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ABSTRACT

CHAPTER 1 (with Robert C. Marshall and Leslie M. Marx): Dominant-Firm Conduct by Cartels

We document that many cartels, once they have achieved the concordant suppression of within cartel rivalry engage in dominant-firm conduct, while discordant cartels do not. We construct a model in which a firm that was not invited to join the cartel, or that chose to remain outside the cartel, can be eliminated by the cartel if the cartel turns out to be concordant, but not if the cartel turns out to be discordant. This dominant-firm conduct by a cartel can be an incremental source of profits for cartel members beyond the narrow suppression of within-cartel rivalry. This work has implications for the evaluation of competitive versus anticompetitive explanations for certain types of dominant-firm conduct.

CHAPTER 2 (with Vikram Kumar, Robert C. Marshall and Leslie M. Marx): Cartel versus Merger

Prior to federal antitrust and merger laws, when firms were largely unconstrained in their decision to either form a cartel or merge, many firms organized as cartels rather than merging. Procurement practices are affected by the nature of competition among suppliers, including mergers, and by uncertainty about whether suppliers are colluding. We show that the payoff to a cartel exceeds that of a merged entity in a procurement setting where a buyer that is dissatisfied with the bids of incumbent bidders can resolicit bids after qualifying a new entrant. 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.

CHAPTER 3: Buyer Resistance to Cartel Conduct

A common feature of most procurements is that if the bids are viewed as too high a buyer may make no award and re-auction the project at a later date. In practice, the highest bid that a buyer accepts is set based on the buyer’s own estimate of the project’s cost which may or may not be publicly released prior to bidding. I analyze the role of information disclosure in a two-period procurement model with the following information structure. The sellers' costs have both private and common components. The common component is known to all the sellers, but the buyer privately observes only the realization of a noisy signal which is correlated with the sellers' common cost component. In addition, the buyer is uncertain as to whether he faces a cartel or noncooperative sellers. I show that in this model the buyer can increase his expected payoff by following a policy of concealing the signal in the initial round of bidding. Intuitively, if the buyer's signal is sufficiently correlated with the true costs, then through a policy of concealing his signal, the buyer can limit the incentives of a low cost cartel to represent itself as high cost. It is also shown that the disclosure of the signal is irrelevant for the buyer when collusion is not a possibility. Thus, nondisclosure of the buyer's signal may be viewed as a tool to combat collusion

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Chapter 1

Dominant-Firm Conduct by Cartels

> "Another way in which cartel members tried to ensure that the price levels which they had agreed could be maintained in practice in the marketplace was by exchanging information on and jointly acting against competitors. ... The main strategies in this respect were: ... To drive competitors out of business in a coordinated fashion or at least teach them a serious lesson not to cross the cartel ...."[1]

1.1 Introduction

Agreements that successfully suppress rivalry among firms in an industry are profitable. It is well known that cartels have non-trivial problems to solve en route to higher profits.[2] Because members of a cartel do not have access to the judicial system to enforce the terms of their agreements, cartel members may engage in profitable deviations from the cartel's proscriptions for their conduct. Some cartels struggle with deviant conduct and confront ongoing challenges in their attempts to suppress within-cartel rivalry. For other cartels, deviations are not a problem, and the cartel functions in a concordant manner.

[1] Case C.38.359 — Electrical and Mechanical Carbon and Graphite Products, Comm'n Decision 167 (Dec. 3, 2003), available at ec.europa.eu/competition/antitrust/cases/decisions/38359/en.pdf

[2] See, e.g., Stigler (1964) on the issue of secret price cutting among cartel members. For an overview of factors affecting cartel success, see Levenstein and Suslow (2006).

Concordant cartels may look for additional sources of profits beyond those achieved through the suppression of within-cartel rivalry. A cartel that has suppressed rivalry among its members has the potential to act like a dominant firm.[3] Prior to the formation of the cartel, each individual firm may find the incremental profit to itself from dominant-firm conduct, which benefits multiple firms in the industry, to be less than the incremental cost; however, once the cartel forms, the incremental profit to the cartel as a whole may be positive.[4] One example of such an action is driving small non-cartel firms out of business.[5] The cost of taking actions with cartel-wide benefits can be spread among the cartel members, for example according to their market shares.[6]

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[3] The analysis of recent explicit cartels provided in Heeb et al. (2009) suggests that colluding firms often coordinate efforts to engage in dominant-firm conduct, including, among other things, the use of exclusive-dealing provisions. Exclusive-dealing provisions may enable a cartel to exclude non-cartel rivals in the same way they may enable a firm to monopolize a market. The seminal papers on this topic include Aghion and Bolton (1987), Mathewson and Winter (1987), and Rasmusen, Ramseyer, and Wiley (1991). See also Schwartz (1987), Besanko and Perry (1993), O'Brien and Shaffer (1997), Bernheim and Whinston (1998), and Segal and Whinston (2000).

[4] As described in Jones (1922, pp.261–274), trade associations may coordinate activities typically associated with a dominant firm in order to disadvantage non-member firms. Although Jones' focus is on trade associations, the examples of activities he provides apply equally well to cartels, regardless of whether a trade association is involved. Jones' examples include: controlling channels of distribution, organizing boycotts, establishing blacklists or whitelists, cutting non-members' supply, interfering with non-members' labor supply or procurement of storage facilities, predatory pricing, malicious litigation, espionage, intimidation and coercion, and misuse of governmental agencies. See Jones (1922, pp.261–274) for discussion, examples, and cites to cases related to each of these.

[5] We are aware of many cartels that engage in predation against non-cartel firms, but we are unaware of predation ever taking the form of market-wide price cuts. Two common types of predation are restricting access to a critical factor input and targeting the specific customers of non-cartel firms. A public statement by the Department of Justice Division for Enforcement of Antitrust Laws released June 27, 1939, states: "Another device is the creation of a fund among a small group to buy competing plants which are troublesome competitors. Upon acquisition, such plants are often shut down and dismantled. Thus, the socially desirable small independent operation is eliminated from the field of competition." (Temporary National Economic Committee, 1941, Exhibit No. 2176)

[6] As described in the European Commission (EC) decision in *Vitamins* (see Appendix A.1 for the full citations for cited EC decisions), the cost of activities targeting the non-cartel firm Coors were shared among the cartel firms according to their market share allocations: "In 1993 the parties [Roche and BASF] realised that a U.S. producer [of vitamin B2], Coors, had a larger production capacity for vitamin B2 than they had estimated in 1991. In order to prevent Coors from disrupting their arrangements by the export of its production surplus, Roche and BASF agreed that the former would contract to purchase 155 tonnes of vitamin B2 (representing half of Coor's capacity) in 1993. BASF in turn would purchase 43 tonnes from Roche: the burden was thus to be shared in the same 62:38 proportion as their quotas." (*Vitamins*, paragraph 287)

In another example, Article XX of the International Merchant Bar Agreement of 1933 states:

In this paper, we review the European Commission's (EC's) decisions regarding industrial cartels for the period 2000–2009. For cartels that are concordant in that the suppression of within-cartel rivalry appears to be without internal struggle, we find that the cartel often engages in dominant-firm conduct. For cartels that are discordant in that the suppression of within-cartel rivalry appears to be an ongoing challenge, we find that the cartel does not engage in dominant-firm conduct.

We construct a model of collusive behavior in a three-firm industry. In the model, two firms can form a cartel, and if they do, they can then invite the third firm to join the cartel. If invited, the third firm decides whether to join or not. After the cartel membership is determined, the concordance of the cartel is realized. We model dominant-firm behavior by assuming that when a two-firm cartel turns out to be concordant, it can eliminate the third firm from the market. If the two-firm cartel turns out to be discordant, it lives with competition from the third firm.

The empirical finding and our modeling result that concordant cartels engage in dominant-firm conduct are important for multiple reasons. First, the social harm of cartels often extends beyond the suppression of competition among members. As we observe in the EC decisions and as our model shows, concordant cartels can damage the competitive process through dominant-firm conduct.[7] Second, public enforcement authorities treat Sherman Act Section 1 cases as separate and distinct from Sherman Act Section 2 cases, but in light of our finding, Section 1 cases can potentially provide insight into Section 2 cases. The discovery record from a cartel case may contain descriptions of the cartel firms' deliberations with respect to potential dominant-firm conduct. Public enforcement authorities can use this record to shed light on the nature of dominant-firm conduct in industries with similar characteristics. This suggests that the 'firewall' between Section 1 and Section 2

"The Management Committee shall, whenever it deems necessary, call upon groups for contributions proportional to their quotas, to provide for or participate in the general expenses or other funds disbursed in the common interest." (Hexner, 1943, p.317)

As described in Stocking and Watkins (1991, p.160), the International Nitrogen Cartel collected payments from its members in proportion to their sales to compensate Belgian producers for restricting their output. Also described in Stocking and Watkins (1991, p.447), DuPont and ICI contributed in proportion to their shares in the cooperative arrangement Explosives Industries, Ltd. to the compensation made to Westfalische-Anhaltische Sprengstoff A. G. (Coswig) for restricting its exports.

[7] The social harm associated with a concordant cartel in one industry may be less than the social harm associated with a discordant cartel in another industry. In a similar vein, a cartel in an industry with a set of fringe competitors may produce much larger social harm than a cartel in another industry without a set of fringe competitors.

cases that exists within public enforcement agencies should be reexamined.[8] Third, if actions can be taken that lead to cartel discordance, even though the cartel may still function, then an incremental social harm may be mitigated because dominant-firm activities by the cartel may be prevented.

In our model, the third firm, which is capacity constrained, may prefer not to join the cartel so it can take advantage of the price umbrella provided by a potentially discordant cartel. There is a literature that addresses cartel "stability" – firms inside the cartel do not find it desirable to exit and firms outside the cartel do not find it desirable to enter.[9] Among these papers are Donsimoni(1985), Donsimoni, Economides, and Polemarchakis (1986), Diamantoudi (2005), and Bos and Harrington (2010). In particular, Bos and Harrington (2010) endogenize the cartel formation process, showing that smaller firms are more likely to remain outside the cartel with colluding firms setting a price that serves as an umbrella with non-cartel firms pricing below it and producing at capacity. Their main finding is that a small firm finds it optimal not to join any stable cartel when its capacity is sufficiently low.

The paper proceeds as follows. In Section 1.2, we review the EC decisions for industrial cartel cases in the period 2000–2009 and extract the essential features. In Section 1.3, we describe the model. In Section 1.4, we present results consistent with the findings from Section 1.2. In Section 1.5, we offer concluding comments.

1.2 Review of EC decisions

In this section, we describe the salient empirical phenomena that emerge from a review of 21 decisions published between 2000 and 2009 regarding industrial cartels prosecuted by the EC antitrust authorities.[10] Overall, the EC decisions provide an

[8] For related discussion, see Heeb et al. (2009, p.231).

[9] Levenstein and Suslow (2004) use "stability" to indicate a lack of cheating/deviations by cartel members, which is similar to our notion of concordance. They examine cross-sectional studies of cartels and describe the stylized facts on cartel stability/concordance, duration, and profitability based on that literature.

[10] We have excluded five EC decisions from the period 2000–2009 because they relate to products that are not industrial in nature: *Interbrew (beer)*, *Visa Credit Card Network*, *Bank Cards*, *Professional Videotape*, and *Fine Art Auction Houses*. We have also excluded *Soda Ash* because it is, at its essence, a monopolization case. A detailed review of recent EC cartel cases can be found in Harrington (2006).

excellent description of many aspects of the market and industry, as well as cartel conduct.[11] In what follows, we refer to the EC decisions by their case names. See Appendix A.1 for the formal references.

As background, most cartels in our sample have a high aggregate market share. Some control the entire market. As shown in Table 1.1, four of the cartels in our sample have close to or exactly 100% market share, four have a market share around 90%, and the rest have market shares less than 90%.

Table 1.1: EC Cartel and Price-Fixing Decisions (2000–2009)

Case name	Number of cartel members	Cartel market share	Cartel concordance	Dominant-firm conduct reported
Amino Acids (Lysine)	5	almost 100%	very discordant	no
Carbonless Paper	11	85-90%	concordant	no
Choline Chloride	6	82%	very discordant / very concordant*	no
Citric Acid	5	1991 - 70%, 1993 - 60%, 1994 - 52%	discordant	no
Copper Plumbing Tubes	8	79%	concordant	yes
Electrical and Mechanical Carbon and Graphite Products	6	90%+	very concordant	yes
Flat Glass	4	about 80%	concordant	no
Food Flavour Enhancers	4	almost 100%	discordant	no
Graphite Electrodes	8	almost 100%	concordant	no
Industrial and Medical Gases	7	about 90%	discordant	no
Industrial Tubes	6	60-90%	discordant	no
Methionine	4	60-70%	very concordant	yes
Methylglucamine	2	100%	very concordant	no
Organic Peroxides	5	70-80%	very concordant	yes
Plasterboard	4	90%+	discordant	no
Rubber Chemicals	4	58%	discordant	no
Sorbates	5	70-80%	very concordant	yes
Specialty Graphite (Isostatic)	8	75-90%	very concordant	yes
Vitamins	13	70%+	concordant	yes
Zinc Phosphate	6	90%+	discordant	no

*According to our criteria, the global Choline Chloride cartel (1992-1994) was very discordant, but the European cartel (1994-1999) was very concordant.

In Table 1.1, for each cartel in our sample, we report the number of cartel members, the market share of the cartel,[12] our assessment of cartel concordance,

[11] We recognize that the EC decisions for these cartel cases, which focus on documenting the suppression of within-cartel rivalry, may have omitted descriptions of dominant-firm conduct by the cartels.

[12] We use the relevant market as defined by the EC. In some cases, the data in the EC decision provides only approximations regarding the cartel's market share. For example, the table contains entries such as 70–80%, by which we mean that the cartel's share was described as being in this interval. When exact shares are not available, we approximate the share using statements in

which we describe later, and our assessment of whether the EC decision describes dominant-firm conduct.

1.2.1 Large pre-cartel firms do not remain outside a cartel

Firms with relatively large pre-cartel market shares typically join the cartel, while the outsiders, if there are any, are the firms with relatively small pre-cartel market shares.[13] For example, the *Specialty Graphite* cartel consisted of eight members that controlled 75%–90% of the world market throughout the years 1993–1998. Based on the EC decisions, this was an effective cartel. The top-two world producers of specialty graphite products, SGL and LCL, together accounted for about two-thirds of the world market. They were the founders and leaders of the cartel. According to the EC decision, "SGL was the leader and instigator of the infringement in the isostatic specialty market. It was this undertaking which took the initiative to launch the cartel and steered its development throughout the infringement period."[14] The EC also concludes that "LCL had played a specific leading role in the isostatic specialty cartel."[15]

In the *Vitamins* cartel, the world's two largest vitamin producers, Roche and BASF, initiated the creation of cartels in many vitamin products and played a leadership role throughout the existence of the cartels.[16]

In some cases (e.g. *Flat Glass*, *Choline Chloride*), the market shares were fairly evenly distributed across the cartel members, and we cannot identify a clear leader. Nevertheless, in these cases, the large producers joined the cartel at an early stage. In addition to these examples, in all other cartel cases that we have reviewed, the evidence suggests that the largest producers typically do not remain outside of an existing cartel.[17]

the decision such as, "the cartel controlled more than 2/3 of the market" or "top 2 companies accounted for almost one half of the market." Or sometimes, there are statements like "non-cartel firms' total share was less than 7%," allowing us to infer the cartel's market share. The relevant paragraph numbers in the EC decisions for the market shares are provided in Table A.2.1 in Appendix A.2.

[13] Non-cartel firms that were relatively small just prior to the cartel's formation can become much larger during the cartel period.

[14] *Specialty Graphite (Isostatic)*, paragraph 485.

[15] *Specialty Graphite (Isostatic)*, paragraph 486.

[16] *Vitamins*, paragraphs 160, 244, 271, 196, 330, 354, 388, 459, 484, 520.

[17] The relevant paragraph numbers in the EC decisions regarding our assessment that large pre-cartel firms do not remain outside a cartel are collected in Table A.2.1 in Appendix A.2.

1.2.2 Conduct towards small non-cartel firms

Cartel members may threaten relatively small non-cartel firms with predatory conduct in order to coerce participation in the cartel. For example, in the case of *Electrical and Mechanical Carbon and Graphite Products*, one of the cartel members, Hoffmann, was a small company relative to Carbone Lorraine, Morgan, Schunk, and SGL, which were the largest producers and the initial conspirators. According to the EC decision, Hoffmann joined the cartel under pressure from the existing members.[18]

There are other cartels in our sample in which smaller members join the cartel after pressure from existing participants. Examples include Gyproc in *Plasterboard*,[19] Sewon and Cheil in *Amino Acids*,[20] smaller Japanese producers in *Graphite Electrodes*,[21] Cheil in *Food Flavor Enhancers*,[22] Gerestar Bioproducts in *Citric Acid*,[23] the five smaller producers in *Industrial and Medical Gases*,[24] several small firms in *Carbonless Paper*,[25] Nippon Soda and Sumitomo in *Methionine*,[26] six small firms in *Specialty Graphite (Isostatic)*,[27] Perosa and Laporte in *Organic Peroxides*,[28] and several small producers in *Copper Plumbing Tubes*.[29]

There are cases where small firms do not join cartels. For example, in *Vitamins* there were small non-cartel fringe players for many of the individual vitamins, including A, E, B1, B2, B5, and B6.[30] The *Vitamins* cartel was recognized by the EC as being effective despite there being numerous non-cartel fringe firms.[31] This is

[18] "A degree of uncertainty exists regarding the precise moment when Hoffmann first started to participate in the illegal activities of the cartel. In the early years of the cartel ... there is no evidence of Hoffmann's participation in cartel meetings. In those years, Hoffmann was usually mentioned in agenda's of cartel meetings under the heading of 'Competition' and the participants in the discussion would regularly complain about Hoffmann's behavior in the market." (*Electrical and Mechanical Carbon and Graphite Products*, paragraph 198)

[19] *Plasterboard*, paragraphs 3, 489, 510–512, 565, 570–572.

[20] *Amino Acids*, paragraphs 102, 110, 128, 358–60, 361, 364.

[21] *Graphite Electrodes*, paragraph 46.

[22] *Flood Flavour Enhancers*, paragraphs 193–195.

[23] *Citric Acid*, paragraphs 189–192.

[24] *Industrial and Medical Gases*, paragraphs 443–447.

[25] *Carbonless Paper*, paragraphs 105–106.

[26] *Methionine*, paragraph 82.

[27] *Specialty Graphite (Isostatic)*, paragraphs 479–480.

[28] *Organic Peroxides*, paragraphs 415–417, 422.

[29] *Copper Plumbing Tubes*, paragraph 597.

[30] *Vitamins,* paragraph 123.

[31] *Vitamins,* paragraphs 667–672.

consistent with the US Department of Justice securing criminal fines of $500 million against Roche and $225 million against BASF.[32]

Electrical and Mechanical Carbon and Graphite Products provides a good illustration of a range of predatory conduct by a cartel. The quote provided at the beginning of this paper describes the cartel's strategy of driving non-cartel firms out of business. A number of examples of implementation of such dominant-firm conduct by the cartel are provided in the decision.[33] The EC concludes that "these different actions took care of virtually all of the 'outsiders' active in the EEA market."[34] That is, the cartel succeeded in monopolizing the entire market by means of its members' coordinated efforts.

1.2.3 Collusive mechanisms

The majority of the cartels in our sample use a market share allocation scheme. Some cartels use customer allocations or geographic allocations.[35] A few cartels use a combination of these schemes. In Table A.2.2 in Appendix A.2, we characterize the market allocation mechanisms used by the cartels in our sample. The references to the relevant paragraph numbers in the EC decisions are provided.

As shown in Table A.2.2, it is common in our sample for cartels to freeze market shares at their levels during a period prior to the cartel's formation. For many cartels, maintaining the status-quo market shares was the cornerstone of the collusive mechanism. In the case of cartels in vitamins A and E, "the fundamental idea underlying the cartel was to freeze market shares in both products at the 1988 level. As the market expanded, each company could increase its sales only in accordance with its agreed quota and in line with market growth and not at the expense of a competitor."[36]

Baseline market shares were also important in folic acid:

[32] See http://www.justice.gov/atr/public/press_releases/1999/2450.htm.

