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Abstract

CHAPTER 1 (with Robert C. Marshall, Leslie M. Marx and Lily Samkharadze): *Buyer Resistance for Cartel versus Merger*

Procurement practices are affected by uncertainty regarding suppliers' costs, the nature of competition among suppliers, and uncertainty regarding possible collusion among suppliers. Buyers dissatisfied with bids of incumbent suppliers can cancel their procurements and resolicit bids after qualifying additional suppliers. Recent cartel cases show that cartels devote considerable attention to avoiding such resistance from buyers. We show that in a procurement setting with the potential for buyer resistance, the payoff to firms from forming a cartel exceeds that from merging. Thus, firms considering a merger may have an incentive to collude instead. We discuss implications for antitrust and merger policy.

CHAPTER 2: *Collusive Price Announcements with Strategic Buyers*

The international vitamins cartel that operated in the 1980s and 90s issued coordinated public price announcements in an attempt to influence prices. This was done in an environment where buyers had the ability to take incremental actions to increase competition among the sellers. A particularly striking feature of the price announcements was their arrival in gradual increments which, in turn, served to raise transaction prices gradually. Motivated by these observations, this paper constructs a two period dynamic model of (explicitly) collusive price announcements, featuring a buyer who can (at a cost) increase competition in the procurements it conducts by qualifying a non-cooperative "outside" seller. In this setting, the paper shows that there exists an explicitly collusive mechanism that for an interesting range of parameter values exhibits gradually increasing price announcements, resulting in transaction prices that rise gradually. Moreover, the cartel in our model obtains payoffs greater than those under competition by submitting bids that are completely indistinguishable from non-cooperative bids. Thus, the paper not only formalizes the notion that a cartel may raise prices gradually to counter buyer "resistance", but also highlights the role of a cartel's price announcements in doing so. Understanding the latter aspect of collusive pricing is of particular interest because issuing public price announcements can be consistent even with non-cooperative conduct.

CHAPTER 3: *Collusion in Auctions with Endogenous Quantity: A Numerical Exploration*

The effects of the presence of a non all-inclusive bidding ring on the outcome of endogenous demand procurements is explored. We build on Hansen (1988), where a buyer with a publicly known demand curve conducts a procurement, and the quantity transacted is a function of the bids. In a first-price procurement (FPP) the per unit transaction price equals the lowest bid and the quantity transacted corresponds to that price.

The transaction price and quantity are determined analogously in a second-price procurement. Numerical results show that irrespective of the underlying demand curve, the buyer and the non-cartel bidder prefer the endogenous demand FPP over the endogenous demand SPP. However, while the cartel prefers the SPP over the FPP for relatively *inelastic* demand curves, for *sufficiently elastic* demand curves it prefers the FPP over the SPP. The numerical exercises also suggest that although the payoff for two out of three sellers to form a cartel is *lower* in a FPP than an SPP when demand is relatively inelastic, when demand is sufficiently elastic, the incentive to form such a cartel is *higher* in an FPP than an SPP.

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To Raji paati...

Chapter 1

Buyer Resistance for Cartel versus Merger

1.1 Introduction

In the late 1800s, although neither mergers nor cartels were illegal,[1] many firms chose to form a cartel rather than merge.[2] Although cartels in this period did not need to hide their existence to avoid prosecution, they operated in a clandestine manner to disguise their presence from their customers.[3] This suggests that a key benefit of cartel formation versus merger is that a cartel can take advantage of customer beliefs that the policing action of competition is still in place.

Procurements commonly include an element of "buyer resistance," whereby buyers that are concerned that the policing action of competition is not adequate can resist high prices. As shown through a review of municipal procurements (see Appendix A), which are typically organized as sealed-bid competitive procurements, buyer resistance to high prices often comes in the form of buyers rejecting all bids in an initial procurement and then after some delay holding a new procurement with additional bidders present.[4] Colluding firms often face buyer resistance that limits their ability to implement collusive price increases.[5]

Considering the tradeoffs between merger and cartel formation, a merged entity does

[1]Mergers as an effort to monopolize were not recognized as a violation of the law until the resolution of *Northern Securities v. U.S.* (197 U.S.400) (hereafter *Northern Securities*) in 1904. The operation of a cartel was not recognized as a violation until decisions of 1897 and thereafter (Bittlingmayer, 1985, p.77).

[2]As described by George Bittlingmayer, 1985, p.77: "Perhaps as much as one-half of U.S. manufacturing capacity took part in mergers during the years 1898 to 1902. These mergers frequently included most of the firms in an industry and often involved firms that had been fixing prices or that had been operated jointly through the legal mechanism of an industrial trust. ... The Sherman Antitrust Act was passed in 1890, and the first crucial decisions making price fixing illegal – *Trans-Missouri* (1897), *Joint Traffic* (1898), and *Addyston* (1899) – occurred just before or during the first stages of the merger wave. Merger of competing firms remained unchallenged until 1904."

[3]See Hylton (2003, pp.30–37).

[4]The ability of federal procurement officials to reject all bids is formalized in the U.S. Federal Acquisition Regulations, which state: "Invitations may be cancelled and all bids rejected before award but after opening when ... (6) All otherwise acceptable bids received are at unreasonable prices, or only one bid is received and the contracting officer cannot determine the reasonableness of the bid price; (7) The bids were not independently arrived at in open competition, were collusive, or were submitted in bad faith." (U.S. Federal Acquisition Regulations, Section 14.404 Rejection of bids, https://www.acquisition.gov/Far/reissue/FARvol1ForPaperOnly.pdf)

[5]In the Vitamins Cartel, which included firms BASF, Roche, and Daiichi, "When BASF's customers resisted the increase, Roche supported the rise by also announcing an increase.... According to Daiichi, the concerted increase was unsuccessful because of customer resistance...." (EC Decision in *Vitamins*, par. 325) In the Cartonboard Cartel, where colluding firms sold product to packaging manufacturers referred to as converters, "The converters have on some occasions resisted a proposed price increase for cartonboard on the ground that their own customers would in their turn refuse to accept a price increase for packaging ...." (EC Decision in *Cartonboard*, par. 19)

not incur costs associated with disguising its existence from its customers, and a merged entity does not have to overcome the difficulties faced by cartels associated with incentives for cartel members to secretly deviate from the terms of a collusive agreement (see Stigler, 1964). Thus, in the absence of agency problems and transaction costs inherent in large firms as in Williamson (1985) or Coase (1937), one might expect a merged entity to be able to duplicate any actions that a cartel can undertake and also potentially take additional actions that a cartel cannot. However, a clandestine cartel may be able to take advantage of customer beliefs that the policing action of competition might still be in place, and thus may face reduced buyer resistance.

In this paper, we examine whether one can understand the decision by firms to form a cartel rather than merge as an equilibrium response to buyer resistance. We consider a model in which firms have an opportunity to merge, collude, or remain noncooperative and in which there is a procurement process with the possibility for buyer resistance, which we model as the ability of the buyer to reject initial bids and hold a new procurement after inviting additional bidders to participate.[6]

As we show, firms may find a cartel structure to be more profitable than a merger when customers are uncertain as to whether nonmerged firms are operating as a cartel or not. We show that in an environment where buyers are strategic, firms prefer to collude rather than merge.

We are able to quantify the expected payoff gain from collusion versus a merger within the context of our model. We show that the incremental payoff from collusion relative to a merger with no cost efficiencies can be substantial and that the efficiency effects of a merger may not be sufficient to offset these gains. Evidence from prosecuted cartels is consistent with a choice of collusion over merger. For 44% of industrial cartel cases reported by the European Commission between 2001 and 2010, in the period after the end of the illegal conduct, some subset of cartel firms were involved in mergers, acquisitions, or joint ventures. Clearly, merger efficiencies were inadequate during the cartel period to induce these firms to choose merger over cartel, although such a choice was apparently feasible.

Furthermore, the evidence is consistent with the benefit to firms from merging being reduced by buyer resistance. Considering the 25 EC decisions for industrial cartels in the period 2001–2005, we classify the demand side of the market as relatively concentrated or

[6] In Section 1.2, we discuss the details of one such episode that received attention in the landmark Addyston Pipe conspiracy. For additional examples, see Appendix A.1.1.

relatively fragmented based on the information in the EC decisions. If significant buyer resistance is less likely from fragmented buyers, then firms will have more of an incentive to merge when buyers are fragmented. Consistent with this, in our sample we find that a merger, acquisition, or joint venture among the former co-conspirators is more than twice as likely when the buyers are fragmented than when they are concentrated.[7]

While cartels and horizontal mergers have been widely studied in the past,[8] there is not much work that addresses these two forms of industrial organization as potential alternatives for incumbent firms.[9] An exception is Bittlingmayer (1985), which directly addresses why many firms preferred colluding over merging in the past. Building on Sharkey (1973), Bittlingmayer (1985) emphasizes the role of fixed costs in industries with a small number of firms and uncertain demand. Bittlingmayer argues that a cartel may be a cheaper form of organization than a merger in cyclical industries, where costs can be recovered during periods of high demand and cooperation between firms is required only occasionally when demand is low.[10]

Our paper is also related to the literature examining whether a merger might trigger entry.[11] In our model, a cost to firms that merge rather than forming a cartel is that buyers respond to the merged market structure by being more likely to encourage entry. The Horizontal Merger Guidelines of the U.S. Department of Justice and Federal Trade Commission recognize the issue of merger-induced entry with discussion of how such entry affects their evaluation of proposed mergers. Werden and Froeb (1998) use merger simulations to show that in the absence of significant efficiency gains, mergers by price-setting

[7]For additional details, see Tables A.2 and A.3 in Appendix A.

[8]On cartels, see the survey article by Levenstein and Suslow (2006) and the references therein. On mergers, see the survey article by Mookherjee (2006) and the references therein.

[9]One could offer a Coasian (1937) explanation for the choice between a cartel and a merged entity. The trade-off between the costs of maintaining and operating a cartel versus the cost of running a large merged entity due to, say, diseconomies of scale or agency problems, is likely to influence the "merge or cartelize" decision for firms. See Nocke and White (2007) for the effects of vertical mergers on incentives to collude and Kovacic et al. (2009) for effects of horizontal mergers. For an examination of the tradeoff between merger and predation, see, e.g., Persson (2004).

[10]Bittlingmayer (1985)also argues that early antitrust decisions against cartels raised the cost of maintaining cartels, which left firms with merger as the next best option and resulted in the first large-scale merger wave in the U.S. between 1898 and 1904.Stigler (1950) suggests that firms in the past might have preferred to cartelize rather than merge due to the obstacles posed by large capital requirements for mergers. Stigler argues that mergers became feasible because of the development of a sound market for securities by the New York Stock Exchange at the end of the 19th century and the removal of restrictions on the formation of large corporations after 1880.

[11]The literature has foundations in the literature on incentives for horizontal mergers, including Salant et al. (1983), Perry and Porter (1985), Deneckere and Davidson (1985), and Farrell and Shapiro (1990).

firms may not induce entry, implying that competition authorities cannot rely on entry to remedy anticompetitive effects from mergers. Spector (2003) extends this work, establishing conditions under which, in the absence of efficiency gains, any profitable merger decreases welfare even if it does induce entry. In contrast, Cabral (2003) shows that with endogenous entry, the possibility of post-merger entry substantially improves the effect of a merger on consumer welfare, and Davidson and Mukherjee (2007) show that with endogenous entry, under certain conditions, all privately beneficial mergers are socially beneficial.[12]

In additional related literature, in a durable goods environment, Ausubel and Deneckere (1987) show that a cartel has the commitment power to maintain static monopoly prices while a monopolist lacks this ability. Thus, industry profits are higher when incumbent firms collude rather than merge.[13] Ganslandt et al. (2012) consider whether merger choices can be affected by the sustainability of collusion post merger, showing that mergers that create moderate asymmetries may facilitate collusion when there is an indivisible cost of collusion.

The remainder of this paper is organized as follows. Section 1.2 provides motivating background and empirical evidence. Section 1.3 presents our model. Section 1.4 provides our results. Section 1.5 considers merger efficiencies. Section 1.6 concludes.

1.2 Background

The *U.S. v. Addyston Pipe and Steel Co.*[14] case of 1898 is considered to be a landmark event in antitrust history (Bittlingmayer, 1982). In 1894, six southern manufacturers of cast iron pipes,[15] which are used to transport water and gas by cities and municipalities, entered

[12]Pesendorfer (2005) analyzes a dynamic model in which there is gradual (exogenous) entry over time and endogenous merger decisions, showing that mergers that are not profitable in the short run can be profitable in the long run if they lead to additional mergers in the future, even in the absence of merger efficiencies. Marino and Zábojník (2006) focus on the speed of post-merger entry. See Berger et al. (2004) for empirical work examining mergers and acquisitions (M&As) in banking and finding that M&As are associated with statistically and economically significant increases in the probability of entry.

[13]In the same paper, Ausubel and Deneckere (1987) also show that the monopolist gains the ability to commit to maintaining future prices at the static monopoly level if there is a potential entrant at each time period.

[14]*U.S. v. Addyston Pipe and Steel Co.*, 85 Fed. 271 (6th Cir. 1898) (hereafter *Addyston*). See also *U.S. v. Addyston Pipe & Steel Co.*, 175 U.S. 211 (1899).

[15]The firms involved were: Addyston Pipe and Steel Company, Dennis Long & Co., Howard-Harrison Iron Company, Anniston Pipe and Foundry Company, South Pittsburgh Pipe Works, and Chattanooga Foundry

into a conspiracy.[16] Before a procurement, the cartel members would participate in a pre-auction knock-out, bidding on the per-ton bonus payment they would make into the cartel pool. The winner – the firm that bid the highest per-ton bonus payment – would represent the cartel in the actual procurement and bid an amount fixed by the "representative board" of the cartel.[17] The other cartel members would "protect" this bid by submitting phantom bids.[18]

After about two years of operation, suspicion about the existence of the cartel was raised when at a procurement in Atlanta, cartel members that were within a hundred miles of the city bid one to two dollars higher than a noncartel company (R.D. Wood & Co.) that was a thousand miles away. All bids were rejected as being too high and a new procurement was held. Anniston (for whom Atlanta was reserved) then bid considerably lower than its original bid, suggesting that bids were not competitive in the first instance.[19]

An initial civil suit against the defendants in 1896 was decided in favor of the cartel, but in a landmark 1898 verdict, Howard Taft declared the cartel illegal.[20] The *Addyston* case, along with the railroad cartel cases involving the Trans-Missouri Freight Association and the Joint Traffic Association,[21] was instrumental in defining illegal collusion under Section 1 of the Sherman Act (Bittlingmayer, 1985).

Cartels were not illegal under the common law that existed before the Sherman Act,[22] although agreements among cartel members may have been deemed unenforceable if

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and Pipe Works.

[16]The cartel divided the U.S. into two territories, Pay Territory and Free Territory. For every ton of pipe shipped into the Pay Territory by a member, the member made a payment, referred to as a bonus payment, into a pool. For shipments into the Free Territory, no bonus payments were necessary. The cartel "reserved" certain cities for particular cartel members, which meant that other cartel members would not meaningfully compete for any contract with the designated cartel members in those cities. At the end of every month, the bonus payments made by the members were tallied and divided among the members based on their capacities. Transcript of Record of the Supreme Court of the United States, October Term 1899, No. 51, *Addyston Pipe and Steel et al. vs The United States* (hereafter *Addyston* Transcript of Record), p.296.

[17]*Addyston* Transcript of Record, p.70.

[18]*Addyston* Transcript of Record, p.296.

[19]*Addyston* Transcript of Record, p.299.

[20]The Supreme Court upheld the decision in 1899 in the first unanimous decision in a Sherman Act case (Whitney, 1958).

[21]*U.S. v. Trans-Missouri Freight Association*, 166 U.S. 290 (1897) (hereafter *Trans-Missouri*); *U.S. v. Joint Traffic Association*, 171 U.S. 505 (1898) (hereafter *Joint Traffic*).

[22]According to Hylton (2003, p.37), "no common law action for conspiracy to restrain trade existed." Thorelli (1954, p.53) argues that "the vast majority of cases at common law were private suits between parties to restrictive arrangements." For a more detailed discussion see Thorelli (1954, pp.36–53).

their primary function was restraint of trade (Jones, 1921, p.17; Hylton, 2003, pp.30–37). The Sherman Act of 1890 made cartel agreements criminal offenses and thus a matter for public enforcement authorities.[23]

While the *Addyston*, *Trans-Missouri,* and *Joint Traffic* verdicts set precedents for *collusion* being a criminal offense under the Sherman Act, in 1904 the *Northern Securities* verdict set a precedent for *merging* to form a monopoly being an offense under the Act.[24] In fact in 1895, in *U.S.v. E.C. Knight,* the Supreme Court decided in favor of the American Sugar Refining Company, which was a virtual monopoly formed through the consolidation of sugar refineries.[25] Thus, there was a period between 1895 and 1904 when a large consolidation was not deemed illegal by the Supreme Court, but a cartel was.

In a little more than a year after the antitrust decision against the *Addyston* cartel by the Sixth Circuit in 1898, the cartel members merged in 1899 to form the United States Cast Iron Pipe and Foundry Company (USCIP&F).[26] The firms initially chose collusion over merging, and only upon being prosecuted for collusion did they decide to merge. In fact, prior to the first wave of industrial mergers, which happened between 1898 and 1904, the chosen form of cooperation among firms in a wide range of industries seems to have been collusion rather than merger (Jones, 1921, p.6).

A review of the ten largest (in net value) manufacturing industry groups according to the U.S. census of 1900, shows that at least eight of those ten industry groups include industries in which firms that had previously cartelized went on to merge. (See Appendix A.) For example, in the meat packing industry, cartel members agreed to merge just ten days after their cartel was disrupted by a Department of Justice investigation.[27]

For more recent evidence, we review the European Commission decisions in cartel

[23]See Hylton (2003, pp. 90-104) for a detailed discussion of the Sherman Act and the common law principles.

[24]*Northern Securities v. U.S.*,197 U.S. 400, was an historic Supreme Court case under the Sherman Act involving the merger of major railroad companies, which lead to the creation of Northern Securities. In 1904, the merged entity was dissolved.

[25]*U.S. v. E.C. Knight*, 156 U.S. 1 (hereafter *E.C. Knight*).

[26]Whitney (1958, vol. 2, p.7). The event involved the merger of more than two firms and so might also be referred to as a consolidation.

[27]Whitney (1958, vol. 1, p.33). As an example from the "chemicals and allied products" industry group, there was a cartel in gunpowder manufacturing called the Gunpowder Trade Association from 1872 to 1902 (by which time 95% of the industry was in the association). In 1902, Du Pont Co. took over the second-largest manufacturer, Laflin & Rand, which was also part of the association. This and subsequent mergers were consistent with the advice of Du Pont's lawyers, who cited *Addyston* as an example of collusion being perceived as illegal and cited *E.C. Knight*, where consolidation resulting in a virtual monopoly was allowed, as an example of a merger being less likely to be prosecuted (Bittlingmayer, 1985).

cases available on the European Commission website. (See Appendix A.) We focus on the 55 industrial cartel decisions between 2001 and 2010 for which there is a published decision. For these cases, we find evidence of mergers, acquisitions, or joint ventures among at least two of the co-conspirators after the end of the cartel period in 24 (44%) of the cases. Thus, it seems that when authorities take away collusion as an option, firms sometimes turn to mergers, acquisitions, or joint ventures as second-best options.[28]

For the 25 EC decisions for industrial cartels issued in years 2001–2005, we classify the demand side of the market (i.e., parties purchasing from the cartel) as relatively concentrated or relatively fragmented, with the expectation that significant buyer resistance is more likely to come from relatively concentrated buyers. Among the cases where significant buyer resistance was less likely, 45% have mergers, acquisitions, or joint ventures among at least two of the co-conspirators after the end of the cartel period, but only 20% among the cases where significant buyer resistance was more likely. This evidence is consistent with the results of this paper showing that the payoff to merging (or other observable coordination) is reduced in environments with buyer resistance.

1.3 Model

1.3.1 Overview

We begin by considering a benchmark model that does not account for merger efficiencies, and then we introduce merger efficiencies.

We consider a procurement setting with a buyer, two incumbent sellers, and one potential new seller. In terms of the number of players, this is minimal if we are going to allow for buyer resistance by a strategic buyer that enhances competition by inviting a previously unqualified seller to participate.

We consider two coordination regimes, one in which sellers must compete noncooper-

[28] It is also possible for a merger to trigger the detection of a cartel. For example, cartel conduct may be detected during the due diligence process by the purchaser or evidence of collusion may be identified during the merger investigation. Thus, one must be cautious about inferring causality. One might hypothesize that if a proposed merger caused a cartel to be detected, then one of the merging cartel firms would likely be the first leniency applicant in the case. In the 55 EC decisions in industrial cartel decisions between 2001 and 2010, we identify 24 cases with subsequent merger activity. In 2 of those 24 cases (*Food Flavour Enhancers* and *Methacrylates*), the merger activity we identify (see Appendix A) involves a firm that received a 100% reduction in fines based on a leniency application. Thus, there remains substantial evidence consistent with merger activity following from the dissolution of collusive activity.

atively and another in which sellers may form a cartel or merge. If the sellers merge, this is observed by all players. If the sellers do not merge, then the sellers observe whether a cartel has been formed, but the buyer does not and so is uncertain about the existence of a cartel. The cost state for the sellers is either low cost or high cost. The cost state is observed by the sellers but not by the buyer. The buyer purchases through a competitive procurement, but the buyer retains the right to suspend the procurement and invite the potential new seller as a bidder.[29] It is costly to the buyer to do this, but it may allow the buyer to obtain a better price.

After observing the initial bids, the buyer forms beliefs about the cost state and whether there is collusion. There is a cost to the buyer of reprocurement, so if the cost state were known to be high, then there would be nothing to be gained from reprocurement and the buyer would be better off accepting high initial bids. But if the cost state is low, then the buyer may prefer to reject high initial bids because of the potential for obtaining a lower price through reprocurement. Firms would like to submit high bids but are disciplined by the threat that the buyer might reject the bids and qualify additional sellers in response.

We show that in this model, the two incumbent sellers are able to obtain higher profits if they form a cartel than if they merge. Relative to the case of merged firms, when nonmerged firms submit high bids, the buyer, who is uncertain about the existence of the cartel, attaches a greater probability to high bids being the result of high costs. Thus, given that the new seller only reduces the buyer's expected payment in a low-cost environment, the buyer is less likely to incur the cost to invite the new seller when a cartel (whose existence is not observable to the buyer) submits a high bid compared to when a merged entity submits a high bid. As a result, in the absence of merger efficiencies, firms find it more profitable to collude than to merge.

1.3.2 Framework

There is one buyer that wishes to procure a single item by means of a first-price procurement. We assume the buyer has value greater than 1 for the item. There are three potential sellers: two incumbent sellers, which we label seller 1 and seller 2, and one new potential seller, which we label seller 3. We assume that with probability $\rho \in (0, 1)$, the cost state is low and each seller i has cost zero, and that with probability $1 - \rho$, the cost state is high

[29] For other approaches to modeling buyer resistance, see Harrington and Chen (2006) and Marshall et al. (2008).

and all sellers' costs are equal to 1. Sellers observe whether they are in the low-cost or high-cost state, but the buyer does not. The buyer knows that costs are bounded above by one and so does not accept bids greater than 1.

We assume that with probability $\xi \in (0,1)$, sellers 1 and 2 are able to form a cartel or merge if they so choose. However, with probability $1-\xi$, communication costs or other organizational impediments (or, in the case of collusion, aversion to illegal activity) prevent sellers 1 and 2 from being able to form a cartel or merge. The sellers observe whether the environment permits them to form a cartel or merge, but the buyer does not, although if the sellers choose to merge, that is observed by the buyer.

We assume that the buyer can qualify seller 3 to participate as a bidder and reconduct the procurement at cost $k > 0$ to the buyer.[30]

The timing and information in the model is as follows:

Stage 0 (industry structure): The cooperation state determining the ability of the sellers to form a cartel or merge is realized and observed by the sellers but not by the buyer: cartel or merger is possible with probability ξ and not possible with probability $1-\xi$. If the formation of a cartel or merger is possible, then sellers 1 and 2 choose between merging and forming a cartel.[31] A decision to merge is observed by all players. A decision by sellers 1 and 2 to form a cartel is observed by the sellers, including seller 3, but not by the buyer. The state of the sellers' costs is realized and observed by the sellers but not by the buyer: low with probability ρ and high with probability $1-\rho$.

Stage 1 (initial bidding): The buyer announces a procurement and all players observe the buyer's reprocurement cost k. Sellers costs are determined by the cost state.[32] A

[30] In many industries potential suppliers have to be pre-qualified before they are allowed to participate in the procurement. Supplier qualification process is usually costly for the procurer as it typically involves verification of quality and reliability requirements, on-site visits, and verification of insurance coverages and credit-worthiness. By limiting job size or otherwise redefining procurement terms, buyers may be able to encourage entry by alternative suppliers.

[31] We can also allow the firms to have the option of choosing to remain as noncooperative bidders, but in equilibrium this option is not chosen.

[32] If the cost state is realized prior to the sellers' choice of industry organization, then the sellers are indifferent between merging, colluding, and remaining independent in the high-cost state. If we suppose some small cost to the sellers to merge or collude, then firms in the high-cost state would prefer to remain independent. In that case, upon observing nonmerged firms, the buyer would believe it is either facing a cartel in the low-cost state or noncooperative firms. The buyer's posterior belief on the low-cost state following a bid of 1 would be the same as described above, so the equilibrium of the continuation game would be unchanged.

merged entity or cartel bids to maximize the joint payoff of the merged or colluding sellers. In the noncooperation state, sellers bid noncooperatively.

Stage 2 (evaluation of bids): After observing the bids, the buyer decides either to make an award to the low bidder at the amount of its Stage-1 bid or to void the initial bids and incur cost k to reconduct the procurement with seller 3 as an additional qualified bidder, in which case Stage 3 is reached.

Stage 3 (reprocurement): Sellers submit bids (the cost state remains the same), with seller 3 bidding noncooperatively, and the buyer makes an award to the low bidder at the amount of its Stage-3 bid.

We use Perfect Bayesian Equilibrium (PBE) as our solution concept.[33] In analyzing the equilibria of this game, it will be useful to break it into two separate games. We define the "merger game" to be the game above but with $\xi = 1$ and where the sellers' are required to merge. We define the "cartel game" to be the game above, but where sellers are required to act as a cartel when the cooperation state allows them to do so. This allows us to analyze the tradeoff to sellers between merging and forming a cartel and so identify equilibria of the larger game. In particular, given a PBE of the merger game and a PBE of the cartel game, where the merged entity's expected payoff in the merger game is less than a cartel's expected payoff in the cartel game, then there exists a PBE of the larger game involving the same behavioral strategies and beliefs in which the firms choose to form a cartel when the cooperation state allows them to do so.

1.4 Results

To analyze the game, consider the stages in reverse order.

1.4.1 Stage 3: Post-entry bidding

Stage 3 is only reached if seller 3 has entered. Seller 3 knows whether it is competing against a merged entity, cartel, or two other noncooperative bidders.

[33] If the sellers always choose to collude in the favorable cooperation state, then following the observation of a merged entity, the buyer's beliefs as to the cost state are not pinned down by Bayes' Rule. However, in a Perfect Bayesian Equilibrium, Bayes' Rule is applied even following histories that have probability zero in equilibrium and so the buyer's belief on the low-cost state conditional on observing merged firms is ρ, the prior probability of the low-cost state. See Fudenberg and Tirole (1991, p.332, condition B(ii)).

In the high-cost state, each bidder has a cost of 1 and bids 1. The buyer pays 1 and all sellers have zero surplus. In the low-cost state, each bidder has a cost of 0 and bids 0. The buyer pays 0 and all sellers have zero surplus.

In what follows, to avoid uninteresting cases in which the buyer never qualifies seller 3, we assume that $k < 1$. If k is greater than 1, then the buyer prefers to accept the maximum bid of 1 in Stage 1 rather than move to Stage 3, where the buyer's expected payment is at most 0.

1.4.2 Stage 2: Evaluation of bids

Whether the buyer invites seller 3 to enter depends upon whether the firms merged in Stage 0, the reprocurement cost k, and the buyer's inferences from the observed bids regarding the cost state and collusion.

In the merger game, a bid less than or equal to k is accepted because the buyer can do no better in expectation through reprocurement.[34] A bid greater than k but less than 1 is rejected if it leads to the inference that the cost state is low because then the buyer can do better in expectation through reprocurement.

It remains to consider the buyer's response to a bid of 1. If the buyer rejects a bid of 1, its payment will be 0 or 1 depending on whether the cost state is low or high. Thus, the buyer is indifferent between accepting and rejecting the bid of 1 if

$$\Pr(\text{low cost} \mid b_m = 1) \cdot 0 + (1 - \Pr(\text{low cost} \mid b_m = 1)) \cdot 1 + k = 1.$$

Solving this for k, we get

$$k = \Pr(\text{low cost} \mid b_m = 1). \tag{1.4.1}$$

We let α_m denote the probability with which the buyer accepts a Stage-1 bid of 1 by a merged entity.

