cartelists in developing strategy profiles.

Appendix A.

References to cases in the Official Journal of the E.U.

Case	Reference
SAS / Maersk Air	OJ L 265, 05.10.2001, p. 15 - 41
Graphite electrodes	OJ L 100, 16.04.2002, p. 1 - 42
Vitamins	OJ L 6, 10.01.2003, p. 1 - 89
Luxembourg brewing industry	OJ L 253, 21.09.2002, p. 21 - 41
Belgian beer market	OJ L 200, 07.08.2003, p. 1 - 58
Citric acid	OJ L 239, 06.09.2002, p. 18 - 65
Bank charges - Germany	OJ L 15, 21.01.2003, p. 1 - 34
Zinc Phosphate	OJ L 153, 20.06.2003, p. 1 - 39
Carbonless paper	OJ L 115, 21.04.2004, p. 1 - 88
Austrian banks	OJ L 56, 24.02.2004, p. 1 - 75
Methionine	OJ L 255, 08.10.2003, p. 1 - 32
Industrial and medical gases	OJ L 84, 01.04.2003, p. 1 - 55
Fine art Auction Houses	OJ L 200, 30.07.2005 p. 92 - 95
Plasterboard	OJ L 166, 28.06.2005 p. 8 - 11
Methylglucamine	OJ L 138, 10.02.2004 p. 18 - 46
Food flavour enhancers	OJ L75, 12.03.2004, p. 1 - 31
Speciality graphite $*$	OJ L 180, 04.07.2006, p. 20 - 24
Concrete reinforcing bar $*$	OJ L 353, 13.12.2006, p. 1 - 4
French beef $*$ †	OJ L 209, 19.08.2003, p. 12 - 41
Sorbates	OJ L 182, 13.07.2005, p. 20 - 25
Electrical and mechanical carbon and graphite products	OJ L 125, 28.04.2004, p. 45 - 49
Organic peroxide	OJ L 110, 30.04.2005, p. 44 - 47
Industrial tubes	OJ L 125, 28.04.2004, p. 50 - 53

Case	Reference
Copper plumbing tubes	OJ L 192, 13.07.2006, p. 21 - 24
French beer market	OJ L 184, 15.07.2005, p. 57 - 59
Spanish Raw Tobacco ∗ †	OJ L 102, 19.04.2007, p. 14
Needles	OJ C 147, 27.06.2009, p. 23 - 25
Choline chloride	OJ L190, 22.07.2005, p. 22 - 26
Monochloroacetic Acid	OJ L 353, 13.12.2006, p. 12 - 15
Thread	OJ C 21, 26.01.2008, p. 10 - 14
Italian raw tobacco ∗ †	OJ L 353, 13.12.2006, p. 45 - 49
Industrial bags	OJ L 282, 26.10.2007, p. 41 - 46
Rubber chemicals	OJ C 353, 13.12.2006, p. 50 - 53
Hydrogen peroxide	OJ L 353, 13.12.2006, p. 54 - 59
Methacrylates	OJ L 322, 22.11.2006, p. 20 - 23
Bitumen Nederland	OJ L 196, 28.07.2007, p. 40 - 44
Fittings	OJ L 283, 27.10.2007, p. 63 - 68
Steel beams	OJ C 235, 13.09.2008, p. 4 - 6
Synthetic rubber (BR/ESBR)	OJ C 7, 12.01.2008, p. 11 - 14
Gas insulated switchgear	OJ C 5, 10.01.2008, p. 7 - 10
Elevators and escalators	OJ C 75, 26.03.2008, p. 19 - 24
Netherlands beer market	OJ C 122, 20.05.2008, p. 1 - 3
Hard haberdashery: fasteners ∗	OJ C 210, 16.07.2011, p. 26-27
Bitumen Spain	OJ C 321, 29.12.2009, p. 15-17
Professional videotapes	OJ C 57, 01.03.2008, p. 10 - 12
Flat glass	OJ C 127, 24.05.2008, p. 9 - 11
Chloroprene rubber	OJ C 251, 03.10.2008, p. 11 - 13
International removal services	OJ C 188, 11.8.2009, p. 16-18
Sodium Chlorate ∗	OJ C 162, 08.06.2012, p. 6-7
Aluminium Fluoride †	OJ C 40, 9.2.2011, p. 22 - 23
Candle waxes	OJ C 295, 04.12.2009, p. 17-21
Bananas	OJ C 189, 12.8.2009, p.12-14
Car glass	OJ C 173, 25.7.2009, p. 13 - 16
Marine hoses ∗ †	OJ C 168, 21.7.2009, p.6-8
E.ON - GdF collusion ∗ †	OJ C 248, 16.10.2009, p.5-6
Calcium carbide ∗ †	OJ C 301, 11.12.2009, p.18-20
Concrete reinforcing bar ∗ †	OJ C 98, 30.3.2011, p. 16 - 19
Power transformers ∗ †	OJ C 296; 5.12.2009, p. 21-22