[33] *Electrical and Mechanical Carbon and Graphite Products,* paragraphs 168–173.

[34] *Electrical and Mechanical Carbon and Graphite Products*, paragraph 173.

[35] Posner (1976) highlights three cartel organizations: a customer allocation, a geographic allocation, and a market share allocation. Posner states, "If the major firms in a market have maintained identical or nearly identical market shares relative to each other for a substantial period of time, there is good reason to believe that they have divided the market (whether by fixing geographical zones or sales quotas or by an assignment of customers), and thereby eliminated competition, among themselves." Posner (1976, p.62)

[36] *Vitamins*, paragraph 189.

> "As with all other vitamins, the basis of the collusive arrangements for folic acid was the establishment of a quota scheme. The fundamental principle of the quota allocation scheme was the division of the world market between Roche on the one hand and the three Japanese producers on the other; on the basis of achieved 1990 results, Roche was given 42 %, the Japanese 58 %. The Japanese producers agreed the division amongst themselves of their 58 % quota on the basis of their respective 1990 achieved sales performance. The annual quotas (by region) in volume terms had to maintain the agreed 42:58 division overall, while allowing for natural growth rate."[37]

The *Organic Peroxides* cartel used sales from 1969–1970 to set sales quotas for 1971.[38] Market shares were also fixed at the level achieved in the year(s) prior to the cartel in: *Carbonless paper*, *Specialty Graphite (Isostatic)*, *Electrical and Mechanical Carbon and Graphite Products*, *Industrial Tubes*, *Rubber Chemicals*, and *Graphite Electrodes*.[39]

Instead of pre-cartel market shares in one recent year, some cartels used the average historic market shares of each firm to determine sales quotas. For example, in *Zinc Phosphate,* "respective market shares were initially calculated in 1994 on the basis of the figures for the years 1991 to 1993. Each cartel member had to adhere to its allocated market share."[40] Similarly, the *Sorbates* cartel used four-year average market shares: "the corresponding volume allocation between the Japanese producers was based on the average of their actual sales volumes from 1973 to 1977."[41] The *Citric Acid* cartel used the average of each firm's sales over 1988–1990 to set sales quotas in 1991.[42]

Larger cartel members generally favored maintaining the fixed market share agreement. As the EC notes in the *Sorbates* cartel, "the amount of sales for each company was limited according to the fixed market share: the companies with the greatest market shares benefited most from maintaining the status quo, and were

[37] *Vitamins*, paragraph 357.
[38] *Organic Peroxides*, paragraph 85.
[39] See the references in Table A.2.2.
[40] *Zinc Phospate*, paragraph 66.
[41] *Sorbates*, paragraph 106.
[42] *Citric Acid*, paragraph 81.

the most insistent on making sure market share levels remained unchanged."[43] In contrast, there are examples in which smaller members were dissatisfied with their cartel shares and tried to renegotiate their position in the cartel, but the larger firms were reluctant to grant concessions to smaller ones. For example, when the top vitamin producers and the cartel leaders, Roche and BASF, discussed smaller cartel member Takeda's allocated market share of 13.5%, BASF noted, "If they go higher → war ?"[44]

There are cases in our sample in which the cartel's inability to reach an agreement over the market shares led members to exit the cartel. One of the members of the *Copper Plumbing Tubes* cartel, Wieland, described the disagreement among the cartel members in a memo to other participants, indicating that several smaller companies attempted to increase their sales beyond their fixed pre-cartel levels. The top member, KME group, insisted on maintaining the prevailing market shares. As Wieland reports, this was "jeopardizing everything we (the cartel) have achieved so far just because of the KME/BCZ WICU dispute and the resulting exit of BCZ."[45]

1.2.4 Cartel concordance

In a number of the cases in our sample, it appears the cartel unsuccessfully struggled to suppress rivalry among its members, as evidenced by frequent bargaining problems and departures from the collusive mechanism (e.g., the inability to reach an agreement over market shares and prices, violations of agreed market shares or assigned quotas, or undercutting other cartel members).

In order to analyze dominant-firm conduct by cartels, we introduce the notion of cartel concordance. As shown in Table 1.1, we characterize each cartel according to the following four concordance categories:

- *very discordant:* We find evidence of frequent bargaining problems and deviations by the cartel members, occurring almost throughout the entire cartel period.

- *discordant:* We find evidence of a few bargaining problems and deviations by the cartel members.

[43] *Sorbates*, paragraph 109.
[44] *Vitamins*, paragraph 273.
[45] *Copper Plumbing Tubes*, paragraph 350.

- *concordant:* We find almost no actual deviations. The cartel could have experienced some minor bargaining problems, e.g., certain members were dissatisfied with their position in the cartel and/or the agreement over market shares was not reached easily and/or only after several meetings, negotiations and renegotiations.

- *very concordant:* We find no signs of deviations and not even minor bargaining problems.

Cartel concordance, defined this way, measures only the extent of deviations by the cartel members from different aspects of the collusive mechanism. In Table A.2.3 in Appendix A.2, we provide the references to the paragraphs in the EC decisions that support our classification. For cartels labelled as very concordant, there are no paragraph references because that label denotes the absence of any reported deviations by the EC.

As an illustration, the *Amino Acids* cartel, which is labeled as very discordant, was confronted by discipline problems throughout the cartel period. Despite regular cartel meetings, most of the price and quantity agreements reached during these meetings were short-lived or not implemented at all. Constant disagreements over sales quotas, as well as frequent deviations and price wars among the members, undermined the concordance of the cartel.[46] The EC found that "the absence of a comprehensive agreement on production quotas was felt to be a destabilizing factor in terms of the relationship between the producers."[47] As a result of numerous failures to implement cartel policies, the participants "blamed each other for not respecting the price agreements. Consequently, the relationships among the producers deteriorated."[48]

Deviations by the members also occur in discordant cartels, but they are not as pervasive as in very discordant cartels. For example, in the case of the *Citric Acid* cartel, one of the members, Jungbunzlauer,

> "was seen to be 'causing problems' in the group because it did not strictly adhere to the agreement at all times and was perceived to be 'badly

[46] The evidence provided in *Amino Acids* paragraphs 66, 69, 73, 77, 87, 89–91, 93, 98, 101–102, 109–110, 118, 134, 143, 145, and 340 confirms that such deviations often took place.

[47] *Amino Acids*, paragraph 87.

[48] *Amino Acids*, paragraph 91.

> disciplined' by the other participants ... the main point of discussion was the lack of discipline on the part of certain members vis-a-vis adherence to the agreement that all customers (except the five largest) were to pay the list price. In particular, ADM and Haarmann & Reimer expressly accused Jungbunzlauer of this lack of discipline."[49]

In the *Industrial Tubes* cartel, which we classify as discordant, "no punishment mechanism was agreed upon or implemented and deviation occurred frequently. When cheating occurred, the cheated member attempted to gain back lost market shares, for instance, by making competitive offers to the cheater's customers, which led to 'price wars'."[50]

In contrast, the larger members of concordant cartels effectively disciplined the behavior of smaller ones so that deviations never happened or were only occasional. For example, in the *Carbonless Paper* cartel, "it appears that AWA's threats worked better on the smaller competitors. Mougeot claims that in view of the small scale of their production the sanctions and threats they received were limited to reprimands ('reproches'), to which they replied by promising to implement any future price increases."[51]

In the case of the *Vitamins* cartel, despite occasional deviations by the smaller members, the cartel leaders, Roche and BASF, effectively used their joint market power to ensure compliance with the agreements by the smaller cartel members. For example, the EC reports that "Roche and BASF senior executives went (separately) to Japan in order to persuade Takeda to agree to the proposed market allocation in vitamin B2, which it ultimately did by late1991/early 1992."[52]

1.2.5 Relation between dominant-firm conduct and cartel concordance

As shown in Table 1.1, we record for each cartel whether the EC decision reports dominant-firm conduct. For the assessment of whether dominant-firm conduct is reported in the decisions, we rely in part on Table 1 of Heeb et al. (2009), which

[49] *Citric Acid*, paragraph 117.
[50] *Industrial Tubes*, paragraph 105.
[51] *Carbonless Paper*, paragraph 106.
[52] *Vitamins,* paragraph 274.

identifies in the EC decisions the following types of dominant-firm conduct: (i) harming non-cartel rivals directly, (ii) harming non-cartel rivals through buyers by using contracts with cartel buyers or by targeting non-cartel buyers, (iii) harming non-cartel rivals through suppliers by using contracts with cartel suppliers or by targeting non-cartel suppliers, (iv) harming potential entrants, (v) harming substitutes, or (vi) eliminating non-cartel rivals by purchasing them.

Although Heeb et al. (2009) identify the *mention* of dominant-firm conduct in the EC decisions, we use a stricter criterion by additionally requiring that the conduct was actually implemented and harmful to existing non-cartel rivals. In all but two cases, our assessment agrees with that of Heeb et al. (2009). In the case of *Citric Acid,* although Heeb et al. (2009) cite paragraphs mentioning the cartel's intention to pursue dominant-firm conduct, we find no indication that the conduct was implemented, so we list *Citric Acid* as showing no dominant-firm conduct. In the case of *Graphite Electrodes*, the cartel was essentially all inclusive, so the agreement "not to transfer technology outside the circle of cartel participants" (*Graphite Electrodes*, paragraph 2) does not satisfy our criterion of harm to existing non-cartel rivals.[53] We list this cartel as showing no dominant-firm conduct. Finally, the *Flat Glass* and *Butadiene Rubber and ES Butadiene Rubber* decisions are not included in the analysis of Heeb et al. (2009), so we reviewed those decisions independently, finding no dominant-firm conduct in either case.

The fact that we do not have evidence of dominant-firm conduct based on the EC decision for a cartel does not exclude the possibility that such conduct existed. It means only that the EC did not describe it in its decision. Nevertheless, we find a clear pattern in the cases. We find that the less-than-all-inclusive cartels that were discordant or very discordant did not engage in dominant-firm conduct,[54] while several less-than-all-inclusive cartels that were concordant or very concordant tended to engage in dominant-firm conduct.

As shown in Table 1.1, the cartels that engaged in dominant-firm conduct were concordant. Also, the concordant cartels often engage in such conduct. This empirical regularity is consistent with the intuition that, "once a cartel controls intra-cartel

[53] It may have been harmful to potential non-cartel rivals by creating a barrier to entry.

[54] Discordant and very discordant cartels can be divided into two sub-categories: cartels that intended to predate against the competitors but never implemented their intentions (e.g., *Citric Acid* and *Plasterboard*), and those that, as far as is reported in the EC decision, did not consider predation at all.

rivalry, it moves on to implement practices designed to diminish competition from existing and potential non-cartel rivals." (Heeb et al., 2009, p.223)

1.2.6 Summary

The EC cartel decisions since 2000 reveal the following phenomena:

1. At the time a cartel forms, large firms in the industry are members of the cartel.[55]

2. Cartels typically allocate collusive gains and share cartel costs according to their pre-cartel market shares.

3. If a cartel exists in an industry, small firms may or may not be members of the cartel.

4. Non-cartel firms are left alone, threatened, or eliminated by a cartel.

5. The extent of deviant conduct by cartel members varies between cartels.

6. Cartels that are concordant often engage in dominant-firm conduct, while cartels that are discordant do not engage in such conduct.

1.3 Model

In this section, we propose a model with three firms in an industry. The firms confront the question of whether or not to participate in an explicit cartel. Participation decisions are taken sequentially. If the cartel consists of only two of the three firms, the cartel may or may not be able to exclude the third firm from the market. We define cartel concordance as an exogenous state of the world that determines the cartel's ability to exclude the non-cartel rival from the market. We model exclusionary behavior by assuming that when a two-firm cartel is concordant, the cartel can eliminate the third firm from the market at cost k. If a two-firm cartel is discordant, then the cost to eliminate the third firm is prohibitively high. We assume the

[55] As an industry evolves, especially in the presence of a cartel, the size of external firms may increase. For example, by the time the *Vitamins* cartel collapsed, non-cartel firms produced more than 30% of the world market for vitamin C and, in aggregate, were larger than any cartel producer of vitamin C except Roche. (*Vitamins*, paragraph 670)

firms in a concordant cartel are able to negotiate a mutually agreeable division of the cost k, including the possibility of transfer payments, whenever excluding firm 3 increases their joint profit.

Consistent with the timing as it occurs in practice, we model the cartel participation decision as being prior to the realization of cartel concordance. If cartel concordance was never in doubt then, for sufficiently low k, the third firm would always want to join the cartel because it would be eliminated as an outside firm. If it were known that the cartel would never achieve concordance, then the third firm would often want to remain outside the cartel, undercutting the price umbrella provided by the cartel.

1.3.1 Timing

The timing in the model is as follows:

- $t = 1$ (cartel formation): Firms 1 and 2 decide to form a cartel or not. If a cartel of 1 and 2 forms, this is observed by firm 3, and the cartel can offer to include firm 3 in the cartel. We assume firms 1 and 2 must both agree in order to extend the offer to firm 3.[56] If the offer is made, then firm 3 either accepts or rejects the offer.[57]

- $t = 2$ (cartel concordance): The state of the world is realized, either concordant with probability ρ or discordant with probability $1 - \rho$. This state remains in place throughout time.[58]

- $t = 3$ (market outcome): The market outcome is: *noncooperative* if no cartel formed in $t = 1$; *all-inclusive* if a cartel of 1, 2, and 3 formed in $t = 1$; *non-all-inclusive* if a cartel of only 1 and 2 formed in $t = 1$ and the state realized in $t = 2$ is discordant or the state is concordant and firms 1 and 2 choose not to incur cost k to exclude firm 3; and *exclusionary* if only 1 and 2 formed a

[56] The assumption is not critical. In our model, both cartel members have the same incentive constraint.

[57] As discussed in Sections 1.2.1 and 1.2.2, large firms form the foundation of a cartel and then smaller firms are invited to join. In the numerical examples we consider, firms 1 and 2 are at least as large as firm 3.

[58] One can view the state as determining the cost of predation, where it is k if the cartel is concordant and ∞ if the cartel is discordant.

cartel in $t = 1$, the state realized in $t = 2$ is concordant, and firms 1 and 2 choose to incur cost k to exclude firm 3.

- $t \geq 4$: Payoffs are determined.

As we show in Section 1.4, for a price competition model of oligopoly, there exist parameters for our model such that in equilibrium one of the three firms chooses to remain outside of the cartel and then, with some probability, is able to either (i) profitably free ride on the suppression of rivalry created by the cartel or (ii) is driven from the market. The third firm is driven from the market if the cartel is concordant, but it benefits from the cartel's suppression of rivalry if the cartel is discordant. The advantage of functioning outside the cartel appears to be more substantial for smaller firms. Thus, the model provides a theoretical framework that is consistent with the characterization of cartels described in Section 1.2 and in the related literature.

1.3.2 Equilibrium behavior

We define the payoffs associated with the four possible competition outcomes: *non-cooperative*, *all-inclusive*, *non-all-inclusive*, and *exclusionary*. As notation, we let π_i^{nc} denote firm i's noncooperative payoff, π_i^{all} denote firm i's payoff in the all-inclusive outcome, $\pi_i^{non\text{-}all}$ denote firm i's payoff in the non-all-inclusive outcome, and π_i^{excl} denote firm i's payoff in the exclusionary outcome, where $\pi_3^{excl} = 0$. We break ties in favor of the larger cartel forming.

We assume that for $i \in \{1, 2\}$, $\pi_i^{excl} > \pi_i^{all}$, which says that firms 1 and 2 have higher payoffs if they collude and eliminate firm 3, not including the elimination cost k, than if they collude with firm 3. We also assume that for $i \in \{1, 2\}$, $\pi_i^{non\text{-}all} > \pi_i^{nc}$, which says that firms 1 and 2 have higher payoffs in the non-all-inclusive cartel outcome than in the noncooperative outcome.

Working backwards, assuming that the cartel of only firms 1 and 2 has formed and that the cartel is concordant, the cartel firms eliminate firm 3 if and only if

$$k < \left(\pi_1^{excl} + \pi_2^{excl}\right) - \left(\pi_1^{non\text{-}all} + \pi_2^{non\text{-}all}\right). \tag{1.1}$$

When (1.1) holds, we let $\lambda_i \in \mathbb{R}$ denote the share of cost k paid by firm i, with

$\lambda_1 + \lambda_2 = 1$ and for $i \in \{1, 2\}$,

$$\pi_i^{excl} - \lambda_i k > \pi_i^{non\text{-}all}.$$

If (1.1) does not hold, exclusion does not occur in the continuation game and so firms 1 and 2 offer to include firm 3 in the cartel if $\pi_1^{all} \geq \pi_1^{non\text{-}all}$ and $\pi_2^{all} \geq \pi_2^{non\text{-}all}$.

If (1.1) holds, then at the time of cartel formation (before cartel concordance is realized), firms 1 and 2 offer to include firm 3 in the cartel if for $i \in \{1, 2\}$,

$$\pi_i^{all} \geq \rho(\pi_i^{excl} - \lambda_i k) + (1 - \rho)\pi_i^{non\text{-}all}. \tag{1.2}$$

Condition (1.2) together with the assumption that for $i \in \{1, 2\}$, $\pi_i^{excl} > \pi_i^{all}$, implies that the cartel does not extend an invitation to firm 3 if k is sufficiently low and ρ is sufficiently high.

Firm 3 prefers to join the cartel if and only if its expected payoff from an all-inclusive cartel is weakly greater than its expected payoff from remaining outside the cartel. If (1.1) does not hold, 3 prefers to join if $\pi_3^{all} \geq \pi_3^{non\text{-}all}$, and if (1.1) holds, then 3 prefers to join if

$$\pi_3^{all} \geq (1 - \rho)\pi_3^{non\text{-}all}. \tag{1.3}$$

If conditions are such that the all-inclusive cartel does not form, then firm $i \in \{1, 2\}$ has expected payoff from forming a cartel of either $\pi_i^{non\text{-}all}$ or $\rho(\pi_i^{excl} - \lambda_i k) + (1-\rho)\pi_i^{non\text{-}all}$, depending on the size of k. It follows from the definition of λ_i and the assumption that for $i \in \{1, 2\}$, $\pi_i^{non\text{-}all} > \pi_i^{nc}$ that firms 1 and 2 always prefer cartel formation over the noncooperative outcome, thus the noncooperative outcome never occurs in the equilibrium of this model.

We summarize in Tables 1.2 and 1.3 below.

Table 1.2: Summary of model outcomes if (1.1) holds

Conditions (1.2) and (1.3)	**Concordance realization**	**Market outcome**
hold		all-inclusive
do not hold	discordant	non-all-inclusive
do not hold	concordant	exclusionary

Table 1.3: Summary of model outcomes if (1.1) does not hold

for $i \in \{1,2,3\}$, $\pi_i^{all} \geq \pi_i^{non\text{-}all}$	**Concordance realization**	**Market outcome**
holds		all-inclusive
does not hold	concordant or discordant	non-all-inclusive

If conditions (1.1), (1.2), and (1.3) are satisfied, the all-inclusive cartel forms. In addition, if (1.1) is not satisfied and all firms prefer the all-inclusive cartel over the non-all-inclusive cartel, then the all-inclusive cartel forms. In the remaining cases, the cartel of firms 1 and 2 forms and remains a cartel of just two firms, with firm 3 remaining outside the cartel or being eliminated, depending on the realization of cartel concordance and the elimination cost k.

Proposition 1.1 *If* $k < \left(\pi_1^{excl} + \pi_2^{excl}\right) - \left(\pi_1^{non\text{-}all} + \pi_2^{non\text{-}all}\right)$ *and either* $\rho > \max_{i \in \{1,2\}} \frac{\pi_i^{all} - \pi_i^{non\text{-}all}}{\pi_i^{excl} - \pi_i^{non\text{-}all} - \lambda_i k}$ *or* $\rho < \frac{\pi_3^{non\text{-}all} - \pi_3^{all}}{\pi_3^{non\text{-}all}}$*, the all-inclusive cartel does not form, and instead firms* 1 *and* 2 *form a cartel, which eliminates firm* 3 *if and only if the cartel is concordant.*

Proof. The proof follows from Table 1.2 and conditions (1.2) and (1.3). Q.E.D.