In the cartel game, noncooperative firms 0 in the low-cost state. In this case, if the buyer observes that both bids are equal to 1, it believes it is facing either a cartel in the low-cost state or it is facing bidders in the high-cost state. The buyer is indifferent between

[34]Given that we allow continuous bidding increments, there is no equilibrium in which the buyer rejects a bid of k because then the merged entity's best response would be to bid arbitrarily close to but less than k.

accepting and rejecting a bid of 1 if

$$\begin{aligned}&\Pr\left(\text{low cost and cartel} \mid b_1 = b_2 = 1\right) \cdot 0 \\ &+ \left(1 - \Pr\left(\text{low cost and cartel} \mid b_1 = b_2 = 1\right)\right) \cdot 1 + k = 1,\end{aligned}$$

where the left side is the buyer's expected cost if it rejects the bids, and the right side is the buyer's cost if it accepts a bid of 1. Solving this for k, we get

$$k = \Pr\left(\text{low cost and cartel} \mid b_1 = b_2 = 1\right). \tag{1.4.2}$$

If a buyer facing nonmerged firms receives two bids of 1, we let α_c be the probability that it accepts a randomly chosen bid and $1 - \alpha_c$ be the probability that it rejects both bids.

1.4.3 Stage 1: Initial bidding

In the initial bidding, in the high-cost state, all bids less than 1 are weakly dominated by a bid of 1, and so we have the following result.

Lemma 1. *In any PBE involving non-weakly-dominated bids, all bidders bid* 1 *in the high-cost state.*

Given Lemma 1, in any PBE involving non-weakly-dominated bids, the buyer's posterior belief on the low-cost state following a bid less than 1 is 1. Thus, it is a unique best reply for the buyer to accept bids that are less than k and reject bids that are greater than k but less than 1. It follows that in equilibrium a merged entity or cartel will never bid less than k. It also follows that in equilibrium a merged entity or cartel will never bid more than k but less than 1. To see this, note that in the low-cost state a merged entity or cartel prefers a positive bid less than k, which is accepted, over a bid that is more than k but less than 1, which is rejected. Thus, we have the following result.

Lemma 2. *In any PBE involving non-weakly-dominated bids, in the low-cost state a merged entity or cartel bids either k or* 1*.*

Given Lemma 2, we consider equilibria in which in the low-cost state the merged entity or cartel mixes between bidding k and 1, with probability β_m on a bid of 1. We consider equilibria in which a bid of k is accepted with probability 1,[35] and as described

[35]In any equilibrium in which the merged entity or cartel bids k, that bid is accepted with probability 1. If

above we let α_m be the probability with which the buyer accepts a bid of 1 from a merged entity and α_c be the probability with which the buyer accepts a bid of 1 when it receives two bids of 1 from nonmerged firms. Competitive firms bid zero in the low-cost state.

Given bidding strategy β_m, the buyer's posterior on the low-cost state following a bid of 1 from a merged entity is

$$\gamma_m \equiv \frac{\beta_m \rho}{\beta_m \rho + 1 - \rho}.$$

In equilibrium, if $\beta_m \in (0,1)$, the merged entity must be indifferent between bidding k and receiving payoff k and bidding 1 and receiving payoff 1 with probability α_m and payoff zero with probability $1 - \alpha_m$. If $\beta_m = 0$, then it must be that $k \geq \alpha_m$, and if $\beta_m = 1$, then it must be that $k \leq \alpha_m$. We can write this as

$$\alpha_m \begin{cases} \leq k & \text{if } \beta_m = 0 \\ = k, & \text{if } \beta_m \in (0,1) \\ \geq k, & \text{if } \beta_m = 1. \end{cases}$$

In equilibrium, if $\alpha_m \in (0,1)$, the buyer must be indifferent between accepting a bid of 1 and paying 1 and rejecting a bid of 1 and paying zero with probability γ_m and 1 with probability $1 - \gamma_m$ plus the reprocurement cost k, implying that $1 = 1 - \gamma_m + k$, which using the definition of γ_m implies $\beta_m = \frac{k - \rho k}{\rho - \rho k}$, which lies in $(0,1)$ if and only if $k < \rho$. If $\beta_m = 0$, then $\gamma_m = 0$, which implies $\alpha_m = 1$, which implies $\beta_m = 1$, which is a contradiction. Putting these together, we have

$$\beta_m = \begin{cases} \frac{k-\rho k}{\rho - \rho k}, & \text{if } k < \rho \\ 1 & \text{otherwise} \end{cases} \quad \text{and } \alpha_m = \begin{cases} k, & \text{if } k < \rho \\ \in [k, 1], & \text{if } k = \rho \\ 1, & \text{otherwise.} \end{cases}$$

As this shows, for high reprocurement cost, the merged entity always bids 1. Otherwise, the merged entity mixes. As the reprocurement cost increases from zero to ρ, the merged entity is increasingly likely to bid 1.

In the cartel game, similar to the case of a merged entity, there exists an equilibrium in which cartel firms submit identical bids, randomized between k and 1, with probability β_c on bids of 1. The difference is that with nonmerged firms, the buyer's posterior on the

there exists an equilibrium in which a bid of k is not accepted with probability one, then there is an outcome-equivalent equilibrium in which it is.

low-cost state following bids of 1 is

$$\gamma_c \equiv \frac{\beta_c \rho \xi}{\beta_c \rho \xi + 1 - \rho},$$

implying that

$$\beta_c = \begin{cases} \frac{k-\rho k}{\rho\xi - \rho\xi k}, & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ 1 & \text{otherwise} \end{cases} \quad \text{and } \alpha_c = \begin{cases} k, & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ \in [k, 1], & \text{if } k = \frac{\rho\xi}{1-\rho+\rho\xi} \\ 1, & \text{otherwise.} \end{cases}$$

Thus, the cartel bids 1 for a larger range of reprocurement costs relative to a merged entity. In the range of reprocurement costs where both the cartel and merged entity mix, the cartel places greater probability weight on bids of 1.

As Figure 1.4.1 shows, in the low-cost state, the cartel's expected bid is greater than the merged entity's expected bid for all values of the reprocurement cost less than ρ.

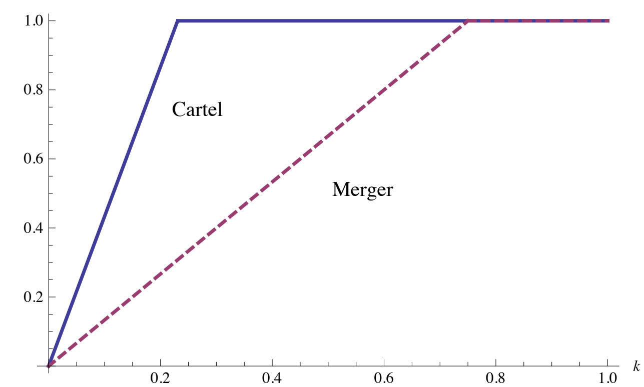


Figure 1.4.1: Expected bids in the low-cost state by a cartel and merged entity as a function of k (assumes $\rho = 0.75$, $\xi = 0.1$)

The equilibria for the cases of merged and nonmerged firms are similar. However, the key difference is that the posterior beliefs following the observation of bids of 1 differ. For the case of nonmerged firms, bids of 1 could be the result of high costs or possibly a low-cost cartel attempting to pool with the high-cost bidders. Because the cartel has the possibility to pool with high-cost noncooperative firms as well as high-cost cartels, the posterior belief on costs being low following the observation of bids of 1 is lower in the case of nonmerged firms than in the case of merged firms. That means that the buyer is more likely to accept bids of 1 made by nonmerged firms than a bid of 1 made by a merged firm. Because the buyer is more likely to accept bids of 1 made by a cartel, the cartel is more likely to submit bids of 1 than the merged entity.

1.4.4 Stage 0: Cartel versus merger

Consider Stage 0, during which the industry structure for the suppliers is determined. If the state is such that coordination is possible, firms 1 and 2 decide whether to merge or form a cartel. Conditional on k, the expected payoff from merging is

$$\rho\left(\beta_m\alpha_m + (1-\beta_m)k\right) = \begin{cases} \rho k, & \text{if } k < \rho \\ \in [\rho k, \rho], & \text{if } k = \rho \\ \rho, & \text{if } k > \rho, \end{cases}$$

and the expected payoff from forming a cartel is

$$\rho\left(\beta_c\alpha_c + (1-\beta_c)k\right) = \begin{cases} \rho k, & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ \in [\rho k, \rho], & \text{if } k = \frac{\rho\xi}{1-\rho+\rho\xi} \\ \rho, & \text{if } k > \frac{\rho\xi}{1-\rho+\rho\xi}. \end{cases}$$

Thus, for any reprocurement cost k, firms at least weakly prefer to form a cartel rather than merge, and for $k \in (\frac{\rho\xi}{1-\rho+\rho\xi}, \rho)$, the firms strictly prefer to form a cartel.

As shown in Figure 1.4.2, which depicts expected payoffs in the low-cost state, for low values of k, i.e., $k < \frac{\rho\xi}{1-\rho+\rho\xi}$, the expected payoff from merging and forming a cartel is the same. In both cases, the bidders mix between bidding k and bidding 1, and since the bid of k is accepted with probability 1 and the bid of 1 is accepted with probability k, the expected payoff for both is k. The expected payoff is also the same for high values of k, i.e., $k > \rho$, where the buyer always accepts a bid of 1 regardless of whether the bidders are merged or not. For intermediate values of k, the expected payoff from cartel is greater.

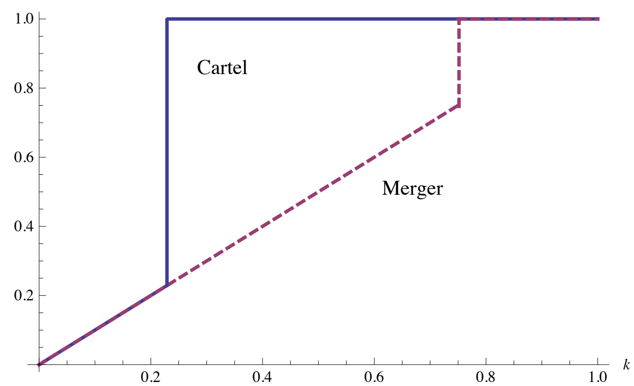


Figure 1.4.2: Expected payoffs to sellers 1 and 2 in the low-cost state as a function of k (assumes $\rho = 0.75$, $\xi = 0.1$)

In the context of our model, the incremental payoff from forming a cartel versus merging can be substantial. For example, for the parameters shown in Figure 1.4.2, in the low-cost state, the payoff from a cartel can be over three times that of a merger. If we assume k is uniformly distributed on $[0, 1]$, then under the parameters of Figure 1.4.2, in the low-cost state the expected payoff from forming a cartel is almost 50% larger than from merging. The advantage of cartel over merger varies with ρ and ξ as depicted in Figures 1.4.3 and 1.4.4. For extreme values of ρ, the probability of the low-cost state, of either zero or 1, there is no benefit to cartel over merger. The benefit to cartel comes from its affect on the buyer's posterior belief on the low-cost state following the observation of a high bid, but if there is no uncertainty about the cost state, then this effect is not present.

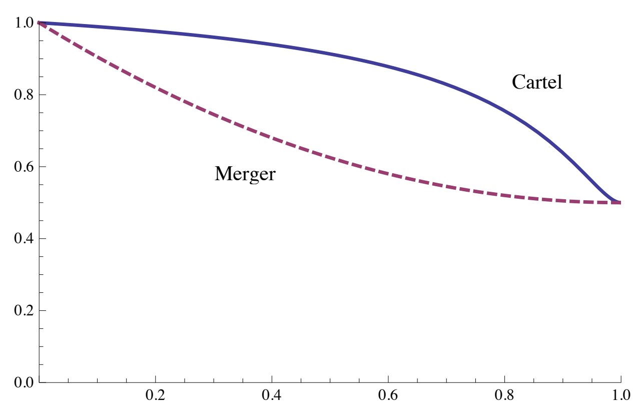


Figure 1.4.3: Expected payoffs to sellers 1 and 2 in the low-cost state as a function of ρ (assumes $k \sim U[0, 1]$ and $\xi = 0.1$)

As shown in Figure 1.4.4, the incremental benefit of forming a cartel over merging is greater when ξ, the probability that the state of the world permits collusion, is low. The cartel benefits from a buyer's belief that a cartel is unlikely and so high bids most likely reflect competitive bidders in the high-cost state.

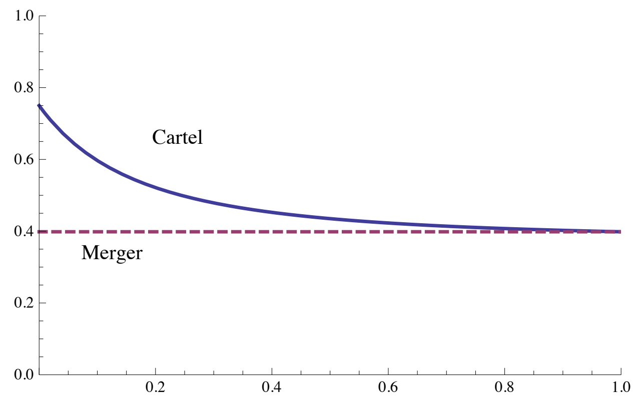


Figure 1.4.4: Expected payoffs to sellers 1 and 2 in the low-cost state as a function of ξ (assumes $k \sim U[0,1]$ and $\rho = 0.75$)

We formally state our result that the sellers are weakly better off choosing a cartel over a merger, and strictly better off for some values of k, as follows.

Proposition 3. *In the unique PBE outcome involving non-weakly-dominated bids, the continuation payoff from forming a cartel is weakly greater than from merging, and strictly greater for* $k \in \left(\frac{\rho\xi}{1-\rho+\rho\xi},\ \rho\right)$.

As we have demonstrated above, a cartel is better able to exploit the buyer's uncertainty about the state to successfully submit high bids when in the low-cost state. Additional uncertainty about the existence of a cartel leads the buyer to be more lenient in terms of accepting higher prices relative to when it faces a merged entity. Stated differently, a merged entity faces greater buyer resistance than firms operating as a cartel when the buyer is uncertain as to whether the firms are in a cartel or acting noncooperatively.

We assume a particular type of buyer resistance, namely the ability of the buyer to, at a cost, induce a third supplier to bid at the procurement. In the low-cost state, this effort on the part of the buyer reduces the price it must pay to zero. We can allow more general buyer resistance by letting R_m and R_c denote the benefit to the buyer from resistance in the low-cost state relative to paying a price of 1 when facing a merged entity and cartel, respectively. In the model of this paper, $R_m = R_c = 1$ since the presence of seller 3 reduces the price to zero in the low-cost state; however, buyer resistance might take different forms and might be differentially effective against a merged entity versus a cartel. Assuming that following a bid of one in the low-cost state, when the buyer resists, the merged entity or cartel receives an expected payment of $1 - R_m$ or $1 - R_c$, respectively, then the equilibrium in the more general model has similar characteristics to the one derived here, but the decision in stage 0 by sellers 1 and 2 whether to merge or collude depends on the effectiveness of buyer resistance vis-a-vis merged firms versus cartels.

1.4.5 Immediate qualification of seller 3

In our model, it is not a choice for the buyer to immediately qualify seller 3; however, that option can be introduced. If the buyer immediately qualifies seller 3, then it holds a single auction, buying at the lowest bid. In this extensive form, the buyer at least weakly prefers to consider bids from sellers 1 and 2 before potentially qualifying seller 3. In fact, the buyer's expected payment is lower if it holds the Stage 1 procurement without seller 3 than if it immediately qualifies seller 3, regardless of the cost state.[36] A similar result holds conditional on the buyer's observing nonmerged firms. Thus, the buyer weakly prefers to "test the waters" by soliciting bids from sellers 1 and 2 before qualifying seller 3. The buyer benefits from being able to use the information obtained in the first procurement to inform its decision about whether or not to incur the expense of qualifying an additional supplier.

[36] If the buyer immediately qualifies seller 3, its expected payment is $\rho \cdot 0 + (1-\rho) \cdot 1 + k = 1 - \rho + k$. Conditional on observing a merged entity, the buyer's expected payment in the low-cost state is

$$\begin{aligned} \beta_m \alpha_m + (1-\beta_m)k + \beta_m(1-\alpha_m)k &= \beta_m \alpha_m (1-k) + k \\ &= \begin{cases} \frac{k^2}{\rho}(1-\rho) + k, & \text{if } k < \rho \\ 1, & \text{otherwise.} \end{cases} \\ &\leq 1 - \rho + k, \end{aligned}$$

and the buyer's expected payment in the high-cost state is

$$\begin{aligned} \alpha_m + (1-\alpha_m)(k+1) &= \begin{cases} 1 - k^2 + k, & \text{if } k < \rho \\ 1, & \text{otherwise.} \end{cases} \\ &\leq 1 - \rho + k. \end{aligned}$$

1.4.6 Cartel detection

In our model a cartel has no incentive to try to disguise its presence other than using bids that mimic bids in the high-cost state. However, in the case of nonmerged firms, bids of k in Stage 1 allow the inference of collusion. In addition, Stage 3 bids that are zero when the Stage 1 bids are 1 also allow the inference of collusion in the first stage. If a cartel faced penalties from detection, either from legal enforcement or from lost future profits due to increased buyer resistance in the future (for example, the equilibrium might revert to that associated with a merged entity), then that would potentially affect cartel behavior.

As an example, suppose that any payments to a colluding firm from the buyer must be reimbursed (plus some infinitesimally small penalty paid to a regulator to avoid indifferences) if the behavior produces an inference that with probability one the cost state is low but the firms were bidding above zero because they were colluding. Then a cartel in the low-cost state will only bid 0 or 1 in the low-cost state. If a bid of 1 by the cartel is accepted, the cartel is not detected and there is no penalty, but if a bid of 1 is rejected, then the cartel's payoff is zero. In this revised model, let $\hat{\beta}_c$ be the probability weight on 1 in the cartel's strategy, $\hat{\gamma}_c$ be the buyer's posterior on the low-cost state following bids of 1, and $\hat{\alpha}_c$ be the buyer's acceptance probability. The optimality of the cartel's strategy implies that $\hat{\alpha}_c = 0$ whenever $\hat{\beta}_c < 1$, and the optimality of the buyer's strategy implies that when $\hat{\alpha}_c \in (0,1)$, the buyer is indifferent between accepting a bid of 1 and paying 1 and rejecting it and having an expected payment of $1 - \hat{\gamma}_c + k$, which implies $\hat{\beta}_c = \frac{k-\rho k}{\rho\xi - \rho\xi k}$. It follows that an equilibrium is

$$\hat{\beta}_c = \begin{cases} \frac{k-\rho k}{\rho\xi-\rho\xi k}, & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ 1 & \text{otherwise} \end{cases} \quad \text{and } \hat{\alpha}_c = \begin{cases} 0 & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ \in [0,1], & \text{if } k = \frac{\rho\xi}{1-\rho+\rho\xi} \\ 1, & \text{otherwise.} \end{cases}$$

The expected payoff for a cartel with detection concerns as modeled here, conditional on k, is

$$\rho\hat{\beta}_c\hat{\alpha}_c = \begin{cases} 0, & \text{if } k < \frac{\rho\xi}{1-\rho+\rho\xi} \\ \in [0,\rho], & \text{if } k = \frac{\rho\xi}{1-\rho+\rho\xi} \\ \rho, & \text{if } k > \frac{\rho\xi}{1-\rho+\rho\xi}. \end{cases}$$

It is clear that the expected payoff for a cartel is reduced when there are detection concerns, in particular the cartel with detection concerns has payoff 0 instead of k in the low-cost state when $k < \frac{\rho\xi}{1-\rho+\rho\xi}$, but it is still the case that the expected payoff from forming a cartel is greater than from merging when $k \in \left(\frac{\rho\xi}{1-\rho+\rho\xi},\ \rho\right)$. This size of this range is concave in ρ and decreasing in ξ. As shown in Figure 1.4.5, depending on parameters, sellers may still prefer to form a cartel even with detection concerns. The figure shows that when k is uniformly distributed on $[0,1]$, the expected payoff from forming a cartel with detection concerns exceeds that from forming a merger for values of ρ and ξ sufficiently low, i.e., when the cost-state is sufficiently likely to be low and when it is sufficiently unlikely that cartels are able to form.

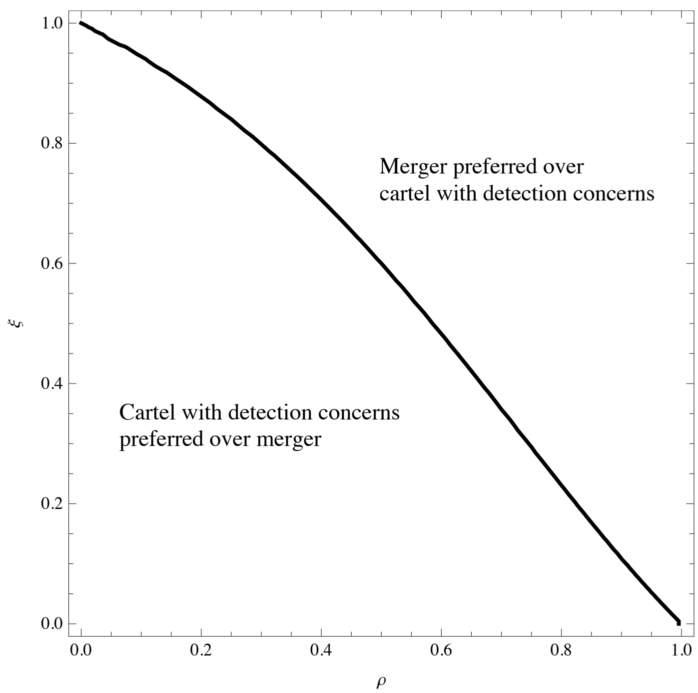


Figure 1.4.5: Parameter ranges for which the expected payoff to sellers 1 and 2 in the low-cost state is greater as a merged entity versus a cartel with detection concerns (assumes $k \sim U[0,1]$)

We conclude that even with detection concerns, as long as penalties for collusion are not too severe, low-cost cartels can continue to have an advantage over merged entities because they face less buyer resistance, enabling them to more often obtain business at high prices.

1.5 Merger efficiencies

The U.S. Horizontal Merger Guidelines state that "a primary benefit of mergers to the economy is their potential to generate significant efficiencies."[37] A prior history of collusion between merger applicants indicates that, in the past, the firms chose collusion over merger, indicating that efficiency gains were outweighed by other considerations, such as the increase in buyer resistance that comes with merger. Competition authorities may want to evaluate claims of cost efficiencies from the proposed merger in light of this history.

When authorities take away collusion as an option, firms may turn to merger as a second-best option. For example, as discussed in Section 1.2, there are many examples of mergers, acquisitions, and joint ventures among firms that were found by the European Commission to have engaged in collusion. These transactions typically do not involve all of the firms that were involved in the conspiracy, which may suggest another advantage of clandestine cartel over merger, namely that it allows the suppression of rivalry among a larger number of firms than would have been permitted through a merger. However, the evidence from the industrial merger wave of 1898 to 1904 suggests that there is a benefit to forming a clandestine cartel even when compared to a merger among all of the firms in an industry.[38]

The timing of a merger raises interesting questions. A merger following a period of collusion may reflect value to the parties from suppression of rivalry as well as from merger efficiencies, where those merger efficiencies were previously outweighed by the benefit of reduced buyer resistance from collusion. A merger that apparently does not follow a period of collusion raises the question of why any merger efficiencies are sufficient now to induce a merger, but not previously.

There are a number of ways in which one might allow for merger efficiencies within the context of our model. To offer one extreme example, consider the case in which when firms merge, the probability of the low-cost state is one.[39] We can compare the expected

[37]U.S. Horizontal Merger Guidelines, p.29, available at http://www.justice.gov/atr/public/guidelines/hmg-2010.pdf (accessed November 26, 2012).

[38]See Waehrer (1999) on incentives for firms to form smaller versus larger merged entities and Waehrer and Perry (2003) on incentives for only a subset of firms in an industry to merge in environments with strategic buyers.

[39]We have considered other ways to model this, including assuming that sellers draw their costs from the uniform distribution on $[0,1]$ in the low-cost state and that a merger with efficiencies has a cost of zero in the low-cost state. This reinforces the basic conclusion that the buyer resistance effect can outweigh even

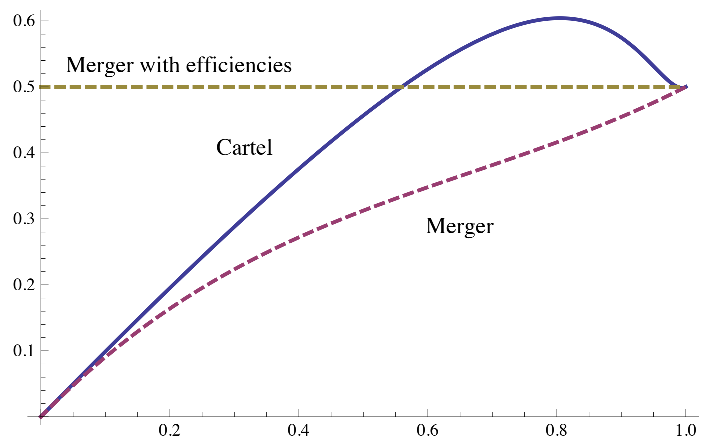


Figure 1.5.1: Expected payoffs to a cartel and merged entity with and without cost efficiencies as a function of ρ (assumes $k \sim U[0,1]$ and $\xi = 0.1$)

payoffs of a merged entity with this type of extreme cost efficiencies to a merged entity without efficiencies and to a cartel. For the purposes of this comparison, we assume that the reprocurement cost k is uniformly distributed over the interval $[0,1]$. The merged entity with extreme cost efficiencies always bids k, so the merged entity's expected payoff is $\frac{1}{2}$. The cartel's payoff for a given k is $\rho\left(\beta_c\alpha_c + (1-\beta_c)k\right)$, implying an expected payoff of

$$\begin{aligned}
\pi_c(\rho) &= \int_0^{\frac{\rho\xi}{1-\rho+\rho\xi}} \rho\left(\frac{k-\rho k}{\rho\xi - \rho\xi k}k + (1 - \frac{k-\rho k}{\rho\xi-\rho\xi k})k\right) dk + \int_{\frac{\rho\xi}{1-\rho+\rho\xi}}^1 \rho dk \\
&= \int_0^{\frac{\rho\xi}{1-\rho+\rho\xi}} \rho k dk + \int_{\frac{\rho\xi}{1-\rho+\rho\xi}}^1 \rho dk,
\end{aligned}$$

which one can show is greater than $\frac{1}{2}$ for $\rho \in \left(\frac{3+\sqrt{1-4\xi}-2\xi}{4-4\xi+2\xi^2}, 1\right)$, which is nonempty for $\xi \in \left(0, \frac{1}{4}\right)$. Thus, as long as the cooperation state that allows cartel formation is sufficiently rare, there exists $\overline{\rho} < 1$ such that cartel is preferred to merger for all $\rho \in (\overline{\rho}, 1)$.

As you can see from Figure 1.5.1, for $\xi = 0.1$, cartel formation is preferred over a merger with extreme cost efficiencies for all ρ greater than approximately 0.55. (Note that Figure 1.4.3 provides expected payoffs in the low-cost state, whereas Figure 1.5.1 provides overall expected payoffs, multiplying by the probability ρ of the low-cost state.)

seemingly significant merger efficiencies.

We conclude from Figure 1.5.1 and related calculations that the value to a clandestine cartel in terms of reduced buyer resistance relative to merger is sufficiently large that it can potentially outweigh even significant merger efficiencies.

1.6 Conclusion

It might seem that a merged entity should be able to do anything that a cartel can do, plus more, and so should earn higher profits than a cartel. But in the late 1800s, when firms were relatively unencumbered in the choice between merging or forming a cartel, many chose to function as a cartel. In a review of recent cartel cases at the European Commission, a substantial number of cartel cases are followed by mergers, acquisitions, or joint ventures among a subset of the colluding firms.

Whereas a merger is a publicly observed event, a cartel is a clandestine operation. Other noncartel firms in an industry may be aware of the existence of a cartel, but the buyers that procure from colluding firms are usually uncertain of the existence of the cartel. In a model that parallels buyer procurement practices as well as the informational environment that confronts procurement participants, we show that a cartel can hide behind the possibility that their members might be noncooperative bidders to enhance their profits relative to a merged entity.

Our model suggests that the incremental profits available to firms from collusion rather than merger can be substantial and can potentially outweigh even significant merger efficiencies.