Case	Reference
Heat stabilisers ∗ †	OJ C 307, 12.11.2010, p. 9-12
DRAM †	OJ C 180, 21.06.2011, p. 15-17
Bathroom fittings & fixtures ∗ †	OJ C 348, p. 12 - 17
Prestressing steel †	OJ C 339, 19.11.2011, p. 7-11
Animal Feed Phosphates ∗ †	OJ C 111, 9.4.2011, p. 15 - 18
LCD †	OJ C 295, 7.10.2011, p. 8-9
Consumer Detergents †	OJ C 193, 02.07.2011, p. 14 - 16
Exotic fruit (bananas) †	OJ C 64, 3.3.2012, p. 10 - 11
CRT glass bulbs †	OJ C 48, 18.02.2012, p. 18 - 19
Refrigeration compressors †	OJ C 122, 27.4.2012, p. 6 - 7

All of these may be found at the website of DG Comp http://ec.europa.eu/competition/cartels/cases/case

Some decisions (most notably *Vitamins*) detail multiple cartels which are treated as separate in the analysis.

∗ Data on cartel share unavailable

† Data on cartel coverage unavailable

Appendix B.

Alternative and Unexpurgated Model Estimations

Table B.1.: Probit models predicting early exit for firms with control variables included

	Model 1	Model 2	Model 2 (b)	Model 3	Model 4
Early exit					
Late entry	0.637**	0.595**	0.686***		0.508**
	(0.204)	(0.190)	(0.203)		(0.169)
Number of members	0.0771*	-0.0117	0.0637*	0.0855**	0.00518
	(0.0317)	(0.0253)	(0.0304)	(0.0308)	(0.0198)
Cartel coverage	-1.635*			-1.922**	
	(0.706)			(0.698)	
Market share	-1.074	-1.910**	-1.032	-1.851*	
	(0.708)	(0.687)	(0.660)	(0.740)	
Full leniency	0.287	0.199	0.259	0.241	0.317
	(0.273)	(0.246)	(0.274)	(0.285)	(0.205)
Global	0.132	-0.0635	0.159	0.259	-0.237
	(0.292)	(0.256)	(0.288)	(0.299)	(0.222)
Europe-wide	0.305	0.188	0.309	0.452†	-0.00440
	(0.264)	(0.256)	(0.270)	(0.261)	(0.207)
Regional	-0.114	0.385	0.323	-0.0736	-0.0325
	(0.395)	(0.275)	(0.312)	(0.380)	(0.254)
Food and agriculture	0.367	0.189	0.454	0.436	-0.254
	(0.393)	(0.376)	(0.380)	(0.417)	(0.334)
Manufacturing	0.212	0.179	0.137	0.245	0.0702
	(0.227)	(0.199)	(0.224)	(0.229)	(0.168)
Metals	0.619*	0.326	0.685*	0.646*	0.597*
	(0.309)	(0.310)	(0.313)	(0.297)	(0.239)
Other	0.296	0.338	0.425	0.265	0.394
	(0.346)	(0.325)	(0.335)	(0.350)	(0.300)
Constant	-0.332	-0.908**	-1.715***	0.0711	-1.133***
	(0.731)	(0.344)	(0.396)	(0.753)	(0.237)
Observations	328	379	328	328	478
r2_p	0.184	0.124	0.172	0.155	0.0747
ll	-136.7	-166.5	-138.7	-141.5	-223.1
chi2	57.87	52.23	60.14	48.78	40.19