In Section 1.4, we describe a model of oligopolistic interaction based on price competition and provide numerical examples showing that for certain parameterizations, the conditions for the formation of an all-inclusive cartel are not satisfied, so the equilibrium outcome is exclusionary or non-all-inclusive, depending on the outcome of cartel concordance.

1.4 Price competition model of oligopoly

There are three firms, 1, 2, and 3, competing in a differentiated products oligopoly. We assume firms have capacities equal to their unconstrained noncooperative outputs. These capacity constraints do not bind on colluding firms, which reduce output as a result of the suppression of rivalry, but can bind on firm 3 when it operates outside the cartel.

We adopt a symmetric version of the model presented in Singh and Vives (1984), although we extend the model to allow three firms. We work with inverse demand functions

$$p_i = 1 - q_i - \sum_{j \neq i} s q_j,$$

where $s \in (0, 1)$.[59] As one can see from these demand functions, the market price for firm i's product is decreasing in its own quantity. This is a standard downward sloping demand curve. The market price for firm i's product is also decreasing in the quantities produced by firm i's rivals; however, because s is less than one, the impact on firm i's price of an increase in the rivals' total quantity is less than the impact of an equal increase in firm i's own quantity.

We assume firm i has constant marginal cost $c_i < 1$ up to its capacity constraint and zero fixed costs. Thus, firm i's payoff is equal to its price minus its marginal cost, times the quantity it produces: $(p_i - c_i)q_i$.

1.4.1 Payoffs

To define the payoffs, we refer to the findings described in Section 1.2 and assume that in any market outcome involving a cartel, the cartel firms set their prices to maximize their joint payoff subject to the constraint that the firms' pre-cartel noncooperative relative market shares are maintained. Specifically, we let m_i denote firm i's noncooperative market share, where m_i is defined as firm i's share of the total production in the noncooperative market, i.e. $m_i \equiv \frac{q_i^{nc}}{q_1^{nc}+q_2^{nc}+q_3^{nc}}$, where q_i^{nc} is firm i's noncooperative quantity. In the all-inclusive cartel, firms' quantities are constrained to maintain the noncooperative shares. In the non-all-inclusive and exclusionary outcomes, the quantities of firms 1 and 2 are constrained to maintain relative shares $\frac{m_1}{m_1+m_2}$ and $\frac{m_2}{m_1+m_2}$.

If the market outcome is noncooperative, the equilibrium price vector p^{nc} is such that for all i, p_i^{nc} solves

$$p_i^{nc} \in \arg\max_{p_i} (p_i - c_i) q_i(p_i, p_{-i}^{nc}).$$

[59] When $s = 0$, goods are unrelated and so collusion is meaningless within the context of this framework. The case with $s = 1$ corresponds to perfect substitutability. We consider examples with an intermediate value for s.

We restrict attention to parameterizations such that all noncooperative quantities are positive.

If the market outcome is an all-inclusive cartel, then firms 1, 2, and 3 are in a cartel and choose prices to maximize their joint payoff subject to maintaining noncooperative market shares. The price vector p^{all} solves

$$p^{all} \in \arg\max_{p_1,p_2,p_3} \sum_{i=1}^{3} (p_i - c_i) q_i(p) \text{ subject to for all } i, \ \frac{q_i(p)}{q_1(p) + q_2(p) + q_3(p)} = m_i.$$

If the market outcome is non-all-inclusive, then firms 1 and 2 are in a cartel with firm 3 outside the cartel. In this case, the cartel firms choose their prices to maximize their joint payoff subject to maintaining noncooperative relative market shares while firm 3 reacts to the cartel prices to maximize its payoff. The price vector $p^{non\text{-}all}$ solves

$$p_3^{non\text{-}all}(p_1, p_2) \in \arg\max_{p_3} (p_3 - c_3) q_3(p) \text{ subject to } q_3(p) \leq q_3^{nc}$$

and

$$\begin{aligned}
(p_1^{non\text{-}all}, p_2^{non\text{-}all}) &\in \arg\max_{p_1,p_2} \sum_{i=1}^{2} (p_i - c_i) q_i(p_1, p_2, p_3^{non\text{-}all}(p_1, p_2)) \\
\text{subject to for all } i &\in \{1, 2\}, \ \frac{q_i(p_1, p_2, p_3^{non\text{-}all}(p_1, p_2))}{q_1(p_1, p_2, p_3^{non\text{-}all}(p_1, p_2)) + q_2(p_1, p_2, p_3^{non\text{-}all}(p_1, p_2))} \\
&= \frac{m_i}{m_1 + m_2}.
\end{aligned}$$

If the market outcome is exclusionary, then firms 1 and 2, who constitute the cartel, incur a one-time cost k, and coordinate their prices to maximize their payoff, while firm 3 is eliminated from the market. The cartel chooses price p_1^{excl} and p_2^{excl} to maximize the cartel payoff, while firm 3 does not operate. In the model, this amounts to assuming that firm 3's price is such that the quantity demanded from it is zero. The price vector p^{excl} solves

$$\begin{aligned}
p^{excl} &\in \arg\max_{p_1,p_2,p_3} \sum_{i=1}^{2} (p_i - c_i) q_i(p) \\
\text{subject to for all } i &\in \{1, 2\}, \ \frac{q_i(p)}{q_1(p) + q_2(p)} = \frac{m_i}{m_1 + m_2} \text{ and } q_3(p) = 0.
\end{aligned}$$

1.4.2 Numerical examples

In this section, we provide two numerical examples. In both cases, we assume $s = 0.6$, but we make different assumptions about the firms' marginal costs.

The results for Example 1 are shown in Table 1.4. In this example, firm 1 has the lowest marginal cost and firm 2 has slightly higher marginal cost, while firm 3 has substantially higher marginal cost. As a result, in the noncooperative outcome, firms 1 and 2 have larger shares that firm 3.

As shown in Table 1.4, for firms 1 and 2, payoffs are increasing as the environment moves from noncooperative to non-all-inclusive, to all-inclusive, to exclusionary. However, as long as firm 3 is not eliminated, it prefers the non-all-inclusive environment over the other two.

Table 1.4: Example 1

	Firm 1	Firm 2	Firm 3	Total
c_i	0	0.05	0.20	
m_i	0.42	0.37	0.21	1
π_i^{nc}	0.0975	0.0747	0.0244	0.1965
$\pi_i^{non\text{-}all}$	0.1251	0.1006	0.0570	0.2828
π_i^{all}	0.1369	0.1112	0.0489	0.2970
π_i^{excl}	0.1639	0.1338	0	0.2978

Given the profit values in this example, we can calculate values of ρ and k such that firms 1 and 2 prefer to invite firm 3 to join the cartel and those such that they do not. They prefer to invite firm 3 when ρ is sufficiently small and k is sufficiently large, in which case firms 1 and 2 expect it to be unlikely and costly to eliminate firm 3, so they prefer to invite firm 3 into the cartel. However, when ρ is sufficiently small, the probability that firm 3 is eliminated is small and so firm 3 declines the invitation and remains outside the cartel. We illustrate this in Figure 1.1.

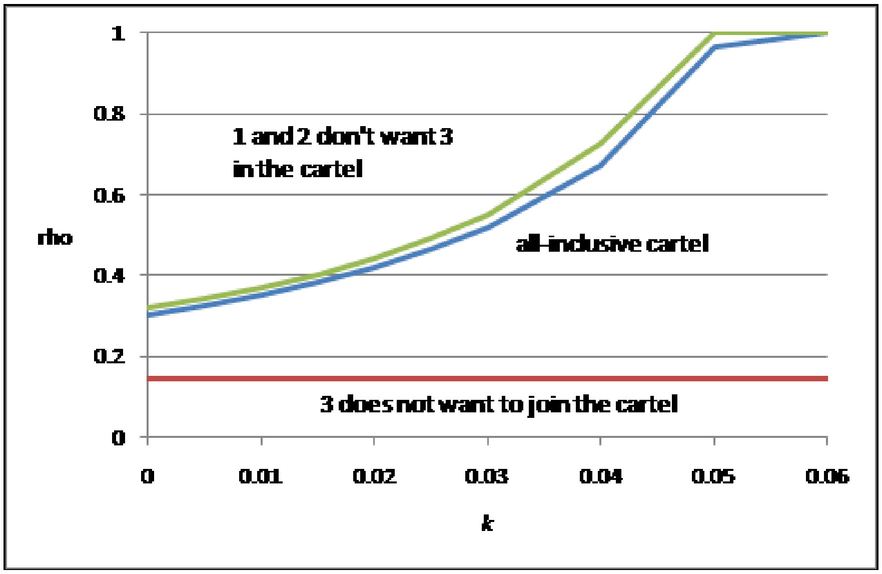

Figure 1.1. Cartel formation in Example 1

Given the parameters for Example 1, an unconstrained all-inclusive cartel can achieve a total payoff of 0.30. However, as shown in Table 1.4, the constraint that the cartel fix the collusive production shares in proportion to their noncooperative market shares reduces the total payoff below this level. In fact, with the asymmetric firms of this example, the total payoff in the exclusionary environment is greater than the total payoff in the all-inclusive environment. As we will see, this result no longer holds when firms are symmetric.

The results for Example 2 are shown in Table 1.5. In this example, all firms have marginal cost of zero. As a result, the noncooperative outcome is symmetric. The results for Example 2 are similar to those for Example 1, except that in Example 2, the overall surplus of the firms is maximized in the all-inclusive outcome rather than in the exclusionary outcomes as in Example 1. In Example 2, an unconstrained all-inclusive cartel has total payoff of 0.3409, which is the same as the total for the all-inclusive cartel shown in Table 1.5 because with symmetric firms the constraint that cartel production be in the same proportions as noncooperative production does not bind.

Table 1.5: Example 2

	Firm 1	Firm 2	Firm 3	Total
c_i	0	0	0	
m_i	$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	1
π_i^{nc}	0.0727	0.0727	0.0727	0.2182
$\pi_i^{non\text{-}all}$	0.0955	0.0955	0.1248	0.3158
π_i^{all}	0.1136	0.1136	0.1136	0.3409
π_i^{excl}	0.1563	0.1563	0	0.3125

The figure showing cartel formation for different values of k and ρ for Example 2 is similar to that for Example 1, although the region where firm 3 does not want to join the cartel is smaller.

These examples show that if an all-inclusive cartels fails to form, then either colluding firms choose not to invite a third firm to join their cartel, or the excluded firm chooses not to join. Then, if the cartel turns out to be concordant, it may find it optimal to eliminate the non-cartel third firm.

1.5 Conclusion

Firms engaging in a cartel are attempting to increase their profits through an agreement to suppress competition among themselves. In this paper, we document that many cartels, once they have achieved the concordant suppression of within-cartel rivalry, go even further in pursuit of profits by engaging in dominant-firm conduct. The cartels in our sample that are described by the EC as struggling with the suppression of rivalry all have the characteristic that the EC decision does not report meaningful dominant-firm conduct.

There are numerous implications of our finding that concordant cartels engage in dominant-firm conduct to further increase their profits. First, if one observes a subset of firms in an oligopoly engaging in dominant-firm conduct, but no single firm appears to have sufficient market share to undertake such conduct unilaterally, then this suggests the presence of a cartel. This observation is not new. Posner (2001, p.93) notes, "... the existence of a cartel might be inferred from proof of exclusionary practices plus the fact that the market was not monopolized by a single firm."[60] Thus, dominant-firm conduct in the absence of monopolization is a "plus factor" in inferring the existence of a cartel.[61]

Second, anti-competitive dominant-firm conduct by a cartel increases the social cost of a cartel beyond that associated with the suppression of rivalry among cartel members. Public enforcement authorities should consider any incremental damage from dominant-firm conduct when assessing criminal penalties.

Third, we may be able to use the discovery record available in Section 1 cases to inform policy regarding Section 2 matters. An analysis of dominant-firm conduct pursued by cartels may better enable enforcement authorities to assess whether a particular dominant-firm conduct is likely to have harmful effects.[62] Although our review of the EC decisions suggests that the dominant-firm conduct undertaken by cartels is largely anti-competitive, this assessment requires further investigation because it may be that the EC authorities tend to highlight dominant-firm conduct that is of the greatest social concern. The discovery record that is retained by public enforcement authorities, much of which might be confidential, creates an opportunity for in-house research programs regarding dominant-firm conduct. Such analyses could provide insight into dominant-firm conduct in related industries.

Fourth, when horizontal mergers are evaluated by public authorities, there is attention given to the possibility of post-merger coordinated conduct, but this concern focuses on the suppression of rivalry and does not extend to the possibility of dominant-firm conduct by firms engaged in the coordinated conduct. This omission is odd given that the same guidelines emphasize the importance of a "maverick" firm, which in our context is the firm that opts not to join the cartel in order to profit from the suppression of rivalry among the colluding firms, but that may be the target of predatory conduct by a concordant cartel.

We conclude by noting an extension of our model. In our model, concordance is handled as an exogenous event. However, a cartel might have a greater incentive

[60] Posner (2001, p.93) also notes that, "Cartels often have great difficulty coordinating exclusionary conduct, ..." Posner's meaning with this assertion is unclear. We have found corroboration in that discordant cartels do not engage in exclusionary conduct.

[61] "Courts generally have held that 'conscious parallelism' or oligopolistic interdependence, without more, does not permit an inference of conspiracy. Courts typically require plaintiffs who rely on parallel conduct to introduce additional facts, often termed 'plus factors', to justify an inference of agreement." (Gellhorn and Kovacic, 1994, p.237) For discussion of the evaluation of the probative value of plus factors and "super plus factors," see Kovacic et al. (2011), who argue that dominant-firm conduct in the absence of a dominant firm is often a "super plus factor."

[62] For more discussion of this point, see Heeb et al. (2009).

to achieve concordance if the payoff from the dominant-firm conduct were higher. The more profitable it is for a cartel to eliminate an outside firm, the more likely it may be that the cartel achieves concordance and eliminates that firm.

Chapter 2

Cartel versus Merger

2.1 Introduction

As described by Bittlingmayer (1985),

> "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." Bittlingmayer (1985, p.77)

As this describes, in the late 1800s, although neither mergers nor cartels were illegal,[1] many firms chose to form a cartel rather than merge. 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.[2] This

[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] See Hylton (2003, pp.30–37).

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. This effect is an essential feature of our modeling environment.

A merged entity does 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, as we show, firms may find a cartel structure to be more profitable than a merger when customers are uncertain as to whether non-merged firms are operating as a cartel or not. We show that in an environment where buyers are strategic, with the ability to take incremental actions such as voiding initial bids and reconducting the procurement after inviting new additional bidders to participate when bids appear to be "too high,"[3] the expected payoff to firms can be greater if they form a cartel rather than a merge.

We consider a setting with two incumbent sellers and one potential new seller. All sellers operate in either a low-cost environment or a high-cost environment, which is known to them but not known to the buyer. We consider two communication regimes, one in which sellers must compete non-cooperatively 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, 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 buyer purchases through a competitive procurement, but the buyer retains the right to suspend the procurement and invite the new seller as a bidder.[4] It is costly to the buyer to extend this invitation, but if the new seller enters, the buyer can re-conduct the procurement. The new seller only enters if the environment is one with low costs.

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

[3] In Section 2.2, we discuss the details of one such episode that received attention in the landmark Addyston Pipe conspiracy. For additional examples, see Appendix B.2.

[4] For other approaches to modeling buyer resistance, see Harrington and Chen (2006) and Marshall, Marx, and Raiff (2008).

firms, when non-merged 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 enters 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 fully observable to the buyer) submits a high bid compared to when a merged entity submits a high bid. As a result, a cartel is more profitable than a merged entity.

While cartels and horizontal mergers have been widely studied in the past,[5] there is not much work that addresses these two forms of industrial organization as potential alternatives for incumbent firms.[6] 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. Akin to the natural monopoly case, when demand is low the operation of, say, two small plants is more expensive than the operation of a single large plant, and coordinating production (by perhaps operating one plant below its capacity) is necessary to recover costs.[7] 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.[8]

There are also strategic considerations external to incumbent firms that influence their merger decisions. One such consideration is the threat of post-merger entry, which directly affects the incumbent firms' profitability. Gelman and Salop

[5] 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.

[6] 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.

[7] For a more detailed discussion and illustrative examples, see Bittlingmayer (1982, 1985).

[8] 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.

(1983) show that when an entrant can commit to serving a small enough portion of the demand, an incumbent monopolist (merged entity) may find it optimal to accommodate the entrant rather than fight it. For the monopolist to accommodate the entrant, the monopolist must expect a payoff at least equal to what it would obtain by matching the entrant's price. In the model of Gelman and Salop (1983), the entrant ensures this by committing to serve a small enough portion of the market, leaving the residual demand for the monopolist.[9]

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.[10]

The remainder of this paper is organized as follows. Section 2.2 provides a historical overview of the *Addyston* cartel and other cartels/mergers of the same period. Section 2.3 reviews the salient features of procurement practices. Section 2.4 presents our model. Section 2.5 provides our results. Section 2.6 concludes.

2.2 Background

The *U.S. v. Addyston Pipe and Steel Co.*[11] case of 1898 is considered to be a landmark event in antitrust history.[12] In 1894, six southern manufacturers of cast iron pipes,[13] which are used to transport water and gas by cities and municipalities, entered into a conspiracy. 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.

[9] As an example, after the International Paper Company was created in 1898, several small firms entered the business. Instead of attempting to fight these smaller firms, the company let them fill their order books and charged monopoly prices on future orders. (Lamoreaux, 1985, p.129)

[10] 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.

[11] *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).

[12] See Bittlingmayer (1982).

[13] 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 and Pipe Works.

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.[14]

Before a procurement, the cartel members would participate in a pre-auction knock-out and bid on the per-ton bonus payment they would make into the 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.[15] The other cartel members would "protect" this bid by submitting phantom bids.[16]

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 non-cartel 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.[17]

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.[18] The *Addyston* case, along with the railroad cartel cases involving the Trans-Missouri Freight Association and the Joint Traffic Association,[19] 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,[20] although agreements among cartel members may have been deemed unen-

[14] 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.

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

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

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

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

[19] *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*).

[20] 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 Torelli (1954,

forceable if their primary function was restraint of trade.[21] The Sherman Act of 1890 made cartel agreements criminal offenses and thus a matter for public enforcement authorities.[22]

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 a criminal offense under the Act.[23] Thus, collusion was deemed illegal under the Sherman Act before merging to monopolize was. 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.[24] Thus, there was a period between 1898 and 1904 when a large consolidation was not deemed illegal by the Supreme Court, but a cartel was.

Operating prior to 1904, in a legal environment in which there was no legal prohibition against mergers, and where cartel agreements may have been deemed unenforceable by courts, it is noteworthy that the pipe manufacturers formed a cartel rather than merging. But even more interesting is the fact that 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).[25] 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.[26]

Table 2.1 lists the ten largest (in net value) manufacturing groups according to U.S. census of 1900 (U.S. Census Office, 1902, p.325).[27] For each industry group, we

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pp.36–53).

[21] Jones (1921, p.17), also Hylton (2003, pp.30–37).

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

[23] *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.

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

[25] 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.

[26] Jones (1921, p.6).

[27] The Twelfth Census classified industries into fifteen groups. The industry groups absent in

provide evidence of industries in which firms that had previously cartelized went on to merge. In at least eight out of the ten industry groups, we find such behavior.[28] Remarkably, in the meat packing industry the cartel members agreed to merge just ten days after their cartel was disrupted by a Department of Justice investigation.[29]

Table 2.1: Evidence of the pattern of collusion followed by merger

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	Gun powder	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 (tanning)	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 decided against 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).

In the Table 2.1 example of gun powder, there was a cartel in gunpowder manufacturing called the Gunpowder Trade Association from 1872 to 1902 (by which time

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.

[28] The list is not exhaustive. We provide representative examples of the observed phenomenon.

[29] Whitney (1958, vol. 1, p.33).

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).

2.3 Buyer procurement practices

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.[30] 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.