In our model, the buyer can invoke additional competitive pressure by inviting a new firm to bid in a reconducted procurement. In practice, reserving the right to void a procurement and resolicit bids is commonplace. Overall, our analysis highlights the importance of accounting for strategic action by buyers during the procurement process. In practice, buyers are not passive but, rather, actively evaluate the competitive process during a procurement and make profit-enhancing adjustments to increase the policing function of competition as deemed appropriate.

Chapter 2

Collusive Price Announcements with Strategic Buyers

2.1 Introduction

The international vitamins cartel that operated in the 1980s and 90s issued coordinated public price announcements in order to influence prices.[1] In particular, the cartel increased prices gradually by orchestrating its price announcements to arrive in a series of small incremental steps. The announcements continued until the transaction prices peaked around the mid-1990s.[2] Once a target price was achieved the cartel's objective, evidently, was to maintain the prices at that elevated level.[3]

In fact, the use of coordinated public price announcements by cartels and the *gradual* increment of collusive prices—from a presumably non-cooperative level to a higher, potentially joint profit maximizing level—has been documented in several other industries. For instance, apart from the vitamins cartel case they were also recorded in cartel cases in cartonboard, graphite electrodes and carbonless paper.[4] This raises two quite related questions:

1. If a cartel's objective is to achieve a target price, why would it try to reach that price gradually?

2. Rather than passively accepting any price announced or posted by the sellers, large industrial buyers typically rely on competitive procurements and potentially have access to sellers worldwide. Given that not all these sellers may be part of the cartel, how does a cartel tailor its price announcements?

The questions are of particular interest for two reasons: (i) they deal with phenomema that are a commonly observed aspect of collusive conduct, and (ii) issuing public price

[1]The announcements were made in the trade publications, *Feedstuffs* and *Chemical Marketing Reporter*.

[2]See, for e.g., Figure 2.2.1, in which the solid black shapes (squares, circles etc.) represent "joint" price announcements by the cartel members for Vitamin A 650 Feed Grade, and the red dotted line below the shapes is the average transaction price for that vitamin.

[3]For e.g., according to the European Commission decision in Vitamins at 221: "Prices for both vitamins increased substantially between 1991 and 1994...*the goal after 1994 was to maintain the achieved price levels*." (Emphasis added. Not in original text.) European Commission Decision of November 21, 2001, Case COMP/E-1/ 37.512—Vitamins. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_006/l_00620030110en00010089.pdf

[4]Marshall et al. (2008) document the evidence of price announcements in these industries (among many others) and Harrington (2006) documents the gradual increase in collusive prices in them (also among many others).

According to the EC decision on the Cartonboard cartel: "Rather than allowing prices to rise naturally in accordance with market conditions...The price was raise in a series of regular and clearly defined 'steps'." At 72, European Commission Decision of 13 July 1994, IV/C/33.833—Cartonboard. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:1994:243:0001:0078:EN:PDF announcements can be consistent even with non-cooperative conduct.[5] So to understand collusive pricing it is important to understand the role of coordinated public announcements.

This paper addresses the above questions with an explicitly collusive model in a two period dynamic setting.[6] There is a single buyer, two incumbent/local sellers and one "outside" seller. The incumbent sellers may or may not be colluding (from the buyer's perspective). The outside seller always behaves non-cooperatively. The buyer inelastically demands a single unit of an object in each period. In each period the incumbent sellers simultaneously announce a price after observing a common cost shock. The buyer, which is uncertain about both the presence of a cartel, and the actual common cost shock, interprets the announced prices as a signal about the underlying costs and updates its beliefs about the presence of a cartel. It can then either conduct a procurement in which only the incumbent sellers participate, or, if it has not already done so in the past, it can qualify (at a cost) the outside seller to compete with them. In other words, the buyer can take a costly action to increase competition among the sellers. Allowing for such buyer behavior is crucial in understanding collusive price announcements; especially in a market like the one for vitamins, in which large buyers have access to sellers worldwide.

The paper shows that there exists an explicitly collusive mechanism that for an interesting range of parameter values exhibits gradually increasing price announcements and transaction prices. Moreover, the price announcements enable the cartel to obtain payoffs greater than those under competition by submitting bids that are completely indistinguishable from non-cooperative bids.

The intuition for the main result is as follows: A forward-looking cartel that wishes to raise prices above competitive levels must take into consideration the effects of its actions on its future profits as well. If a cartel attempts to raise prices too aggressively in the first period itself, it increases the incentives of the buyer to seek an additional seller at an early stage. This is detrimental to the cartel. To counter such "resistance" from the buyer to higher prices, the cartel prefers raising prices in gradual increments. The announcements achieve this by exploiting the buyer's uncertainty about both the sellers' underlying costs

[5] A seller experiencing a cost shock may unilaterally find it worthwhile to publicly announce an impending price increment to its customers. Without such an announcement, a customer encountering an unexpectedly high price may want investigate the price increase, delay the procurement, or perhaps negotiate with the seller. All of which could be costly to the seller (Marshall and Marx (2012)).

[6] By explicit collusion (as opposed to tacit collusion) we mean that the colluding members communicate actively to undertake actions which manipulate market outcomes.

and the presence of a cartel.

Specifically, when the buyer observes "high" price announcements, it interprets them as either having come from sellers operating in a high-cost environment or from collusive sellers operating in a low-cost environment. However, when it observes "low" price announcements, it interprets them as having come from sellers operating in a low-cost environment. Given the additional source of uncertainty upon observing a high announcement, relative to when it observes low price announcements, the buyer puts additional weight on the sellers being collusive when it observes high price announcements. The cartel exploits this by announcing a low price in the first period thereby reducing the likelihood of the outside seller being invited when it announces a higher price in the second period. Then, with no competition from the outside seller in the second period, the cartel is able to bid *as if* it is in the high-cost state even when costs are actually low.

Thus, apart from formalizing the notion (suggested in Harrington (2006), Marshall et al. (2008) and Marshall and Marx (2012)) that a cartel may raise prices gradually to counter buyer resistance, the paper also provides a link between increasing price announcements and increasing transaction prices in an industrial procurement setting.

The gradual increase in collusive prices has been analyzed before, but with no emphasis on *how* the cartel chooses its *announcements* to effect the gradual increase. In Harrington (2004) and Harrington (2005) gradually increasing collusive price paths are explored without an active buyer's side. Rather, the articles assume the probability of cartel detection to be an exogenously specified function increasing in either price changes or levels.

In Harrington and Chen (2006), the phenomenon is explained as a way for the cartel to prevent being detected and prosecuted by antitrust authorities. The authors construct an infinite period dynamic computational model in which the buyer suspects the presence of a cartel if it observes a sequence of prices inconsistent with a non-cooperative price path. Suspicion leads to the cartel's discovery by antitrust authorities, which the cartel seeks to avoid. It does so by raising prices gradually in order to avoid generating an "anomalous" price path. While cartels are certainly concerned about detection, in this paper we address a more immediate concern for the cartels: preventing the entry of new sellers induced by the cartel's actions. For instance, the vitamins cartel's concern with this possibility is apparent from the following excerpt from the European Commission's decision on the vitamins cartel:

> "The objective for vitamin A was to increase prices in CHF [Swiss franc]

> by 5 % to 10 % for 1991 while balancing out the USD/DEM price differential to discourage brokers."[7]

In fact, the EC decision also points to evidence of individual cartel members being wary of buyers seeking new sellers after price increments:

> "Daiichi says that in November 1997 it opposed a planned increase to DEM 46/kg from DEM 42/kg for Spring 1998 proposed by BASF, partly because at so high a price, its pre-mixer customers in Europe would have every incentive to switch to DL-calpan suppliers in Poland and Romania."[8, 9]

In a related paper, also on the vitamins cartel, Marshall et al. (2008) build on Deneckere and Kovenock (1992) to explain certain empirical regularities about the price announcements.[10] In a model of price leadership with capacity-constrained sellers, they establish key differences between explicitly collusive and non-collusive price announcements.[11] They also show that when facing buyer resistance to price increments, an explicit market-sharing cartel is able to maintain its members' market shares and obtain payoffs above competitive levels by pre-announcing a price increase that will come into effect at a future date. This way, if buyer resistance is likely to disrupt the market sharing agreement, the cartel can retract the announced prices to maintain status quo. While Marshall et al. (2008) account for the buyer's reaction to an impending price increase, in doing so they take a reduced form approach. This paper, on the other hand, not only explains a different set of observations compared to Marshall et al. (2008), but also includes a more active role for the buyer. It does so by incorporating a strategic buyer as in Kumar et al. (2012).

The rest of the paper is organized as follows. Section 2.2 briefly describes the vitamins industry and describes the key features of the cartel's price announcements. Section 2.3 introduces the model, followed by the key results in Section 2.4. The cartel in our model is not optimal, in the sense that even though it obtains a higher payoff relative to non-cooperative play, its bids in the procurements conducted by the buyer are *not* joint profit

[7] EC decision in Vitamins at 207.

[8] EC decision in Vitamins at 323.

[9] "Premix" is a blend of different vitamins and other nutrients (Bernheim (2002)). It must be noted here that although Daiichi was concerned with this possibility, BASF and Roche were not, because unlike Daiichi, they were vertically integrated into the production of premix.

[10] These will be discussed in greater detail in the next section.

[11] For tacitly collusive price leadership models see Rotemberg and Saloner (1990) and Mouraviev and Rey (2011).

maximizing. In Section 2.5 we provide a simple example in which the cartel is joint profit maximizing. Section 2.6 concludes.

2.2 The vitamins cartel and price announcements

2.2.1 The vitamins industry and the cartel[12]

Marshall et al. (2008) provide a concise characterization of the vitamins industry:

> "1. Vitamins are largely produced through processes of chemical synthesis, with petroleum as a primary factor input, although fermentation technologies can be used for some vitamins. 2. The vitamins industry is highly concentrated. 3. The large capital investments and production experience required for the manufacture of vitamins are a barrier to entry. 4. When considering the cost of producing animal feed or human food, the incremental cost of vitamin additives is small. 5. A given vitamin product made by one firm is chemically identical to the same product made by another firm. 6. With the possible exception of the Chinese manufacturers, most sizable producers of vitamins were involved in explicit collusion throughout much of the 1990s."

Table B.1 in Appendix B indicates the cartel members in each of the vitamins.

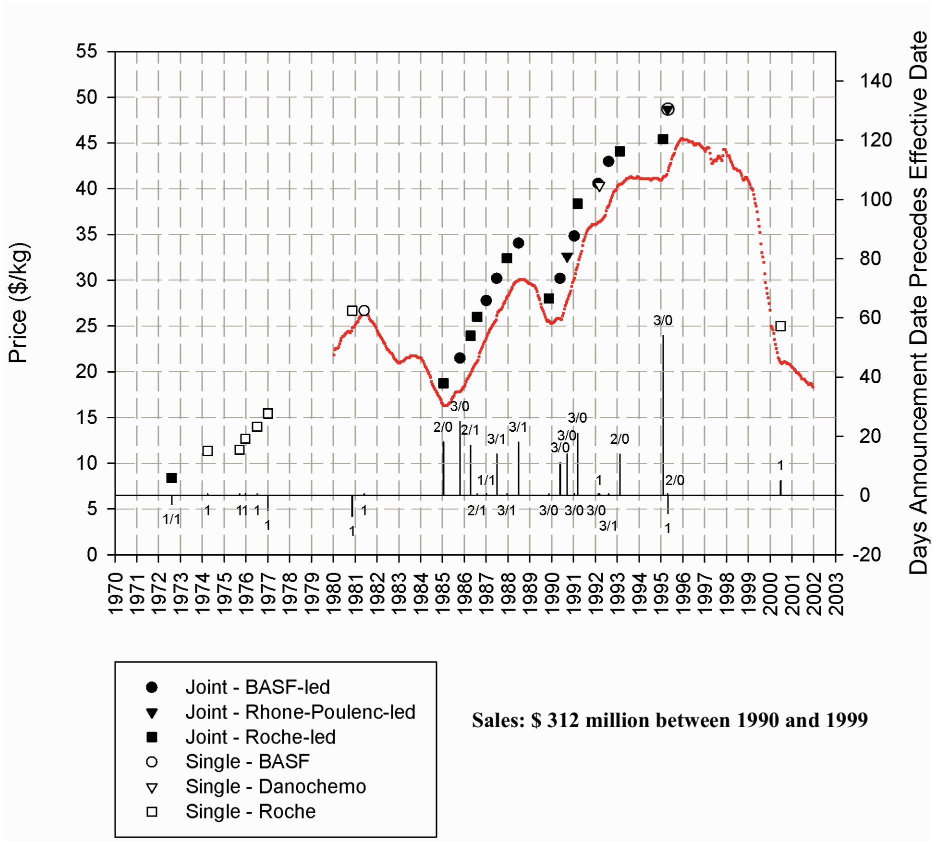
The meat and poultry industry was the largest consumer of vitamins.[13] Buyers in the industry included some of the largest meat processing companies (e.g. Tyson Foods). For human consumption, vitamins are used as food additives (e.g. fortified breakfast cereal), dietary supplements and cosmetics. Customers here included large food manufacturers (e.g. Kraft Foods and Land O'Lakes) (Bernheim (2002)).

The senior executives of the major vitamins manufacturers participated in annual "budget meetings" to fix market shares for the coming year. In addition, other executives attended quarterly meetings to exchange information on pricing, demand conditions, and to agree upon future price increments. One of the key features of the price announcements was how the firms took turns to lead new price increments, with other co-conspirators

[12] This subsection draws on Marshall et al. (2008). See Appendix A of that paper for a more detailed description of the industry and uses of vitamins.

[13] Vitamins are crucial in reducing the time it takes for animals to reach full maturity. Since most animals cannot synthesize vitamins by themselves, vitamins are added to their feed.

making supporting announcements in quick succession.[14]



Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure 2.2.1: Price announcements and transaction prices of Vitamin A Acetate 650 - Feed Grade

Figure 2.2.1 depicts, among other information, the average transaction price of the vitamins across customers in the US and *every* price announcement made by the sellers of

[14]According to the EC decision in Vitamins at 203–204: "The parties normally agreed that one producer should first 'announce' the increase, either in a trade journal or in direct communication with major customers. Once the price was announced by one cartel member, the others would generally follow suit. In this way the concerted price increases could be passed off, if challenged, as the result of price leadership in an oligopolistic market." European Commission Decision of November 21, 2001, Case COMP/E-1/ 37.512—Vitamins. Available at http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_006/l_00620030110en00010089.pdf.

Vitamin A650 (a specific product of vitamin A) between 1972 and 2002.[15] On the horizontal axis are dates and the left vertical axis indicates dollar amounts. Roche, BASF and Rhone Poulenc were colluding in this particular vitamin product for which they pled guilty for the period between January 1990 and February 1991. In the figure, the red dotted line indicates the transaction price and the geometric shapes above the line indicate the amounts of the announcements. Identical announcements by two or more sellers within a 90-day period are labeled "joint", with the date of the leader's announcement being the indicated date. Joint announcements are depicted by the filled in geometric shapes. The shapes themselves indicate the seller who led the announcement. If no other seller makes an identical announcement within 90-days, such announcements are labeled "single". Singleton announcements are depicted by the geometric shapes which are not filled in. The vertical bars below each announcement indicates the number of days between the date of the announcement and the date the announced price would be effective. It is measured on the right vertical axis. The numbers on top of the vertical bars indicate the number of cartel and non-cartel members that made the announcement. For instance, the "2/0" above the vertical bar corresponding to the first announcement in 1985 indicates that the particular announcement was made by two cartel members and no non-cartel members (which in this case was Danochemo).

Evidently, prior to 1985, when collusion was not very likely, most of the announcements were singletons, with the announced prices being effective immediately. In some cases the announcements came after the new prices were effective (vertical bars are negative). However, most of the announcements after 1985 were joint, with long "lead-times" before the prices came into effect. Moreover, announcements prior to 1985 are primarily made by Roche (the largest producer of vitamin A), while those after 1985 are led by other firms as well. It is also apparent that compared to the period before, there are many more announcements after 1985, and that they arrive at regular intervals. These observations were made and analyzed in Marshall et al. (2008).

In this paper we analyze the other striking feature of the data: the incremental nature of the announcements and their effect on transaction prices. Note that the patterns in the data are not isolated to vitamin A 650. Figures B.2.1–B.2.5 in Appendix B indicate other vitamin products where similar patterns are observed. As mentioned earlier a key motivation for such pricing behavior seems to be to counter buyer induced entry. It is

[15]These announcements were made in the trade journals, Feedstuff and Chemical Marketing Reporter.

worth noting that price announcements are not exclusively a feature of collusive behavior. Table B.2 in Appendix B provides a list of fifteen industries with no known allegations of collusion, where sellers made price announcements in trade journals.

2.3 Model

We begin by laying out the general environment and then go on to describe the timing and information structure. The results are provided subsequently.

2.3.1 Preliminaries

The game consists of two periods, $t = 1, 2$.[16] There is one risk neutral buyer who wishes to procure one unit of an object in each period by means of a first price procurement. The buyer's value for the object is v_B and its surplus from transacting at a price b is $v_B - b$.

There are three sellers: two local sellers, labeled S1 and S2, and one "outside" seller labeled S3.

There are two possible cost states. With probability $\omega_l \in (0, 1)$ the cost state is *low* (l) and with probability $\omega_h = 1 - \omega_l$ the cost state is *high* (h). In the l-cost state *all* sellers draw their idiosyncratic costs from the distribution F over $[\underline{x}, \bar{x}] \subseteq \mathbb{R}_+$ and in the h-cost state sellers draw their costs from F over $[\underline{x} + \Delta, \bar{x} + \Delta]$, where $\Delta \geq \overline{x} - \underline{x} > 0$. Thus, the only difference between the two cost states is a shift in the cost support, where the shift is such that the supports do not overlap.[17] We assume that the pdf of F is continuously differentiable and bounded away from zero on both $[\underline{x}, \bar{x}]$ and $[\underline{x} + \Delta, \bar{x} + \Delta]$, and that F has a decreasing reverse hazard rate. For notational ease we will call the two distributional sources F_l and F_h. To guarantee that a transaction occurs in each period we assume $v_B > \bar{x} + \Delta$.

We model price announcements as follows: when a seller makes a price announcement, it publicly announces (perhaps insincerely) the upper support of a cost state, i.e., seller i's announcement at time t is an element from the set $\{\bar{x}, \bar{x} + \Delta\}$. This is motivated by the notion that when a seller publicly announces that a new price will come into effect shortly, it is effectively claiming that *no* buyer will pay a price greater than what is being

[16]There is also a preliminary period, $t = 0$, when whether the cartel forms or not is determined. However there is no transaction between the buyer and the sellers in this period. This will be clear when the timing of the game is introduced more formally.

[17]Except perhaps at one point.

announced.[18] Therefore, rather than an announcement being a commitment to a transaction price, we interpret it as a commitment to an *upper bound* on the transaction price. In our model, since in each period sellers will make announcements after observing the cost state, but *before* observing their idiosyncratic costs, in equilibrium they will never commit to a price upper bound that is less than the upper support of the cost distribution for that period. Thus, a price announcement in this environment is equivalent to signaling the cost state to the buyer. How a cartel can manipulate this signal to obtain greater payoffs relative to non-cooperative conduct is the essence of this paper.

Apart from the uncertainty about the cost state, there is a second source of uncertainty for the buyer. With probability $\lambda \in (0, 1)$ the environment is *cooperative*; in which case an incentive-less cartel center proposes a collusive mechanism to S1 and S2 (only), and with probability $(1 - \lambda)$ the environment is *non-cooperative*; in which case no such mechanism is proposed. A cartel forms *only* if both S1 and S2 accept the center's mechanism. S3 *always* behaves non-cooperatively.

We assume that the center only proposes mechanisms which entail the local sellers completely surrendering their autonomy to the cartel center. Specifically, we make three assumptions regarding the information structure and logistics of the collusive mechanism the center will propose: (i) the center perfectly observes the cartel members' idiosyncratic costs, (ii) the center makes price announcements on behalf of the cartel members, and (iii) as in the "bid submission mechanism" in Marshall and Marx (2007), the center submits bids on behalf of the cartel members.[19] This allows us to abstract away from incentive compatibility issues when it comes to the cartel members' bids in the procurements and helps us focus on the role of price announcements.[20]

Finally, as in Kumar et al. (2012) the buyer in our model is "strategic" due to its ability to take incremental actions that increase the level competition in the market. In particular, if it so desires, and if it has not already done so in the past, prior to conducting a procurement, the buyer can incur a publicly known cost, κ, and qualify S3 to compete with

[18] Moreover, if cartels foresee that there is some possibility of an attempted price increase encountering pushback from buyers, then it is conceivable that in their attempts to increase prices they allow for such reaction from buyers and announce prices greater than what they hope to achieve.

[19] Note that unlike the present case where the center observes the cartel members' idiosyncratic costs, in the bid submission mechanism of Marshall and Marx (2007) the center does *not* observe the cartel members' idiosyncratic valuations (in an auction setting).

[20] For more on incentive compatibility issues in bidding rings see Marshall and Marx (2007) and the cites therein.

S1 and S2.[21, 22] If S3 is qualified at $t = 1$ it does not have to be re-qualified at $t = 2$. If, however, S3 was not qualified at $t = 1$, it may be qualified at $t = 2$. Thus κ is a one time expenditure that permanently increases competition among the sellers because S3 always acts non-cooperatively.

2.3.1.1 Timing and Information

The sequence of events and the information structure in the model are as follows:

$t = 0$ (cartel formation) : Uncertainty about the environment being cooperative or non-cooperative is resolved: with probability λ the local sellers have the opportunity to collude and with probability $(1 - \lambda)$ they act non-cooperatively. λ is public information. If a cartel forms, it stays in place forever. *All* sellers observe whether the state is cooperative or non-cooperative and the formation of the cartel. The buyer observes neither the state nor the formation of the cartel.

$t = 1(a)$ (announcement) : The cost state is determined: it is *low* with probability ω_l and *high* with probability ω_h. The probabilities are public information. All sellers observe the cost state, but the buyer does not. After observing the cost state, S1 and S2 simultaneously and publicly announce (perhaps insincerely) the upper support of a cost state.[23] S3 makes no announcement.

[21] As the following quote from the EC Decision on *Prestressing Steel* suggests, qualifying a new seller is often an expensive process: "Technical approval by national authorities is mandatory in many countries. Time and resource intense certification procedures increase costs, lessen flexibility and are an impediment to export. The lead time of around 6 months for accomplishment of the certification does give an early warning of potential competition to incumbents." (paragraph 5) European Commission Decision of September 30, 2010, Case COMP/38.344—Prestressing Steel. Available at http://ec.europa.eu/competition/antitrust/cases/dec_docs/38344/38344_5856_3.pdf.

[22] Kumar et al. (2012) consider a single period game in which, if a buyer finds the initial bids from the incumbent sellers to be unsatisfactory ("too high"), it can void all bids, invite a new seller, and reconduct the procurement in which all the sellers participate. The authors use such an environment to show that in the presence of buyer resistance incumbent sellers may want to form a cartel rather than merging to form a single entity.

[23] Although in practice, buyers do not mandate price announcements as part of their procurement process, such announcements are a commonly observed phenomenon in many industrial markets. Table B.2 in Appendix B.2 provides a list of industries with no allegation of collusion, where price announcements were observed. In our model we assume that sellers–whether or not they are cooperative–will make announcements in each period. Also, industrial cartels typically stagger their price announcements to make it seem like price leadership behavior in a competitive oligopoly. Although this is an important feature of collusive pricing, here, to keep the model simple we will think of the cartel members making announcements simultaneously. In a different modeling environment Marshall et al. (2008) consider sequential price announcements by market-sharing cartel members.

$t = 1(b)$ (procurement) : After observing the announcements the buyer either conducts a first price procurement in which only S1 and S2 participate (i.e. S3 is *out*), or, it incurs κ to qualify S3, and conducts a first price procurement in which all sellers participate (i.e. S3 is *in*). If qualified, S3 enters with probability 1. Sellers draw their time $t = 1$ idiosyncratic costs prior to bidding in a procurement. The buyer transacts with the lowest bidder at a price equal to its bid. This ends $t = 1$.

$t = 2(a)$ (announcement) : The cost state is re-determined and like in $t = 1(a)$, S1 and S2 make public price announcements. S3 makes no price announcement even if it was qualified at $t = 1$.[24] The information structure is identical to $t = 1(a)$.

$t = 2(b)$ (procurement) : If S3 was not qualified at $t = 1$, then the sequence of events are identical to those at $t = 1(b)$. If S3 was qualified at $t = 1$ it remains qualified at $t = 2$ and the buyer conducts a first price procurement. Prior to bidding sellers redraw their idiosyncratic costs from the distribution corresponding to the current cost state.

2.4 Results

The solution concept used is Perfect Bayesian Equilibrium. Since announcements are interpreted as signals about the underlying cost state, we will continue the rest of the discussion in terms of the sellers announcing l and h instead of $\bar{x}$ and $\bar{x} + \Delta$ respectively. Moreover, we will refer to the vectors (l, l) and (h, h) as L and H, respectively. When necessary we will put a time subscript on these notations.

Our first observation is that since an announcement is a commitment to an upper bound on the transaction price, it is dominated for a seller in the h-cost state to announce L.

Lemma 4. *In the h-cost state, sellers (collusive or non-cooperative) will announce high with probability one.*

A consequence of the above lemma is that if at least one seller announces l, it is fully revealed to the buyer that the true cost state is l.

[24] For e.g., in the vitamins industry, the Eastern European manufacturers never made price announcements in the U.S.

The remaining analysis will proceed as follows. We begin by supposing that at $t = 0$ the center proposes a mechanism that satisfies the local sellers' IR constraints, i.e., S1 and S2 accept the proposed mechanism. As part of the proposed mechanism we assume a particular bidding strategy for the cartel in the procurements. Then, taking as given this bidding strategy, we characterize the equilibrium announcements and non-cooperative bids for each period, starting with $t = 2$ and progress backward. Finally, we show that a collusive mechanism that consists of the assumed bidding strategy and equilibrium announcements does indeed satisfy the sellers' IR constraints at $t = 0$.

Collusive bidding

Let x_{it} be seller i's time t idiosyncratic cost draw, β_s^{out} be the equilibrium non-cooperative bidding strategy in a symmetric *two*-seller (one-shot) first price auction in which both sellers draw their costs from F_s, $s \in \{l, h\}$, and β_s^{in} be the equilibrium non-cooperative bidding strategy in a symmetric *three*-seller (one-shot) first price auction in which all sellers draw their costs from F_s. The existence and uniqueness of these equilibria are well known.[25] We assume that on behalf of cartel member i the center bids

$$\begin{array}{ll} \beta_l^{out}(x_{it}), & \text{if } l\text{-cartel announces } L\text{, S3 out} \\ \beta_h^{out}(x_{it} + \Delta), & \text{if } l\text{-cartel announces } H\text{, S3 out} \\ \beta_h^{out}(x_{it}), & \text{if } h\text{-cartel announces } H\text{, S3 out} \\ \beta_l^{in}(x_{it}), & \text{if } l\text{-cartel announces } L \text{ or } H\text{, S3 in} \\ \beta_h^{in}(x_{it}), & \text{if } h\text{-cartel announces } L \text{ or } H\text{, S3 in.} \end{array} \tag{2.4.1}$$

Note that in the above specification, if the l-cartel announces H and the buyer does not invite S3, then the center transforms each cartel member's cost to lie within $[\underline{x} + \Delta, \bar{x} + \Delta]$ and submits the corresponding non-cooperative bid in a two-seller procurement.

There are two related points to note about the supposed bidding strategy. First, it does *not* maximize the cartel's joint expected payoff. For instance, if S3 is not invited in either period, then at $t = 2$, since it is the final period, it is optimal for the cartel to bid the upper support of the cost state it announced. Apart from this solely being a consequence of a finite period model, observing such bids from sellers is unrealistic. Even though antitrust authorities may be wary of committing scarce resources into investigating every complaint by buyers, compared to seemingly non-cooperative bids, such a bid is more

[25] See Athey (2001); Bajari (2001); Lebrun (1996, 1999).

likely to induce costly (to the cartel) antitrust scrutiny. Thus, we do not consider the cartel's optimal bidding strategy here. Instead, we show that by using price announcements even a cartel that submits bids that are indistinguishable from non-cooperative bids can obtain payoffs above competitive levels.[26]

Second, since conditional on a price announcement, collusive bids are indistinguishable from non-cooperative bids, the buyer will make no additional inference about a cartel's presence based on the bids it receives. So all inference by the buyer is based solely on price announcements.

We continue the analysis taking as given the above bidding behavior by the cartel. For the time being, we assume that at $t = 0$, in the cooperative state, the cartel center proposed a mechanism that *did* satisfy the local sellers' IR constraints.