Baseline for Geographical Scope is National Scope. Baseline for Industry is Chemicals

Robust standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.2.: Average Marginal Effects for models predicting early exit from cartels with control variables included

	(1)	(2)	(3)	(4)	(5)
Late entry	0.148**	0.146**	0.161***		0.132**
	(0.0451)	(0.0443)	(0.0451)		(0.0429)
Number of members	0.0179*	-0.00286	0.0149*	0.0206**	0.00134
	(0.00720)	(0.00618)	(0.00704)	(0.00723)	(0.00513)
Cartel coverage	-0.378*			-0.463**	
	(0.159)			(0.163)	
Market share	-0.249	-0.467**	-0.242	-0.446*	
	(0.162)	(0.165)	(0.153)	(0.174)	
Full leniency	0.0664	0.0486	0.0605	0.0580	0.0823
	(0.0630)	(0.0599)	(0.0641)	(0.0688)	(0.0530)
Global	0.0292	-0.0141	0.0349	0.0584	-0.0595
	(0.0648)	(0.0570)	(0.0632)	(0.0673)	(0.0558)
Europe-wide	0.0717	0.0463	0.0718	0.109†	-0.00121
	(0.0620)	(0.0626)	(0.0625)	(0.0612)	(0.0571)
Regional	-0.0231	0.102	0.0754	-0.0146	-0.00886
	(0.0776)	(0.0764)	(0.0773)	(0.0741)	(0.0687)
Food and agriculture	0.0867	0.0448	0.112	0.108	-0.0545
	(0.101)	(0.0941)	(0.103)	(0.114)	(0.0650)
Manufacturing	0.0473	0.0421	0.0299	0.0566	0.0176
	(0.0515)	(0.0471)	(0.0498)	(0.0537)	(0.0420)
Metals	0.158†	0.0814	0.181†	0.171*	0.182*
	(0.0889)	(0.0831)	(0.0942)	(0.0873)	(0.0800)
Other	0.0681	0.0849	0.104	0.0618	0.112
	(0.0847)	(0.0879)	(0.0885)	(0.0862)	(0.0931)
Observations	328	379	328	328	478

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.3.: Probit models predicting late entry for firms with control variables included

	Model 1	Model 2	Model 3
Number of members	0.0476	0.0503*	0.134***
	(0.0330)	(0.0254)	(0.0193)
Cartel coverage	-1.991**		
	(0.726)		
Market share	-4.898***	-4.757***	
	(1.088)	(1.039)	
Global	0.594†	0.624*	0.547*
	(0.326)	(0.297)	(0.268)
Europe-wide	0.754**	0.783**	0.911***
	(0.274)	(0.272)	(0.244)
Regional	0.109	0.556†	0.627*
	(0.383)	(0.300)	(0.260)
Food and agriculture	0.177	0.318	0.0356
	(0.439)	(0.420)	(0.373)
Manufacturing	0.300	0.170	-0.0412
	(0.233)	(0.207)	(0.164)
Metals	0.279	0.365	-0.0462
	(0.284)	(0.259)	(0.234)
Other	-0.236	0.0255	-0.119
	(0.380)	(0.344)	(0.309)
Constant	0.806	-1.039**	-2.210***
	(0.789)	(0.384)	(0.308)
Observations	328	379	478
r2_p	0.232	0.247	0.183
ll	-135.5	-159.8	-230.9
chi2	47.46	61.51	89.85

Baseline for Geographical Scope is National Scope. Baseline for Industry is Chemicals
Robust standard errors in parentheses
† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.4.: Average marginal effects for probit models predicting late entry for firms with control variables included

	(1)	(2)	(3)
Number of members	0.0112	0.0121*	
	(0.00769)	(0.00605)	
Cartel coverage	-0.467**		
	(0.166)		
Market share	-1.149***	-1.141***	
	(0.221)	(0.220)	
Global	0.131†	0.137*	0.0729
	(0.0704)	(0.0615)	(0.0522)
Europe-wide	0.173**	0.179**	0.228***
	(0.0571)	(0.0557)	(0.0520)
Regional	0.0204	0.119†	0.406***
	(0.0730)	(0.0652)	(0.0760)
National	0	0	0
	(.)	(.)	(.)
Chemicals	0	0	0
	(.)	(.)	(.)
Food and agriculture	0.0410	0.0788	-0.134
	(0.105)	(0.108)	(0.0848)
Manufacturing	0.0719	0.0407	-0.000588
	(0.0567)	(0.0501)	(0.0482)
Metals	0.0666	0.0911	0.175*
	(0.0703)	(0.0681)	(0.0731)
Other	-0.0483	0.00589	-0.158*
	(0.0740)	(0.0797)	(0.0669)
Observations	328	379	478