[30] See Federal Acquisition Regulations, Section 14.404 Rejection of bids (https://www.acquisition. gov/Far/reissue/FARvol1ForPaperOnly.pdf): "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."

Overall, a common sequence for procurements in private industry and the public sector is as follows. (See Appendix B.2 for examples.)

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.

2.4 Model

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 that we label S_1 and S_2, and one new potential seller that we label S_3. We assume that with probability $\rho \in (0,1)$, costs are "low" and each seller S_i draws its cost x_i independently from the uniform distribution on zero to one, and that with probability $1-\rho$, costs are "high" and all sellers' costs are equal to 1. All sellers and the buyer know the distributional source of costs conditional on the low or high-cost state. We let G denote the cdf for the minimum of two random variables drawn from the uniform distribution on zero to one, i.e., for $x \in [0,1]$, $G(x) = 2x - x^2$.

Sellers observe whether they are in the low-cost or high-cost state, but the buyer does not. Because the buyer knows that costs are bounded above by one, the buyer 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 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 model both a merged entity and a cartel as a bidder that draws two costs and then bids to maximize its payoff based on the minimum of those two costs.

We assume that the buyer can invite seller S_3 to participate as a bidder at cost k to the buyer.[31] We assume that S_3 must pay a small positive cost to become an eligible bidder.[32] We assume that this cost is sufficiently small that S_3 enters when invited as long as the environment is one with low costs.

The timing and information in the model is as follows:

Nature: The state of sellers' costs is realized: low with probability ρ and high with probability $1 - \rho$. The ability of the sellers to form a cartel or merge is realized: cartel or merger is possible with probability ξ and not possible with probability $1 - \xi$. These states are observed by the sellers – S_1, S_2 and S_3 – but not by the buyer.

Stage 0 (merge, collude, or compete): If the formation of a cartel or merger is possible, then S_1 and S_2 choose between (i) merging to form S_M, (ii) acting as a cartel, or (iii) remaining as non-cooperative bidders. A decision to merge is observed by all players. A decision by S_1 and S_2 to form a cartel is observed by the sellers, including S_3, but not by the buyer.

Stage 1 (initial bidding by incumbent sellers): If the sellers S_1 and S_2 merge, S_M draws two independent costs and bids based on the minimum of these two costs. If the sellers S_1 and S_2 did not merge, then sellers S_1 and S_2 each draw independent costs. If S_1 and S_2 formed a cartel then they submit bids based on the minimum of the two costs. If S_1 and S_2 did not form a cartel then they each just submit individual bids.

Stage 2 (potential entry by new seller): After observing the bids, the buyer decides either to make an award to the lowest bidder at the amount of their Stage-1 bid, or, incur cost k and invite S_3 to bid in Stage 3. If S_3 is invited

[31] 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.

[32] This may reflect the cost of quality certifications or of making changes to the production process to ensure compatibility with the buyer's requirements.

to bid in Stage 3, S_3 decides whether or not to enter before drawing its cost (from either the low-cost or high-cost distribution according to the state of sellers' costs). To enter, S_3 must pay a small positive cost. If S_3 does not enter, then the buyer makes an award to the lowest Stage-1 bidder and pays the lowest Stage-1 bid to the corresponding bidder. Ties are resolved by a fair randomization device. If S_3 chooses to enter, then Stage 3 is reached.

Stage 3 (post-entry bidding): If S_3 enters, then the procurement is re-conducted. The buyer voids the initial bids. The incumbent sellers, S_M, or S_1 and S_2 acting as a cartel, or S_1 and S_2 acting non-collusively draw new costs (from either the low-cost or high-cost distribution according to the state of sellers' costs). The bidder with the lowest bid wins the procurement and receives a payment from the buyer equal to its bid.

We use perfect Bayesian Nash equilibrium as our solution concept.

To help the reader keep track of notation, we summarize the key notation in Table 2.2. Notation not yet defined will be introduced in Section 2.5.

Table 2.2: Summary of notation

Notation	**Explanation**
S_1, S_2, S_3	Names of sellers (the bidders)
ρ	Probability of the low-cost state
ξ	Probability that formation of cartel or merger is possible (with probability $1-\xi$ bidding is necessarily non-cooperative)
k	Cost to the buyer to invite S_3 to bid in Stage 3
P_{nc}	Stage 3 expected winning bid in the low-cost state when bidding is non-cooperative
P_M	Stage 3 expected winning bid in the low-cost state when S_1 and S_2 have merged or formed a cartel
π_{nc}	Stage 3 expected surplus to a non-cooperative bidder in the low-cost state
π_M	Stage 3 expected surplus to the merged entity or cartel in the low-cost state
G	Distribution of the minimum of two random variables drawn from the uniform distribution on $[0,1]$
$k^M, \bar{k}^M, k^C, \bar{k}^C$	Threshold values for k defined in Sections 2.5.2 and 2.5.2
b^*	An arbitrary bid in the interval $(P_M + k, 1)$

2.5 Results

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

2.5.1 Stage 3

We only reach Stage 3 if Seller S_3 has entered. Seller S_3 knows if it is competing against a merged entity, cartel, or two other non-cooperative bidders.

In the low-cost state, bidding is as in a standard IPV first-price procurement (with asymmetric bidders if S_1 and S_2 have merged or formed a cartel). In our setting, this equilibrium exists and is unique.[33] Let P_{nc} be the expected winning bid in the low-cost state when bidders are non-cooperative and P_M be the expected winning bid in the low-cost state when bidders 1 and 2 have merged or formed a

[33] See, e.g., Athey (2001), Bajari (2001), and Lebrun (1996, 1999).

cartel.[34] Let π_{nc} be the expected surplus to a non-cooperative bidder in the low-cost state, and let π_M be the expected surplus to the merged entity or cartel in the low-cost state.

In what follows, to avoid uninteresting cases in which the buyer never qualifies S_3, we assume that $k \leq 1 - P_M$. If k is greater than $1 - P_M$, then the buyer prefers to accept a bid of 1 in Stage 1 rather than move to Stage 3, where the buyer's expected payment is P_M.

In the high-cost state, each bidder has a cost of 1 and bids 1 in any equilibrium in non-weakly-dominated strategies. The buyer pays 1 and all sellers have zero surplus.

2.5.2 Stage 2

By assumption, S_3's fixed cost of entry is sufficiently small that S_3 enters in the low-cost state, regardless of whether it faces non-cooperative bidders, a cartel, or a merged entity.

Seller S_3 does not enter in the high-cost state because doing so yields a negative expected payoff due to the positive entry cost.

Whether the buyer invites S_3 to enter depends upon the invitation cost k, whether the firms merged in Stage 0, and the buyer's inferences from the observed bids as to the cost state and, for the case of non-merged firms, whether there is a cartel.

Thresholds for the case of a merged entity

Consider the case of a merged entity. Let $\Pr(\text{low cost} \mid b_M = 1)$ denote the buyer's posterior belief that the state is low cost when it observes a bid of 1. The buyer is indifferent between accepting and rejecting the bid of 1 if

$$\Pr(\text{low cost} \mid b_M = 1)\, P_M + (1 - \Pr(\text{low cost} \mid b_M = 1)) + k = 1,$$

where the left side is the buyer's expected cost if it rejects the bid of 1, and the right side is the buyer's cost if it accepts the bid of 1.

[34] The expected winning bid in Stage 3 is the same for a buyer facing a merged entity and one facing a cartel.

Solving this for k, we get

$$k = \Pr(\text{low cost} \mid b_M = 1)(1 - P_M). \tag{2.1}$$

Different scenarios generate different values for $\Pr(\text{low cost} \mid b_M = 1)$ and so different threshold values for k as defined by (2.1). It will be useful to define two in particular, which we denote by k^M and $\bar{k}^M$.

Define k^M The buyer is indifferent between accepting and rejecting a bid of P_M+k from a merged entity. The bid reveals that costs are low (we assume $P_M + k \leq 1$), so if the buyer accepts it, its cost is $P_M + k$, and if it rejects it, its expected cost is $P_M + k$. Thus, when there is a merged entity, one relevant case involves the buyer accepting bids less than or equal to $P_M + k$ and rejecting greater bids, including rejecting bids of 1.

In this case, the merged entity bids 1 rather than $P_M + k$ if the state is low cost and

$$P_M + k - \min\{x_1, x_2\} < \pi_M,$$

which occurs with probability $(1 - G(P_M + k - \pi_M))\rho$. Thus, the relevant posterior in this case is $\Pr(\text{low cost} \mid b_M = 1) = \frac{(1-G(P_M+k-\pi_M))\rho}{(1-G(P_M+k-\pi_M))\rho+(1-\rho)}$. Substituting this into (2.1), we implicitly define the threshold k^M as follows:

$$k^M = \frac{(1 - G(P_M + k^M - \pi_M))\rho}{(1 - G(P_M + k^M - \pi_M))\rho + (1 - \rho)}(1 - P_M). \tag{2.2}$$

Define $\bar{k}^M$ Another relevant case is when the buyer accepts a bid of 1. In that case, the merged entity prefers to bid 1 rather than go to Stage 3 if the state is low cost and $1 - \min\{x_1, x_2\} \geq \pi_M$, which occurs with probability $G(1 - \pi_M)\rho$. Thus, the relevant posterior in this case is $\Pr(\text{low cost} \mid b_M = 1) = \frac{G(1-\pi_M)\rho}{G(1-\pi_M)\rho+1-\rho}$. Substituting this into (2.1), we define the threshold $\bar{k}^M$ as follows:

$$\bar{k}^M \equiv \frac{G(1 - \pi_M)\rho}{G(1 - \pi_M)\rho + 1 - \rho}(1 - P_M). \tag{2.3}$$

Thresholds for the case of non-merged firms

Consider the case of non-merged firms, and focus on equilibria in which non-cooperative firms never both bid 1, but cartel firms sometimes do. 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 accepting and rejecting a bid of 1 if

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

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

$$k = \Pr(\text{low cost and cartel} \mid b_1 = b_2 = 1)\,(1 - P_M). \tag{2.4}$$

Different scenarios generate different values for the probability in (2.4) and so different threshold values for k. It will be useful to define two in particular, which we denote by k^C and $\bar{k}^C$.

Define k^C. Assuming that firms are not merged and non-cooperative firms do not bid 1 in equilibrium in the low cost state, the buyer is indifferent between accepting and rejecting a bid of $P_M + k^M$. Thus, one relevant case involves the buyer accepting bids less than or equal to $P_M + k^M$ and rejecting greater bids, including rejecting bids of 1.

In this case, the firms bid 1 rather than $P_M + k^M$ if the state is low cost, they are in a cartel, and

$$P_M + k^M - \min\{x_1, x_2\} < \pi_M,$$

which occurs with probability $(1 - G(P_M + k^M - \pi_M))\rho\xi$. Thus, Pr(low cost and cartel$|\ b_1 = b_2 = 1) = \frac{(1-G(P_M+k^M-\pi_M))\rho\xi}{(1-G(P_M+k^M-\pi_M))\rho\xi+(1-\rho)}$. Substituting this into (2.4), we define the threshold k^C as follows:

$$k^C = \frac{(1 - G(P_M + k^C - \pi_M))\rho\xi}{(1 - G(P_M + k^C - \pi_M))\rho\xi + (1 - \rho)}(1 - P_M). \tag{2.5}$$

Define $\bar{k}^C$. Another relevant case when firms are not merged and non-cooperative firms do not bid 1 in equilibrium in the low cost state is when the buyer accepts one of the bids when both bids are 1. In that case, firms bid 1 if the state is low cost, they are in a cartel, and $1-\min\{x_1, x_2\} \geq \pi_M$, which occurs with probability $G(1-\pi_M)\rho\xi$. Thus, $\Pr(\text{low cost and cartel} \mid b_1 = b_2 = 1) = \frac{G(1-\pi_M)\rho\xi}{G(1-\pi_M)\rho\xi+1-\rho}$. Substituting this into (2.4), we define the threshold $\bar{k}^C$ as follows:

$$\bar{k}^C \equiv \frac{G(1-\pi_M)\rho\xi}{G(1-\pi_M)\rho\xi + 1 - \rho}(1 - P_M). \tag{2.6}$$

Ordering of thresholds

As a preliminary result, we consider four thresholds just defined for the buyer's cost to invite S_3 to bid and prove Lemma 2.1 characterizing these thresholds.

Lemma 2.1 *$k^M, \bar{k}^M, k^C, \bar{k}^C \in (0, 1-P_M)$, $k^C < k^M < \bar{k}^M$, $k^C < \bar{k}^C < \bar{k}^M$, and for ξ sufficiently close to zero, $\bar{k}^C < k^M$.*

Proof. See the Appendix.

Lemma 2.1 shows that for ξ sufficiently close to zero, the invitation cost thresholds are ordered as $k^C < \bar{k}^C < k^M < \bar{k}^M$. The range of ξ for which this ordering holds depends on the parameter ρ. For example, for $\rho = 0.5$, the ordering holds for $\xi \in (0, 0.208)$.

2.5.3 Stage 1

We begin by considering the case of merged firms. We show below that in this case, when invitation costs for the buyer are less than $\bar{k}^M$, there is no equilibrium in which the buyer accepts a bid of 1 with probability 1. It is clear that if k is sufficiently low, the buyer prefers to reject a bid of 1. To see why $\bar{k}^M$ is a relevant threshold, note that a merged entity would only want a bid of 1 to be accepted if its Stage-1 cost draws were such that $1 - \min\{x_1, x_2\} > \pi_M$. But if the merged entity were to bid 1 only when the state was high cost or its minimum cost draw was less than $1 - \pi_M$, then the appropriate posterior would be $\Pr(\text{low cost} \mid b_M = 1) = \frac{G(1-\pi_M)\rho}{G(1-\pi_M)\rho+1-\rho}$. As shown in Section 2.5.2, with this posterior, the buyer rejects a bid of 1 for invitation costs less than $\bar{k}^M$.

Proposition 2.1 *Assume $k < \bar{k}^M$. In Stage 1, if S_1 and S_2 have formed a merged entity S_M, in any equilibrium involving non-weakly-dominated strategies, the buyer does not accept a bid of 1 with probability 1.*

Proof. In any equilibrium involving non-weakly-dominated strategies, S_M bids 1 in the high-cost state. In the low-cost state, if S_M wins at a price of 1 with probability 1, then S_M bids 1 for all $x < 1 - \pi_M$. Thus, the buyer's posterior belief on the low-cost state after observing a bid of 1 is bounded below by $\gamma \equiv \frac{G(1-\pi_M)\rho}{G(1-\pi_M)\rho+1-\rho}$. Because the buyer accepts a bid of 1, it must be that $1 \leq \gamma P_M + (1-\gamma) + k$, which we can write as $k \geq \bar{k}^M$, which contradicts the assumption that $k < \bar{k}^M$. Q.E.D.

In the low-cost state, the merged entity can potentially bid in such a way that induces the buyer to invite S_3 to enter, which would give the merged entity an expected payoff of π_M. Thus, we can use Proposition 2.1 to construct an upper bound on the merged entity's expected payoff in Stage 1 as follows:

Corollary 2.1 *For $k < \bar{k}^M$, in any equilibrium involving non-weakly-dominated strategies, in Stage 1 a merged entity with cost draws x_1 and x_2 has expected payoff less than*
$\max\{1 - \min\{x_1, x_2\}, \pi_M\}$.

Despite the fact that, as shown in Proposition 2.1, in the low-cost state the merged entity does not win at a price of 1 when $k < \bar{k}^M$, there is an overlapping range of invitation costs for the buyer such that the cartel does win at a price of 1.

Proposition 2.2 *Assume $k \geq \bar{k}^C$. In Stage 1, if S_1 and S_2 have not formed a merged entity, then there exists an equilibrium involving non-weakly-dominated strategies in which in the low-cost state a cartel with cost draws x_1 and x_2 has expected payoff equal to*
$\max\{1 - \min\{x_1, x_2\}, \pi_M\}$.

Proof. The proof is by construction. We show that there exists an equilibrium in which in the low-cost state, cartel firms submit identical bids according to the bid function

$$\beta^C(\min\{x_1, x_2\}) \equiv \begin{cases} 1, & \text{if } x \leq 1 - \pi_M \\ b^*, & \text{otherwise,} \end{cases}$$

where $b^* \in (P_M + k, 1)$; the buyer accepts the lowest bid if it is less than or equal to the maximum non-cooperative bid and accepts one of the bids at random if both bids are equal to 1; but otherwise, the buyer invites S_3 to bid.[35] See the Appendix for a complete statement and verification of the equilibrium.

In the low-cost state, given cost draws x_1 and x_2 in Stage 1, an expected payoff of $\max\{1 - \min\{x_1, x_2\}, \pi_M\}$ is the most that a cartel or merged entity can obtain. To obtain such a payoff requires that the cartel or merged entity wins at the maximum price of 1, except when the cartel or merged entity prefers not to win in Stage 1, but rather to have the buyer invite S_3 so that the firms can compete in the Stage-3 procurement with expected payoff π_M. Thus, the payoff obtained by the cartel in Proposition 2.2 is the maximum possible.

We can now state our main results. Proposition 2.3 states that firms at least weakly prefer to form a cartel when the buyer's invitation costs are above threshold $\bar{k}^C$. The result obtains because in this range, as established in Proposition 2.2, there exists an equilibrium in which the cartel obtains the maximum payoff of $\max\{1 - \min\{x_1, x_2\}, \pi_M\}$, but for a subset of the range of invitation costs, namely $k \in (\bar{k}^C, \bar{k}^M)$, a merged entity has strictly lower payoff in every equilibrium. In this range, the buyer rejects a bid of 1 by the merged entity but the buyer accepts bids of 1 from non-merged bidders.

Proposition 2.3 *For all $k \geq \bar{k}^C$, there exists equilibrium cartel behavior that gives the firms weakly higher expected payoff if they form a cartel than in any equilibrium as a merged entity, with strictly higher expected payoff for $k \in (\bar{k}^C, \bar{k}^M)$.*

Proof. The proof follows from Corollary 2.1 and Proposition 2.2. Q.E.D.

The result of Proposition 2.3 is illustrated in Figure 2.1. It shows that the cartel can obtain the maximum payoff of $\max\{1 - \min\{x_1, x_2\}, \pi_M\}$ for all $k \geq \bar{k}^C$, while a merged entity is always held strictly below that level for $k \in (\bar{k}^C, \bar{k}^M)$.

We have shown that there exists an equilibrium for the non-merged game such that the firms' expected joint payoff is weakly greater if they form a cartel than

[35] In this equilibrium, there is no incentive for the cartel to use one of its bids to attempt to disguise its presence. For environments in which this may be the case, see Graham and Marshall (1987) and Graham, Marshall, and Richard (1996).

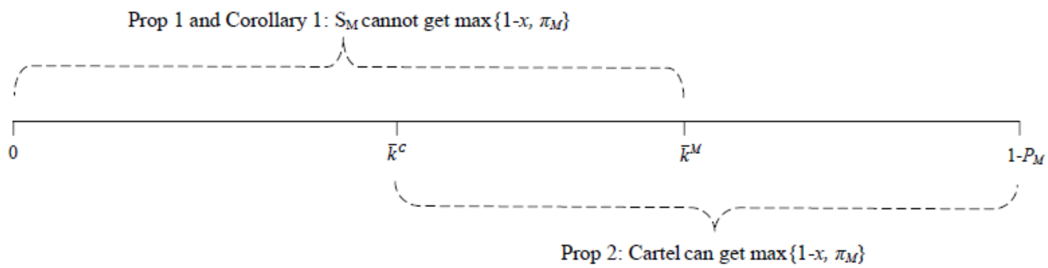

Figure 2.1: Illustration of Proposition 2.3 equilibria

in any equilibrium of the merged game. We have not shown that for *all* equilibria for the non-merged game, the firms' expected joint payoff is weakly greater if they form a cartel than in *any* equilibrium of the merged game. However, focusing on threshold equilibria, we can show that the cartel's expected payoff is always weakly greater than the merged entity's expected payoff. Specifically, we focus on equilibria in which a merged entity or cartel bids one of three ways. It bids 1 or $P_M + k$, or it bids so as to induce the buyer to invite S_3. (Recall from Section 2.5.2 that $P_M + k$ is the maximum bid such that the buyer accepts given beliefs that the state is low cost.)