2.4.1 Time $t = 2$

The history in this period consists of the announcements and bids at $t = 1$,[27] and whether or not S3 was qualified at $t = 1$. Based on whether S3 was qualified or not, there are two possible scenarios at $t = 2$.

Scenario 1 – S3 qualified at $t = 1$:

In this scenario the buyer takes no action apart from conducting a procurement in which S3 also participates. Thus, price announcements have no influence on the buyer's actions. So irrespective of whether the local sellers are colluding or not, in the l-cost state they are indifferent between announcing L and h, and in the h-cost state, by Lemma 4, they announce h. Since the cartel members' bids are just non-cooperative bids and because the difference between the two cost states is just a shift in the support of the cost distribution, the cartel's total expected payoff in either cost state is $\pi_c^{in} = 2\pi_{nc}^{in}$; π_{nc}^{in} is each cartel member's ex-ante expected payoff from a symmetric independent private values first price procurement when S3 is *in*. Let P_s^{in} be the buyer's expected payment in cost state $s \in \{l, h\}$ under this scenario. It is the expected payment in a symmetric three-seller first price procurement with sellers drawing their costs from F_s.

[26] In Section 2.5 we provide a simple discretized version of the current environment in which bids are optimal. The simplification allows us to sidestep the complexities involved with the buyer's inference about the seller's idiosyncratic costs upon observing the first period bids.

[27] The bids are uninformative.

Scenario 2 – S3 not qualified at $t = 1$:

In this scenario price announcements can influence the buyer's decision to qualify S3. Let $A_1 \in \{L, H\}$ be the $t = 1$ announcement observed by the buyer,[28] and let θ_1 be the probability with which the l-cartel announces H at $t = 1$.[29] Given these, let $\lambda_2^{A_1}(\theta_1) \equiv \Pr(cartel|A_1)$. That is, $\lambda_2^{A_1}(\theta_1)$ is the buyer's "prior" belief at $t = 2$ about S1 and S2 being in a cartel *before* the $t = 2$ announcements.[30]

After observing the $t = 2$ announcements, the buyer updates its beliefs about whether it is facing an h-cartel or an l-cartel, and based on those beliefs it decides whether or not to invite S3.

If S3 is not invited, in cost state s, let P_s^{out} denote the buyer's expected payment,[31] $\pi_{nc,s}^{out}(A)$ denote the expected payoff to a non-cooperative seller if the sellers announced A, and $\pi_{c,s}^{out}(A)$ denote the cartel's expected payoff if it announced A. Note that $\pi_{c,l}^{out}(H) > \pi_{c,l}^{out}(L) = \pi_{c,h}^{out}(H) = 2\pi_{nc,l}^{out}(L) = 2\pi_{nc,h}^{out}(H) > \pi_c^{in}$.[32]

Now given A_1, suppose that at $t = 2$ the l-cartel announces H with probability $\theta_2^{A_1} \in [0, 1]$ and L with probability $1 - \theta_2^{A_1}$.[33] Further suppose that non-cooperative sellers announce the cost state truthfully. Then, by Bayes' rule

$$\Pr(\text{cartel}|H \text{ at } t = 2) = \frac{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1)}{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1) + \omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)}$$

So if the cartel bids according to (2.4.1) and non-cooperative sellers in the s-cost state bid according to β^s, then upon observing an announcement of H, the buyer's expected surplus if S3 is not invited at $t = 2$ is $v_B - P_h^{out}$.[34]

[28] Recall that $L \equiv (l, l)$ and $H \equiv (h, h)$.

[29] We are specifically interested in the probability with which the l-cartel announces H because given the cartel's bidding strategy, it obtains a payoff above that under competition *only* if the buyer does not invite S3 in the l-cost state after it observes an announcement of H.

[30] $\lambda_2^{A_1}(\theta_1)$ is also a function of the $t = 1$ bids, but as mentioned earlier the buyer cannot infer anything from the bids in a procurement. So its dependence on the bids is not explicitly indicated.

[31] P_s^{out} equals the buyer's ex-ante expected payment in a symmetric two-seller procurement in which sellers draw their costs from F_s.

[32] Given the cartel's bidding strategy it is obvious that $\pi_{c,l}^{out}(H) > \pi_{c,l}^{out}(L)$. The first equality follows because the only difference between the l and h cost states is a shift in the support of the cost distribution, and in both cases the cartel just bids as non-cooperative sellers would. All other rankings are obvious.

[33] Note that θ_2 is also a function of the probability with which at $t = 1$ the cartel announces state j, because the seller's beliefs depends on it.

[34] Because according to the l-cartel's bidding strategy if S3 is not invited after it announces H, the buyer's

If, instead, the buyer invites S3 after observing H, its expected surplus is

$$v_B \quad - \quad \left[\underbrace{\frac{\omega_l \theta_2^{A_1} \lambda_2^{A_1}(\theta_1)}{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1) + \omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)}}_{\Pr(l\text{-cartel}|A_1, H_2)} \times P_l^{in} + \underbrace{\frac{\omega_h \lambda_2^{A_1}(\theta_1)}{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1) + \omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)}}_{\Pr(h\text{-cartel}|A_1, H_2)} \times P_h^{in} \right.$$

$$\left. + \underbrace{\frac{\omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)}{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1) + \omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)}}_{\Pr(\text{no cartel}|A_1, H_2)} \times P_h^{in} \right] - \kappa.$$

Thus, given A_1 and a $t = 2$ announcement of H, the buyer is indifferent between inviting and not inviting S3 at $t = 2$ if (and only if)

$$\kappa \quad = \quad \frac{\lambda_2^{A_1}(\theta_1) \omega_l \theta_2^{A_1} \left(P_h^{out} - P_l^{in}\right) + \omega_h \left(P_h^{out} - P_h^{in}\right)}{\left(\omega_l \theta_2^{A_1} + \omega_h\right) \lambda_2^{A_1}(\theta_1) + \omega_h \left(1 - \lambda_2^{A_1}(\theta_1)\right)} \equiv \hat{\kappa}(\theta_1, \theta_2^{A_1} | A_1, H_2). \quad (2.4.2)$$

Analogously, we also define the buyer's indifference condition upon observing L at $t = 2$:

$$\begin{aligned} \kappa \quad &= \quad \frac{\lambda_2^{A_1}(\theta_1) \omega_l (1 - \theta_2^{A_1}) \left(P_l^{out} - P_l^{in}\right) + \omega_l \left(1 - \lambda_2^{A_1}(\theta_1)\right) \left(P_l^{out} - P_l^{in}\right)}{\omega_l (1 - \theta_2^{A_1}) \lambda_2^{A_1}(\theta_1) + \omega_l \left(1 - \lambda_2^{A_1}(\theta_1)\right)} \\ &= \quad P_l^{out} - P_l^{in} \equiv \hat{\kappa}(\theta_1, \theta_2^{A_1} | A_1, L_2). \end{aligned} \quad (2.4.3)$$

Note: As notational convention, we will indicate the history of announcements after the vertical separator "—". The history should also indicate whether or not S3 was invited at $t = 1$. But since we are mainly interested in how the cartel behaves when S3 has not been already invited, we will not include this information in the notation. Appendix B.3 provides a glossary of the notation used in the paper.

Using indifference condition (2.4.2), we define two specific threshold κ values that are

expected payment is P_h^{out}.

crucial in characterizing the $t = 2$ equilibrium:

1. $\bar{\kappa}_2(\theta_1|A_1) \equiv \hat{\kappa}(\theta_1, 1|A_1, H_2)$: If the l-cartel announces H at $t = 1$ with probability θ_1, then given a $t = 1$ announcement A_1, $\bar{\kappa}_2(\theta_1|A_1)$ is the *smallest* κ value for which if the l-cartel announces H with probability 1 at $t = 2$, the buyer's best response is to *not* invite S3.

2. $\underline{\kappa}_2 \equiv \hat{\kappa}(\theta_1, 0|A_1, H_2)$: Given θ_1 and a $t = 1$ announcement of A_1, $\underline{\kappa}_2$ is the *largest* κ value for which if the l-cartel announces H with any probability $\theta_2^{A_1} > 0$ at $t = 2$, the buyer's best response is to invite S3.

Note that $\hat{\kappa}(\theta_1, \theta_2^{A_1}; A_1, H_2)$ is strictly increasing in $\theta_2^{A_1}$.[35] So $\hat{\kappa}(\theta_1, 1|A_1, H_2) > \hat{\kappa}(\theta_1, 0|A_1, H_2) \Leftrightarrow \bar{\kappa}_2(\theta_1|A_1) > \underline{\kappa}_2$.

Given these thresholds, the equilibrium behavior for $t = 2$ if S3 was not invited at $t = 1$ can be described as follows: For "high" κ values ($\kappa \geq \bar{\kappa}_2(\theta_1|A_1)$) the l-cartel announces H with probability 1, for "low" κ values ($\kappa \leq \underline{\kappa}_2$) it announces L with probability 1, and for "intermediate" κ values ($\kappa \in (\underline{\kappa}_2, \bar{\kappa}_2(\theta_1|A_1))$ it mixes between L and H; to support the mixture by the cartel, the buyer mixes between qualifying and not qualifying S3 when sellers announce H. The mixture is such that the l-cartel is indifferent between announcing truthfully and deceitfully.

Proposition 5. *Suppose a cartel which bids according to (2.4.1) forms in the cooperative state. If S3 was not invited at $t = 1$ after an announcement $A_1 \in \{L, H\}$, then there exists a $t = 2$ PBE which consists of the following strategies:*

Non-cooperative sellers announce the true cost state, and in cost state $s \in \{l, h\}$ they bid according to β_s^{out} if S3 is not invited and β_s^{in} if S3 is invited. Moreover,

(i) For $\kappa \geq \bar{\kappa}_2(\theta_1|A_1)$: Irrespective of the announcement, the buyer will not invite S3. And if

(a) Cost state is l : The cartel announces H.

(b) Cost state is h : The cartel announces H.

(ii) For $\kappa \in (\underline{\kappa}_2, \bar{\kappa}_2(\theta_1|A_1))$: If the sellers announce H, the buyer does not invite S3 with probability α_2, and invites S3 with probability $(1 - \alpha_2)$, where $\alpha_2 = \frac{\pi_{c,l}^{out}(L) - \pi_c^{in}}{\pi_{c,l}^{out}(H) - \pi_c^{in}}$. If the sellers announce L, the buyer does not invite S3. And if

[35] $\frac{\partial \hat{\kappa}(\theta_1, \theta_2^{A_1}; A_1, H_2)}{\partial \theta_2^{A_1}} = \frac{(P_h^{out} - P_l^{in})\lambda_2^{A_1}(1-\omega_l)\omega_l}{[1-(1-\lambda_2^{A_1}(\theta_1)\theta_2^{A_1})\omega_l]^2} > 0.$

(a) Cost state is l : The cartel announces H with probability $\theta_2^{A_1}$, where $\theta_2^{A_1}$ is such that equation (2.4.2) is satisfied, and L with probability $1 - \theta_2^{A_1}$.

(b) Cost state is h : The cartel announces H.

(iii) *For $\kappa \leq \underline{\kappa}_2$: Irrespective of the announcement, the buyer invites S3. And if*

(a) Cost state is l : The cartel announces L.

(b) Cost state is h : The cartel announces H.

Proof. To support this equilibrium we assume that off-equilibrium the buyer believes that the sellers are collusive if it observes at least one of the following: (a) non-identical announcements,[36] (b) bids other than the ones it would expect to see if in cost state $s \in \{l, h\}$ the sellers followed β^s if S3 is invited and $\tilde{\beta}^s$ if S3 is not invited.

The fact that sellers announce H in the h cost state follows from Lemma 4. Moreover, since there are no future periods, it is optimal for non-cooperative sellers to bid according to the specified strategies. Now if

(i) $\kappa \geq \bar{\kappa}_2(\theta_1|A_1)$: Given that the l-cartel announces H with probability 1 (i.e. $\theta_2^{A_1} = 1$) and non-cooperative sellers announce the cost state truthfully, upon observing H the buyer's beliefs are determined by Bayes' rule which imply the indifference condition (2.4.2). So it is a best response to not invite S3 for κs in this range. Since in either cost state the cartel announces L with probability 0, if the buyer observes L, it infers that it is facing non-cooperative sellers in the l-cost state and the buyer's indifference condition is $\kappa = P_l^{out} - P_l^{in} = \underline{\kappa}_2 < \bar{\kappa}_2(\theta_1|A_1)$. Thus, the buyer's best response after observing L is to not invite S3.

If the buyer does not invite S3 when the sellers announce H, it is a best response for

[36] As a related matter, the Vitamins cartel expected to pass off identical announcements as price leadership in an oligopoly; the EC decision on Vitamins at 203 and 204 states: "The parties normally agreed that one producer should first announce the increase, either in a trade journal or in direct communication with major customers. Once the price increase was announced by one cartel member, the others would generally follow suit. In this way the concerted price increases could be passed off, if challenged, as the result of price leadership in an oligopolistic market."

If we do not assume that the buyer believes that non-identical announcements are collusive, there is another equilibrium in which the l-cartel announces L by announcing (l, l) with probability $\frac{1}{2}$ and (l, h) with probability $\frac{1}{2}$. Furthermore, non-cooperative S1 announces l with probability 1 in the l-cost state and non-cooperative S2 mixes equally between l and h. However, such an equilibrium does not explain the data in which cartel members make identical announcements.

the cartel to announce H with probability 1. If in the l-cost state non-cooperative S1, announces l, then given the buyer's off-equilibrium beliefs, it is a best response for S2 to also announce the state truthfully.

(ii) $\kappa \in (\underline{\kappa}_2, \bar{\kappa}_2(\theta_1|A_1))$: We first establish that in equilibrium for κs in this range $\theta_2 \in (0,1)$. Suppose $\theta_2 = 1$. Then the buyer's Bayesian beliefs when it observes H are such that it will invite S3 with probability 1 for $\kappa < \bar{\kappa}_2(\theta_1|A_1)$. But then, setting $\theta_2 = 0$ is the l-cartel's best response since the buyer will *not* invite S3 if it observes L (since $\kappa > \underline{\kappa}_2$). On the other hand, if $\theta_2 = 0$, the cartel is announcing the cost state truthfully. But then the buyer's Bayesian beliefs imply that for $\kappa > \underline{\kappa}_2$, its best response upon observing H is to *not* invite S3 with probability 1. But then setting $\theta_2 = 1$ is the l-cartel's best response. Given that the l-cartel announces H with probability $\theta_2^{A_1}$ such that the buyer is indifferent between inviting and not inviting S3 after observing H, the prescribed strategy for the buyer when it observes H is a best response. Furthermore, since the indifference condition upon observing L is given by (2.4.3) (i.e. $\kappa = \underline{\kappa}_2$), the buyer's best response if it observes L is to not invite S3. Now suppose the buyer follows the prescribed strategy. Then if the l-cartel announces H it obtains an expected payoff of $\alpha_2 \pi_{c,l}^{out}(H) + (1-\alpha_2)\pi_c^{in}$. But if the l-cartel announces L, it obtains $\pi_{c,l}^{out}(L)$. The prescribed α_2 is such that $\alpha_2 \pi_{c,l}^{out}(H) + (1-\alpha_2)\pi_c^{in} = \pi_{c,l}^{out}(L)$. So the l-cartel's prescribed strategy is a best response. Given the buyer's off-equilibrium beliefs it is optimal for both non-cooperative sellers to announce the cost state truthfully.

(iii) $\kappa \leq \underline{\kappa}_2$: The specified announcements for the cartel and non-cooperative sellers fully reveal the true underlying cost state. So the buyer's Bayesian beliefs are such that its indifference condition upon observing $j \in \{L, H\}$, is $\kappa = \lambda_2^{A_1}(\theta_2)(P_j^{out} - P_j^{in}) + (1 - \lambda_2^{A_1}(\theta_2))(P_j^{out} - P_j^{in}) = (P_j^{out} - P_j^{in}) = \underline{\kappa}_2$. Thus, for $\kappa \leq \underline{\kappa}_2$ it is a best response for the buyer to invite S3 with probability 1 no matter what the sellers announce. If the buyer invites S3 no matter what the sellers announce, in the l-cost state both collusive and non-cooperative sellers are indifferent between announcing L and H. So announcing L is a best response. $\square$

A corollary of the above proposition is that the buyer is more likely to invite S3 at $t = 2$ if the sellers announced H at $t = 1$ rather than L.

Corollary 6. *$\forall \theta_1 \in (0,1]$, $\lambda_2^{H_1}(\theta_1) > \lambda_2^{L_1}(\theta_1)$, which implies $\underline{\kappa}_2 < \bar{\kappa}_2(\theta_1|L_1) < \bar{\kappa}_2(\theta_1|H_1)$,* *which, in turn, implies*

$$
\begin{array}{ll}
\theta_2^{L_1}, \theta_2^{H_1} = 1, & \textit{if } \kappa \geq \bar{\kappa}_2(\theta_1|H_1) \\
\theta_2^{L_1} = 1, \theta_2^{H_1} \in (0,1), & \textit{if } \kappa \in [\bar{\kappa}_2(\theta_1|L_1), \bar{\kappa}_2(\theta_1|H_1)) \\
\theta_2^{L_1}, \theta_2^{H_1} \in (0,1), & \textit{if } \kappa \in (\underline{\kappa}_2, \bar{\kappa}_2(\theta_1|L_1)) \\
\theta_2^{L_1}, \theta_2^{H_1} = 0, & \textit{if } \kappa \leq \underline{\kappa}_2.
\end{array}
$$

Proof. It is straightforward to check that $\lambda_2^{H_1}(\theta_1) > \lambda_2^{L_1}(\theta_1)$. The first implication follows from the definitions of the thresholds. The announcement probabilities are a direct result of Proposition 5 given the ranking of the thresholds. □

2.4.2 Time $t = 1$

The $t = 1$ equilibrium behavior and its analysis is similar to that at $t = 2$. The difference is that when making price announcements at $t = 1$, the cartel must take into consideration how the buyer's beliefs will affect its payoffs in the next period as well.

Let λ_1 be the probability that the buyer attaches to the local sellers being in a cartel *before* the sellers make any $t = 1$ announcements. At $t = 1$ this is just equal to the prior probability of the state being cooperative, i.e., $\lambda_1 = \lambda$. If it is optimal for the non-cooperative sellers to bid their cost draws at $t = 1$ as well (which is true in equilibrium), the buyer's surplus if it does not invite S3 after observing H is,

$$
\underbrace{v_B - P_h^{out}}_{\text{Expected surplus at } t=1}
$$
$$
+
$$
$$
\underbrace{v_B - \left[\left(\lambda_2^{H_1}(\theta_1)\omega_l\theta_2^{H_1} + \omega_h \right) P_h^{out} + \left(\lambda_2^{H_1}(\theta_1)\omega_l(1-\theta_2^{H_1}) + (1-\lambda_2^{H_1}(\theta_1))\omega_l \right) P_l^{out} \right]}_{\text{Ex-ante expected surplus at } t=2}.
$$

The expected surplus at $t = 1$ is obvious. Consider the expression for the buyer's ex-ante expected surplus for $t = 2$. If the $t = 1$ announcement is H, then according to Proposition 5 at $t = 2$ the l-cartel announces H with probability $\theta_2^{H_1} \in [0,1]$ and L with probability $1 - \theta_2^{H_1}$. Given this, from an ex-ante perspective, the buyer expects to observe H at $t = 2$ with probability $\left(\lambda_2^{H_1}(\theta_1)\omega_l\theta_2^{H_1} + \omega_h \right)$, where because the buyer makes no additional inference about the cartel's existence from the bids, by Bayes' rule $\lambda_2^{H_1}(\theta_1) = \frac{(\omega_l\theta_1+\omega_h)\lambda_1}{(\omega_l\theta_1+\omega_h)\lambda_1+\omega_h(1-\lambda_1)}$.[37] And if it observes H the buyer will either pay P_h^{out} (case (*i*) of Proposition 5), or, be indifferent between paying P_h^{out} and paying $\frac{\omega_l\theta_2\lambda_2^{H_1}(\theta_1)P_l^{in}+\omega_h P_h^{in}}{(\omega_l\theta_2+\omega_h)\lambda_2^{H_1}(\theta_1)+\omega_h\left(1-\lambda_2^{H_1}(\theta_1)\right)} - \kappa$ (case (*ii*) of Proposition 5). On the other hand, the buyer expects the sellers to announce L at $t = 2$ with probability $\left(\lambda_2^{H_1}(\theta_1)\omega_l(1-\theta_2^{H_1}) + (1-\lambda_2^{H_1}(\theta_1)) \times \omega_l\right)$, in which case from Proposition 5 the buyer will not invite S3 and expects to pay P_l^{out}.

If, instead, the buyer invites S3 after observing H at $t = 1$, its expected surplus is,

$$\underbrace{v_B - \left[\frac{(\omega_l\theta_1 P_l^{in} + \omega_h P_h^{in})\lambda_1 + \omega_h P_h^{in}(1-\lambda_1)}{(\omega_l\theta_1+\omega_h)\lambda_1 + \omega_h(1-\lambda_1)}\right] - \kappa}_{\text{Expected surplus at } t=1}$$
$$+$$
$$\underbrace{v_B - \left[\omega_l P_l^{in} + \omega_h P_h^{in}\right]}_{\text{Ex-ante expected surplus at } t=2},$$

where the expression for the buyer's surplus at $t = 2$ reflects the fact that S3 does not have to be re-qualified at $t = 2$. The buyer is, therefore, indifferent between inviting and not inviting S3 if (and only if)

$$\begin{aligned}
\kappa \quad &= \quad \left[\frac{\lambda_1\left(\omega_l\theta_1\left(P_h^{out}-P_l^{in}\right)+\omega_h\left(P_h^{out}-P_h^{in}\right)\right)+(1-\lambda_1)\omega_h\left(P_h^{out}-P_h^{in}\right)}{(\omega_l\theta_1+\omega_h)\lambda_1+\omega_h(1-\lambda_1)}\right] + \\
&\left\{\lambda_2^{H_1}(\theta_1)\left(\omega_l\left[\theta_2^{H_1}\left(P_h^{out}-P_l^{in}\right)+(1-\theta_2^{H_1})\left(P_l^{out}-P_l^{in}\right)\right]+\omega_h\left(P_h^{out}-P_h^{in}\right)\right)\right. \\
&\left.+\left(1-\lambda_2^{H_1}(\theta_1)\right)\left(\omega_l\left(P_l^{out}-P_l^{in}\right)+\omega_h\left(P_h^{out}-P_h^{in}\right)\right)\right\} \\
\equiv \quad &\hat{\kappa}(\theta_1, \theta_2^{H_1}|H_1).
\end{aligned} \tag{2.4.4}$$

Following the same reasoning as earlier, we also define the indifference condition when

[37] Recall that θ_1 is probability with which the l-cartel at $t = 1$ announces H. Since this is the first period, θ_1, unlike $\theta_2^{A_1}$, is not history dependent.

the buyer observes L at $t = 1$:

$$\begin{aligned}
\kappa &= \left(P_l^{out} - P_l^{in}\right) + \\
&\quad \Big\{\lambda_2^{L_1}(\theta_1)\left(\omega_l\left[\theta_2^{L_1}\left(P_h^{out} - P_l^{in}\right) + (1-\theta_2^{L_1})\left(P_l^{out} - P_l^{in}\right)\right] + \omega_h\left(P_h^{out} - P_h^{in}\right)\right) \\
&\quad + \left(1 - \lambda_2^{L_1}(\theta_1)\right)\left(\omega_l\left(P_l^{out} - P_l^{in}\right) + \omega_h\left(P_h^{out} - P_h^{in}\right)\right)\Big\} \\
&\equiv \hat{\kappa}(\theta_1, \theta_2^{L_1}|L_1). \qquad (2.4.5)
\end{aligned}$$

By Bayes' rule $\lambda_2^{L_1}(\theta_1) = \frac{(1-\theta_1)\lambda_1}{(1-\theta_1)\lambda_1 + (1-\lambda_1)}$.

Analogous to the previous section we define two threshold κ values for $t = 1$:

1. $\bar{\kappa}_1 \equiv \hat{\kappa}(1,1|H_1)$: $\bar{\kappa}_1$ is the smallest κ value for which even if the l-cartel announces H with probability 1 in both periods, the buyer's best response in either period is to not invite S3.

2. $\underline{\kappa}_1 \equiv \max\{\bar{\kappa}_2(0|L_1), \hat{\kappa}(0,1|L_1)\}$: $\underline{\kappa}_1$ is determined by two factors: *(i)* As it will be shown in the next section, $\bar{\kappa}_2(0|L_1)$ is the smallest κ value for which at $t = 0$ the sellers' IR constraints are satisfied by our collusive mechanism. Obviously we are not interested in lower κ values. *(ii)* Given that we are interested only in κ values for which the cartel forms, $\hat{\kappa}(0,1|L_1)$ is the κ value for which the buyer is indifferent between inviting and not inviting S3 at $t = 1$ when the cartel announces the cost state truthfully. To keep things interesting we confine the analysis to κ values greater than this threshold. Note that $\bar{\kappa}_1 > \underline{\kappa}_1$.

In the full equilibrium, at $t = 1$, given the equilibrium behavior at $t = 2$, the l-cartel announces H with probability 1 for "high" κ values ($\kappa \geq \bar{\kappa}_1$), and mixes between H and L for "low" κ values ($\kappa \in [\underline{\kappa}_1, \bar{\kappa}_1)$).

Since our objective is to explain gradually increasing collusive price announcements and transaction prices, we will achieve this if there is a range of κ values for which the l-cartel announces H with some probability strictly *less* than 1 at $t = 1$, but announces H with probability 1 at $t = 2$. This will occur when the range of κ values for which the l-cartel mixes announcements at $t = 1$ overlaps with the range of κ values for which it announces H with probability 1 at $t = 2$. In other words, this will occur when $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$.[38] The following claim identifies stronger than necessary conditions under which this will occur.

[38]Unlike here, when $\bar{\kappa}_2(0|L_1) > \bar{\kappa}_1$ there exists an equilibrium that given our collusive scheme, does *not*

Claim 7. If $\lambda \geq \frac{(3-2\omega_l)\omega_l - 1}{(3-2\omega_l)\omega_l}$, *then* $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$.

Proof. See Appendix A. Note that under the supposed conditions, if $\omega_l \leq \frac{1}{2}$, then $\forall\, \lambda \in [0,1]$, $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$ □

We now characterize the equilibrium when $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$.

Proposition 8. *Suppose a cartel which bids according to (2.4.1) forms in the cooperative state. Further suppose that* $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$. *Then in a PBE which constitutes of* $t = 2$ *conduct as in Proposition 5, conduct at* $t = 1$ *is as follows:*

Non-cooperative sellers announce the true cost state and in cost state $s \in \{l, h\}$ *they bid according to* β_s^{out} *if S3 is not invited and* β_s^{in} *if S3 is invited. Furthermore,*

(i) *For* $\kappa \geq \bar{\kappa}_1$: *Irrespective of the announcement, the buyer will not invite S3. And if*

(a) cost state is l : *The cartel announces* H.

(b) cost state is h : *The cartel announces* H.

(ii) *For* $\kappa \in [\underline{\kappa}_1, \bar{\kappa}_1)$: *If the sellers announce H, the buyer invites S3 with probability* α_1 *, where*

$$\alpha_1 = \begin{cases} \frac{\pi_{c,l}^{out}(L)+\omega_l \pi_{c,l}^{out}(H)+\omega_h \pi_{c,h}^{out}(H)-2\pi_c^{in}}{\pi_{c,l}^{out}(H)+\omega_l \pi_{c,l}^{out}(H)+\omega_h \pi_{c,h}^{out}(H)-2\pi_c^{in}} & \text{if } \kappa \geq \bar{\kappa}_2(1|H_1) \\ \frac{\pi_{c,l}^{out}(L)+\omega_l \pi_{c,l}^{out}(H)+\omega_h \pi_{c,h}^{out}(H)-2\pi_c^{in}}{\pi_{c,l}^{out}(H)+\omega_l \pi_{c,l}^{out}(L)+\omega_h (\alpha_2 \pi_{c,h}^{out}(H)+(1-\alpha_2)\pi_c^{in})-2\pi_c^{in}} & \text{otherwise,} \end{cases}$$

and invites S3 with probability $1 - \alpha_1$. *If the sellers announce L, the buyer does not invite S3. And if*

(a) cost state is l : *The cartel announces* H *with probability* θ_1, *where* θ_1 *is such that equation 2.4.4 is satisfied, and L with probability* $1 - \theta_1$.

(b) cost state is h : *The cartel announces* H.

Proof. Like in the proof for Proposition 5 we assume that off equilibrium, the buyer believes that the sellers are collusive if it observes at least one of the following: (a) non-identical announcements, (b) bids other than the ones it would expect to see if in cost state $s \in \{l, h\}$ the sellers followed β^s if S3 is in or $\tilde{\beta}^s$ if S3 is out.

exhibit gradually increasing collusive price announcements and transaction prices. This equilibrium is quite similar to the one discussed here. Only the roles of $\bar{\kappa}_1$ and $\bar{\kappa}_2(1|H_1)$ are reversed.