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.5.: Logit models predicting agreement types

	(1) Price fixing	(2) Bid rigging	(3) Territorial allocation	(4) Customer allocation	(5) Quota allocation
main					
Number of members	0.704†	0.286†	-0.147	0.102	0.0404
	(1.84)	(1.95)	(-0.88)	(0.96)	(0.32)
Share coefficient of variation	-3.460†	-0.877	2.825	-0.750	3.293*
	(-1.79)	(-0.62)	(1.62)	(-0.69)	(2.09)
Global	omitted	-2.140*	2.889	-2.825**	3.020**
		(-2.06)	(1.49)	(-3.03)	(2.91)
Europe-wide	2.712*	-2.670**	1.751	-0.570	0.217
	(2.09)	(-2.72)	(0.81)	(-0.75)	(0.20)
Regional	2.355	-2.210	baseline	-0.964	omitted
	(1.60)	(-1.61)		(-0.96)	
Food and agriculture	3.599	-0.323	2.276	0.438	-1.727
	(1.61)	(-0.22)	(1.22)	(0.39)	(-1.18)
Manufacturing	1.058	2.376*	0.786	-0.342	-1.711†
	(0.55)	(2.50)	(0.75)	(-0.49)	(-1.75)
Metals	0.572	-0.550	1.737	-0.805	0.349
	(0.24)	(-0.30)	(1.05)	(-0.73)	(0.28)
Other	omitted	0.621	2.094	-1.307	omitted
		(0.37)	(1.16)	(-0.89)	
Constant	-3.032	-1.605	-5.664*	0.875	-3.632*
	(-0.99)	(-1.28)	(-2.19)	(0.82)	(-2.53)
Observations	37	75	59	75	65

Baseline for Geographical Scope is National Scope except for Territorial Allocation where regional used due to omission of national scope cartels.
Baseline for Industry is Chemicals
t statistics in parentheses
† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table B.6.: SUR model predicting agreement types, excluding market share coefficient of variation

	Price fixing	Bid rigging	Territorial allocation	Customer allocation	Quota allocation
Number of members	0.0269*	0.0178	0.00230	0.0159	0.0214
	(0.0110)	(0.0126)	(0.0125)	(0.0165)	(0.0138)
Global	0.290**	-0.286*	0.341**	-0.401**	0.415**
	(0.102)	(0.117)	(0.116)	(0.153)	(0.128)
Europe-wide	0.239*	-0.401***	0.183	-0.0507	0.0951
	(0.0995)	(0.114)	(0.112)	(0.149)	(0.125)
Regional	0.129	-0.328*	0.117	-0.221	-0.0360
	(0.131)	(0.149)	(0.148)	(0.195)	(0.164)
Food and agriculture	0.0412	-0.179	0.155	-0.0358	-0.305†
	(0.127)	(0.145)	(0.143)	(0.190)	(0.159)
Manufacturing	-0.218**	0.333***	0.0921	-0.0101	-0.393***
	(0.0778)	(0.0890)	(0.0880)	(0.116)	(0.0976)
Metals	-0.170	-0.0114	0.117	-0.178	-0.107
	(0.135)	(0.154)	(0.152)	(0.202)	(0.169)
Other	-0.394*	0.0564	0.312†	-0.205	-0.436*
	(0.159)	(0.182)	(0.180)	(0.238)	(0.200)
Constant	0.629***	0.291*	-0.125	0.509**	0.287†
	(0.117)	(0.134)	(0.133)	(0.175)	(0.147)
Observations	91				
r2	0.261	0.283	0.111	0.143	0.384
ll	-162.7				
chi2	32.12	36.00	11.38	15.22	56.71

Baseline for Geographical Scope is National Scope. Baseline for Industry is Chemicals

Standard errors in parentheses

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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