The equilibrium outcomes can be characterized by what the buyer does when it receives two bids equal to 1. The buyer will either: accepts one of the bids, invites S_3, or randomize between those two.

Proposition 2.4 completes the argument that for this class of equilibria for our model, forming a cartel weakly dominates merging.

Proposition 2.4 *For all k, there exist equilibria for the merged and non-merged games such that a cartel with cost draws x_1 and x_2 has expected payoff greater than or equal to a merged entity with the same cost draws.*

Proof. See the Appendix.

Here we sketch the key components of the proof. The equilibria we construct have the feature that for low k, the buyer invites S_3 when it receives a bid of 1; for high k, the buyer accepts bids of 1; and for intermediate k, the buyer mixes between accepting a bid of 1 and inviting S_3 when it receives a bid of 1. When the buyer accepts a bid of 1, the cartel or merged entity has expected payoff

$\max\{1-\min\{x_1,x_2\},\pi_M\}$. When the buyer invites S_3 when it receives a bid of 1, the cartel or merged entity has expected payoff $\max\{P_M+k-\min\{x_1,x_2\},\pi_M\}$. When the buyer mixes, the cartel or merged entity has a payoff that is intermediate between $\max\{1-\min\{x_1,x_2\},\pi_M\}$ and $\max\{P_M+k-\min\{x_1,x_2\},\pi_M\}$. As depicted in Figure 2.2, when ξ is sufficiently small that the invitation cost thresholds are ordered as $k^C<\bar{k}^C<k^M<\bar{k}^M$ (Lemma 2.1), then the cartel's expected payoff is always weakly greater, and is strictly greater for $k\in\left(k^C,\bar{k}^M\right)$.

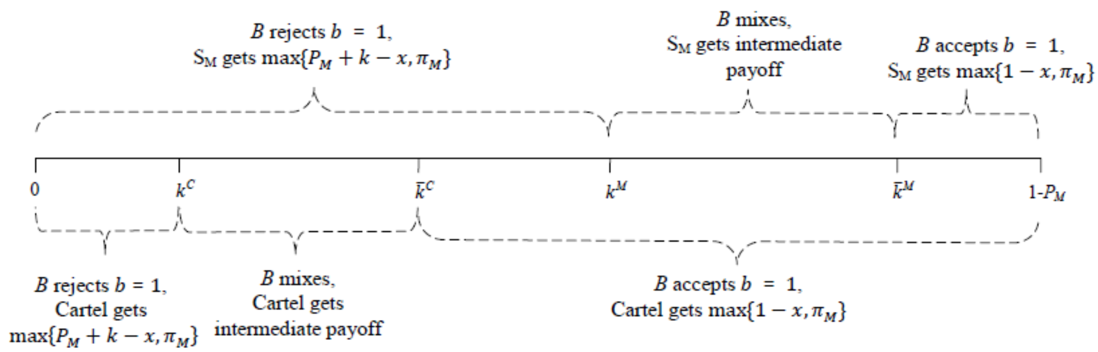

Figure 2.2: Illustration of Proposition 2.4 equilibria for sufficiently low ξ

The basic result that firms prefer forming a cartel to merging continues to hold when the invitation cost thresholds are ordered as $k^C<k^M<\bar{k}^C<\bar{k}^M$. This case is depicted in Figure 2.3. In this case, the intervals of mixing by the buyer overlap; however, for the region of overlap, the expected payoff to a cartel is greater than the payoff to a merged entity. This occurs because in that region, the probability with which the buyer accepts a bid of 1 is greater for a cartel than for a merger. Intuitively, a buyer facing non-merged firms places some probability weight on bids of 1 coming from non-cooperative firms in the high-cost state, in which case the buyer prefers to accept one of the bids.

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 non-cooperatively.

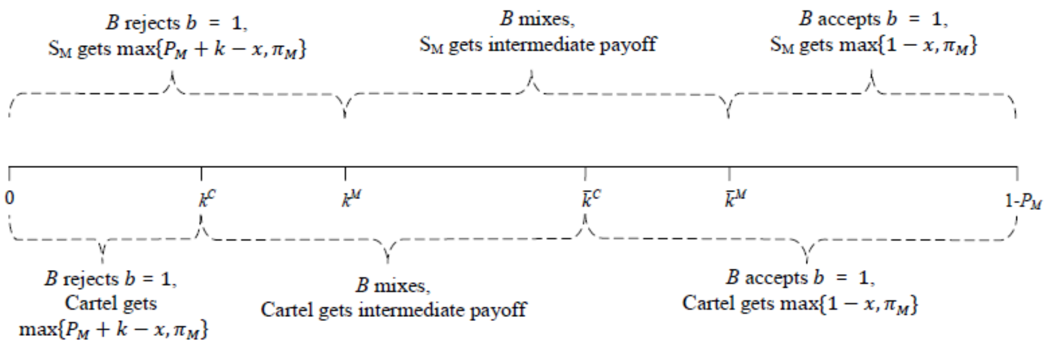

Figure 2.3: Illustration of Proposition 2.4 equilibria for sufficiently high ξ

2.6 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. For a more recent example, a steel cartel involving 17 prestressing steel producers operated a global price-fixing and market-sharing cartel between January 1984 and September 2002.[36] In 2002, DWK Saarstahl revealed the existence of the cartel under the EU Leniency Programme introduced that year. The cartel included Mittal Steel and Arcelor, the first and second-largest steel producers in the world, but in 2006, Mittal and Arcelor merged. Thus, it appears Mittal and Arcelor chose collusion when a merger was possible.

Whereas a merger is a publicly observed event, a cartel is a clandestine operation (even back in the late 1800s). Other non-cartel firms in an industry may know 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 non-cooperative bidders to enhance their profits relative to

[36]Statements in this paragraph rely on: Case No COMP/M.4137 - Mittal / Arcelor, Article 6(2) Non-Opposition, 02/06/2006, http://ec.europa.eu/competition/mergers/cases/decisions/m4137_20060602_20212_en.pdf; and "Corrected Antitrust: Commission fines prestressing steel producers € 458 million for two-decades long price-fixing and market-sharing cartel," Reference: IP/10/1297, 06/10/2010, http://europa.eu/rapid/pressReleasesAction.do?reference=IP/10/1297&format=HTML&aged=0&language =EN&guiLanguage=en.

a merged entity.

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 (see Appendix B.2).

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 3

Buyer Resistance to Cartel Conduct

3.1 Introduction

Public and private buyers often rely on a competitive bidding process to purchase required goods or services. Government agencies are usually required by law to purchase all goods, works and services through competitive procurement processes, and billions of dollars are awarded annually.

Competitive bidding can allow buyers to obtain substantial surplus from their purchase. The competitive process only generates this surplus, however, when sellers act independently. When sellers collude, competition is suppressed and prices are artificially inflated.

When collusion is a concern, buyers may react strategically to counter the potential collusion by sellers. There are a number of actions that the buyer can take in a procurement context to oppose collusive bidding. For example, the buyer may refuse to purchase if the bids are viewed as too high. Almost all procurement rules are designed so that the buyer has the discretion to make no award and reject all bids if the bids appear to be unacceptably high. In practice, it is often the case that the buyer refuses to award the project when the lowest received bid is in excess of what is considered a reasonable market price by the buyer. Unawarded projects are typically re-procured at a later date.[1] In most real-world procurements, it is

[1] Re-auctioning of the unsold items is common in auctions as well. See e.g. Cassady (1967),

common for a buyer to use its own estimate of the project's cost to judge the acceptability of the bids. Interestingly, it is also common that the buyer's cost estimate is not announced prior to bidding, but is only revealed after the initial bidding has ended.

For non-collusive bidders, it is a well-known result in auction theory that the public announcement of all information known to the auctioneer/procurer about the item for sale/procurement may benefit the auctioneer/procurer. In an environment with common value uncertainty, the release of information has two effects on bidding behavior. First, it can undermine the winning bidder's private information and, as a result, reduce his information rents and second, it can lead to more aggressive bidding by reducing the "winner's curse." While much of the existing literature on information disclosure maintains the assumption of competitive bidding, the question of whether it is in the auctioneer's interest to reveal his information to potentially collusive bidders is less explored.

In this paper, I study the problem of information disclosure in a procurement context where sellers may be colluding. The setting for my analysis is a procurement market in which the buyer is relatively uninformed about the project to be procured.

There are many procurement environments in which sellers have superior information that is relevant to the project. Sellers typically have better information about various aspects of their production costs than a buyer. They are usually more familiar with demand and input market conditions as well. As a result, the quality of information held by the buyer is often scarce compared to that of the sellers. For example, highway construction companies may be more accurate in their estimation of the cost of a particular road construction project than the government transportation agencies that are generally the buyers in this industry. Likewise, in the auction setting, timber mills may be more accurate in assessing the quality of timber in a particular area than the Forest Service. In such environments, collusion may enable bidders to extract a potentially substantial rent for their information that would be transferred to the buyer if their bidding were competitive.[2]

Ashenfelter (1989), and Porter (1995).

[2] The Government buyers may be more susceptible to collusion by informationally advantaged sellers. "It is also difficult for agency personnel to identify collusive patterns or inflated bidding if they are not familiar with the products used in the contracts they are to procure. This problem is exacerbated by the dwindling government acquisition workforce. With fewer contracting offices, the current contract officers are handling a larger number of contracts for a variety of different products and services. As a result, the contracting officers may be less familiar with the products or

Motivated by common procurement practices, I envision a strategic buyer who is relatively uninformed about the cost of a project but may resist the collusive price increases by rejecting "unreasonable" bids and re-auctioning the project. Re-auctioning is costly to the buyer, but enables the buyer to have a more reliable estimate of the sellers' costs by the second procurement. Sellers, who may or may not be collusive, need to take account of such resistance by the buyer in order to achieve high profits. In the setting I consider, the disclosure of the buyer's information has nothing to add to what the sellers' believe about their costs. Although, by manipulating the information that is revealed to the sellers, the buyer may influence the sellers' perceptions about buyer resistance, i.e., as to whether the bids get accepted or rejected. The main finding of this paper is that nondisclosure of the buyer's information combined with re-auctioning can be useful for combating collusion in an environment where sellers are informationally advantaged and the buyer's signal is sufficiently informative regarding the project's cost.

I construct a two-stage procurement model in which a single buyer faces two potential sellers. The sellers' costs have both common and private components. The common component is known to all sellers but not to the buyer, and the private component is privately observed by each seller. The buyer privately observes the realization of a noisy signal that is correlated with the sellers' common cost component. After the initial round of bidding, the buyer can purchase from one of the sellers or reject all bids and re-conduct the procurement. If the buyer makes no purchase in the initial round, the buyer may suspend the procurement to acquire a more accurate signal for the second round. Acquiring a more accurate signal causes a delay in purchasing. To prevent the delay, the buyer can re-conduct the procurement without acquiring a new signal.

The buyer is strategic in this model. In each round, the buyer sets a minimum acceptable bid according to the pre-announced *award rule*, which is a mapping from the buyer's signal and the observed bids to a decision whether to award the project. I consider two information disclosure policies, one under which the buyer publicly reveals his private signal in the initial round of bidding and another under which the buyer reveals no information at all. The buyer commits to either a revealing or concealing policy before observing the signal and prior to soliciting bids.

services on which contractors are bidding." ("Procurement of Construction and Design Contracts", Michael T. Callahan, 2005, pg. 1110)

I analyze the buyer's expected payoff under a revealing and a concealing policy in two circumstances: when there is a cartel of all sellers and when individual sellers act non-cooperatively. Collusion is modeled as an exogenous event. In the event of collusion, only the seller with the lowest cost submits a "serious" bid, and this is common knowledge.

I show that in this model the revealing and the concealing policies are payoff-equivalent for the buyer when sellers act non-cooperatively. However, when the sellers are functioning as a cartel, the buyer can increase his payoff by following a policy of concealing the signal if the buyer's signal is sufficiently correlated with the sellers' costs. When the buyer publicly reveals his signal, both low and high cost cartels bid the highest amount that the buyer is willing to accept, conditional on the information that is revealed to the cartel. Unlike the public disclosure policy, when the buyer follows a concealing policy, the cartel remains uncertain about how high to bid without causing rejection of the bid by the buyer. Since the sellers' costs are correlated with the buyer's signal, the low (high) cost cartel attaches a greater probability to the buyer's signal and hence the highest acceptable bid being low (high). Therefore, given that the low signal buyer is more likely to re-auction for a given bid, the highest bid the low-cost cartel believes it can submit without generating rejection is less than the highest bid the high-cost cartel expects it can get away with. If correlation between the buyer's signal and the sellers' costs is strong, the low-cost cartel has incentives to bid closer to its actual cost. Thus, the buyer can limit the incentives of a low-cost cartel to represent itself as high cost through a concealing policy. As a result, the concealing policy yields a higher expected payoff for the buyer.

While the objective of this paper is to study the impact of a disclosure of relatively "uninformative" signals on the cartel's ability to elevate prices, most previous studies examine the effect of the release of information from the auctioneer in a competitive bidding environment where the auctioneer and all bidders receive signals that are affiliated in the Milgrom and Weber sense.[3]

Closer to this paper is the literature on secret reserve prices. Several authors have argued that the use of a secret reserve price may be useful for deterring collusive bidding (see, e.g., Ashenfelter (1989), Porter (1993), McAfee and McMillan (1992)).

[3] Goeree and Offerman (2000) study the effect of the public release of information in a first-price auction model in which bidders receive both private and common value signals.

The intuition of this argument is that a secret reserve price introduces additional noise into the auction process and, hence, makes collusion more difficult; however, it is not apparent why the auctioneer would prefer a secret reserve price to a more aggressive public reserve price which would also reduce the rents available to the cartel (as in Graham and Marshall (1987)). Alternative justifications of the use of secret reserve prices include increasing bidder participation in common value auctions (Vincent (1995)) or risk aversion on the part of bidders (Li and Tan (2000), Brisset and Naegelen (2006)).

There is also literature on multi-round auctions that is relevant to this paper. Most related is the paper by Horstmann and LaCasse (1997), where the authors show that the joint use of re-auctioning and secret reserve prices can be profitable for the auctioneer.[4] In contrast to my paper, they consider a pure common value environment in which the auctioneer knows the true value of the object and may re-auction the item to signal his private information that can not be directly transmitted to the bidders.[5]

The paper proceeds as follows. In Section 3.2, I review the common procurement practices adopted by the US government purchasing agencies and extract some essential features. In Section 3.3, I describe a two-stage procurement model that closely parallels the procurement settings described in Section 3.2. In Section 3.4, I present results of my model which are consistent with the findings from Section 3.2. In Section 3.5, I provide the numerical results. I conclude in Section 3.6.

3.2 Background

In this section, I describe the public procurement practices currently adopted by the US government agencies.[6] I focus on some common features of public procurements that were implemented by the government purchasers to police collusive behavior.

In the United States most government procurements are held as first-price sealed-bid auctions and proceed as follows. Before solicitation of bids, usually prequalifi-

[4] See Ji and Li (2008) for an empirical analysis of multi-round procurement auctions with secret reserve prices.

[5] Other studies of multi-round auctions include Brusco, Lopomo and Marx (2010), McAfee and Vincent (1997), Skreta (2004), among others.

[6] See Appendix B.2 for examples.

cation is used to identify and invite potential bidders. For a firm to become prequalified, its work experience, resources and financial assets are typically assessed to determine its capability of undertaking the project. In most procurements, it is common for a buyer to prepare independent cost estimates of the project before soliciting bids. This is called the engineer's cost estimate and is used as a benchmark for evaluating proposed bids.[7] Bidding is then open to all eligible bidders.

After the bid submission deadline, the bids are evaluated. The purpose of bid evaluation is to determine whether the received bids are acceptable to the buyer. This is a key component of any procurement process. After evaluating the bids, the buyer either awards the contract to the lowest responsible bidder or makes no award and rejects all bids. Almost all procurement rules give the buyer the right to reject any or all bids if the bids appear to be unacceptably high.[8]

Buyers often void the initial procurement when the low bid exceeds the engineer's estimate by a substantial margin.[9] If great differences between bid prices and the engineer's estimate are found, the proposed bids are often viewed as unreasonably high. The procurement agency then rejects all bids and re-auctions the project at a later date.

Since the engineer's estimate is used to establish a reserve value for a project, its reliability is considered essential. Under-estimating the project value causes delay while overestimating causes inefficient use of funds. There are three main methods for estimating the project costs: cost-based, historical, and a combination of the two.[10] Regardless of the method used to prepare the estimates, buyers generally do not have access to the detailed information held by the contractors. As a result, the cost estimates prepared by the buyer usually are not as accurate as those prepared

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[7] Preparation of the engineer's estimate is optional for private buyers, but typically required by law when a purchaser is a public agency.

[8] See Federal Acquisition Regulations, Section 14.404 Rejection of bids: "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." (Available on-line at http//:www.acquisition.gov/Far/reissue/FARvol1ForPaperOnly.pdf)

[9] Rejection of all bids and re-bidding can be initiated due to other reasons as well, e.g., bids are found to be substantially non-responsive, bid documents are defective and/or incomplete, or there is evidence of inadequate competition.

[10] For a detailed review of different methods, see the report "*Best Practices for Developing the Engineer's Estimate*", prepared by The Department of Civil Engineering, Clemson University, 2007. Available on-line at http://www.clemson.edu/t3s/scdot/pdf/projects/661%20Part2.pdf

by contractors for bidding purposes.

Although it is realized that the engineer's estimate may not always accurately reflect the market value of the project, most government procurement rules explicitly prohibit making an award to the lowest bidder if the lowest bid is not within a certain percent, usually 10%-15%, of the engineer's estimate. These rules are typically pre-announced. When the lowest bid is above the maximum tolerance of the engineer's estimate, usually a more thorough review of the project costs is required to investigate causes for the excessive bids. An additional investigation is especially important when limited competition is anticipated by the purchasing authorities. In those circumstances where the level of competition for the project is considered as adequate, even an apparently excessive bid may be accepted, but a proper justification is required to ensure that the bids are not collusive.[11]

An interesting feature of procurements that varies across U.S. states is the information provided to bidders regarding the engineer's estimate. Some states release this information prior to bidding, while others withhold the engineer's estimate and use it as a secret reserve price. For example, the evidence from the U.S. transportation industry suggests that more than 60% of state departments of transportation do not release the engineer's estimate prior to bidding.[12]

There are different views and justifications, both pro and con, for keeping the engineer's estimate secret. In some states, public procurement rules require publication of the engineer's estimate to ensure that contracts are fairly awarded.[13]

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[11] The evidence on cartel behavior in the US construction industry prior to 1980's suggests that it was ineed a normal practice for cartels to achieve excess profits by manipulating the engineer's estimate. For example, such practice was common in the case of a New York State highway bid-rigging cartel: "the evidence was ample to permit the jury to find that the bid-rigging conspiracies resulted in the low bidders' submitting bids that were well in excess of what they would have been in the absence of bid rigging, and that the State and the County therefore were in fact injured by the conspiracies... In some instances, the State simply revised its estimate upward on the theory that 'the competitive bids [were] a better reflection of costs in the current market.' The State accepted at face value the bidders' noncollusion representations and operated on the assumption that the bids received reflected the operation of free market forces without any collusion among bidders." (State of New York v. Hendrickson Brothers Inc., et al, 840 F.2d 1065 (United States Court of Appeals, 2nd Circuit, 1988))

See also Feinstein, et al (1985) for more examples of cartels that manipulated engineer's estimates on highway construction projects let by NCDOT.

[12] See Appendix C, Table C.5 for a symmary of the EE disclosure policy for individual state DOT's.

[13] Publication of the engineer's estimate leads to a more transparent procudere for the award of public contracts as it eliminates the possibility from state employees to secretly release the estimate to only one or some of the bidders.

In the absence of legal constraints, publication of the engineer's estimate is justified for efficiency reasons. The argument for publishing the engineer's estimate is that disclosure of the estimate helps prospective bidders understand the scope of the project better and makes the project value more predictable to them.