Given these beliefs, if S2 announces truthfully, it is optimal for S1 to also announce truthfully because not doing so will weakly increase the likelihood of S3 being invited. To see that it is optimal for non-cooperative sellers to bid as specified, suppose S3 has not been invited and non-cooperative S2 bids as specified. The only reason S1 may want to deviate from the prescribed strategy is to reveal to the buyer that the sellers are non-cooperative (to prevent the invitation of S3 at $t = 2$ as well). But to do so it must submit a bid that the cartel will not. But with the specified off-equilibrium beliefs if S1 submits such a bid, it weakly increases the likelihood of S3 being invited next period. Thus it is a best response for S1 to also follow the prescribed bidding strategy.

(i) $\kappa \geq \bar{\kappa}_1$: If the buyer will not invite S3 with probability 1 in either period even if it observes H in both of them, it is a best response for the l-cartel to announce H with probability 1 at $t = 1$. If non-cooperative sellers announce truthfully and the cartel always announces H, the buyer's Bayesian beliefs imply that the indifference condition is given by (2.4.4). Thus it is a best response for the buyer to not invite S3 when it observes H. By Lemma 14 in Appendix A it is a best response for the buyer to not invite S3 when it observes L.

(ii) $\kappa \in [\underline{\kappa}_1, \bar{\kappa}_1)$: To see that the l-cartel cannot announce according to a pure strategy for κs in this range, suppose the l-cartel announces H with probability $\theta_1 = 0$. That is, the cartel is announcing the cost state truthfully. From their definitions, this implies $\lambda_2^{L_1} = \lambda_2^{H_1} = \lambda$. So the $t = 2$ outcome will be the same after either $t = 1$ announcement. From equations (2.4.2) and (2.4.3) this implies that the buyer's indifference condition upon observing either L or H at $t = 1$ is $\kappa = \underline{\kappa}_1$. But by assumption $\kappa \geq \underline{\kappa}_1$, so the buyer's best response upon observing H is to not invite S3. But then the l-cartel's best response is to set $\theta_1 = 0$. Setting $\theta_1 = 1$ is also not optimal for the l-cartel because $\kappa < \bar{\kappa}_1$, which implies the buyer will invite S3 with probability 1 whenever it observes H. Thus the l-cartel will mix for κs in this range.

Given the buyer's strategy, if the l-cartel announces L with probability 1, (i.e. $\theta_1 = 0$) its expected payoff is $\pi_{c,l}^{out}(L) + \{\omega_l \pi_{c,l}^{out}(H) + \omega_h \pi_{c,h}^{out}(H)\}$, where $\pi_{c,l}^{out}(L)$ is its payoff at $t = 1$ and the term within the curly brackets is its expected payoff at $t = 2$ (because $\kappa > \bar{\kappa}_2(0|L_1)$). When the l-cartel announces H with probability 1 (i.e. $\theta_1 = 1$), its payoff depends upon whether $\kappa \geq \bar{\kappa}_2(1|H_1)$ or $\kappa < \bar{\kappa}_2(1|H_1)$. Specifically,

(a) If $\kappa \geq \bar{\kappa}_2(1|H_1)$ by case (i) of Proposition 5 the buyer will not invite S3 if it observes H at $t = 2$. So the l-cartel's expected payoff at $t = 2$ is $\omega_l \pi_{c,l}^{out}(H) + \omega_h \pi_{c,h}^{out}(H)$, which implies that the l-cartel's expected payoff if the buyer does not invite S3 at $t = 1$

(with probability α_1) is $\pi_{c,l}^{out}(H) + \{\omega_l \pi_{c,l}^{out}(H) + \omega_h \pi_{c,h}^{out}(H)\}$. If the buyer invites S3 (with probability $1-\alpha_1$), then in both periods the cartel's payoff is π_c^{in}. Thus the l-cartel's ex-ante payoff at $t=1$ is $\alpha_1 \left[\pi_{c,l}^{out}(H) + \{\omega_l \pi_{c,l}^{out}(H) + \omega_h \pi_{c,h}^{out}(H)\}\right] + (1-\alpha_1) \times 2\pi_c^{in}$.

(b) If $\kappa < \bar{\kappa}_2(1|H_1)$, by Proposition 5 (case (*ii*)) the buyer mixes at $t = 2$ when the sellers announce H at $t = 2$. So the cartel's payoff is $\alpha_1 \left[\pi_{c,l}^{out}(H) + \{\omega_l \pi_{c,l}^{out}(L) + \omega_h(\alpha_2 \pi_{c,h}^{out}(H) + (1-\alpha_2)\pi_c^{in})\}\right] + (1-\alpha_1) \times 2\pi_c^{in}$. The first term within the curly brackets reflects the fact that when the buyer is mixing at $t=2$, the l-cartel is indifferent between announcing L and H in that period.

In each of the above cases α_1 is chosen such that the l-cartel is indifferent between announcing L and H.

Since θ_1 influences the buyer's Bayesian beliefs so that it is indifferent between inviting and not inviting S3 when it observes H, the prescribed strategy is a best response for the buyer. The buyer does not invite S3 when it observes L by Lemma 14 in Appendix A. □

Combining case $(ii)(a)$ of Proposition 8 and case (i) of Proposition 5 we obtain our main result:

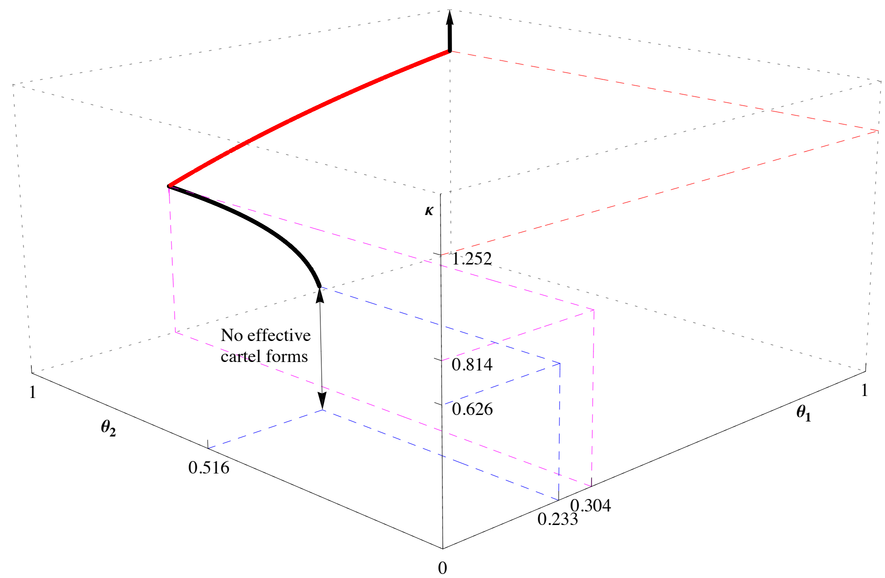
Corollary 9. *Under collusive behavior, as long as the cost of qualifying the outside seller is neither "too high" nor "too low", both, the expected price announcements and the expected transaction price, are lower in the first period relative to the second period.*

To simultaneously visualize the l-cartel's equilibrium announcements at both $t = 1$ and 2, it may be useful to turn to the numerical example depicted in Figure 2.4.1. For the underlying computations we assume $F_l = U[0,1]$, $F_h = U[1,2]$, $\omega_l = 0.85$, and $\lambda = 0.15$. For different values of κ (the z-axis), the curve traces (i) θ_1–the probability with which the first period l-cartel announces H and (ii) $\theta_2^{H_1}$–the probability with which the second period l-cartel announces H if the cartel had announced H in the first period as well.

For the chosen parameter values $\underline{\kappa}_1 = 0.626$ and $\bar{\kappa}_1 = 1.252$.[39] Thus, when $\kappa \geq 1.252$ the cost of qualifying S3 is so high that even if the l-cartel announces H with probability 1 in both periods, the buyer does not invite S3 in either period. So both θ_1 and $\theta_2^{H_1}$ equal 1 for κs in this range.

For κ values between 0.814 and 1.252 we have our main result. Here, the cost of qualifying S3 is not high enough for the l-cartel to be able to announce H with probability 1 in

[39]As per the discussion after equation (2.4.5), $\underline{\kappa}_1 = \max\{\bar{\kappa}_2(0|L_1), \hat{\kappa}(0,1|L_1)\}$. For the chosen parameter values $\bar{\kappa}_2(0|L_1) = 0.626$ and $\hat{\kappa}(0,1|L_1) = 0.461$. Furthermore, $\bar{\kappa}_1 = \hat{\kappa}(1,1|H_1) = 1.252$.



$F_l = U[0,1]$; $F_h = U[1,2]$; prior probability of l-cost state, $\omega_l = 0.85$; prior probability of collusion, $\lambda = 0.15$.

Figure 2.4.1: Probabilities with which the l-cartel announces H in each period for different κ values.

both periods. Doing so will induce the qualification of S3 with probability 1 at $t = 1$ itself. However, by mixing announcements at $t = 1$, the l-cartel keeps the buyer's uncertainty about its presence high enough to (i) reduce the probability of S3 being invited at $t = 1$ and (ii) ensure that S3 is not invited at $t = 2$ even if the l-cartel in that period announces H with probability 1. The upper portion of the curve where $\theta_1 \in [0.304, 1)$ and $\theta_2^{H_1} = 1$ illustrates this.

When κ takes values between 0.626 and 0.814, the cost of qualifying S3 is so low that even if the first period l-cartel mixes announcements, the buyer's uncertainty is not sufficiently high to prevent the invitation of S3 at $t = 2$, if the l-cartel in that period announces H with probability 1. Referring to the lower portion of the curve, for κs in this range, in both periods the l-cartel mixes announcements: $\theta_1 \in [0.233, 0.304)$ and $\theta_2^{H_1} \in [0.516, 1]$.[40]

[40] Although not illustrated in the figure, when the l-cartel mixes at $t = 1$, for $\kappa \in [0.921, 1.252)$ if the buyer observes H it does *not* invite S3 with probability $\frac{\pi^{out}_{c,l}(L)+\omega_l\pi^{out}_{c,l}(H)+\omega_h\pi^{out}_{c,h}(H)-2\pi^{in}_c}{\pi^{out}_{c,l}(H)+\omega_l\pi^{out}_{c,l}(H)+\omega_h\pi^{out}_{c,h}(H)-2\pi^{in}_c}$ and for $\kappa \in [0.626, 0.921)$ it does not invite S3 with probability $\frac{\pi^{out}_{c,l}(L)+\omega_l\pi^{out}_{c,l}(H)+\omega_h\pi^{out}_{c,h}(H)-2\pi^{in}_c}{\pi^{out}_{c,l}(H)+\omega_l\pi^{out}_{c,l}(L)+\omega_h(\alpha_2\pi^{out}_{c,h}(H)+(1-\alpha_2)\pi^{in}_c)-2\pi^{in}_c}$. When the cartel mixes at $t = 2$, if the buyer observes H at $t = 2$ it does not invite S3 with probability $\frac{\pi^{out}_{c,l}(L)-\pi^{in}_c}{\pi^{out}_{c,l}(H)-\pi^{in}_c}$.

As it will be shown in the next section, if κ is "too low" our collusive mechanism does not satisfy the local sellers' IR constraints. In other words, given our collusive mechanism, if the cost of qualifying S3 is low enough, the cartel will not form in the cooperative state at $t = 0$. For the chosen parameter values, this occurs when $\kappa < \underline{\kappa}_1 = 0.626$.

Remark. As one might expect, the equilibrium defined by Propositions 5 and 8 is not unique. For instance, there is another equilibrium in which, when facing S3, the cartel center bids as if it is a merged entity whose cost is the minimum of two cost draws. The threshold κ values, in that case, are all greater than those specified in the propositions, but the equilibrium is qualitatively the same. One can construct yet another equilibrium with the buyer's off equilibrium beliefs specified as in footnote 36. However, even in that case the equilibrium is qualitatively the same.

We now proceed to analyze the local sellers' acceptance or rejection of the collusive mechanism described so far at $t = 0$.

2.4.3 Time $t = 0$ (Cartel Formation)

In this section we show that for suitable parameter values the collusive mechanism described by Propositions 5 and 8 does indeed satisfy the sellers' IR constraints. To gain some intuition, note that if a seller joins the cartel, whenever it is in the l-cost state it obtain a payoffs (weakly) greater than what it would under non-cooperative conduct. But when it is in the h-cost state, it does (weakly) *worse* compared to non-cooperative conduct. In particular, if the buyer employs a mixed strategy in equilibrium, a cartel member in the h-cost state obtains a payoff of $\alpha_t \pi^{out}_{nc,h}(H) + (1-\alpha_t)\pi^{in}_{nc}$, but if the seller had *not* joined the cartel, for the range of κ values we are interested in, its payoff is $\pi^{out}_{nc,h}(H)$. Since the former is strictly less than the latter $\forall \alpha_t \in (0, 1)$, the h-cost seller does worse upon joining the cartel if the buyer mixes. Thus, a local seller accepts the collusive mechanism if and only if the ex-ante gain in the l-cost state is sufficiently high to compensate the ex-ante loss in the h-cost state. As one would expect, for this to be true the cost of qualifying S3 and the likelihood of the cost state being *low* must be sufficiently high.

Proposition 10. *Given the collusive mechanism described in Propositions 5 and 8, there exists an* $\omega^* \in (0, \frac{1}{2})$ *such that, only if* $\kappa \geq \bar{\kappa}_2(0|L_1)$ *and* $\omega_l \geq \omega^*$*, the local sellers will form a cartel in the cooperative state.*

Proof. See Appendix A. □

2.5 An example with optimal collusive bids

Thus far we considered a collusive mechanism in which the cartel was not submitting the optimal joint profit maximizing bid in a procurement. This may seem prudent if the cartel is concerned about its discovery based on its bids. We now consider a simplified version of the original model in which the cartel bids optimally. We show that even in this case the cartel announces and bids more aggressively in the second period compared to the first.

The original game is simplified by discretizing both the cost space and the bid space in a manner that makes the buyer's inference problem with respect to the $t = 1$ bids easy to handle. Specifically, we assume that in the l-cost state seller i's idiosyncratic cost is 0 with probability p and 1 with probability $1 - p$, and in the h-cost state its cost is 1 with probability p and 2 with probability $1 - p$. We discretize the bid space by allowing them to be only one of the cost draws: 0, 1 or 2. Although the environment is highly stylized, it retains the incentive structure present in the original model. Since the analysis closely follows that in the previous section, we will not go through it in its entirety. Rather, the key features of the equilibrium will be discussed.

2.5.1 Time $t = 2$

We begin by noting that at $t = 2$ non-cooperative sellers will bid the upper support of the cost state they announce irrespective of their idiosyncratic costs. To see this, suppose the cost state is, say, *low* and sellers are non-cooperative. Further suppose S3 has not been invited and that S2 bids the upper support no matter what its cost draw. If S1's cost draw $x_{12} = 0$ and it bids 0, its payoff is 0. But if it bids 1, assuming ties are broken evenly, it obtains $\frac{1}{2}$. Thus S1's best response is to also bid 1. Of course, it is a dominant strategy S2 to bid 1 when $x_{12} = 1$. Following the same argument one can see that bidding the upper support is optimal for all sellers even if S3 is participating in the procurement.

Given that non-cooperative sellers only bid the upper support no matter what their cost draw, the cartel will never submit a bid less than the upper support of a cost state. Specifically, if S3 is participating in the procurement, the cartel will bid the upper of the true cost state, and if S3 is not participating in the procurement, the cartel will bid the upper support of the cost state it announced.

Following the same arguments as in Section 2.4.1, the buyer's indifference condition upon observing H at $t = 2$ is

$$\begin{aligned}\kappa &= \frac{\lambda_2^{A_1}(\theta_1)\omega_l\theta_2^{A_1}}{\lambda_2^{A_1}(\theta_1)(\omega_l\theta_2^{A_1}+\omega_h)+(1-\lambda_2^{A_1}(\theta_1))\omega_h} \\ &\equiv \hat{\kappa}(\theta_1,\theta_2^{A_1}|A_1,H_2). \end{aligned} \tag{2.5.1}$$

On the other hand, if the buyer observes L it infers that the sellers are announcing the cost state truthfully. But since all sellers bid the upper support of the cost state the buyer does not gain anything from qualifying S3 if announcements are truthful. Thus, the buyer's indifference condition after observing L at $t = 2$ is $\kappa = 0$.

We can now define

$$\begin{aligned}\bar{\kappa}(\theta_1|A_1) &\equiv \hat{\kappa}(\theta_1, 1|A_1, H_2) \\ &= \frac{\lambda_2^{A_1}(\theta_1)\omega_l}{\lambda_2^{A_1}(\theta_1)+(1-\lambda_2^{A_1}(\theta_1))\omega_h},\end{aligned}$$

and set $\underline{\kappa}_2 = 0$. Using these thresholds, equilibrium behavior at $t = 2$, if S3 was not qualified at $t = 1$, is analogous to that in Proposition 5:

Non-cooperative sellers always announce truthfully. While the h-cartel always announces H, for $\kappa \geq \bar{\kappa}_2(\theta_1|A_1)$ the l-cartel announces H with probability 1 and the buyer does not invite S3 irrespective of the $t = 2$ announcement; for $\kappa \in [0, \bar{\kappa}_2(\theta_1|A_1))$ the l-cartel mixes announcements between H and L so that equation (2.5.1) is satisfied, and the buyer mixes between inviting and not inviting S3 when it observes H. The probability with which it mixes is such that the l-cartel is indifferent between announcing L and H.

2.5.2 Time $t = 1$

It is easy to show that the non-cooperative sellers bid the upper support of the true cost state in this period also. So the cartel has no incentive to bid anything other than an upper support. This, in turn, implies that the buyer will make no additional inference based on the $t = 1$ bids. Thus, analogous to (2.4.4) in Section 2.4.2, the buyer's indifference condition upon observing H at $t = 1$ is

$$\kappa = \frac{\lambda_1\omega_l\theta_1}{\lambda_1(\omega_l\theta_1+\omega_h)+(1-\lambda_1)\omega_h} + \lambda_2^{H_1}(\theta_1)\omega_l\theta_2^{H_1} \equiv \hat{\kappa}(\theta_1,\theta_2^{H_1}|H_1), \tag{2.5.2}$$

where $\lambda_2^{H_1}(\theta_1) = \frac{\lambda_1(\omega_l\theta_1+\omega_h)}{\lambda_1(\omega_l\theta_1+\omega_h)+(1-\lambda_1)\omega_h}$. And analogous to (2.4.5), the buyer's indifference condition upon observing L at $t = 1$ is

$$\kappa = \lambda_2^{L_1}(\theta_1)\omega_l\theta_2^{L_1} \equiv \hat{\kappa}(\theta_1, \theta_2^{H_1}|L_1), \tag{2.5.3}$$

where $\lambda_2^{L_1}(\theta_1) = \frac{\lambda_1(1-\theta_1)}{\lambda_1(1-\theta_1)+(1-\lambda_1)}$.

As usual we define

$$\bar{\kappa}_1 \quad \equiv \quad \hat{\kappa}(1, 1|H_1) = \frac{2\lambda_1\omega_l}{\lambda_1 + (1-\lambda_1)\omega_h},$$

which follows from the fact that if the l-cartel announces H with probability 1 at $t = 1$, then $\lambda_2^{H_1}(1) = \frac{\lambda_1}{\lambda_1+(1-\lambda_1)\omega_h}$. Like in Section 2.4.2 we also define $\underline{\kappa}_1 \equiv \max\{\hat{\kappa}(0, 1|L_1), \bar{\kappa}_2(0|L_1)\}$.

Again, the equilibrium exhibiting gradually increasing price announcements and transaction prices exists when $\bar{\kappa}_1 \geq \bar{\kappa}_2(1|H_1)$. The conditions under which this occurs are the same as in Claim 1,[41] and under these conditions for $\kappa \in [\bar{\kappa}_2(1|H_1), \bar{\kappa}_1)$ at $t = 1$ the l-cartel announces H with probability $\theta_1 \in (0, 1)$ and at at $t = 2$ it announces H with probability $\theta_2^{H_1} = 1$.

2.6 Conclusion

There is substantial evidence that industrial cartels manipulate transaction prices through coordinated price announcements. This is typically done in an environment in which the buyers use competitive procurements, and have access to sellers not all of which are part of the cartel. Motivated by these observations, this paper provides an explanation for why cartels may raise prices gradually, and how collusive price announcements enable them to do so when the buyer can take actions to increase competition in the market. The paper embeds an explicit cartel in a two period dynamic setting in which the buyer can impose competitive pressure on the cartel by qualifying an additional seller to participate in the procurements it conducts. It shows that through coordinated price announcements a cartel can exploit the buyer's uncertainty about the underlying costs to obtain payoffs greater than those under competition, even with bids that are indistinguishable from non-cooperative bids. Furthermore, since the cartel interacts with the buyer over two periods, the forward-looking cartel reduces the likelihood of the outside seller being invited at an

[41] Follows from their definitions.

early stage by being less aggressive with its announcements in the first period compared to the second period. This not only provides a rationale for the gradually increasing price announcements observed in the data, but also provides a mechanism through which price announcements may translate to higher transaction prices when buyers use competitive procurements.

Chapter 3

Collusion in Auctions with Endogenous Quantity: A Numerical Exploration

3.1 Introduction

When bidders collude in a procurement, the underlying price discovery process is compromised. This leaves the buyer worse-off and potentially leads to inefficient allocations. A considerable amount of past research has been devoted towards analyzing of the effects of bidder collusion in auctions/procurements on such matters. Much of this literature assumes that the seller in auctions, or the buyer in procurements, wishes to transact a predetermined (or ex-ante fixed) number of objects. However, in many procurement environments the transaction quantity is not fixed ex-ante. Rather, it is endogenously determined by the bids offered by competing sellers. For example, when competing for Annual Requirements Contracts, sellers bid for the right to provide a production input or service for a fixed period of time. If substitute products are available, the procurer in such cases has some latitude in deciding on the quantity it will demand over the contract period. Thus, the sellers confront a downward sloping demand curve when bidding for such contracts.[1, 2]

This paper explores the effects of bidder collusion on such endogenous quantity procurements. Specifically, it analyzes the effects of the presence of a non all-inclusive bidding cartel in such environments.

Our point of departure is the model of Hansen (1988), where a buyer with a publicly known downward sloping demand curve conducts a procurement and the sellers operate with a constant returns to scale technology. A seller's bid in the procurement is its quote for the per unit price. In a first-price procurement (FPP) the per unit transaction price equals the lowest bid and the quantity transacted—read off the demand curve—corresponds to that price. The transaction price and quantity are determined analogously in a second-price procurement (SPP), with the price being the second lowest bid.

In this setting, Hansen (1988) first shows that in an FPP bidders bid more aggressively when quantity is endogenous than when it is fixed, i.e., for the same cost draw a seller's bid is *lower* in the former than in the latter. The intuition for this is as follows: In an FPP a

[1] Of course, demand conditions in downstream markets may also affect the quantity demanded. To keep things simple we will abstract away from these considerations.

[2] In many applications such contracts are also used because it is impossible to predict the quantity required in advance. To cover for this underlying uncertainty buyers require the sellers to commit to sell the necessary inputs in advance. In this paper we will not be dealing with demand uncertainty. Rather, we will focus on an environment where the buyer's underlying demand curve is fixed and publicly known.

bidder increases its bid till the increase in profits due to the higher bid is perfectly offset by the decrease in the probability of winning the contract from doing so. When quantity demanded is endogenous, compared to the fixed demand case, the gain from a higher bid is lower because fewer units are sold. Thus, bidding is more aggressive in the former than in the latter.

Note, however, that irrespective of whether the quantity demanded is fixed or endogenous, sellers continue bidding their costs in an SPP. Consequently, Hansen is able to invoke the Revenue Equivalence Theorem to show that the expected price when quantity is endogenous is lower in an FPP than an SPP, and as a result, the expected quantity sold in an FPP is greater than that sold in an SPP. This results in both the buyer and the sellers preferring the FPP over the SPP.

The objective of the current paper, however, is to compare these two auction formats in the presence of a non all-inclusive bidding cartel. The bidding cartel in our setting behaves as a single joint profit maximizing entity, while the non-cartel bidder behaves optimally given that such a cartel is in operation.[3] This necessarily introduces asymmetries between the cartel and the non-cartel bidder. Due to well-known difficulties in analytically solving for the equilibrium in asymmetric environments, we numerically solve for the equilibrium outcomes for the FPP and compare them to outcomes in the SPP.

Our numerical exercises suggest that irrespective of the underlying demand curve, the buyer and the non-cartel bidder prefer the endogenous demand FPP over the endogenous demand SPP. However, while the cartel (which in this case is the "strong" bidder) prefers the SPP over the FPP when demand is relatively *inelastic*, for *sufficiently elastic* demand curves it prefers the FPP over the SPP. This is unlike earlier results which show that when quantity is fixed the strong bidder prefers the SPP over the FPP (Maskin and Riley, 2000a; Arozamena and Cantillon, 2004; Marshall et al., 1994).[4] Thus, under suitable demand conditions, Hansen's (1988) result that both the buyer and the sellers prefer the FPP over the SPP continues to hold even under the bidder asymmetries considered here.

Further, we compare the incentives of a subset of bidders to form a bidding cartel between the two auction formats. Interestingly, the numerical exercises suggest that although the payoff to forming a two-seller bidding cartel (starting from the symmetric

[3]Note that we will not be concerned about the internal cartel mechanism. One may therefore view this paper as an analysis of a particular type of bidder asymmetry in endogenous quantity environments.

[4]Maskin and Riley (2000a) obtain their results under slightly different distributional assumptions to compared to the other papers.

three-seller case) is *lower* in an FPP than an SPP when demand is relatively inelastic, when demand is sufficiently elastic, the incentive to form such a cartel is *higher* in an FPP than an SPP. Thus, although the incentive to collude may be lower in an FPP than in an SPP when demand is fixed (Marshall et al., 1994),[5] our numerical results suggest that under suitable demand conditions the incentive to collude in an FPP may be greater than that in an SPP.

3.2 Literature

The paper lies at the intersection of three literatures: auctions with asymmetric bidders, bidder collusion, and endogenous quantity auctions.

The analysis of asymmetric first-price auctions started with the existence and uniqueness results of Lebrun (1996, 1999) and Maskin and Riley (2000b, 2003). Further, Maskin and Riley (2000a) characterized the equilibrium in the asymmetric two-bidder case. Specifically, in an auction environment they show that a weak bidder will bid more aggressively than a strong bidder,[6] and that the weak bidder prefers a first-price auction over a second-price auction, while the strong bidder's preferance goes the other way. Arozamena and Cantillon (2004) extend the characterization for the n-bidder case in a procurement framework. They also show that the incentive for one of the bidder's to improve its cost distribution (say through investments) is lower in an FPP than in an SPP. Marshall et al. (1994) provide the first numerical algorithm to solve for the equilibrium in asymmetric first-price auctions (the idea behind this algorithm is used for the numerical exercises in the current paper).

In the bidder collusion literature important early papers include Robinson (1985), which focuses on the stability of a bidding cartel once it has formed, and Graham and Marshall (1987), which focuses on collusion in second-price and English auctions. In terms of comparing the first-price and second-price environments with respect to bidder collusion, Marshall et al. (1994) use their numerical algorithm to conjecture that the incentives to collude in a first-price auction is less than that in a second-price auction. Incorporating the most general set up Marshall and Marx (2007) show, among other things, that sustaining a collusive outcome is easier in a second-price environment than in a first-

[5] Although Marshall et al. (1994) analyze auctions, their results will carry over to procurements as well.

[6] Recall that in an auction "more aggressively" means that for a given valuation the optimal bid is higher, while in a procurement it means that for a given cost draw the optimal bid is lower.

price environment.

In all of the above papers the quantity transacted is fixed ex-ante and not determined by the bids. Hansen (1988) was the first to analyze the endogenous quantity environment in a symmetric two-bidder procurement. He showed that both the buyer and the sellers prefer the FPP over the SPP. This is because the expected quantity transacted in the former is greater than in the latter, leaving a comparatively larger "pie" to be shared in the FPP. Dasgupta and Spulber (1989) consider an environment in which the sellers have increasing returns to scale and and show that the Hansen (1988) mechanism is sub-optimal for the buyer. Lengwiler (1999) considers a discrete bid, divisible good auction, in which the seller may vary the quantity sold (up or down) after the bids have been submitted. For other auction settings in which the seller may alter the fraction or number of units sold after observing the bids, see Back and Zender (2001) and subsequent papers. None of these papers, however, consider a situation in which a subset of the bidder are explicitly colluding.

3.3 Model

There are three ex-ante identical sellers who draw their idiosyncratic costs from the same distribution, F over $[0, \bar{c}] \subset \mathrm{R}_{+}$. The pdf f is bounded away from zero on its support. There is a single buyer with a public known differentiable demand function $q(p)$ such that $q'(p) < 0$. Without loss of generality, we set $q(\bar{c}) = 0$. We assume that the buyer can to commit to this demand function ex-ante. To guarantee the existense and uniqueness of the equilibrium in the endogenous FPP, it is further assumed that the price elasticity of demand, $\epsilon(b) \equiv \frac{q'(b)b}{q(b)}$, is non-increasing in b.[7] All sellers operate with a *constant returns to scale* technology. The sellers each have enough capacity to satisfy all of the buyer's requirements. All agents are risk-neutral.

When referring to a non all-inclusive bidding cartel, we will refer to a cartel consisting of two out of the three sellers; say sellers 1 and 2. We assume that the cartel acts as a single joint profit maximizing entity. In particular, the cartel can perfectly monitor its members' cost draws and can fully control its members' bids. The member with the lowest cost bids on behalf of the cartel against the non-cartel bidder. So the cartel's cost is the minimum of the two cartel members' cost draws, who each draw from F. A meaningless higher bid is

[7] See Arozamena and Cantillon (2004) for the reasoning behind this assumption.

submitted on behalf of the other cartel member.[8]

The non-cartel bidder is aware of the cartel's presence and bids accordingly. Note that although we interpret this construct as a cartel bidding against a non-cartel member, one can just view this as a two-bidder asymmetric procurement, with a specific kind of asymmetry between the bidders.

Let F_s denote the cost distribution of the cartel and F_w ($\equiv F$) denote the cost distribution of the non-cartel member. The associated pdfs are denoted f_s and f_w respectively. We have used s to indicate that the cartel is the "strong" bidder and w to indicated that the outside bidder is "weak."

In both the FPP and the SPP the lowest bidder wins the contract. The transaction prices and quantities are, however, different between the two formats. If b_1 and b_2 are the lowest and second lowest bids respectively, in the FPP the buyer procures $q(b_1)$ units at a price of b_1 per unit, whereas in the SPP the buyer procures $q(b_2)$ at a price of b_2 per unit.

The buyer's surplus when it purchases $q(b)$ units at a per unit price of b is denoted by $W(b)$. It equals the area the demand curve, less the total payment. That is, letting $p \equiv q^{-1}$,

$$W(b) = \int_0^{q(b)} p(t)dt - q(b)b. \tag{3.3.1}$$

If seller i, with cost draw c_i, wins the contract with a bid of b, its payoff is $q(b)(b - c_i)$.

3.4 Analysis and Results

3.4.1 Second-Price Procurement

In an SPP, even under endogenous demand and bidder asymmetries, it is a weakly dominant strategy for both the sellers to bid their respective costs. Thus seller i's *ex-ante* expected payoff from bidding c is

$$\pi_i^{SPP} = \int_0^{\bar{c}} \int_c^{\bar{c}} q(t)(t - c)\, dF_j(t)\, dF_i(c).$$

The inner integral is its expected profit from bidding a particular cost draw c, and the outer integral integrates over all possible cost draws.

[8]We are thus implicitly assuming the *Bid Submission Mechanism* of Marshall and Marx (2007).

Furthermore, if seller i has the lowest cost draw, the buyer's expected surplus due to that seller is $\int_{c_i}^{\bar{c}} W(t)dF_j(t)$, $j \neq i$. So the buyer's *ex-ante* surplus from conducting an SPP is

$$CS_{SPP} = \int_0^{\bar{c}} \int_c^{\bar{c}} W(t)dF_w(t)dF_s(c) + \int_0^{\bar{c}} \int_c^{\bar{c}} W(t)dF_s(t)dF_w(c). \tag{3.4.1}$$

The following lemma gives us a more convenient way of writing equation (3.4.1).

Lemma 11. *$CS_{SPP} = W(\bar{c}) + \int_0^{\bar{c}} F_s(c)F_w(c)q(c)dc$.*

Proof. Changing the order of integration in the second term on the RHS of equation (3.4.1) we have,

$$\begin{aligned}\int_0^{\bar{c}} \int_c^{\bar{c}} W(t)dF_s(t)dF_w(c) &= \int_0^{\bar{c}} \int_0^{c} dF_w(t)W(c)dF_s(c)\\ &= \int_0^{\bar{c}} F_w(c)W(c)dF_s(c)\end{aligned}$$

Thus,

$$CS_{SPP} = \int_0^{\bar{c}} \left(\int_c^{\bar{c}} W(t)dF_w(t) + F_w(c)W(c) \right) dF_s(c)$$

Integrating by parts the first term within the parentheses we have,

$$\int_c^{\bar{c}} W(t)dF_w(t) = W(\bar{c})F_w\left(\bar{c}_i\right) - F_w(c)W(c) - \int_c^{\bar{c}} F_w(t)W'(t)\mathrm{dt}$$

Substituting this in the previous equation we get

$$\begin{aligned}CS_{SPP} &= \int_0^{\bar{c}} \left(W(\bar{c}) \underbrace{F_w(\bar{c})}_{=1} - \int_c^{\bar{c}} F_w(t)W'(t)dt \right) dF_s(c)\\ &= W\left(\bar{c}\right) - \int_0^{\bar{c}} \int_c^{\bar{c}} F_w(t)W'(t)dt\, dF_s(c)\\ &= W\left(\bar{c}\right) + \int_0^{\bar{c}} \int_c^{\bar{c}} F_w(t)q(t)dtdF_s(c),\end{aligned}$$

where the third equality comes from applying Leibniz rule to the definition of $W(t)$.[9] Finally, changing the order of integration one more time we get the required expression. □

[9] $W(t) \equiv \int_0^{q(t)} p(s)ds - tq(t) \Longrightarrow W'(t) = -q(t)$.

The above lemma shows that the consumer surplus is just a weighted sum of the quantities transacted. The weight on a particular quantity is just the probability that the transaction price in the SPP is at most equal to the price resulting in that quantity.

3.4.2 First-price Procurement

Bidding in an endogenous quantity FPP:

In an FPP the lowest bidder wins and the buyer procures the number of units corresponding to the lowest bid at a per unit price equal to that bid. Therefore bidder i with cost draw c_i solves

$$\max_b (b - c_i) q(b) \Pr(i \text{ wins with bid } b).$$

With the assumptions placed on the cost distributions and the demand curve, the existense of a unique solution to the system of differential equations described by the FOCs of bidders' maximization problems is guaranteed (Maskin and Riley (2000b, 2003)). Specifically, if ψ_i is bidder i's inverse bid function in equilibrium, then $\psi_i : [b^*, \bar{c}] \to [0, \bar{c}]$ and solves

$$\psi_j'(b) = \frac{1 - F_j(\psi_j(b))}{f_j(\psi_j(b))} \times \frac{1}{(b - \psi_i(b))} \left(\frac{q(b) + q'(b)(b - \psi_i(b))}{q(b)} \right) \tag{3.4.2}$$

for $i, j \in \{s, w\}$ and $j \neq i$. The common lower bound, b^*, of the domain of the inverse bid functions is endogenously determined in equilibrium, and the upper bound equals $\bar{c}$ because a seller with the maximum possible cost draw will never have an incentive to bid anything less than its cost draw.[10]

Using the equilibrium conditions above, we can infer a key qualitative aspect of the equilibrium inverse bid functions. Specifically, like in Maskin and Riley (2000a), the non-cartel (weak) bidder bids more aggressively than the cartel (strong). More formally:

Lemma 12. *For all $b \in (b^*, \bar{c})$, $\psi_w(b) > \psi_s(b)$. That is, for a given cost draw, the non-cartel bidder bids less than the strong bidder.*

Proof. Towards a contradiction, suppose this is not the case.[11] Then, either $\psi_w(b) < \psi_s(b)$, $\forall b \in (\underline{b}, \bar{c})$, or there exists some $z \in (b^*, \bar{c})$ such that $\psi_w(z) = \psi_s(z)$. Since F_s is the dis-

[10] If it bids less than its cost, it wins the contract with non-zero probability and make a loss, in which case it is better-off bidding its cost to obtain a profit of zero. For additional details about the equilibrium and a more general treatment than this paper see Maskin and Riley (2003).

[11] The reasoning applied here is similar to Proposition 3.5 of Maskin and Riley (2000a).

tribution of the the minimum of two draws from F_w, we have $\frac{1-F_s(\psi_s(b))}{f_s(\psi_s(b))} < \frac{1-F_w(\psi_w(b))}{f_w(\psi_w(b))}$ (see Arozamena and Cantillon, 2004, p. 5). Thus, from equation (3.4.2), this implies $\psi_w'(z) > \psi_s'(z)$ when they intersect. As a result, $\psi_w(b) < \psi_s(b)$ for $b \in (b^*, z)$ and $\psi_w(b) > \psi_s(b)$ for $b \in (z, \bar{c})$. So irrespective of whether ψ_w lies below ψ_s throughout, or ψ_w interesects ψ_s at z, for b close to b^* we have $\psi_w(b) < \psi_s(b)$. So for such b values,

$$H_w(b) = F_w(\psi_w(b)) < F_s(\psi_s(b)) = H_s(b),$$

where the inequality results from the fact that F_w dominates F_s in terms of hazard rate, which in turn implies that F_w first order stochastically dominates F_s. Additionally, since $H_w(b^*) = H_s(b^*) = 0$, it must be that $h_s(b) > h_w(b)$. So for b close to b^* we have

(i) $\frac{h_w(b)}{1-H_w(b)} < \frac{h_s(b)}{1-H_s(b)}$, and

(ii) Since one can show that $\frac{q(b)+q'(b)(b-x)}{q(b)(b-x)}$ is increasing in x, we have $\left(\frac{q(b)+q'(b)(b-\psi_w(b))}{q(b)(b-\psi_w(b))}\right) < \left(\frac{q(b)+q'(b)(b-\psi_s(b))}{q(b)(b-\psi_s(b))}\right)$ when $\psi_w(b) < \psi_s(b)$.

But from the bidders' FOCs we have

$$\left(\frac{q(b)+q'(b)(b-\psi_w(b))}{q(b)(b-\psi_w(b))}\right)\left(\frac{h_w(b)}{1-H_w(b)}\right) = \left(\frac{h_s(b)}{1-H_s(b)}\right)\left(\frac{q(b)+q'(b)(b-\psi_s(b))}{q(b)(b-\psi_s(b))}\right),$$

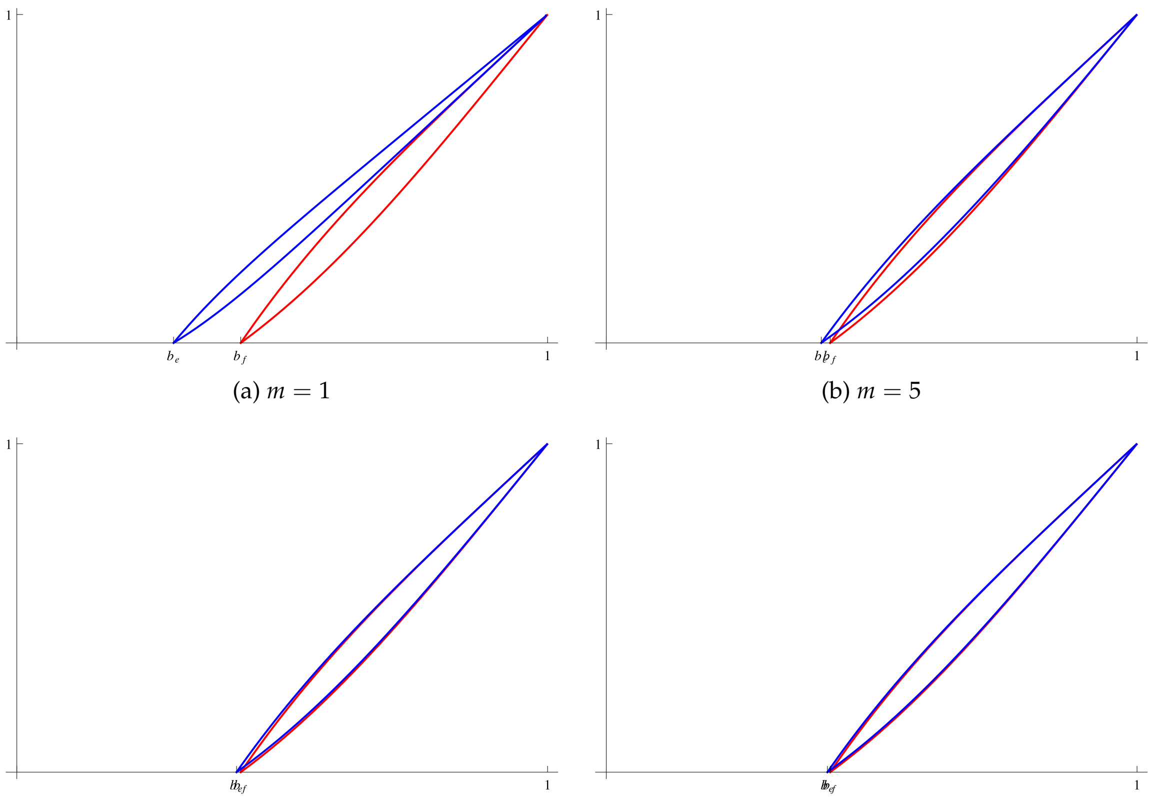
which cannot hold given the two inequalities above at b close to b^*. A contradiction. □

In addition to the difference in bidding behavior between the cartel and the non-cartel bidder, it is useful to understand the effects of the underlying demand curve on the bid functions. Since it has been intractible to explore this idea analytically, we perform numerical experiments to gain further insight. In particular, we are after the effects of demand elasticity on bidding behavior.

Figure 3.4.1 depicts the equilibrium inverse bid functions (bids on x-axis, costs on y-axis) for different underlying linear demand functions. Specifically, for the numerical exercises we set $F_w(c) = c$, $F_s(c) = 2c - c^2$ and $q(p) = 1 - \frac{p}{m}$.[12] Each panel in the figure depicts the equilibrium under endogenous demand (blue) along with the equilibrium under fixed (unit) demand (red). The unique lowest bid for the endogenous demand case is labeled b_e, and that for fixed demand is labeled b_f.[13] To economize on space, we have

[12]We obtain qualitatively similar numerical results for other other underlying distributions as well.

[13]The equilibria were numerically obtained by incorporating in *Mathematica* (version 8) the "backward shooting" method suggested by Marshall et al. (1994).



(a) $m = 1$

(b) $m = 5$

(c) $m = 10$

(d) $m = 15$

Note: $F_w(c) = c$, $F_s(c) = 2c - c^2$ and $q(p) = 1 - \frac{p}{m}$.

Figure 3.4.1: Equilibrium inverse bid functions (bids on x-axis, costs on y-axis)

not depicted the equilbrium for every value of m that was tried. Rather, only the equilibria for $m = \{1, 5, 10, 15\}$ are shown.

As shown in the previous lemma, in all the pictures the non-cartel bidder's inverse bid function is greater than the cartel's inverse bid function even under endogenous demand. That is, the non-cartel bidder bids more aggressively than the cartel. Moreover, within their common support, in every case the blue curves lie above the red curves, except at $\bar{c} = 1$. In other words, for a given cost draw, compared to the fixed demand case, both sellers submit lower bids when demand is endogenous, i.e., they are both more aggressive when demand is endogenous. Finally, since demand elasticity is decreasing in m, as one might expect, the bidding gets progressively less aggressive as m increases—for a given cost draw the sellers' bids are increasing in m.

While not a definitive proof, the numerical exercise clearly suggests that as $m \to \infty$ the endogenous quantity equilibrium will eventually coincide with the fixed quantity equilibrium. Although the intuition seems very strong, a theoretical proof for this result has so far been elusive.[14] In any event, the intuition behind the above numerical result is simple. Recall that when demand is endogenous, because fewer units are sold for higher bids, the gain from a marginally higher bid is lower than that under fixed demand. However, this gain is increasing in m (because demand becomes more inelastic). Thus bidding gets progressively less aggressive as m increases.

This notion of bids getting less aggressive as demand becomes more inelastic is, however, absent in SPPs.[15] One implication of this is that if under fixed demand, for certain asymmetries the consumer's surplus is greater in the FPP than the SPP, then it must be so under endogenous demand as well. The numerical exercises performed in Section 3.4.3 indeed suggest this.

As an immediate matter, however, we turn to deriving the expression for the ex-ante consumer surplus in an endogenous demand FPP.

Consumer Surplus in an endogenous demand FPP:

Let H_j be the equilibrium bid distribution of seller j; $H_j(b) \equiv F_j\left(\psi_j(b)\right)$. When bidder i bids b, it wins with probability $1 - H_j(b)$, resulting in an interim expected consumer surplus of $\left(1 - H_j(b)\right) W(b)$, where $W(b)$ is defined in equation (3.3.1). So the total *ex-ante* consumer surplus is

$$CS_{FPP} = \int_{b^*}^{\bar{c}} \left(1 - H_w(b)\right) W(b) dH_s(b) + \int_{b^*}^{\bar{c}} \left(1 - H_s(b)\right) W(b) dH_w(b). \tag{3.4.3}$$

Like in the SPP, the expression for the consumer surplus can be simplified to be written as a weighted sum of the quantities transacted in equilibrium. Again, the weight on a particular quantity is just the probability that the transaction price in equilibrium is at most equal to the price resulting in that quantity.

Lemma 13. $CS_{FPP} = W(\bar{c}) + \int_{b^*}^{\bar{c}} \left[H_s(b) + H_w(b) - H_s(b)H_w(b)\right] q(b)db.$

[14] One direction towards constructing a proof would be to start with the equilibrium conditions under an arbitrary $m < \infty$, and show that the inverse bid functions are decreasing in m.

[15] Irrespective of the demand curve, it is still optimal for a seller to bid its cost in an SPP.

Proof. Consider the first expression in equation (3.4.3).

$$\int_{b^*}^{\bar{c}} (1 - H_w(b))\, W(b) dH_s(b) = \int_{b^*}^{\bar{c}} \int_{b}^{\bar{c}} dH_w(t) W(b) dH_s(b)$$
$$= \int_{b^*}^{\bar{c}} \int_{b^*}^{b} W(t) dH_s(t) dH_w(b),$$

where the second equality is obtained by changing the order of integration. Using this,

$$CS_{FPP} \quad = \quad \int_{b^*}^{\bar{c}} \left[\int_{b^*}^{b} W(t) dH_s(t) + (1 - H_s(b))\, W(b) \right] dH_w(b).$$

Integrating by parts the first term within brackets,

$$\begin{aligned}
CS_{FPP} &= \int_{b^*}^{\bar{c}} \left[W(b) H_s(b) - W(\underline{b}) \underbrace{H_s(\underline{b})}_{=0} - \int_{b^*}^{b} W'(t) H_s(t)\, dt + W(b)(1 - H_s(b)) \right] dH_w(b) \\
&= \int_{b^*}^{\bar{c}} W(b) dH_w(b) - \int_{b^*}^{\bar{c}} \int_{b^*}^{b} W'(t) H_s(t)\, dt\, dH_w(b) \\
&= \int_{b^*}^{\bar{c}} W(b) dH_w(b) + \int_{b^*}^{\bar{c}} \int_{b^*}^{b} q(t) H_s(t)\, dt\, dH_w(b) \\
&= \int_{b^*}^{\bar{c}} W(b) dH_w(b) + \int_{b^*}^{\bar{c}} (1 - H_w(b))\, q(b) H_s(b) db \\
&= W(\bar{b}) \underbrace{H_w(\bar{b})}_{=1} - W(\underline{b}) \underbrace{H_w(\underline{b})}_{=0} + \int_{b^*}^{\bar{c}} q(b) H_w(b) db + \int_{b^*}^{\bar{c}} q(b)\, (1 - H_w(b))\, H_s(b) db,
\end{aligned}$$

where the third equality results from the fact that $W'(t) = -q(t)$, and the fourth equality comes from changing the order of integration. Collecting terms, we get the required expression. □

We now proceed to compare the FPP and SPP when demand is endogenous.

3.4.3 Comparing FPP and SPP under endogenous demand

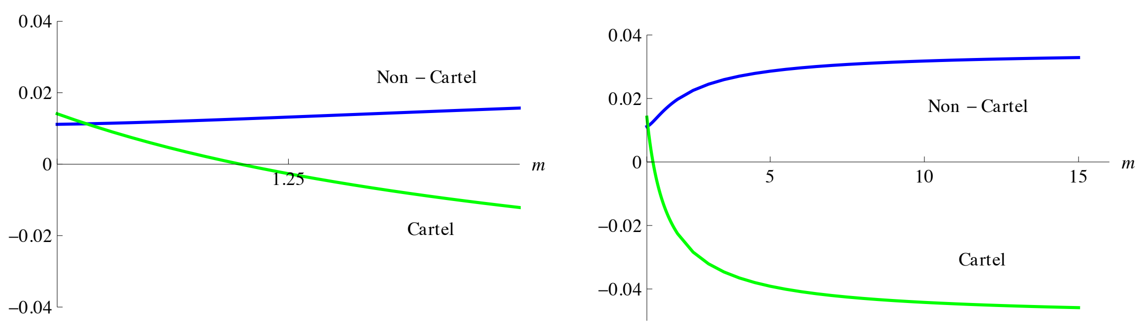
From the sellers' perspective:

Recall that under endogenous demand, since sellers bid their costs in an SPP, seller i's *ex-ante* expected profit is

$$\pi_i^{SPP} = \int_0^{\bar{c}} \int_c^{\bar{c}} q(t)(t-c)\, dF_j(t)\, dF_i(c).$$

Similarly, given the sellers' equilibrium bidding functions in the FPP, seller i's ex-ante expected profit is

$$\pi_i^{FPP} = \int_{b^*}^{\bar{c}} q(b)(b - \psi_i(b))(1 - H_j(b))\, dH_i(b).$$

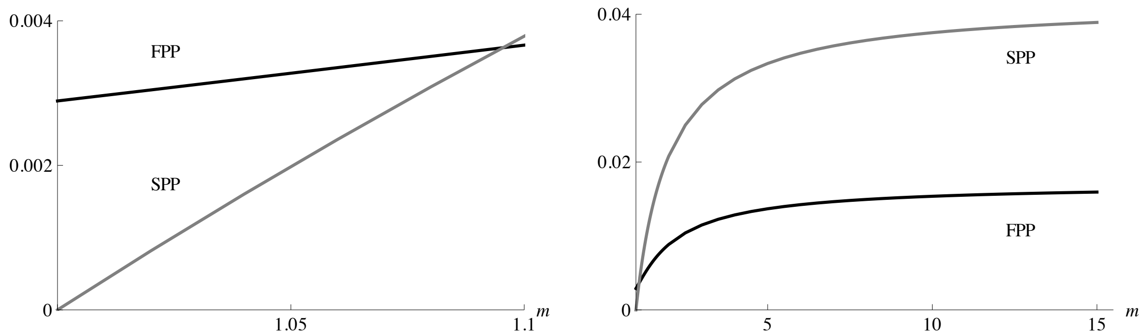


(a) (b)

Note: $F_w(c) = c$, $F_s(c) = 2c - c^2$ and $q(p) = 1 - \frac{p}{m}$.

Figure 3.4.2: $\pi^{FPP} - \pi^{SPP}$ for cartel and non-cartel bidder.

For the same distributional assumptions used to generate Figure 3.4.1, Figure 3.4.2 depicts $\pi_i^{FPP} - \pi_i^{SPP}$ for $i \in \{s, w\}$ for different values of m. In the picture, for large enough values of m, i.e., when demand is sufficiently *inelastic*, the non-cartel bidder prefers the FPP while the cartel prefers the SPP. This is the same outcome as the fixed demand case of Marshall et al. (1994) and Maskin and Riley (2000a), where the cartel (or strong bidder) prefers the SPP over the FPP. However, the figure also shows that when m is small enough, i.e., when demand is sufficiently *elastic*, both the cartel and the non-cartel bidder prefer the FPP over the SPP. In other words, in such scenarios the strong bidder's ranking under fixed demand are inverted and we recover the result of Hansen (1988).



(a) (b)

Note: $F_w(c) = c$, $F_s(c) = 2c - c^2$ and $q(p) = 1 - \frac{p}{m}$.

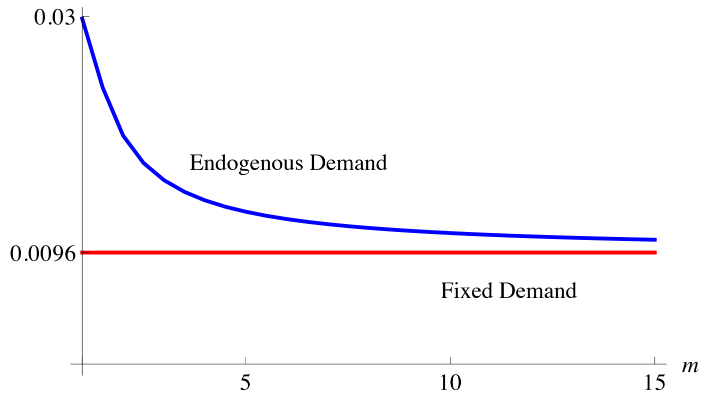
Figure 3.4.3: A seller's gain from joining the cartel.

While the above outcome is itself interesting, it is also useful to know which procurement format provides sellers with a greater incentive collude. Towards this, we now compare a seller's gain from being part of a two-bidder cartel relative to obtaining the non-cooperative payoff in a symmetric three-seller endogenous demand procurement. Let π^{symFPP} and π^{symSPP} denote the seller's ex-ante payoff in such an FPP and SPP respectively.[16] For the computations, since the bidders are ex-ante symmetric, the likelihood of a given cartel member having the lower cost is exactly half. Thus, we compare $\frac{\pi_s^{FPP}}{2} - \pi^{symFPP}$ with $\frac{\pi_s^{SPP}}{2} - \pi^{symSPP}$ for different values of m.

Figure 3.4.3 shows that although the incentive to collude in an FPP is lower than that in an SPP for most demand curves, when demand is sufficiently inelastic, the incentive to collude in an FPP is *greater* than that in an SPP. This is rather interesting because when demand is endogenous, under suitable conditions, we are led to conjecture that the FPP is *more* susceptible to collusion than the SPP.[17] This is unlike Marshall et al. (1994), where

[16] In the endogenous demand non-cooperative SPP, $\pi^{symSPP} = \int_0^{\bar{c}} \int_c^{\bar{c}} q(t)(t-c)\,dG(t)\,dF(c)$, where G is the distribution of the lowest cost among competing bidders. In the endogenous demand non-cooperative FPP, $\pi^{symFPP} = \int_{b^*_{sym}}^{\bar{c}} q(b)(b - \psi(b))(1 - J(b))\,dH(b)$, where ψ is the equilibrium inverse bid function; b^*_{sym} is the unique lower bound of the inverse bid functions in equilibrium; $H(b) \equiv F(\psi(b))$ and J is bid distribution of the lowest of the competing bids.

[17] Of course, this relies on the assumption that the cartel can use the bid submission mechanism of Marshall and Marx (2007). If instead, it must use the *Bid Coordination Mechanism* of that paper, then the endogenous demand FPP may still be *less* susceptible to collusion.



Note: $F_w(c) = c$, $F_s(c) = 2c - c^2$. For endogenous demand $q(p) = 1 - \frac{p}{m}$; for fixed demand $q(p) = 1$.

Figure 3.4.4: $CS_{FPP} - CS_{SPP}$

for fixed demand, the authors conjecture that the FPP is *less* susceptible to collusion than the SPP.

From the buyer's perspective:

In this section we compare $CS_{FPP} - CS_{SPP}$ for different values of m, while maintaining the assumption that $F_w(c) = c$, $F_s(c) = 2c - c^2$ and $q(p) = 1 - \frac{p}{m}$. As evident from Figure 3.4.4, for the assumed distributions and underlying demand curves, $CS_{FPP} > CS_{SPP}$. Moreover, the FPP performs increasingly better as demand becomes more *elastic* (i.e. m becomes smaller). This is because the sellers' bids are increasingly aggressive in the FPP as demand becomes more elastic (see Figure 3.4.1). This progressively reduces the buyer's expected price. However, bidders do not respond to changes in the demand elasticity in an SPP, where the sellers continue bidding their costs. As a result, the FPP dominates the SPP to a greater extent as m decreases.

As demand becomes progressively *inelastic*, the difference in consumer surplus converges to the fixed demand case, which is itself greater than zero for the assumed distributions when demand is fixed. Although a theoretical result comparing the two procurement formats presently seems elusive, the latter observation points us towards a direction one might take in constructing a proof. Specifically, we could start from conditions under which the fixed demand FPP dominates its second-price counterpart. Then, we could perturb the demand curve from one that is perfectly inelastic to one that is marginally elastic, and deduce the direction in which $CS_{FPP} - CS_{SPP}$ changes. If the difference increases as the demand becomes more elastic, it would be definitive proof that under the same (or perhaps under weaker conditions) the endogenous demand FPP will dominate the endogenous demand SPP.