The major concern with respect to releasing the engineer's estimate is that it may facilitate bid rigging. The U.S. Department of Transportation advises (but does not require) buyers to keep the engineer's estimate confidential. The Department's view concerning the confidentiality of the engineer's estimate is that releasing the estimate creates an enhanced opportunity for collusion among bidders.[14] The rationale of this argument is that publishing the engineer's estimate invites bidders to submit bids very close to the estimated amount, even if the cost of the work is less.

According to the Federal Highway Administration guidelines, the state engineer's estimate is a useful piece of information for firms desiring to rig bids. If bidders know what the state thinks a job is worth, the rigged price may then exceed the engineer's estimate but not by so much that the bids will be rejected. However, when the engineer's estimate is kept secret, bidders are uncertain about how high to bid without jeopardizing the award of the project and could be inclined to bid close to competitive prices.

The DOT and DOJ also address this issue in their joint 1983 guidance, "Suggestions for the Detection and Prevention of Construction Contract Bid Rigging," where the primary reason for maintaining confidentiality of the estimate would be to reduce the possibility of collusion by preventing bidders from knowing the maximum amount that the purchasing agency is willing to pay for the project.[15] The suggestions also note that: "it is not necessary to help them [bidders] estimate the cost of materials, since bidders are intimately familiar with these costs," concluding that the "bidding process would not be impaired if the state engineer's estimates were withheld from prospective bidders."[16]

[14] This argument is discussed in "Guidelines on Preparing Engineer's Estimate, Bid Reviews and Evaluation" (2004), prepared by FHWA, Section 4. (Available on-line at http//:www.fhwa.dot.gov/programadmin/ contracts/ta508046.pdf))

[15] See Section 2 in Suggestions for the Detection and Prevention of Construction Bid Rigging (1983), prepared by the US Department of Transportation and the US Department of Justice. Available on line at http://www.fhwa.dot.gov/programadmin/contracts/dotjbid.pdf

[16] "Suggestions for the Detection and Prevention of Construction Bid Rigging" (1983), Section 2, pg. 7.

It is noteworthy that the government policies regarding disclosure of the engineer's estimate went through remarkable changes in the 1980s, in response to the bid rigging problems that were prevalent during the preceding decades. As a result of the bid rigging scandal in early 1980s[17] and the subsequent changes in the government policy, many states adopted the policy of keeping the engineer's estimate secret for the purpose of combating bidder collusion.[18]

Revealing versus concealing the engineer's estimate appears to be an important issue outside the United States as well. For instance, the World Bank advises procurement authorities to keep their engineers' estimates confidential in World Bank-financed road construction projects. The Bank's view on this problem is that publishing the estimates can produce lower bids when the market is competitive. However, publication of the estimate can facilitate collusion as the cost estimate might serve as a target for potential conspirators.[19] In support of this view, the World Bank provides a comparison of the estimated price and the winning bids on

[17] "Two major antitrust scandals in the construction industry highlighted the pervasiveness of the practice. ... In 1979, federal prosecutors undertook a major investigation into bid rigging on federally aided highway and airport runway projects in Illinois ...The expanded investigation ultimately covered 24 states and resulted in 340 criminal suits against 183 companies and 210 individuals. Fines totaling $65.5 million and aggregate jail sentences of more than 61 years were imposed. Other construction-related industries ... have been the focus of federal and state investigations." ("Procurement of Construction and Design Contracts", Michael T. Callahan, 2005, pg. 1110)

[18] The view that collusion is more effective against buyers who reveal the engineer's estimate to potential bidders was largely influenced by the empirical evidence of cartel behavior prior to the 1980s. The following example of a cartel that was convicted for rigging bids on Oklahoma highway construction projects shows that cartel members were indeed using the engineer's estimate in determining their collusive bids: *"The mechanics of the conspiracy remained essentially the same during its operation: After the ODOT advertised its intent to award certain highway contracts, interested contractors would request a bidding proposal, which included specifications for the job and an estimate of costs prepared by the state's engineers. ... Once the winning contractor finished his bid, he would tell the other contractors who had promised to submit 'complimentary bids' the total their bids should exceed the state's cost estimate... the conspiracy, when implemented, usually brought the desired results." (U.S. v. Washita Construction Company,* 789 F.2d 809 (10th Circuit, 1982)).

[19] In some cases bidding cartels were discovered after the procurement officials became suspicious because all the recieved bids were very close to the engineer's estimate. For example, the *"World Bank staff became suspicious when only three bids were submitted for one of the first contracts on the Bali Urban Infrastructure Project. Suspicions were heightened when, despite wide variations in labor and materials prices on the bidders' bills of quantity, the prices submitted by all three were within 0.02 percent of the engineer's estimate...Additional investigation confirmed the existence of a bid-rigging cartel"*. (Aguilar, Gill and Pivio (2000): "Preventing fraud and corruption in World Bank projects. A guide for staff," p. 22).

46 Bank-financed road construction and repair projects let during 2009 and 2010 in Eastern European countries. It was concluded that "this degree of correspondence is unimaginable in the absence of collusion."[20]

The above description of procurement examples establishes several important facts that are relevant to my model: (1) Buyers usually use their own estimate of the project's cost to judge the reasonableness of bids. (2) Most public procurements have rigid award criteria related to the buyer's estimate (i.e. the lowest bid should be within a certain percent of the estimate to be recommended for award). (3) If the initial bids are viewed as reasonable, then the buyer makes an award to the lowest bidder. (4) If the initial bids are viewed as unreasonably high, the bids are subject to a more detailed review and investigation before re-letting the project.

[20] "Preventing fraud and corruption in World Bank projects. A guide for staff," p. 21.

3.3 Model

In this section, I present a stylized two-stage procurement model in which the buyer is relatively uninformed.

3.3.1 The Environment

There is one buyer B who wants to purchase a single good. The buyer's valuation for the good is equal to v_B.

There are two sellers S_1 and S_2 who can provide the good. The cost of providing the good for seller i is c_i, which consists of a common component θ and a private component σ_i. Common and private components are additive: $c_i = \theta + \sigma_i$. The common component θ is low (equal to θ_l) with probability p_l and high (equal to θ_h) with probability p_h. Each seller i independently draws a private cost component σ_i from a distribution $F(\sigma)$ that has a support $[\underline{\sigma}, \overline{\sigma}]$. Thus, conditional on θ, c_i's are drawn independently from $F[\theta + \underline{\sigma}, \theta + \overline{\sigma}]$. I let G denote the cdf for the minimum of two random variables drawn from the distribution F. I assume that the cdf's $F(\cdot)$ and $G(\cdot)$ admit continuously differentiable density functions $f(\sigma)$ and $g(\sigma)$ that are bounded away from zero on $[\underline{\sigma}, \overline{\sigma}]$ and have decreasing reverse hazard rates.[21] I also assume that the following conditions hold: $\underline{\sigma} \geq 0$, $\theta_l \geq 0$, $\theta_l + \overline{\sigma} \leq \theta_h + \underline{\sigma}$ and $v_B \geq \theta_h + \overline{\sigma}$. All the distribution functions and v_B are commonly known by both sellers and the buyer.

The buyer solicits bids via a first-price sealed-bid procurement. There are potentially two rounds of bidding. After the initial round, the buyer either purchases the good from one of the bidders or rejects the initial bids and re-solicits new bids in the second round.

The common cost component θ is drawn in round 1 and remains in place for round 2. The private cost components σ_i's are drawn from $F[\theta + \underline{\sigma}, \theta + \overline{\sigma}]$ in each round, independently of each other and of all past realizations. I assume that θ is commonly observed by S_1 and S_2. Realization of σ_i is privately observed by S_i at the beginning of each round. Neither θ, nor σ_i's are observed by the buyer.

The buyer observes a noisy signal of θ at the beginning of round 1. The signal is labelled as $\widehat{\theta}$. Conditional on θ, $\widehat{\theta}$ takes on two values, high or low: $\widehat{\theta} \in \{\widehat{\theta}_l, \widehat{\theta}_h\}$. The

[21] This is equivalent to the assumption of an increasing hazard rate in auctions.

joint distribution of $(\theta, \widehat{\theta})$ is given by $\Pr(\theta_l, \widehat{\theta}_l) = p_{l\widehat{l}}$, $\Pr(\theta_l, \widehat{\theta}_h) = p_{l\widehat{h}}$, $\Pr(\theta_h, \widehat{\theta}_h) = p_{h\widehat{h}}$ and $\Pr(\theta_h, \widehat{\theta}_l) = p_{h\widehat{l}}$. The conditional probabilities are denoted as follows: $\Pr(\widehat{\theta}|\theta) \equiv p_{\widehat{\theta}|\theta}$ and $\Pr(\theta|\widehat{\theta}) \equiv p_{\theta|\widehat{\theta}}$. I assume that $p_{\widehat{l}|l} > p_{\widehat{h}|l}$ and $p_{\widehat{h}|h} > p_{\widehat{l}|h}$. Thus, the signal $\widehat{\theta}_l$ is more likely to be realized when the sellers' costs are low, and $\widehat{\theta}_h$ is more likely to be realized the higher are the sellers' costs. Realization of $\widehat{\theta}$ is B's private information. If the buyer makes no purchase in the initial round, he may suspend the procurement to acquire an accurate signal $\widehat{\theta}^{acc}$ that is perfectly informative about θ, i.e. $\widehat{\theta}^{acc} = \theta$. Acquiring an accurate signal causes a delay in purchasing. To prevent the delay, the buyer can re-conduct the procurement immediately after the first round, without acquiring a new signal.

Finally, I assume that the buyer is vulnerable to collusion. The environment is such that with probability λ the market is competitive, i.e., S_1 and S_2 are noncooperative bidders. With probability $1 - \lambda$, the environment is collusive, i.e., the sellers form a cartel. I assume that λ is independent of θ and σ_i's. If S_1 and S_2 are in a cartel, the seller with the lowest cost submits a serious bid at the procurement and the second seller submits a complementary bid and this is common knowledge. Both sellers observe if the cartel was formed, but the buyer does not.

All players are risk-neutral. If a purchase is made, the buyer's payoff is his valuation minus his payment and the seller's payoff is the payment he gets from the buyer minus his cost. If the buyer suspends the initial procurement to draw an accurate signal and makes a purchase in the second round, then in round 1 all players discount their payoffs at a rate δ. If the buyer holds the second round immediately after the first round without drawing an accurate signal, then the second round payoffs are not discounted. If the buyer does not purchase the good, both sellers and the buyer get zero payoffs.

3.3.2 Timing and Notation

Consistent with the timing as it occurs in practice, I assume that at the beginning of round 1, prior to bidding and before observing the signal, the buyer announces the first round award rule $R_1(\widehat{\theta}, b_1^1, b_2^1)$. Conditional on the signal value $\widehat{\theta}$ and the received bids b_1^1, b_2^1, this announcement commits the buyer to accept no bid greater than $R_1(\widehat{\theta}, b_1^1, b_2^1)$ and accept the lowest bid if it is less than or equal to $R_1(\widehat{\theta}, b_1^1, b_2^1)$. There are two signal disclosure policies available to the buyer: revealing and concealing. The buyer commits to either a revealing or concealing policy before observing the signal and prior to soliciting the bids.

If the buyer follows a revealing policy, he discloses the signal $\widehat{\theta}$ to the sellers before soliciting the first round bids. The sellers then make their bids. If the lowest bid is below $R_1(\widehat{\theta}, b_1^1, b_2^1)$, the lowest bidder wins the project and pays his bid. If both bids are above the reserve price, the buyer voids the initial bids and announces re-bidding in the second round.[22]

If the buyer follows a concealing policy, he withholds $\widehat{\theta}$ from the sellers. After receipt of the first round bids, $\widehat{\theta}$ is publicly displayed and if $R_1(\widehat{\theta}, b_1^1, b_2^1)$ exceeds the lowest received bid, then the project is awarded to that seller. Otherwise, the buyer rejects both first round bids. I assume that the buyer can credibly commit to not modifying the award rule after observing the bids.[23]

If the first round bids are rejected, the buyer may suspend the procurement to acquire a completely informative signal $\widehat{\theta}^{acc}$ before re-soliciting bids in the second round.[24] If the buyer holds the second round of bidding immediately after the first round, then B keeps the initial signal $\widehat{\theta}$. I assume that when $\lambda < 1$, i.e., when there is a positive probability of collusion among sellers, the buyer must suspend the procurement and obtain an accurate signal $\widehat{\theta}^{acc}$ for the second round if the lowest first round bid is greater than $\max\{R_1, \theta_h + \underline{\sigma}\}$.[25]

In the second round, which is the final stage in the model, the buyer publicly reveals his signal and the first round bids prior to soliciting the second round bids. Based upon his inferences about θ from the initial bids b_1^1, b_2^1 and the signal, the buyer commits to the second round award rule $R_2(b_1^2, b_2^2)$ prior to bidding. If the lowest second round bid is below R_2, the buyer awards the project to the lowest bidder, otherwise he makes no award. If the buyer does not purchase in the second

[22] I assume that each seller must bid in each round. In other words, if a seller wants to withdraw from the procurement, he may submit an arbitrarily high bid, but he may not refrain from bidding.

[23] This assumption is quite realistic in most governemnt procurements. Clearly, though, there may be situations where this assumption is less realistic.

[24] I assume for simplicity that the buyer can draw a perfectly informative signal, but the second signal can be made noisy. The crucial assumption is that the second signal is more informative than the first round bids. Without the latter assumption, finding an optimal award rule is a much more complex problem.

[25] Note that such requirements are very common in most government procurements. Procurement authorities are usually not allowed to revise their estimates upward without conducting a thorough investigation of costs. Such investigations usually take time.

round, then he cancels the project.[26]

The timing in the model is as follows:

Initial procurement

1. B commits to the signal disclosure policy: revealing or concealing.

2. S_1 and S_2 observe θ and λ. Each S_i observes σ_i^1.

3. B announces an award rule R_1 prior to bidding.

4. B observes $\widehat{\theta}$.

5. If B follows revealing policy, then B publicly discloses $\widehat{\theta}$. If the buyer follows concealing policy, B keeps $\widehat{\theta}$ secret.

6. S_1 and S_2 submit their bids b_1^1 and b_2^1.

7. If min $\{b_1^1, b_2^1\} \leq R_1$, the buyer awards the project to the lowest bidder. Otherwise, B voids the first round bids and re-procures the project in the second round.

Potential delay

If the initial procurement is voided, B decides either to hold the re-procurement stage immediately after the initial procurement or to suspend the procurement. If B suspends the procurement, then there is a delay before the re-procurement stage and B draws $\widehat{\theta}^{acc}$. If B does not suspend the procurement, then B keeps the initial signal $\widehat{\theta}$.

Re-procurement

1. Each S_i gets a new draw σ_i^2. θ remains in place.

2. B announces an award rule R_2 prior to bidding.

3. S_1 and S_2 submit their bids b_1^2 and b_2^2.

[26] In certain circumstances the buyer can not credibly commit to cancel the project if the project is of a critical importance to the buyer. This scenario is a special case of my model when the second round reserve price is non-binding.

4. If $\min\{b_1^2, b_2^2\} \leq R_2$, then B awards the project to the lowest bidder. Otherwise, B voids the second round bids and cancels the project.

The players' strategies and payoffs under the revealing and concealing policies are defined as follows.

If the second round is reached, each noncooperative seller i bids $\beta_{nc}^2(\theta, \sigma_i)$, where for all $i \in \{1, 2\}$, the second round noncooperative bid function $\beta_{nc}^2(\theta, \cdot)$ is defined by

$$\beta_{nc}^2(\theta, \sigma_i) \in \arg\max_b \left\{E_{\sigma_{-i}}\left[(b - c_i)1_{b \leq \min\{\beta_{nc}^2(\theta, \sigma_{-i}),\ R_2\}}\right]\right\}.$$

I consider only symmetric equilibria of the noncooperative game, so I omit the subscript i throughout.

If the market is collusive, the cartel member with the lowest cost bids $\beta_c^2(\theta, \sigma_m)$, where $\sigma_m \equiv \min\{\sigma_1, \sigma_2\}$ and the second member provides a complementary bid. The cartel bid function $\beta_c^2(\theta, \cdot)$ is defined by

$$\beta_c^2(\theta, \sigma_m) \in \arg\max_b \{(b - c_m)1_{b \leq R_2}\}.$$

The second round award rule is defined by

$$R_2(b_1^2, b_2^2) \in \arg\max_{R_2} \left\{\rho E_\theta\left[U_{nc}^2(\theta)|\ \widehat{\theta}, b_1^1, b_2^1\right] + (1 - \rho)E_\theta\left[U_c^2(\theta)\ |\ \widehat{\theta}, b_1^1, b_2^1\right]\right\},$$

where $\rho \equiv \Pr(\text{noncooperative sellers}|\widehat{\theta}, b_1^1, b_2^1)$ is the buyer's posterior probability of noncooperative sellers.

$$U_{nc}^2(\theta) \equiv E_{\sigma_1, \sigma_2}\left[\left(v_B - \min\left\{\beta_{nc}^2(\theta, \sigma_1), \beta_{nc}^2(\theta, \sigma_2)\right\}\right)1_{\min\left\{\beta_{nc}^2(\theta, \sigma_1), \beta_{nc}^2(\theta, \sigma_2\right\} \leq\ R_2}|\theta\right]$$

and

$$U_c^2(\theta) \equiv E_{\sigma_1, \sigma_2}\left[(v_B - \beta_c^2(\theta, \sigma_m))1_{\beta_c^2(\theta, \sigma_m) \leq\ R_2}|\theta\right].$$

In round one, under a revealing policy, the buyer announces an award rule $R_1^P(\widehat{\theta}, b_1^1, b_2^1)$ and publicly reveals the signal $\widehat{\theta}$ prior to bidding. Bidder i's problem is then to bid below the highest acceptable price or to wait for the second round. Waiting strategy for bidder i means bidding above the highest price that the buyer accepts in the first round. The second round is reached only if both bidders choose to wait in the first round. Seller i's incentives to bid an acceptable price in the first round or wait depends upon the payoff he expects to get in the second round.