3.5 Conclusion

We have explored the effects of a non all-inclusive bidding cartel on endogenous demand procurements. A traditional result under fixed demand is that the buyer and the non-cartel bidder prefer the FPP over the SPP, while the cartel prefers the SPP over the FPP. However, our numerical exercises suggest that even though this may be true for relatively inelastic demand curves, when demand becomes sufficiently elastic, all bidders prefer the FPP over the SPP. Thus, Hansen's (1988) result with symmetric bidders seems to extend, under certain conditions, to the asymmetric environment as well. Additionally, the numerical exercises also suggest that for sufficiently elastic demand curves, there is a greater incentive for a cartel to form in an FPP than an SPP. This is also unlike the fixed demand case where the incentive is greater in an SPP than an FPP. Finally, the numerical exercises provide a clear direction that one might take in proving some of these results theoretically. The paper therefore, must be viewed as exploratory in this regard.

Appendix A

Appendix for Chapter 1

A.1 Historical evidence of collusion followed by merger

We review the ten largest (in net value) manufacturing industry groups according to the U.S. census of 1900 for evidence of industries with cartels followed by mergers.[1] The information provided in Table A.1 is not exhaustive. We provide representative examples of the observed phenomenon for the time period closely following the passage of the Sherman Act.

Based on a review of the 55 industrial cartel decisions issued by the European Commission in 2001–2010,[2] we find evidence of mergers, acquisitions, or joint ventures among at least two of the co-conspirators after the end of the cartel period in 24 (44%) of the cases.[3] The 24 cases are listed below, with the date following the case name indicating the

[1]U.S. Census Office (1902, p.325). The Twelfth Census classified industries into fifteen groups. The industry groups absent in our sample from the Census classifications are (i) clay, glass, and stone products, (ii) vehicles for land transportation, (iii) shipbuilding, (iv) miscellaneous industries, and (v) hand trades. Our sample includes the ten most valuable groups excluding miscellaneous industries and hand trades.

[2]The EC Decisions are available at http://ec.europa.eu/competition/cartels/cases/cases.html (accessed November 25, 2012). We exclude non-industrial products, such as bananas, grains and oilseeds, beer, and tobacco, banking-related cartels, *SAS/Maersk Air*, and *Fine Art Auction Houses*. We also exclude cases whose decisions do not identify the cartel participants (*Cement and related products*, *Paper envelope*, *Polyurethane foam*, and *Smart card chips)*.

[3]We are grateful to Stephen Davies, Martin Graffenberger, and Jun Zhou for their detailed comments on this analysis. We focus on mergers/acquisitions/joint ventures that take place within the same (relevant) product and geographic market as the cartel. For example, in *Airfreight*, the relevant market for the cartel infringement is "non-passenger air transport" in the EEA and the US. Thus, we exclude a 2011 joint venture among Qantas, JAL, and Mitsubishi that focused on passenger transport in Japan. We exclude *Bitumen Spain* even though Compania Espanola de Petroleos S.A., Galp, BP Oil Espana, and Repsol YPF purchased shares

Census industry group	Industry with cartel followed by merger	Merger year	References for existence of cartel and merger year
Food and kindred products	Meat Packing	1903	Whitney (1958, vol. 1, pp.31,34)
	Sugar Refining	1887	Genesove and Mullin (1998, p.358)
	Corn Refining	1897	Whitney (1958, vol. 2, p.258)
Textiles	Cordage	1887	Thorelli (1954, p.78)
	Cotton Yarn	1899	Dewing (1914, pp.307-308)
Iron and Steel and their products	Wire Nails	1898	Lamoreaux (1985, pp.69-74), Jones (1921, p.194)
	Tin Cans	1901	Whitney (1958, vol. 2, p.197)
	Tin Plates	1898	Lamoreaux (1985, pp.14- 15,115)
Paper and Printing	Newsprint	*	Whitney (1958, vol. 1, pp.334-335)
	Strawboard	1889	Weeks (1916, pp.305-306)
	Wallpaper	1898	Whitney (1958, vol. 1, p.356)
Chemicals and allied products	Gunpowder	1902	Whitney (1958, vol. 1, p.192)
	Cottonseed Oil	1889	Thorelli (1954, p.79)
Metals and metal products, other than Iron and Steel	Farm Machinery	1902	Jones (1912, p.232)
Liquors and beverages	Whiskey	1891	Ripley (1916, pp.27,31)
Leather and its finished products	Sole Leather	1893	Dewing (1914, p.18)
Lumber and its remanufactures	**		
Tobacco	***		

* Some cartel members merged with the Union Bag and Paper Co. The date is uncertain.
** In the lumber industry it was common for manufacturers to participate in price fixing associations. In at least one case the association subsequently attempted to merge, but decidedagainst it due to legal barriers (U.S. Department of Commerce, 1914, pp.256, 274).
*** The five largest tobacco product manufacturers merged in 1890. They merged after considering and deciding against forming a cartel Porter (1969).

Table A.1: Evidence of the pattern of collusion followed by merger.

end of the cartel period (not the release date of the decision): *Airfreight*: (2006) KLM acquired Martinair 2008. *Candle waxes*: (2005) Eni acquired ExxonMobil lubricant businesses 2007; Sasol Wax acquired Shell's stake in Merkur Vaseline Verwaltungs GmbH JV 2007; numerous JVs. *Carbonless paper*: (1995) Bolloré bought Papeteries Mougeot's carbonless paper operations in 2002. *Copper Fittings*: (2001) Aalberts Industries acquired Comap (a Legris subsidiary) 2006. *Copper Plumbing Tubes*: (2001) Boliden acquired HME 2002; KM Europa Metal acquired IMI 2002; Outokumpu-Boliden-others combined. *DRAM*: (2002) Infineon attempted to invest in Hynix 2002; Infineon-Nanya JV 2004; NEC-Toshiba JV 2007; Hynix-Toshiba JV 2011. *Elevators and escalators*: (2003) Schindler Holding AG and ThyssenKrupp AG jointly bought Constructions Industrielles de la Mediterranee 2010. *Food Flavour Enhancers*: (1999) Takeda-Daesang JV 2006. *Gas insulated switchgear*: (2004) Hitachi-Mitsubishi JV 2003; Toshiba-Mitsubishi JV 2003; Areva acquired Alstom 2004; Areva-Mitsubishi JV 2007; Schneider Electric and Alstom acquired Areva T&D SA 2010. *Graphite Electrodes*: (1998) SGL Carbon-Tokai JV 2006. *Hydrogen peroxide*: (2000) Solvay-Air Liquide JV 2012. *Industrial and medical gases*: (1997) AGA AB, NV Hoek Loos, BOC Group Plc joined Linde Group 2000, 2003, 2006; Air Liquide acquired Messer; Air Liquide-Air Products JV 2004. *Industrial Tubes*: (2001) KME acquired Ourokumpu's int. in JV 2004. *International removal services*: (2003) Team acquired Allied 2007. *LCD*: (2006) Hannstar-LG Display strategic alliance 2008. *Methacrylates*: (2002) Degussa-Arkema JV 2007. *Organic Peroxides*: (1999) Degussa acquired Laporte 2001. *Plasterboard*: (1998) BPB acquired Gyproc Benelux SA 2002; Lafarge-Knauf Deutsche JV. *Power transformers*: (2003) Alstom acquired Areva T&D's transmission business 2010. *Prestressing steel*: (2002) Mittal Steel and Arcelor merged 2006. *Sodium Chlorate*: (2000) Kemira acquired Finnish Chemicals 2005; Kemira acquired Arkema's water coagulant business 2007; Kemira acquired Akzo Nobel's iron coagulant business 2009. *Sorbates*: (1996) Daicel Chemical Industries acquired Hoechst Nanning's sorbate capacities 2002. *Specialty Graphite*: (1998) Carbone-Lorraine-Nippon Carbon JV 2005; SGL-Tokai JV 2006. *Vitamins*: (1999) Takeda-BASF JV 2001; Takeda-Sumitomo JV 2002; Solvay-BASF JV 2005; BASF acquired Takeda 2006.

Focusing on the 25 EC decisions for industrial cartels in the period 2001–2005 in order to allow sufficient time for mergers, acquisitions, and JVs to form, and classifying the

of CLH in 2002 because the purchase of CLH shares took place in September 2002, which appears to be prior to the cartel dissolution, which reportedly coincided with the dawn raid in October 2002. Similarly, in *DRAM* we exclude Micron's attempt to acquire Hynix in April 2002 because it was prior to reported cartel dissolution in June 15, 2002.

demand side of the market as relatively concentrated or relatively fragmented based on the information in the EC decisions, we obtain the following two tables.

	Concentrated Buyers		Fragmented Buyers	
EC Decision	No M/A/JV	M/A/JV	No M/A/JV	M/A/JV
Carbonless Paper 20-Dec-01	1			
Choline Chloride 9-Dec-04	1			
Citric Acid 5-Dec-01			1	
Concrete Reinforcing Bar 17-Dec-02			1	
Copper Plumbing Tubes 3-Sep-04		1		
Electrical and mechanical carbon and graphite products 3-Dec-03			1	
Food flavour enhancers 17-Dec-02				1
Graphite electrodes 18-Jul-01				1
Industrial and medical gases 24-Jul-02				1
Industrial Bags 30-Nov-05			1	
Industrial tubes 16-Dec-03				1
Methionine 2-Jul-02			1	
Methylglucamine 27-Nov-02			1	
Monochloroacetic Acid 19-Jan-05	1			
Needles 26-Oct-04			1	
Organic peroxides 10-Dec-03				1
Plasterboard 27-Nov-02				1
Rubber chemicals 21-Dec-05			1	
Sodium Gluconate I 2-Oct-01			1	
Sodium Gluconate II 29-Sep-04			1	
Sorbates 1-Oct-03				1
Specialty Graphite 17-Dec-02				1
Thread 14-Sep-05			1	
Vitamins 21-Nov-01				1
Zinc phosphate 11-Dec-01	1			
Total	4	1	11	9

Table A.2: Buyer power and post-collusion mergers.

	Buyers for cartel product	
	Concentrated	Fragmented
M/A/JV	1	9
No M/A/JV	4	11
Share with M/A/JV	20%	45%

Table A.3: Mergers, acquisitions, or joint ventures by formerly colluding firms.

A.1.1 Appendix: Bid rejections and reprocurement in practice

In order to seek the best value when acquiring products or services, firms typically use competitive procurements. Governments, whether local, state or federal, are typically required by law to use competitive procurements. In order to participate in a procurement, a seller must either be directly invited by the buyer or satisfy a qualification process to be included in the bidding. For example, a seller with inadequate financial resources to ensure completion of a contract, or one that has performed poorly in the past, may be excluded from participation in a current procurement. In addition, a potential bidder that does not expend resources to qualify and that is unknown to the buyer may be excluded. For any typical competitive procurement, it is common for there to exist potential suppliers that are either not invited to bid or that do not seek qualification as a bidder.

Almost all procurement rules allow for the buyer, after receipt of all bids, to make no award and void the procurement. During the course of a procurement, a buyer may observe actions by the bidders, including their actual bids, that cause the buyer to believe that they are not obtaining the best value. In that case, a buyer may undertake some incremental action to invigorate the policing action of the competitive process and reconduct the procurement with this new competitive pressure in place. One such action is to invite and seek qualification of sellers that did not participate in the initial round of bidding. If one or more new sellers can be identified, then the procurement may be reopened and new bids solicited.

Overall, a common sequence for procurements in private industry and the public sector is as follows.

1. *Initial bidding:* Invite qualified sellers to participate and obtain initial bids.

2. *Evaluation:* If the initial bids are "reasonable," then make an award. If the bids provide the buyer with less surplus than expected, then consider voiding the initial procurement.

3. *Possible additional bidding:* If the initial procurement was voided, consider seeking additional competitive pressure, conducting a new procurement, and making an award based on the new bidding.

These common procurement practices guide our modeling framework.

In what follows, we provide a review of public procurements conducted by U.S. cities and towns, which generated the observations above. As background, in these procurements the bid specifications typically indicate that the city has the right to award the contract to the lowest responsive bidder, or to reject any and all bids.

In Table A.4, we summarize twenty recent examples of procurements in which all initial bids were rejected by the relevant government decision maker because the lowest responsive bid was unacceptably high for the buyer.[4]

In the cases we reviewed, it is common for the buyer (the city) to have comprehensive cost estimates of the project before soliciting bids. However, usually no formal reserve price is announced prior to bidding. It can happen that all received bids are beyond initial cost estimates or the cost limits established by the purchasing authorities. When the lowest received bid substantially exceeds the cost estimates or limits, the city councils may void the initial bids and announce reprocurement.

For example, in September 2006, the City Council of Belmont procured a contract for pump station rehabilitation. The contract was to be awarded to the lowest responsible bidder for an amount up to the engineer's estimate of $520,000. Four general contractors submitted bids as follows: $695,000, $724,000, $787,000 and $859,000. After evaluation, the city council rejected all bids and re-advertised the project in Spring 2007.[5]

Bids may be rejected with the expectation of lower future bids. For example, Fresno's reason for rejecting the bid it received in March 2007 was that: "There is a reasonable

[4]The right to reject all bids can be exercised by government purchasing authorities for other reasons as well, e.g., bids are found to be non-responsive, bid documents are defective and/or incomplete, or there is evidence of inadequate competition.

[5]Belmont, pp.1–2.

City	Project	Industry	No. of Bidders	Date	Reason for rejecting initial bids
Belmont	Overhaul and upgrade Sewer and Pump Station pumps, holding tanks, and consultants	Construction /Renovation	4	01.09.07	Not sufficient funding in project budget to award to low bidder
Belmont-2	Sanitary Sewer Rehabilitation Ralston Avenue Pipe Bursting and Pipelining	Construction /Renovation	2	09.14.04	Two received bids exceed the anticipates costs. The City will redesign and re-advertise the project
Clinton	Install water and sewer infrastructure for Sampson Square Apartments	Construction	3	02.16.10	Lowest bid greater than grant funding
Des Moines	Golf Course Repairs – damaged from erosion and slope failure	Construction	2	10.11.10	Lowest bid was 53% over project estimate and exceeded project budget
Folsom	Revitalization Project	Construction	2	07.20.09	Low bid exceeded engineer's estimate
Fresno	Delivery of Ortho Poly Phosphate Blend to the Surface Water Treatment Facility	Transportation	1	05.01.07	Want to obtain greater bidder participation and lower pricing
Fresno-2	Landscaping around City Hall and Santa Fe Depot	Landscaping	4	10.02.07	There is a reasonable expectation that additional bids will be received through a future rebid, thereby, reducing the cost of this item
Lacey	Construct a treatment facility and booster station at reservoir site	Construction	5	05.24.07	Low bidder withdrew because of data errors and next apparent low bidder's value higher than engineer's estimate
Missoula	Stripping and stockpiling topsoil, and large rocks rough grading, earth moving, landscape contouring and removal of excess granular materials	Construction	2	06.03.09	Both bids were above the anticipated budget for this project
Piedmont	Build children's play area	Construction	3	07.19.04	Large discrepancy between architect's estimate for the base bid work versus the low bid
Pinole	Information Network Technology Support Services	IT Support	2	06.15.10	Both responses were for more than double the budgeted amount
Plant City	Furnishing and Installing a 12,000 Gallon Diesel Tank	Construction	13	8.24.09	Lowest bid was above City's budget for project
San Rafael	Tennis and Basketball Court Renovation	Construction	4	08.02.10	Lowest bid exceeded Engineer's Estimate
Shasta Lake	Build Native American Cultural Resource Center	Construction	7	09.08.10	Low bid exceeds available funding
Silver City	Re-roof library and replace HVAC units in library	Construction /Roofing	4	11.10.09	Town issued bid up to $185,000 from fund but all bids exceeded this amount
Suisun City	Landscaping along bikeway	Landscaping	7	09.07.10	Lowest bid exceeded engineer's estimate
Tracy	Fire Department wants to purchase Triple Combination Fire Pumper	Manufacturing	6	08.05.08	The low bid with tax was higher than the authorized budgeted amount
Villa Park	Mesa Drive Widening & Guard Rail Project	Construction	9	12.16.08	The lowest qualified bid was approximately 44% higher than the engineer's estimate of the project.
Woodinville	Build bridge	Construction	2	06.13.05	The lowest bid exceeded engineer's estimate by approximately 30%
Woodinville-2	Install Fire Detection and Alarm System at City Hall Annex Building	Maintenance	2	07.02.01	The lowest bid was higher than the project funding.
We refer to the procurements by the name of the city. The full citations are provided at the end of this appendix.					

Table A.4: Bid rejections and reprocurement.

expectation that additional bids will be received through a future rebid, thereby, reducing the cost of this item."[6] Lacey identified the possibility of seeking more competitive bids as a key reason for rebidding its contract.[7]

In many of the examples listed in Table A.4, all bids were rejected because they were above what buyer believed to be a reasonable level. For example, Piedmont received three bids for its project, but there was a large discrepancy between the architect's cost estimate for the project and the lowest bid. According to the staff report, "the difference between the base bid architect's estimate and base bids actually received is obviously disappointing and troubling."[8] The city council rejected all bids, re-worked the project specifications, and re-conducted the procurement. Folsom rejected all bids because "the lowest responsive bid was received from McGuire and Hester for $3,737,259.80 and was $1.55 million over the engineers estimate."[9] San Rafael rejected all bids because "the lowest bid of $161,232.50 is $36,232.50 more than the Engineer's Estimate."[10] Villa Park rejected all bids due to the high cost of the lowest bid, which was above the engineer's estimate.[11] Woodinville rejected all bids because "the low bid amount for this project exceeded the engineer's estimate by approximately 30%."[12]

In other examples, the stated reason for rejection includes the low bid being above the approved budget for the project.[13]

To summarize, a review of procurement examples reveals the following phenomena: 1. When the buyer is uncertain about the cost environment, it can infer information from the observed bids. 2. If the initial bids are viewed as reasonable, then the buyer makes an award to the lowest bidder. 3. If the initial bids are viewed as too high, the buyer may void the initial procurement and seek additional bidders to participate in a new procurement. 4. Budget-constrained buyers may reject bids even if there is no expectation of obtaining more favorable bids through reprocurement.

[6] Fresno, p.4.
[7] Lacey, paragraph 5.
[8] Piedmont, p.1.
[9] Folsom, p.3.
[10] San Rafael, p.1.
[11] Villa Park, p.1.
[12] Woodinville, p.1.
[13] See, e.g., Clinton, Des Moines, Missoula, Pinole, Plant City, Shasta Lake, Tracy, and Woodinville-2.

A.2 References for Online Appendix A.1.1

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Appendix B

Appendix for Chapter 2

B.1 Omitted Proofs and Lemmas

Lemma 14. *In equilibrium, the κ value at which the buyer is indifferent between inviting and not inviting S3 upon observing an announcement of H at $t = 1$ is at least equal to the corresponding κ value upon observing L at $t = 1$. The inequality is strict as long as the l-cartel does not announce L with probability 1 at $t = 1$. That is, $\forall \theta_1 \in (0, 1]$, $\hat{\kappa}(\theta_1, \theta_2^{L_1}|L_1) < \hat{\kappa}(\theta_1, \theta_2^{H_1}|H_1)$, and for $\theta_1 = 0$, $\hat{\kappa}(\theta_1, \theta_2^{L_1}|L_1) = \hat{\kappa}(\theta_1, \theta_2^{H_1}|H_1)$.*

Proof. First note that the term in the square brackets in (2.4.4) is strictly greater than the corresponding term in (2.4.5). Therefore the claim holds if the term within the curly brackets in (2.4.4) (call it cb(2.4.4)) is weakly greater than the corresponding term (2.4.4), (call it cb(2.4.5)). Now for an arbitrary $\theta_1 \in (0, 1]$, consider the following cases: □

(i) $\theta_2^{L_1}, \theta_2^{H_1} = 1$: In this case, cb(2.4.5) equals $\omega_l(P_l^{out} - P_l^{in}) + \omega_h(P_h^{out} - P_h^{in})$, and cb(2.4.4) equals $\omega_l \left[\lambda_2^{L_1}(\theta_1) \times (P_h^{out} - P_l^{in}) + (1 - \lambda_2^{L_1}(\theta_1)) \times (P_l^{out} - P_l^{in})\right] + \omega_h(P_h^{out} - P_h^{in})$. Thus, cb(2.4.5) $<$ cb(2.4.4).

(ii) $\theta_2^{L_1}, \theta_2^{H_1} \in (0, 1)$: For θ_2's in this interval, according to case (ii) in Proposition 5, they must satisfy equation 2.4.2. Using (2.4.2) in equations (2.4.4) and (2.4.5), the curly bracketed terms in the latter two equations can be rewritten as

$$\kappa \times \left(\left[\omega_l \theta_2^{A_1} \lambda_2^{A_1}(\theta_1) + \omega_h\right]\right) + \left(\lambda_2^{A_1}(\theta_1)(1 - \theta_2^{A_1}) + (1 - \lambda_2^{A_1}(\theta_1))\right)\omega_l(P_l^{out} - P_l^{in}).$$

Solving equation (2.4.2) we obtain that for a given κ, $\lambda_2^{L_1}(\theta_1)\,\theta_2^{L_1} = \lambda_2^{H_1}(\theta_1)\,\theta_2^{H_1} = \frac{\omega_h\left((P_h^{out}+\kappa)-P_h^{in}\right)}{\omega_l\left((P_h^{out}-(P_h^{in}+\kappa)\right)}$. This implies cb(2.4.5) = cb(2.4.4).

(iii) $\theta_2^{L_1} = 1, \theta_2^{H_1} \in (0,1]$: The argument is along lines similar to the previous case. Except here, $\kappa \in [\bar{\kappa}_2(\theta_1|L_1), \bar{\kappa}_2(\theta_1|H_1))$. So we use the fact that $\frac{\omega_h\left((P_h^{out}+\kappa)-P_h^{in}\right)}{\omega_l\left((P_h^{out}-(P_h^{in}+\kappa)\right)}$ is strictly increasing in κ, which implies that $\lambda_2^{H_1}(\theta_1)\,\theta_2^{H_1} \geq \lambda_2^{L_1}(\theta_1)\,\theta_2^{L_1}$, which in turn implies that cb(2.4.4) $\geq$ cb(2.4.5).

(iv) $\theta_2^{L_1} \in (0,1)$, $\theta_2^{H_1} = 1$: This case will never occur in equilibrium because $\forall \theta_1 \in (0,1]$, $\lambda_2^{H_1}(\theta_1) > \lambda_2^{L_1}(\theta_1)$,[1] so Corollary 6 applies.

Finally, the last statement of the lemma follows from the fact that $\lambda_2^{L_1}(0) = \lambda_2^{H_1}(0) = \lambda$, i.e., the buyer enters the next period with the same beliefs irrespective of what announcement it observes at $t = 1$. This implies that $\theta_2^{L_1} = \theta_2^{H_1}$, and so cb(2.4.5) = cb(2.4.4).

Claim 1. *If $\lambda \geq \frac{(3-2\omega_l)\omega_l - 1}{(3-2\omega_l)\omega_l}$, then $\bar{\kappa}_1 > \bar{\kappa}_2(1|H_1)$.*

Proof. From their definitions,

$$\begin{aligned}
\bar{\kappa}_1 \;&=\; \frac{\left(P_h^{out}-P_h^{in}\right)(1-\lambda)\omega_h}{\lambda+(1-\lambda)\omega_h} + \frac{2\lambda\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_h^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h} \\
&\quad + \frac{(1-\lambda)\omega_h\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_l^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h} \\
&=\; \frac{2\lambda\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_h^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h} + \frac{2\left(P_h^{out}-P_h^{in}\right)(1-\lambda)\omega_h}{\lambda+(1-\lambda)\omega_h}, \qquad \text{(B.1.1)}
\end{aligned}$$

where the second equality follows from the fact that $\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_l^{out}-P_l^{in}\right)\omega_l = \left(P_h^{out}-P_h^{in}\right)$, and

$$\bar{\kappa}_2(1|H_1) = \frac{\lambda\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_h^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h^2} + \frac{\left(P_h^{out}-P_h^{in}\right)(1-\lambda)\omega_h^2}{\lambda+(1-\lambda)\omega_h^2}. \qquad \text{(B.1.2)}$$

Since the second term on the RHS of (B.1.1) is strictly greater than the second term in (B.1.2), we can guarantee that $\bar{\kappa}_1 > \bar{\kappa}_2$ if $\frac{2\lambda\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_h^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h} \geq \frac{\lambda\left(\left(P_h^{out}-P_h^{in}\right)\omega_h + \left(P_h^{out}-P_l^{in}\right)\omega_l\right)}{\lambda+(1-\lambda)\omega_h^2}$. From simple algebra, this is true if and only if $\omega_l(1-\lambda)(3-2\omega_l) \leq 1$, or equivalently $\lambda \geq \frac{(3-2\omega_l)\omega_l - 1}{(3-2\omega_l)\omega_l}$. □

[1]This can be easily checked.

Proposition 3. *Given the collusive mechanism at $t = 1$ and 2, there exists an $\omega^* \in (0, \frac{1}{2})$ such that, if $\kappa \geq \underline{\kappa}_1$ and $\omega_L \geq \omega^*$, the local sellers will form a cartel in the cooperative state.*

Proof. (i) If $\kappa \geq \bar{\kappa}_1$: The cartel will obviously form for κs in this range.

(ii) If $\kappa \in [\bar{\kappa}_2(\theta_1|H_1), \bar{\kappa}_1)$: A seller will refuse to collude if and only if

$$\begin{aligned}\omega_l \left[\pi^{out}_{nc,l}(L) + \omega_l \pi^{out}_{nc,l}(H) + \omega_h \pi^{out}_{nc,h}(H)\right] \\ + \omega_h \left[\alpha_1 \left(\pi^{out}_{nc,h}(H) + \omega_l \pi^{out}_{nc,l}(H) + \omega_h \pi^{out}_{nc,h}(H)\right) + (1-\alpha_1) 2\pi^{in}_{nc}\right] < 2\pi^{out}_{nc,l}(L),\end{aligned}$$

where the LHS is the total ex-ante payoff to a cartel member (see Proposition 8, case (ii)), and the RHS is the total ex-ante payoff for a non-cooperative seller.[2] Now suppose the above inequality holds. From case $(ii)(a)$ of Proposition 8 the buyer is going to mix at $t = 1$ with probability $\alpha_1 = \frac{\pi^{out}_{c,l}(L)+\omega_l \pi^{out}_{c,l}(H)+\omega_h \pi^{out}_{c,h}(H)-2\pi^{in}_c}{\pi^{out}_{c,l}(H)+\omega_l \pi^{out}_{c,l}(H)+\omega_h \pi^{out}_{c,h}(H)-2\pi^{in}_c}$, which is also equal to $\frac{\pi^{out}_{nc,l}(L)+\omega_l \pi^{out}_{nc,l}(H)+\omega_h \pi^{out}_{nc,h}(H)-2\pi^{in}_{nc}}{\pi^{out}_{nc,l}(H)+\omega_l \pi^{out}_{nc,l}(H)+\omega_h \pi^{out}_{nc,h}(H)-2\pi^{in}_{nc}}$ (because the cartel's payoff is just the sum of its members' symmetrical payoffs). Using this in the inequality, it becomes

$$\begin{aligned}\left(\pi^{out}_{nc,l}(H) - \pi^{out}_{nc,l}(L)\right) \times \left(\pi^{out}_{nc,l}(L)\omega_h + \pi^{out}_{nc,l}(H)\left(1+\omega_l\right) - 2\pi^{in}_{nc}\right) \\ \times \left(\pi^{in}_{nc} - \pi^{out}_{nc,l}(L)\left(1-\omega_l\right)^2 - 2\pi^{in}_{nc}\omega_l + \pi^{out}_{nc,l}(H)\omega_l\right) < 0,\end{aligned}$$

which, because the product of the first two terms is known to be strictly greater than zero, is equivalent to

$$2\omega_l \left(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc}\right) + \left(\pi^{out}_{nc,l}(H) - \pi^{out}_{nc,l}(L)\right)\omega_l^2 - \left(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc}\right) < 0.$$

Thus, for $\kappa \in [\bar{\kappa}_2(H_1), \bar{\kappa}_1)$ as long as ω_l is such that

$$2\omega_l \left(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc}\right) + \left(\pi^{out}_{nc,l}(h) - \pi^{out}_{nc,l}(L)\right)\omega_l^2 \quad \geq \quad \left(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc}\right)$$

or equivalently

$$\omega_l \geq \frac{\sqrt{(\pi^{out}_{nc,l}(H) - \pi^{in}_{nc})(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})} - (\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})}{\pi^{out}_{nc,l}(H) - \pi^{out}_{nc,l}(L)} \equiv \omega^*,$$

[2] If sellers are non-cooperative with probability 1, the buyer will not invite S3 for all $\kappa \geq 2(P^{out}_l - P^{in}_l)$, which is strictly less than $\underline{\kappa}_1$.

a cartel *will* form if the center proposes the mechanism at $t=0$. Note that $\omega^* < \frac{1}{2}$ because

$$\frac{\sqrt{(\pi^{out}_{nc,l}(H) - \pi^{in}_{nc})(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})} - (\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})}{\pi^{out}_{nc,l}(H) - \pi^{out}_{nc,l}(L)} = \frac{1}{1 + \frac{\sqrt{(\pi^{out}_{nc,l}(H) - \pi^{in}_{nc})(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})}}{(\pi^{out}_{nc,l}(L) - \pi^{in}_{nc})}} < \frac{1}{2}.$$

(iii) If $\kappa \in [\underline{\kappa}_1, \bar{\kappa}_2(\theta_2|H_1))$: A seller will refuse to collude if and only if,

$$\begin{aligned} & \omega_l \left[\pi^{out}_{nc,l}(L) + \omega_l \pi^{out}_{nc,l}(H) + \omega_h \pi^{out}_{nc,h}(H)\right] \\ & + \\ & \omega_h \left[\alpha_1 \left(\pi^{out}_{nc,h}(H) + \omega_l \pi^{out}_{nc,l}(L) + \omega_h \left(\alpha_1 \pi^{out}_{nc,h}(h) + (1-\alpha_1)\pi^{in}_{nc}\right)\right) + (1-\alpha_1) 2\pi^{in}_{nc}\right] \end{aligned} < 2\pi^{out}_{nc,l}(L).$$

Substituting for α_1 from case $(ii)(b)$ of Proposition 8,[3] and for α_2 from Proposition 5, the above inequality is equivalent to

$$\begin{aligned} & (3\pi^{out}_{nc,l}(H) + \pi^{out}_{nc,l}(L)\omega_l - 4\pi^{in}_{nc})\omega_l \\ & + \\ & (\pi^{out}_{nc,l}(H) - \pi^{out}_{nc,l}(L)) \left(\frac{\pi^{out}_{nc,l}(H) + \pi^{out}_{nc,l}(L) - 2\pi^{in}_{nc}}{\pi^{out}_{nc,l}(L) - \pi^{in}_{nc}}\right) \omega_l^2 \end{aligned} < 2(\pi^{out}_{nc,l}(H) - \pi^{in}_{nc}).$$

One can show that the above inequality holds for *weaker* conditions on ω_l than the previous case. That is, the cartel forms for a larger range of ω_ls if $\kappa \in [\underline{\kappa}_1, \bar{\kappa}_2(\theta_1|H_1))$ than if $\kappa \in [\bar{\kappa}_2(\theta_1|H_1), \bar{\kappa}_1)$.

(iv) If $\kappa < \underline{\kappa}_1$: The analysis is similar to the previous two cases. However, here we will find that a seller will *not* collude for *any* $\omega_l \leq 1$. As intuition for the proof, note that in the previous cases κ was high enough that if it observed L at $t=1$, the buyer did not invite S3 when sellers announce H at $t=2$. This provides the l-cartel with enough additional payoff (over competitive levels) to compensate for the h-cartel's loss. However, in this case, κ is so low that irrespective of the announcement at $t=1$, the buyer mixes after observing H at $t=2$. This results in no additional payoff for the l-cartel at $t=2$. And since the buyer is also mixing at $t=1$, the there are no additional payoffs in the first period as well. Thus, from an ex-ante perspective, there are no additional profits for the l-cartel in either period to compensate for its loss in the h-cost state. $\square$

[3] And noting that $\frac{\pi^{out}_{c,l}(L)+\omega_l\pi^{out}_{c,l}(H)+\omega_h\left(\alpha_2\pi^{out}_{c,h}(H)+(1-\alpha_2)\pi^{in}_{c}\right)-2\pi^{in}_{c}}{\pi^{out}_{c,l}(H)+\omega_l\pi^{out}_{c,l}(L)+\omega_h\left(\alpha_2\pi^{out}_{c,h}(H)+(1-\alpha_2)\pi^{in}_{c}\right)-2\pi^{in}_{c}} = \frac{\pi^{out}_{nc,l}(L)+\omega_l\pi^{out}_{nc,l}(H)+\omega_h\left(\alpha_2\pi^{out}_{nc,h}(H)+(1-\alpha_2)\pi^{in}_{nc}\right)-2\pi^{in}_{nc}}{\pi^{out}_{nc,l}(H)+\omega_l\pi^{out}_{nc,l}(L)+\omega_h\left(\alpha_2\pi^{out}_{nc,h}(H)+(1-\alpha_2)\pi^{in}_{nc}\right)-2\pi^{in}_{nc}}$

B.2 Tables and Figures

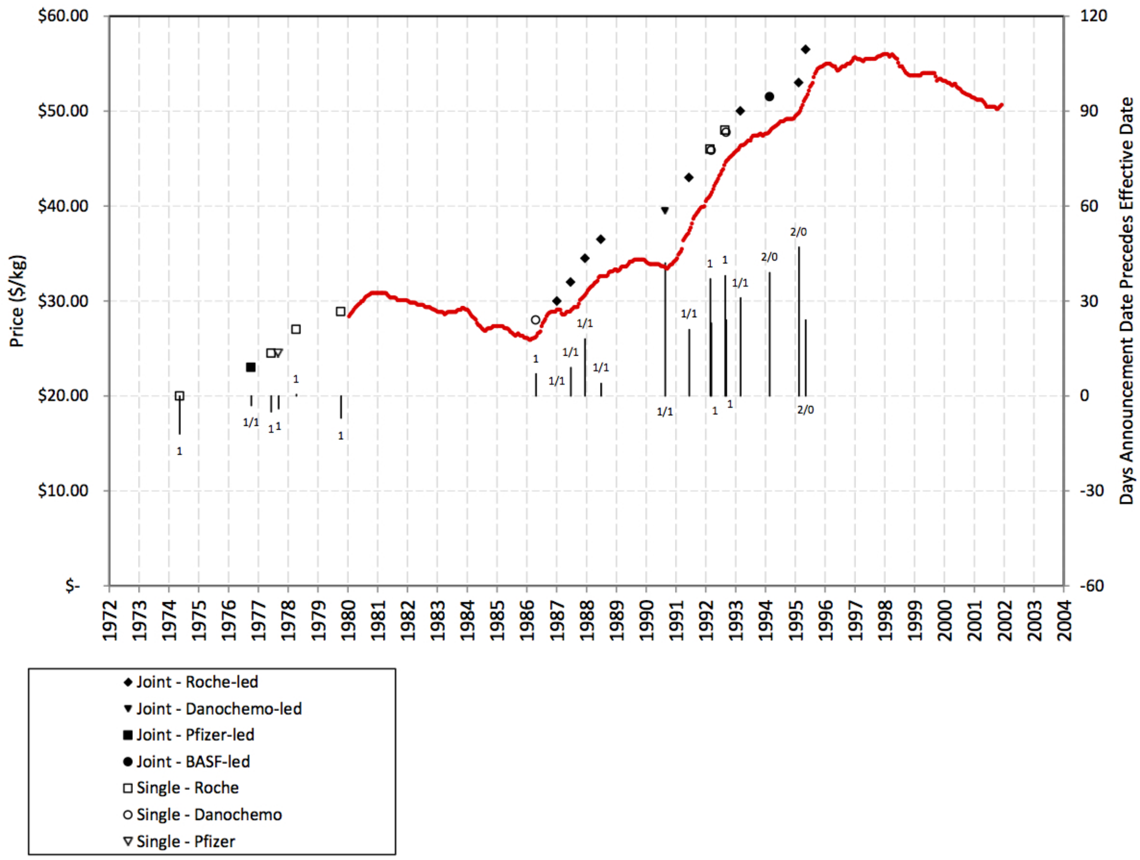
	Vitamin	Vitamin	Vitamin	Beta	Calpan	Riboflavin	Choline Chloride	Niacin	Biotin	Thiamine	Vitamin	Pyridoxine	Carotenoids	Vitamin	Folic Acid
	A	E	C	Carotene	(B5)	(B2)	(B4)	(B3)	H	(B1)	B12	(B6)		D3	(B9)
BASF	x	x	x	x	x	x	x			x			x	x	
Chinook							x								
Daiichi					x							x			
Degussa								x							
DuCoa							x								
Eisai		x													
Hoechst											x				
Kongo															x
Lonza								x	x						
Merck KGaA			x						x						
Nepera								x							
Reilly								x							
Rhone–Poulenc	x	x									x			x	
Roche	x	x	x	x	x	x			x	x		x	x	x	x
Solvay														x	
Sumika															x
Sumitomo									x						
Takeda			x			x				x		x			x
Tanabe									x						

Table B.1: Vitamin production by cartel members during the plea period, generally 1990 through 1998.

* The table is reproduced from Marshall et al. (2008). The plea period refers to the period for which the cartel members pled guilty.

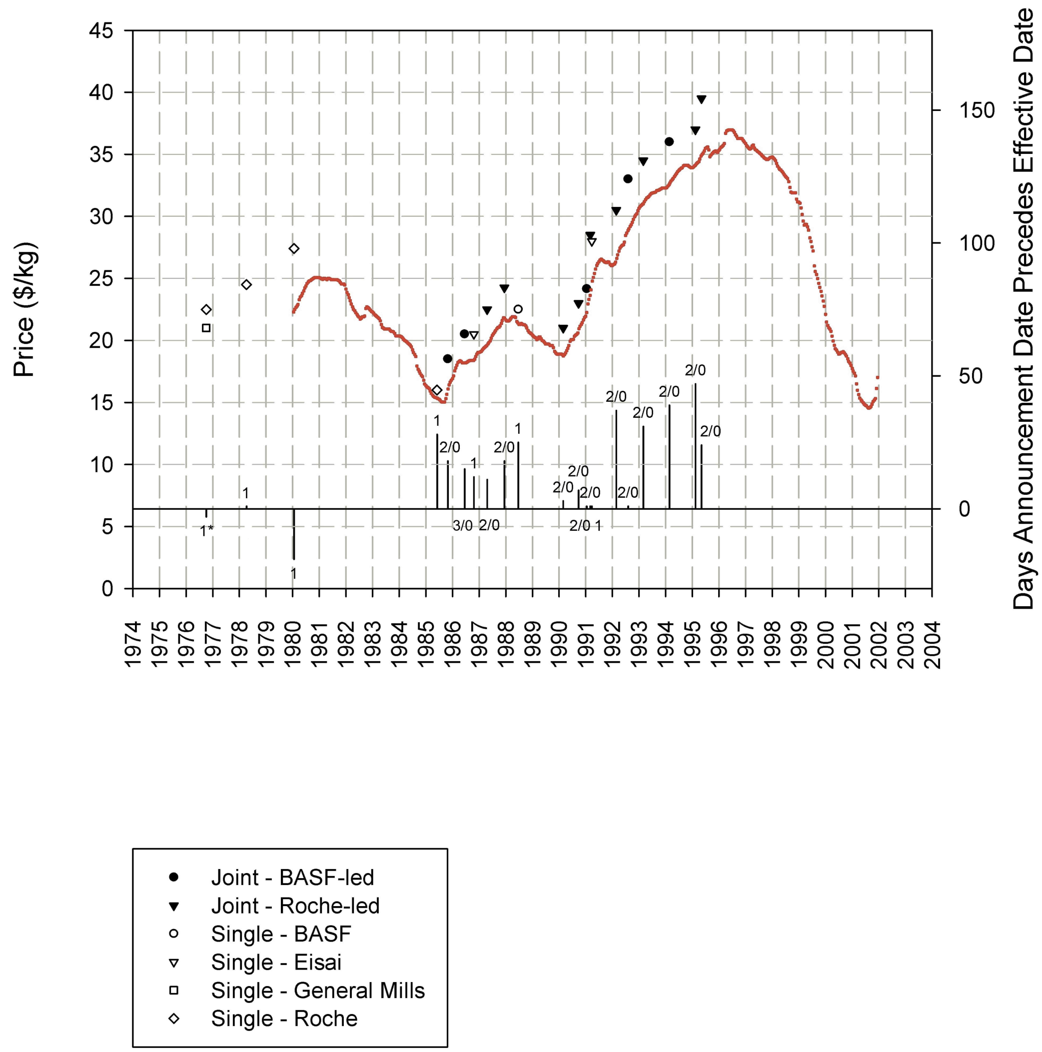
Product	**Source**
Ultramarine pigments	“IN BRIEFMarkets Watch.” ICIS Chemical Business. (May 21, 2007). LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Photo paper	“Confident Kodak Lifts Prices.” The New York Times. (January 3, 1981 , Saturday, Late City Final Edition). LexisNexis Academic. Web. Date Accessed:8 Oct. 2012.
Chlorine	ICIS Chemical Business. (April 16, 2012). LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Rayon	“Courtaulds Hikes Rayon Tabs.” Chemical Week. LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Paper Chemicals	“Imerys Restructures Georgia Unit; Suppliers Boost Prices Further.” Chemical Week. LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Nylon	Adams, Jarrett. “Polyester, Nylon Makers Announce Price Hikes; Fibers.” Chemical Week. LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Wire Rod	“US Domestic Mills Boost Wire Rod Prices.” Metal Bulletin Weekly (2012): n/a. ABI/INFORM Complete. Web. Date Accessed: 8 Oct. 2012.
Ground Freight	Watson, Rip. “FedEx Freight Raises Rates; Other LTLs Increase Prices.” Transport Topics. 4002 (2012): 5,5,35. ABI/INFORM Complete. Web. 8 Oct. 2012.
Silicates	Eleanor, Van Savage. “Silicates See Margin Savings with use of Energy Surcharge.” Chemical Market Reporter 263.12 (2003): 20-. ABI/INFORM Complete. Web. Date Accessed: 8 Oct. 2012.
Baking Soda	Eleanor, Van Savage. “After a Long Hiatus, Sodium Bicarbonate Seeks Price Increase.” Chemical Market Reporter 262.22 (2002): 8-. ABI/INFORM Complete. Web. Date Accessed: 8 Oct. 2012.
Stainless Steel	Triplett, Tim. “Stainless Market: Demand, Pricing Looking Up.” Metal Center News 42.8 (2002): 26-9. ABI/INFORM Complete. Web. Date Accessed: 8 Oct. 2012.
Silicones	Westervelt, Robert. “Dow Corning Leads First Price Hike in Three Years.” Chemical Week 162.22 (2000): 14-. ABI/INFORM Complete. Web. Date Accessed: 8 Oct. 2012.
Caprolactam	“Caprolactam.” Chemical Week. 819 words. LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Tires	Kokish, Bryan. “Goodyear to Hike Tire Prices; Joins 4 Others.” Rubber & Plastics. (January 31, 1994): 277 words. LexisNexis Academic. Web. Date Accessed: 8 Oct. 2012.
Monoethylene Glycol	Allen, Kevin. “US MEG producers announce September price hikes of 4-5 cents/lb”. Platts. Ed. Carla Bass. Platts.com (Aug 16, 2012). Web. Date Accessed: 8 Oct. 2012. http://www.platts.com/RSSFeedDetailedNews/RSSFeed/Petrochemicals/6568069
Cryogenic Storage	“Taylor-Wharton’s CryoScience Business Unit Announces Price Increase,” http://cryogas.com/taylor-whartons-cryoscience-business-unit-announces-price-increase/

Table B.2: Sample of industries with no known criminal finding or admission of guilt of collusion (in the US), where price announcements were observed.



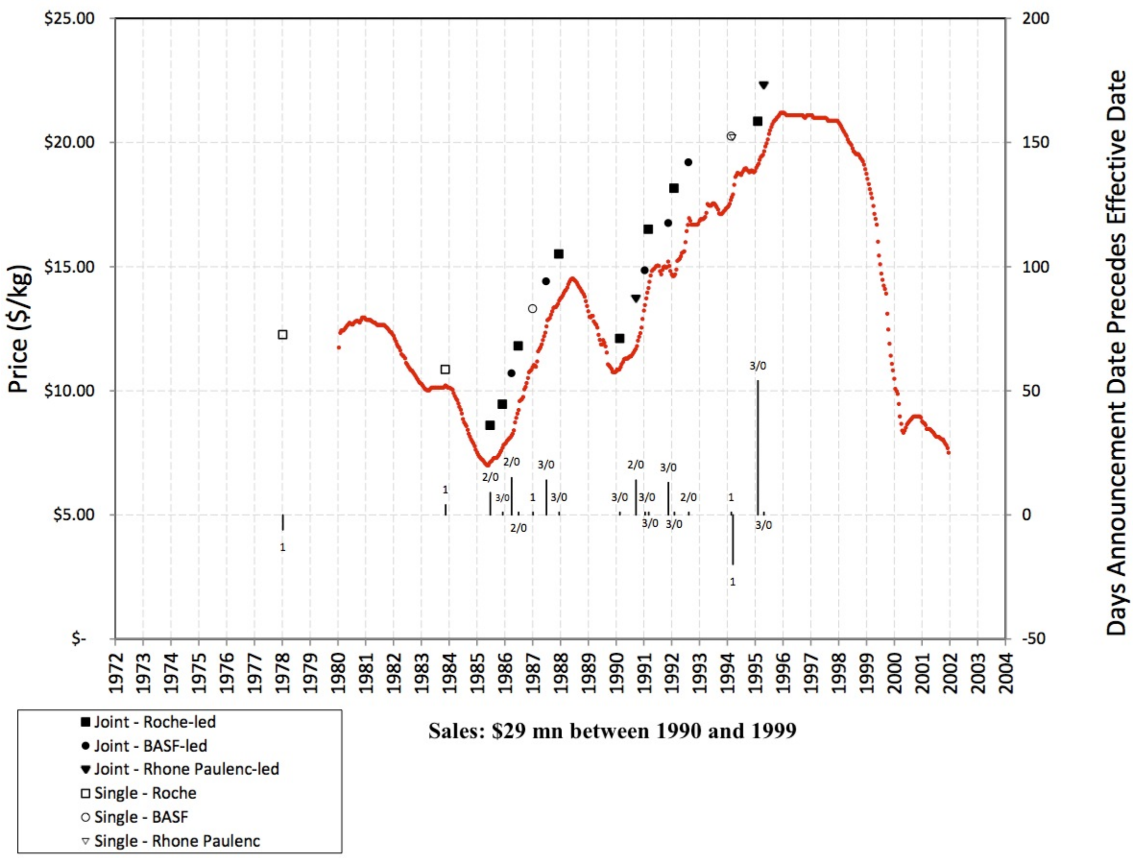
Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure B.2.1: Price announcements and transaction prices of A Acetate 500 - USP



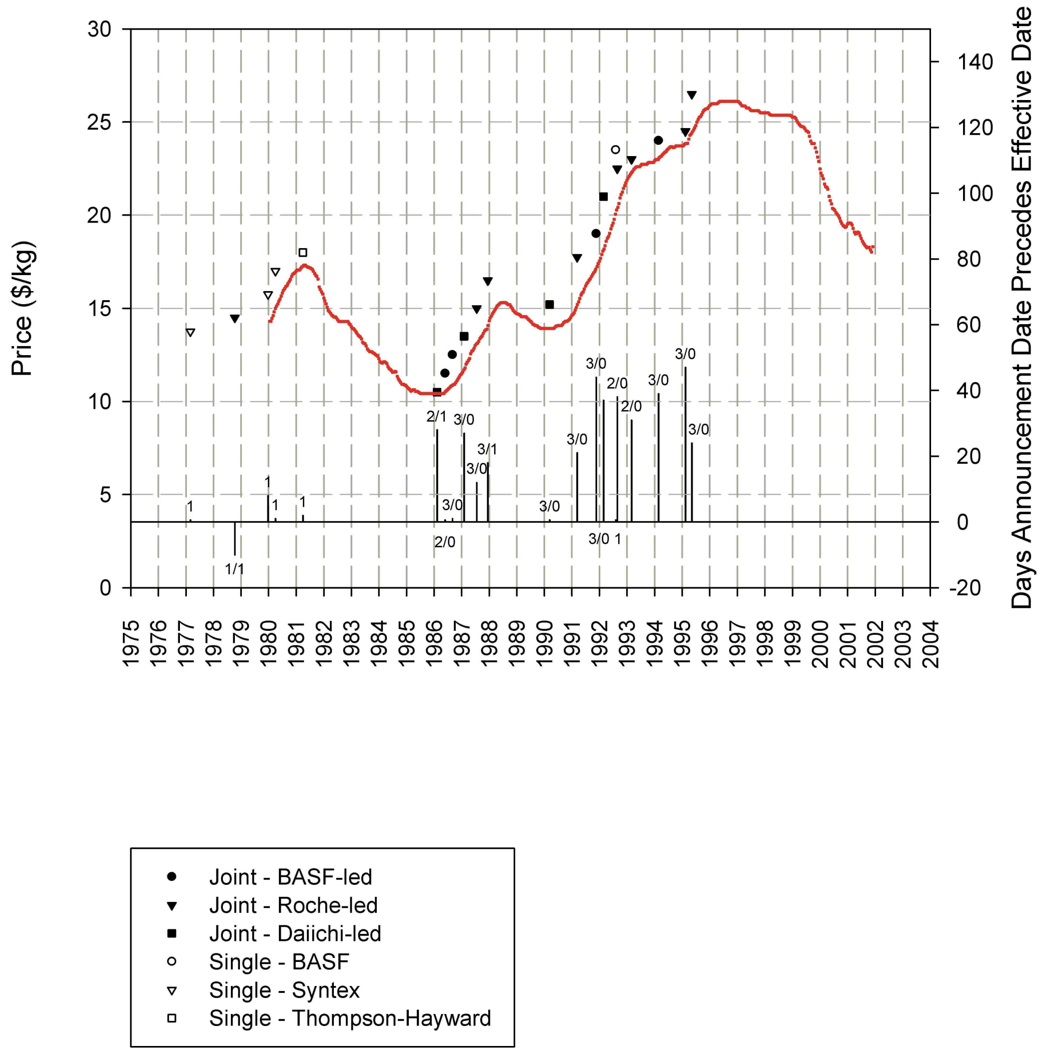
Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure B.2.2: Price announcements and transaction prices of E Acetate Oil - USP



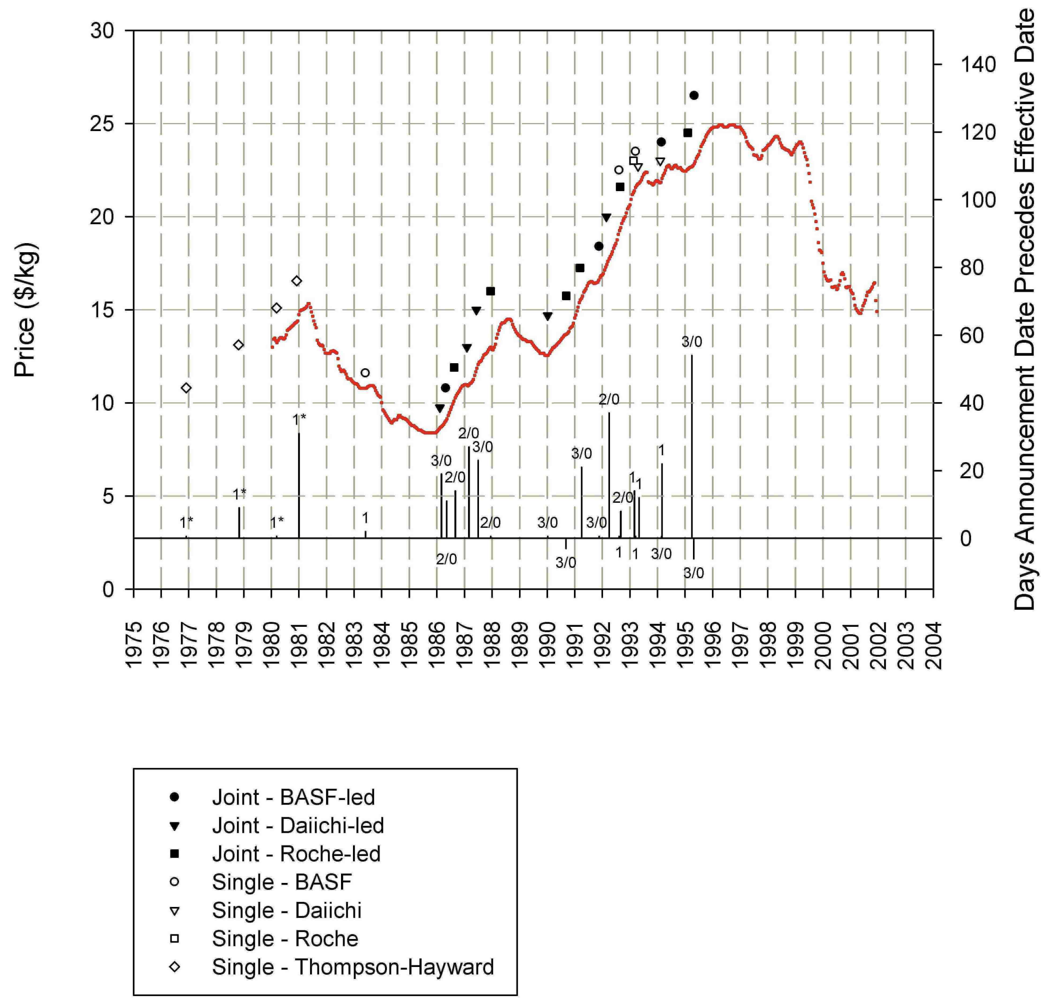
Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure B.2.3: Price announcements and transaction prices of E Acetate 50% SD Feed Grade



Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure B.2.4: Price announcements and transaction prices of Calpan (B5) USP



Note: The data for the transaction prices was reverse engineered from Bernheim (2002). Data on price announcements is from Appendix D in Marshall et al. (2008).

Figure B.2.5: Price announcements and transaction prices of Calpan (B5) SD Feed Grade

B.3 Glossary of Notation

Notation	Description
v_B	Buyer's valuation of the object.
λ (also λ_1)	Prior probability of state being *cooperative* at $t = 1$.
ω_l, ω_h	Prior probability of cost state being *low* and *high* respectively.
Δ	Shift in cost support.
L, H	The vectors (l, l) and (h, h).
x_{it}	Seller i's time t idiosyncratic cost draw.
β_s^{out}	Equilibrium non-cooperative bidding function in cost state $s \in \{l, h\}$ when S3 is *out*.
β_s^{in}	Equilibrium non-cooperative bidding function in cost state $s \in \{l, h\}$ when S3 is *in*.
θ_1	Probability with which the first period l-cartel announces H.
A_1	First period announcement; $A_1 \in \{L, H\}$.
$\theta_2^{A_1}$	Probability with which the second period l-cartel announces H given A_1.
$\lambda_2^{A_1}(\theta_1)$	"Prior" probability of sellers colluding at $t = 2$ given A_1 and θ_1.
P_s^{out}, P_s^{in}	Buyer's expected payment if S3 is *out* and *in* when cost state is $s \in \{l, h\}$.
α_t	Probability with which buyer does *not* invite S3 after observing H in period t.
κ	Buyer's cost of qualifying/inviting S3.
$\hat{\kappa}(\theta_1, \theta_2^{A_1} \| A_1, H_2)$	κ at which buyer is indifferent given A_1 and $t = 2$ announcement H_2, when cartel is mixing according to θ_1 and $\theta_2^{A_1}$.
$\bar{\kappa}_2(\theta_1 \| A_1)$	κ at which buyer is indifferent if at $t = 2$ the l-cartel announces H with probability 1, given A_1. It equals $\hat{\kappa}(\theta_1, 1 \| A_1, H_2)$.
$\underline{\kappa}_2$	κ at which buyer is indifferent if at $t = 2$ the l-cartel announces truthfully.
$\hat{\kappa}(\theta_1, \theta_2^{A_1} \| A_1)$	κ at which buyer is indifferent at $t = 1$ given θ_1, $\theta_2^{A_1}$ and A_1.
$\bar{\kappa}_1$	κ for which S3 is not invited in either period even if the l-cartel announces H in both periods, i.e., $\hat{\kappa}(1, 1 \| A_1)$.
$\underline{\kappa}_1$	Smallest κ of interest to us (see discussion after equation (2.4.5)).
$\pi_{c,s}^{out}(A)$	Cartel's payoff if in s-cost state it announces A and S3 is *out*.
π_c^{in}	Cartel's payoff in either cost state if S3 is *in*.
$\pi_{nc,s}^{out}(A)$	Non-cooperative seller's payoff if in s-cost state the announcement is A and S3 is *out*
π_{nc}^{in}	Non-cooperative seller's payoff in either cost state if S3 is *in*

Appendix C

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