In round 1, the expected second round payoff of a noncooperative seller i is

$$\pi_{nc}^2(\theta) \equiv E_{\sigma_i,\sigma_{-i}} \left[(\beta_{nc}^2(\theta,\sigma_i) - c_i) 1_{\beta_{nc}^2(\theta,\sigma_i) \leq \min\{\beta_{nc}^2(\theta,\sigma_{-i});\ R_2\}} \right].$$

The expected second round payoffs to the cartel is

$$\pi_c^2(\theta) \equiv E_{\sigma_m} \left[(\beta_c^2(\theta,\sigma_m) - c_m) 1_{\beta_c^2(\theta,\sigma_m) \leq\ R_2\}} \right].$$

Each noncooperative bidder i bids $\beta_{nc}^{1,P}(\theta,\sigma_i)$, where for all $i \in \{1,2\}$, the first round bid function $\beta_{nc}^{1,P}(\theta,\cdot)$ under a revealing policy is defined by

$$\beta_{nc}^{1,P}(\theta,\sigma_i) \in \arg\max_b E_{\sigma_{-i}} \left[\begin{array}{c} (b - c_i) 1_{b \leq \min\{\beta_{nc}^{1,P}(\theta,\sigma_{-i}),\ R_1^P\}} + \\ \delta \pi_{nc}^2(\theta) 1_{R_1^P \leq \min\{b,\ \beta_{nc}^{1,P}(\theta,\sigma_{-i})\}} \end{array} \right].$$

The cartel bids $\beta_c^{1,P}(\theta,\sigma_m)$, where the first round cartel bid function $\beta_c^{1,P}(\theta,\cdot)$ is defined by

$$\beta_c^{1,P}(\theta,\sigma_m) \in \arg\max_b \left[(b - c_m) 1_{b \leq R_1^P} + \delta \pi_c^2(\theta) 1_{b > R_1^P} \right].$$

The first round award rule under a revealing policy is defined by

$$R_1^P(\widehat{\theta}, b_1^1, b_2^1) \in \arg\max_{R_1^P} \left\{ \lambda E_\theta \left[U_{nc}^{1,P}(\theta) \right] + (1-\lambda) E_\theta \left[U_c^{1,P}(\theta) \right] \right\}$$

where

$$\begin{aligned} U_{nc}^{1,P}(\theta) \quad \equiv \quad & E_{\sigma_1,\sigma_2}[(v_B - \min\{\beta_{nc}^{1,P}(\theta,\sigma_1), \beta_{nc}^{1,P}(\theta,\sigma_2)\}) 1_{\min\left\{\beta_{nc}^{1,P}(\theta,\sigma_1),\beta_{nc}^{1,P}(\theta,\sigma_2)\right\} \leq\ R_1^P} + \\ & \delta U_{nc}^2(\theta) 1_{R_1^P\ \leq \min\left\{\beta_{nc}^{1,P}(\theta,\sigma_1),\beta_{nc}^{1,P}(\theta,\sigma_2)\right\}} |\theta] \end{aligned}$$

and

$$U_c^{1,P}(\theta) \equiv E_{\sigma_1,\sigma_2}[(v_B - \beta_c^{1,P}(\theta,\sigma_m) 1_{\beta_c^{1,P}(\theta,\sigma_m) \leq\ R_1^P} + \delta U_c^2(\theta) 1_{\beta_c^{1,P}(\theta,\sigma_m) >\ R_1^P}\ |\theta].$$

Under a concealing policy, the buyer announces the first round award rule $R_1^{NP}(\widehat{\theta}, b_1^1, b_2^1)$ prior to bidding, but does not reveal $\widehat{\theta}$ to the bidders. Each noncooperative bidder i bids $\beta_{nc}^{1,NP}(\theta,\sigma_i)$, where for all $i \in \{1,2\}$, the first round bid function $\beta_{nc}^{1,NP}(\theta,\cdot)$ is defined by

$$\beta_{nc}^{1,NP}(\theta,\sigma_i)\in\arg\max_b E_{\sigma_{-i},\widehat{\theta}}\left[\begin{array}{c}(b-c_i)1_{b\leq\min\{\beta_{nc}^{1,NP}(\theta,\sigma_{-i}),\ R_1^{NP}\}}+\\ \delta\pi_{nc}^2(\theta)1_{R_1^{NP}\leq\min\{\ b,\ \beta_{nc}^{1,NP}(\theta,\sigma_{-i})\}}\end{array}\right].$$

The cartel bids $\beta_c^{1,NP}(\theta,\sigma_m)$, where the first round cartel bid function $\beta_c^{1,NP}(\theta,\cdot)$ is defined by

$$\beta_c^{1,NP}(\theta,\sigma_m)\in\arg\max_b E_{\widehat{\theta}}\ \left[(b-c_m)1_{b\leq R_1^{NP}}+\delta\pi_c^2(\theta)1_{b>R_1^{NP}}\right]$$

The first round award rule under a concealing policy is defined by

$$R_1^{NP}(\widehat{\theta},b_1^1,b_2^1)\in\arg\max_{R_1^{NP}}\left\{\lambda E_\theta\left[U_{nc}^{1,NP}(\theta)\right]+(1-\lambda)E_\theta\left[U_c^{1,NP}(\theta)\right]\right\},$$

where

$$\begin{aligned}U_{nc}^{1,NP}(\theta)\ \equiv\ & E_{\sigma_1,\sigma_2}[(v_B-\min\{\beta_{nc}^{1,NP}(\theta,\sigma_1),\beta_{nc}^{1,NP}(\theta,\sigma_2)\})1_{\min\{\beta_{nc}^{1,NP}(\theta,\sigma_1),\beta_{nc}^{1,NP}(\theta,\sigma_2)\}\leq\ R_1^{NP}}+\\ & \delta U_{nc}^2(\theta)1_{R_1^{NP}\ \leq\min\{\beta_{nc}^{1,NP}(\theta,\sigma_1),\beta_{nc}^{1,NP}(\theta,\sigma_2)\}}|\theta]\end{aligned}$$

and

$$U_c^{1,NP}(\theta)\equiv E_{\sigma_1,\sigma_2}[(v_B-\beta_c^{1,NP}(\theta,\sigma_m)1_{\beta_c^{1,NP}(\theta,\sigma_m)\leq\ R_1^{NP}}+\delta U_c^2(\theta)1_{\beta_c^{1,NP}(\theta,\sigma_m)>\ R_1^{NP}}|\theta].$$

Note that, in this model, a concealing policy by the buyer is equivalent to a revealing policy when the signal $\widehat{\theta}$ is completely informative.[27] This is so because the buyer receives no private information when $\widehat{\theta}=\theta$. When buyer is uncertain about the underling distribution, i.e., when $\widehat{\theta}$ is noisy, the buyer has private knowledge of his beliefs about θ. Therefore, disclosure policies of the buyer's signal have different implications regarding what sellers know before participating in the procurement, which leads to differences in equilibrium behavior and payoffs.

[27] The same is true when the signal is completely uninformative.

3.4 Results

To analyze the buyer's expected payoff under revealing and concealing policies, I first focus on the case of noncooperative bidders. In Section 3.4.1, I show that revealing and concealing policies are payoff-equivalent for the buyer, when the buyer is certain that the market is competitive. In section 3.4.2, I consider the case of collusive bidders. I establish in Proposition 3.4 that when $\widehat{\theta}$ is sufficiently correlated with θ, the concealing policy yields strictly higher payoff for the buyer. A similar result holds when the buyer believes with probability λ that the sellers are noncooperative and attaches probability $1-\lambda$ to the existence of a cartel.

The main message of this analysis is that the disclosure of the buyer's private signal is irrelevant for a buyer who faces informationally advantaged noncooperative sellers. However, if the buyer anticipates (with some probability) that the sellers are functioning as a cartel, he can increase his payoff and reduce cartel rents by concealing the signal.

3.4.1 Noncooperative Sellers

In this section, I assume that sellers S_1 and S_2 are noncooperative with probability one.

To analyze the buyer's expected payoff, consider first the best scenario for the buyer, i.e., when $\widehat{\theta} = \theta$. As noted earlier, revealing and concealing policies are identical under the assumption of a completely informative signal. In addition, when the buyer knows with certainty the distributional source of the seller's costs, no additional information can be inferred from the received bids. Therefore, the optimal award rule of the buyer is a simple cutoff rule that is not a function of bids (i.e. a reserve price).

Let $R^1_{nc}(\theta)^*$ and $R^2_{nc}(\theta)^*$ denote the optimal first and second round award rules when the sellers are noncooperative and the buyer observes the realized value of θ at $t=1$.[28] Define $U^1_{nc}(\theta)^*$ and $U^2_{nc}(\theta)^*$ to be the buyer's maximum expected payoffs in rounds one and two, respectively, when $\widehat{\theta}$ is completely informative.

I argue in Proposition 3.1 below that when sellers are noncooperative and the buyer receives a noisy signal of θ, the buyer can achieve the maximum ex ante

[28] When θ is known by the buyer, the optimal award rule in each round is the standard reserve price as in Myerson (1981).

expected payoff $p_l U^1_{nc}(\theta_l)^* + (1-p_l)U^1_{nc}(\theta_h)^*$, as if θ were known to the buyer both under a revealing and a concealing policy.

Proposition 3.1 *Suppose that sellers are noncooperative. Under both revealing and concealing policies, there exists equilibrium award rule that gives the buyer ex ante expected payoff equal to* $p_l U^1_{nc}(\theta_l)^* + (1-p_l)U^1_{nc}(\theta_h)^*$.

Proof. The proof is by construction. I first characterize the equilibrium award rule and bid strategies when θ is common knowledge. Then I show that both under revealing and concealing policies, there exists an equilibrium in which B commits to the following award rule

$$R_1^P(\widehat{\theta}, b_1^1, b_2^1) = \begin{cases} R^1_{nc}(\theta_l)^*, \text{ if } \min\{b_1^1, b_2^1\} \leq \theta_l + \overline{\sigma} \\ R^1_{nc}(\theta_h)^*, \text{ if } \min\{b_1^1, b_2^1\} \geq \theta_h + \underline{\sigma} \end{cases}$$

and S_i's bid as if θ were known to the buyer. *(see Appendix C for the proof)* ■

When the sellers are noncooperative the buyer can rely on the observed bids to learn the true θ, whether high or low, and set the highest acceptable price accordingly. Since the common cost component θ is perfectly correlated across sellers, the buyer can use correlation to fully extract the noncooperative bidders' knowledge about θ irrespective of the signal disclosure policy. Although in the procurement mechanism the buyer can not directly ask the sellers to make reports about θ, he uses the fact that the equilibrium bid functions are disjoint for θ_l and θ_h, to fully extract information about θ. Because the buyer can learn θ through the first round bids, he conditions the award rule on the observed bids and disregards his noisy signal. Thus, a concealing policy by the buyer is equivalent to a revealing policy when the sellers are noncooperative bidders.

The intuition of this result is that even when there is a significant asymmetry in production information between the buyer and his suppliers, the buyer can rely on supplier rivalry to mitigate the sellers' informational advantage if the market is competitive.

3.4.2 Collusive Sellers

In this section, I consider the case of collusive sellers. First, I assume that the buyer faces a known cartel, i.e., the buyer is certain that S_1 and S_2 are functioning as a cartel.

As it was shown in the previous section, when sellers are noncooperative, they are unable to capture positive rents for their common knowledge of θ. When sellers are collusive, however, they can command rents for their superior information by limiting the information that is revealed to the buyer through bidding. The buyer can resist collusive prices by rejecting bids above the highest acceptable price and suspending the procurement to obtain a more accurate estimate of the sellers' costs before re-procuring the project. There are two conflicting factors that govern the buyer's optimal choice of the award rule when the buyer faces a cartel. An award rule that commits the buyer to accept a price higher than the actual costs may result in a substantial payment by the buyer, while an award rule that commits the buyer to set the highest acceptable price below the actual costs leads to a delay in the award. I call these two factors No overpay and No delay effects.

As I argued in the previous section, when the buyer knows the true θ, it is optimal for the buyer to commit to an award rule that does not depend on bids, as there is no useful information contained in the observed bids. Let $R_c^1(\theta)^*$ and $R_c^2(\theta)^*$ denote the optimal first and second round award rules when sellers are collusive and the buyer observes θ at $t = 1$. Define $U_c^1(\theta)^*$ and $U_c^2(\theta)^*$ to be the buyer's maximum expected payoffs in rounds one and two, respectively, and $\pi_c^2(\theta)$ be the cartel's maximum expected payoff when it is a common knowledge that $\widehat{\theta}$ is completely informative.

I begin by considering the case when the buyer commits to a policy of publicly revealing his signal to the bidders. When the buyer reveals the signal $\widehat{\theta}$, the buyer moves first, in the sense that he fully reveals the first round award rule $R_1^P(\widehat{\theta}, b_{ctl}^1)$ prior to bidding. Given the award rule, the cartel's problem is to choose between winning the project in the first round, or waiting for the second round, depending upon the expected payoff that the cartel expects to get if bidding proceeds to the second round. In equilibrium, the cartel bids either the maximum price that the buyer accepts in the first round or submits a bid that will be rejected by the buyer. Because the signal that the buyer uses to design the award rule is noisy, the buyer always makes a mistake with positive probability in his choice of the award rule. In other words, the equilibrium award rule that is revealed to the sellers is always suboptimal compared to when θ is known by the buyer.

The following proposition characterizes the buyer's expected payoff under a revealing policy when $\widehat{\theta}$ is sufficiently accurate.

Proposition 3.2 *Suppose that sellers are collusive. Under the revealing policy, if $p_{l,\widehat{l}}$ is sufficiently high, then in any equilibrium involving non-weakly-dominated strategies, the buyer has ex ante expected payoff strictly less than* $p_l U_c^1(\theta_l)^* + p_h(p_{\widehat{l}|h}\delta U_c^2(\theta_h)^* + p_{\widehat{h}|h}U_c^1(\theta_h)^*)$

Proof. I show in Appendix C that in any PBNE, there exists $\widetilde{p} \in (0,1)$ such that in the first round the buyer with signal $\widehat{\theta}$ adopts the following award rule:

if $p_{l,\widehat{\theta}} \geq \widetilde{p}$,

$$R_1^P(\widehat{\theta}, b_{ctl}^1) = R_c^1(\theta_l)^*, \text{for all } b_{ctl}^1$$

and if $p_{l,\widehat{\theta}} < \widetilde{p}$,

$$R_1^P(\widehat{\theta}, b_{ctl}^1) = \begin{cases} R_c^1(\theta_l)^*, & \text{If } b_{ctl}^1 \leq \theta_l + \overline{\sigma} \\ r(\ p_{l,\widehat{\theta}}), & \text{If } b_{ctl}^1 > \theta_l + \overline{\sigma} \end{cases}$$

where $r(\cdot) : [0,1] \to (\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h),\ R_c^1(\theta_h)^*\ ]$. In the first round, the cartel either bids the highest price that the buyer accepts or waits for the second round. The equilibrium award rule and bid functions are then used to construct an upper bound on the buyer's ex ante expected payoff. ■

Proposition 3.2 shows that under the public disclosure policy, the buyer either incurs unnecessary costs of delay or pays an inflated price with some probability, regardless of the accuracy of the buyer's signal. When $p_{l,\widehat{\theta}}$ is sufficiently high, the buyer with a signal $\widehat{\theta}$ chooses the first round award rule as if $\theta = \theta_l$ were the case, because the No overpay effect dominates the No delay effect. If the true cost environment appears low, then the buyer achieves the maximum possible payoff, however if the true cost environment appears high, the buyer incurs the costs of delaying the procurement. When $p_{l,\widehat{\theta}}$ is sufficiently low, the optimal award rule is such that the highest acceptable bid in the first round is greater than $\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)$, because the No delay effect dominates the No overpay effect. If the true cost environment is high, the buyer incurs the costs of investigation with lower probability, but if the true costs are low, the buyer pays a price substantially higher than the actual costs.

Now I analyze the equilibrium of the game under a concealing policy. Unlike the revealing policy, when the buyer follows a concealing policy, the cartel moves first, i.e., submits a bid without learning the first round award rule $R_1^{NP}(\widehat{\theta}, b_{ctl}^1)$. Let

$R_c^{1,NP}(\widehat{\theta}_l)$ and $R_c^{1,NP}(\widehat{\theta}_h)$ be the highest prices that the buyer accepts in the first round if the signals are $\widehat{\theta}_l$ and $\widehat{\theta}_h$, respectively. (Suppose w.l.o.g. that $R_c^{1,NP}(\widehat{\theta}_l) \leq R_c^{1,NP}(\widehat{\theta}_h)$). Then in the first round the cartel believes that the highest acceptable price is equal to $R_c^{1,NP}(\widehat{\theta}_l)$ with probability $\Pr(\widehat{\theta}_l|\theta)$ and equal to $R_c^{1,NP}(\widehat{\theta}_h)$ with probability $\Pr(\widehat{\theta}_h|\theta)$. Given these beliefs, the cartel's problem is to choose between bidding $R_c^{1,NP}(\widehat{\theta}_l)$ and $R_c^{1,NP}(\widehat{\theta}_h)$ or waiting for the second round by submitting a bid that will be rejected by the buyer with probability one.[29]

Bidding under uncertainty about the award rule involves the following trade-off for the cartel. If the cartel submits a bid substantially greater than the true cost, the cartel might achieve a high payoff. However, if such a high bid gets rejected and the buyer suspends the procurement to draw a more accurate signal, the cartel's payoff is substantially discounted. Proposition 3.3 below shows that when $\widehat{\theta}$ is sufficiently accurate, the buyer can use this disincentive of the cartel to bid too high, to structure the award rule in a way that induces the cartel to lower its bid.

Proposition 3.3 *Suppose that sellers are collusive. Under the concealing policy, if $p_{l,\widehat{l}}$ is sufficiently high, then there exists an equilibrium in which the buyer has ex ante expected payoff equal to $p_l U_c^1(\theta_l)^* + p_h(p_{\widehat{l}|h}\delta U_c^2(\theta_h)^* + p_{\widehat{h}|h}U_c^1(\theta_h)^*)$.*

Proof. I show in Appendix C that there exists $\widetilde{p}^{NP} \in (0,1)$ such that if $p_{l,\widehat{l}} \geq \widetilde{p}^{NP}$, then there is a PBNE in which in the first round the buyer adopts the following award rule:

$$R_c^{1,NP}(\,\widehat{\theta}_l, b_c^1) = R_c^1(\theta_l)^*, \text{ for all } b_c^1$$

$$R_c^{1,NP}(\,\widehat{\theta}_h, b_c^1) = \begin{cases} R_c^1(\theta_l)^*, \text{ if } b_c^1 \leq \theta_l + \overline{\sigma} \\ R_c^1(\theta_h)^*, \text{ if } \; b_c^1 > \theta_l + \overline{\sigma} \end{cases}$$

If $\theta = \theta_l$, the cartel bids $R_c^1(\theta_l)^*$ or $\theta_l + \overline{\sigma}$ and if $\theta = \theta_h$, the cartel bids $R_c^1(\theta_h)^*$ or $\theta_h + \overline{\sigma}$. The equilibrium award rule and bid strategies are then used to construct the buyer's ex ante expected payoff. ∎

To obtain the payoff as in Proposition 3.3, the buyer needs to design the award rule so that the cartel bids as if the true θ were known to the buyer. The intuition of why this can be accomplished through a concealing policy is as follows. The

[29] Clearly, the cartel never bids below $R_c^{1,NP}(\widehat{\theta}_l)$, or in the interval $(R_c^{1,NP}(\widehat{\theta}_l),\ R_c^{1,NP}(\widehat{\theta}_h))$ in equilibrium.

buyer with the signal $\widehat{\theta}_l$ penalizes the cartel by delaying the procurement when he gets bids greater than $\theta_l + \overline{\sigma}$ and rewards the cartel by holding the second round immediately after the first round when bids lower than $\theta_l + \overline{\sigma}$ are received. When $\widehat{\theta}_l$ is sufficiently correlated with θ, the cartel's incentives are such that it never bids above $\theta_l + \overline{\sigma}$ if the true θ is equal to θ_l and it bids above $\theta_l + \overline{\sigma}$ if the true θ is equal to θ_h. Thus, by concealing the signal, the buyer can induce the cartel to reveal the true θ through its bid in the first round.

We can now state the main result of this section.

Proposition 3.4 *Suppose that sellers are collusive. For any prior distribution of θ, if $p_{l,\widehat{l}}$ is sufficiently high, then there exists an equilibrium under the concealing policy in which the buyer has a strictly higher ex ante expected payoff than in any equilibrium under the revealing policy.*

Proof. The proof directly follows from Propositions 3.2 and 3.3. ■

The intuition of why the concealing policy yields a higher expected payoff for the buyer is quite simple. While both high and low cost cartels bid the highest acceptable price when the signal is revealed prior to bidding, under the concealing policy, the buyer can use correlation between his signal and the true costs to induce different incentives for the high and low cost cartels. In particular, the buyer can limit the incentives of the low-cost cartel to represent itself as high cost. As a result, the concealing policy yields a higher payoff for the buyer.

The basic result that the buyer prefers the concealing policy over the revealing policy for sufficiently accurate signals continues to hold when the buyer is uncertain as to whether sellers are operating as a cartel or not.

Proposition 3.5 *Suppose that sellers are noncooperative with probability λ and collusive with probability $1 - \lambda$. For any $\lambda \in (0, 1)$ and any prior distribution of θ, if $p_{l,\widehat{l}}$ is sufficiently high, then there exists an equilibrium under the concealing policy in which the buyer has a strictly higher ex ante expected payoff than in any equilibrium under the revealing policy.*

Proof. See Appendix C for the proof. ■

Similar to the case of a known cartel, the concealing policy enables the buyer to discourage the cartel from misrepresenting the true θ if the buyer's signal is sufficiently accurate. In addition to delaying the procurement, when the buyer believes with positive probability that the sellers are noncooperative, the buyer further penalizes the cartel for misrepresenting the cost environment by announcing a more aggressive award rule in the second round if the initial bids get rejected and the buyer acquires an accurate signal for the second round.

3.5 Numerical Examples

In this section, I illustrate by way of numerical examples the conditions under which a concealing policy may not be preferable for the buyer. In the examples presented below, I assume that the buyer knows that sellers are in a cartel. In addition, I assume the following parameterization: $v_B = 10$, $F(\cdot)$ is uniformly distributed on $[\underline{\sigma}, \overline{\sigma}]$ where $\underline{\sigma} = 0$ and $\overline{\sigma} = 5$; $\theta_l = 0$, $\theta_h = 5$, $p_l = p_h = 0.5$ and $p_{l|\widehat{l}} = p_{\widehat{l}|l} = p_{h|\widehat{h}} = p_{\widehat{h}|h} \equiv \mathbf{p}$.

Given these parametrization, one can solve for the cartel's equilibrium bid function and the buyer's award rule for different values of $\mathbf{p}$ and δ.[30] Figure 3.1 below illustrates a comparison between the buyer's equilibrium ex ante expected payoffs under revealing and concealing policies for a variety of parameters $\mathbf{p}$ and δ.

Consistent with the findings from the previous section, these examples suggest that the buyer's expected payoff under a concealing policy is higher than that under a revealing policy when $\widehat{\theta}$ is sufficiently correlated with θ. However, as one can see from Figure 3.1, if the correlation between $\widehat{\theta}$ and θ is not high, the revealing policy might yield a higher payoff for the buyer.

[30] See Appendix C for a summary of the numerical results.

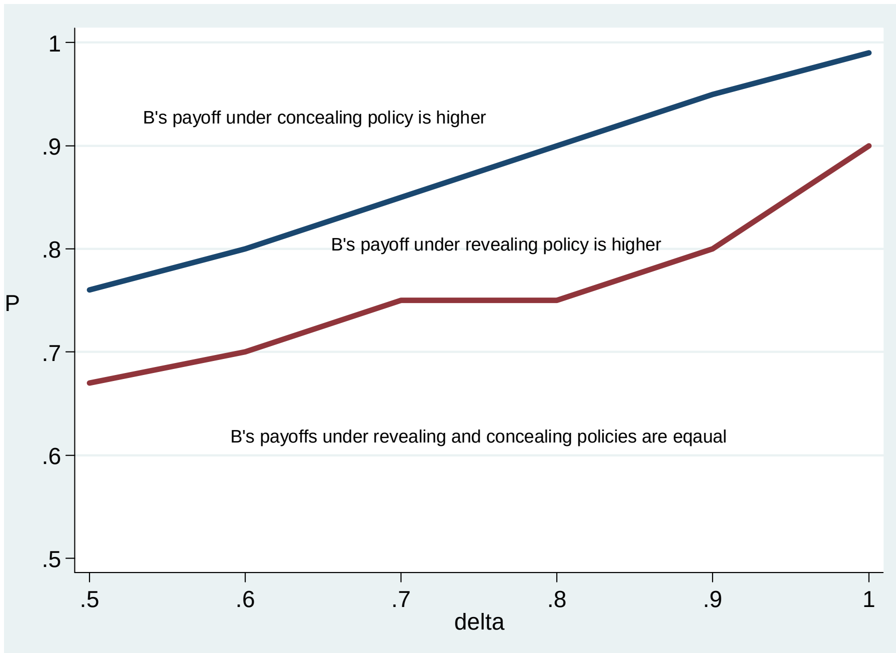


Figure 3.1: Buyer's expected payoff under concealing and revealing policies

As it was argued above, under a concealing policy, the cartel either bids the highest price that the low signal buyer accepts or the highest price that the high signal buyer accepts, given that the cartel prefers to win the project in the first round. Such conduct by the cartel works to the advantage of the buyer if **p** is sufficiently high, but if **p** is not high the buyer may end up paying more to the cartel when he conceals the signal relative to when the signal is publicly revealed. Intuitively, when the buyer's signal is sufficiently correlated with θ, the concealing policy provides incentives for the low-cost cartel to bid below $\theta_l + \overline{\sigma}$ in order to avoid the rejection of the bid by the low signal buyer. But, when the correlation between $\widehat{\theta}$ and θ is weak, the extent to which a concealing policy by the buyer drives down the bid by the low-cost cartel is limited, but the extent to which a low signal publicly revealed by the buyer forces the low-cost cartel to lower its bid is not limited. As a result, the buyer may achieve a greater payoff by revealing a less accurate signal than by concealing it.

There are two additional observations regarding these examples. First, a threshold value of **p** above which a concealing policy does better for the buyer and below which it does worse than a revealing policy, is lower for smaller values of the discount factor δ. When there is a large gap in time between the first and second rounds of bidding, the punishment for the cartel for misrepresenting the true cost environment may be substantial, should the buyer reject the first round bids and suspend the procurement to draw an accurate signal for the second round. However, the delay in the award is less of a concern for the cartel when δ is high and a higher degree of accuracy of the buyer's signal is required to ensure that the buyer achieves a greater expected payoff by concealing the signal.

Second, when the degree of correlation between $\widehat{\theta}$ and θ is sufficiently low, the buyer has the same expected payoff both under revealing and concealing policies. This occurs because, when $\widehat{\theta}$ is very inaccurate, the cost of paying an excessive cartel price outweighs the cost of delaying the award for the buyer and, thus, the buyer adopts the first round award rule that is optimal against the low cost cartel both under a revealing and concealing policy.

In summary, the preceding analysis demonstrates that the buyer's expected payoff is greater under a concealing policy when the buyer's signal is sufficiently informative regarding the sellers' costs and delay in the award due to re-procurement is substantial.

3.6 Conclusion

This paper shows that nondisclosure of the buyer's information, relative to disclosure, can increase the buyer's payoff when sellers collude. In a two-stage procurement model that closely parallels the informational environment present in many real-world procurements, I analyze the effect of information disclosure by the buyer on bidders' behavior and buyer's expected payoff. The model predicts that the disclosure of the buyer's information is irrelevant when sellers act non-cooperatively. When sellers act collusively, the buyer's payoff is higher under a concealing policy if the buyer's signal is sufficiently correlated with the sellers' costs. When the buyer follows a concealing policy, the correlated signals reduce the cartel's expected rent from misrepresenting its true cost and thus helps the buyer to moderate the cartel overcharges. Lastly, I show through numerical analysis that when the degree of correlation is weak, the buyer can be better-off by publicly revealing the signal than by concealing it. These results provide insights into the common procurement policies concerning the confidentiality of the engineer's cost estimate.

A potentially important question for future research is to study how the disclosure of the buyer's signal affects the sellers' ability to collude. For example, it seems reasonable that sellers who have the best information on their costs would be able to come to a collusive agreement relatively easily if the buyer overestimates the cost of a project and reveals the estimate prior to bidding. Thus, the buyer may create stronger incentives for collusion by revealing his imprecise knowledge about the sellers' costs. Then the question is whether the buyer can reduce incentives for collusion by concealing the noisy information that is available to him regarding the project's costs.

Appendix A

Review of EC decision cases (Chapter 1)

A.1 EC decision citations

1. *Amino Acids:* Case COMP/36.545/F3 — Amino Acids, Comm'n Decision (June 7, 2000), *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2001/l_1 52/l_15 220010607en00240072.pdf.

2. *Butadiene Rubber and ES Butadiene Rubber:* Case COMP/F/38.638 — Butadiene Rubber and Emulsion Styrene Butadiene Rubber, Comm'n Decision (Nov. 29, 2006) *available at* http://ec.europa.eu/competition/antitrust/cases/decisions/38638/en.pdf.

3. *Carbonless Paper:* Case COMP/E-1/36.212 — Carbonless Paper, Comm'n Decision, 2004 O.J. (L 115) 1, *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2004/ l_115/l_11520040421en00010088.pdf.

4. *Choline Chloride:* Case COMP/E-2/37.533 — Choline Chloride, Comm'n Decision (Sept. 12, 2004), *available at* http://ec.europa.eu/competition/antitrust/cases/ decisions/37533/en.pdf.

5. *Citric Acid:* Case COMP/E-1/36.604 — Citric Acid, Comm'n Decision, 2002 O.J. (L239) 18, *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/l_239/_23920020906en00180065.pdf.

6. *Copper Plumbing Tubes:* Case COMP/E-1/38.069 — Copper Plumbing Tubes, Comm'n Decision (Sept. 3, 2004) (summary at 2006 O.J.L (192) 21), *available at* http://ec.europa. eu/competition/antitrust/cases/decisions/38069/en.pdf.

7. *Electrical and Mechanical Carbon and Graphite Products:* Case C.38.359 — Electrical and Mechanical Carbon and Graphite Products, Comm'n Decision (Dec. 3, 2003) *available at* http://ec.europa.eu/competition/antitrust/cases/decisions/38359/en.pdf.

8. *Flat Glass:* Case COMP/39165 — Flat glass, Comm'n Decision (Nov. 28, 2007), *available at* http://ec.europa.eu/competition/antitrust/cases/decisions/39165/en.pdf.

9. *Food Flavor Enhancers:* Case COMP/C.37.671 — Flood Flavour Enhancers, Comm'n Decision 2004 (L 75) 1, *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/ 2004/l_075/l_07520040312en00010031.pdf.

10. *Graphite Electrodes:* Case COMP/E-1/36.490 — Graphite electrodes, Comm'n Decision (July 18, 2001) *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2002/ l_100/l_10020020416en00010042.pdf.

11. *Industrial and Medical Gases:* Case COMP/E-3/36.700 — Industrial and medical gases, Comm'n Decision (July 24, 2002) *available at* http://eur-lex.europa.eu/LexUriSer v/site/en/oj/2003/l_123/l_12320030517en00490050.pdf.

12. *Industrial Tubes:* Case COMP/E-1/38.240 — Industrial Tubes, Comm'n Decision (Dec. 16, 2003) (summary at 2004 O.J. L (125) 50), *available at* http://ec.europa.eu/ competition/antitrust/cases/decisions/38240/en.pdf.

13. *Methionine:* Case C.37.519 — Methionine, Comm'n Decision, 2002 (L 255) 1, *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_255/l_25520031008en000 10032.pdf.

14. *Methyglucamine:* Case COMP/E-2/37.978 — Methylglucamine, Comm'n Decision (Nov. 27, 2002), *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2004/l_ 038/l_03820040210en00180046.pdf.

15. *Organic Peroxides:* Case COMP/E-2/37.857 — Organic Peroxides, Comm'n Decision (Dec. 10, 2003) *available at* http://ec.europa.eu/comm/competition/antitrust/cases/ decisions/37784/en.pdf.

16. *Plasterboard:* Case COMP/E-1/37.152 — Plasterboard, Comm'n Decision (Nov. 27, 2002) *available at* http://ec.europa.eu/comm/competition/antitrust/cases/decisions/ 37152/en.pdf.

17. *Rubber Chemicals:* Case COMP/F/38.443 — Rubber Chemicals, Comm'n Decision (Dec. 21, 2005) (summary at 2006 (L 353) 50), *available at* http://ec.europa.eu/ competition/antitrust/cases/decisions/38443/en.pdf.

18. *Sorbates:* Case COMP/E-1/37.370 — Sorbates, Comm'n Decision (Oct. 1, 2003) *available at* http://ec.europa.eu/competition/antitrust/cases/decisions/37370/en.pdf.

19. *Specialty Graphite (Isostatic):* Case COMP/E-2/37.667 — Specialty Graphite, Comm'n Decision (Dec. 17, 2002) *available at* http://ec.europa.eu/comm/competition/antitrust/ cases/decisions/37667/en.pdf.

20. *Vitamins:* Case COMP/E-1/37.512— Vitamins, Comm'n Decision, 2001 O.J. (L6) 1, *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_006/l_00620030110en00010089.pdf.

21. *Zinc Phosphate:* Case COMP/E-1/37.027 — Zinc phosphate, Comm'n Decision (Dec. 11, 2001) *available at* http://eur-lex.europa.eu/LexUriServ/site/en/oj/2003/l_153/ l_15320030620en00010039.pdf.

A.2 EC decision paragraph references

Table A.2.1: EC decision paragraph references for cartel market shares, large firms joining the cartel, and smaller cartel members having weaker participation incentives

Cartel case	Cartel market share (global unless otherwise noted)	Major players are always inside a cartel	Smaller cartel members have weaker participation incentives
Amino Acids (Lysine)	48-49, 73, 154, 267,	49-51	102, 110, 128, 358-360, 361, 364, 372-374
Butadiene Rubber and ES Butadiene Rubber*	302 (p.8), 307 (p.9), 312 (p.10), 313(p.11)	295 (p.28), 448-454	445, 496-497, fn (31)
Carbonless Paper*	16, 18, fn (22)	327-328	105-106
Choline Chloride	42	71-73	
Citric Acid	45-46, 97-98, 118	78-79	189-195
Copper Plumbing Tubes*	24-25	104-105, 583	597
Electrical and Mechanical Carbon and Graphite Products *	37	192, 194-195, 197-198	
Flat Glass*	41	80	
Food Flavour Enhancers	21, 168, 248-249	168, 259	193-195
Graphite Electrodes	15, 21, 30, 71,	44-46	46
Industrial and Medical Gases**	77-80	101, 107	443-447
Industrial Tubes*	52, 327	78	
Methionine	43-44, 79-81, 298-301, fn (98)	79-81	80, 82, 256
Methylglucamine	7-9	43, 68, 77	
Organic Peroxides	39-47	80, 393-394	415-417, 422
Plasterboard*	24-25, 222-223	2-3, 50	3, 489, 510-512, 565, 570-572
Rubber Chemicals	33	205-206	
Sorbates	64, 211, 339	78-79	
Specialty Graphite (Isostatic)	16-17	106, 485, 490	479-480
Vitamins	10, 27, 123	160, 244, 271, 296, 330, 354, 388, 459, 484, 520	273-274
Zinc Phosphate*	113, 219, 308	65, 102, 207	

* Shares of the EEA market, ** Shares of the Netherlands market

Table A.2.2: Summary of market allocation mechanisms with relevant EC decision paragraph references

Cartel case	Market allocation mechanism	Paragraph numbers
Amino Acids (Lysine)	Combination of geographic allocation and pre-cartel market share allocation	57, 58, 211
Butadiene Rubber and ES Butadiene Rubber	Combination of customer allocation and pre-cartel market share allocation	93-98, 130
Carbonless Paper	Fix pre-cartel market shares	81
Choline Chloride	Combination of customer allocation and pre-cartel market share allocation	34, 64, 99
Citric Acid	Fix average of the last three pre-cartel years' market shares	81
Copper Plumbing Tubes	Fix pre-cartel market shares	137, 210, 350, 444
Electrical and Mechanical Carbon and Graphite Products	Fix pre-cartel market shares	2, 128, 131, 219
Flat Glass	Fix target and minimum prices, no formal market share agreement	317
Food Flavour Enhancers	Combination of geographic allocation and customer allocation	65, 68
Graphite Electrodes	Fix pre-cartel market shares	2, 71, 50, 110
Industrial and Medical Gases	Fix target and minimum prices, no formal market share agreement	101-102
Industrial Tubes	Fix pre-cartel market shares	79, 103-104, 107, 151, 195
Methionine	Fix target prices, no formal market share agreement	70-73, 213-214
Methylglucamine	Combination of customer allocation and market share allocation	43, 46, 98
Organic Peroxides	Fix pre-cartel market shares	85, 107-109, 135, 353
Plasterboard	Share information on sale volumes, no formal market share agreement	104, 429
Rubber Chemicals	Fix pre-cartel market shares	66-67
Sorbates	Fix average of the last four years' market shares	84, 106-116
Specialty Graphite (Isostatic)	Fix pre-cartel market shares	130, 141, 143, 147
Vitamins	Fix pre-cartel market shares	189-190, 245-247, 272, 300-301, 331, 357, 392, 463
Zinc phosphate	Fix average of the last three years' market shares	2, 66-68

Table A.2.3: EC decision paragraph references for cartel concordance

Cartel case	Cartel concordance	Paragraph numbers
Amino Acids (Lysine)	very discordant	66, 69, 73, 77, 87, 89-91, 93, 98, 101-102, 109-110, 118, 134, 143, 145, 340
Carbonless Paper	concordant	105, 106, 202, 212, 257
Choline Chloride	very discordant - very concordant*	64-65, 68, 72-74, 86, 89, 95-96
Citric Acid	discordant	90-91, 116-118, 125-128
Copper Plumbing Tubes	concordant	200, 321, 510
Electrical and Mechanical Carbon and Graphite Products	very concordant	
Flat Glass	concordant	361
Food Flavour Enhancers	discordant	94, 96-98, 102, 109, 114, 118, 121, 231, 237, 239, 277-278
Graphite Electrodes	concordant	106-107, 136-137, 211-215
Industrial and Medical Gases	discordant	127, 175, 443-447
Industrial Tubes	discordant	104-105, 314
Methionine	very concordant	278-279, 289, 325
Methylglucamine	very concordant	148, 177
Organic Peroxides	very concordant	
Plasterboard	discordant	229, 230, 257-262, 264-265,
Rubber Chemicals	discordant	210, 212, 234, 288
Sorbates	very concordant	
Specialty Graphite (Isostatic)	very concordant	
Vitamins	concordant	273-274, 449, 713-714, 727, 732
Zinc Phosphate	discordant	122-124, 144-147, 271, 290-297

*According to our criteria, the global Choline Chloride cartel (1992-1994) was very discordant, but the European cartel (1994-1999) was very concordant.

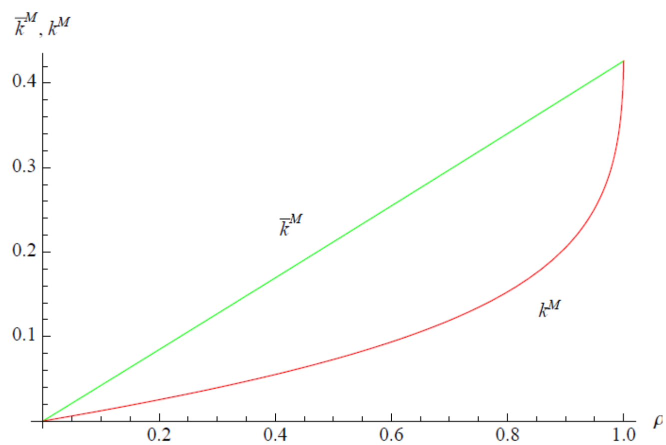
Appendix B

Proofs, review of the US public procurements (Chapter 2)

B.1 Proofs to Chapter 2

Proof of Lemma 2.1. It is clear that $0 < \bar{k}^C, \bar{k}^M < 1 - P_M$. To see that $0 < k^M < 1 - P_M$, note that the left side in (2.2) is obviously continuously increasing in k^M as k^M ranges from zero to $1 - P_M$, and the right side in (2.2) is continuously decreasing in k^M as k^M ranges from zero to $1 - P_M$. At k^M equal to zero, the right side is positive. At k^M equal to $1 - P_M$, the right side is equal to $\frac{(1-G(1-\pi_M))\rho}{(1-G(1-\pi_M))\rho+(1-\rho)}(1-P_M)$, which is less than $1 - P_M$. Thus, k^M is well defined and $k^M \in (0, 1 - P_M)$. A similar argument holds for k^C. The result that for ξ sufficiently close to zero, $\bar{k}^C < k^M$, follows from $\lim_{\xi \to 0} \bar{k}^C = 0$ and $k^M > 0$. The result that $k^M < \bar{k}^M$ for $\rho \in (0, 1)$

follows from a numerical evaluation of the expressions as shown in the figure below.



Similar evaluation shows $k^C < \bar{k}^C$. The inequalities $k^C < k^M$ and $\bar{k}^C < \bar{k}^M$ follow from $\xi \in (0,1)$. Q.E.D.

Proof of Proposition 2.2. We construct an equilibrium characterized by supplier cost thresholds $x^C \equiv 1 - \pi_M$ and $x^{nc}(k) \equiv P_{nc} + k - \pi_{nc}$ as follows. In the high-cost state, both cartel and non-cooperative sellers bid 1. In the low-cost state, cartel firms submit identical bids according to the bid function

$$\beta^C(\min\{x_1, x_2\}) \equiv \begin{cases} 1, & \text{if } x \leq x^C \\ b^*, & \text{otherwise.} \end{cases}$$

where $b^* \in (P_M + k, 1)$. In the low-cost state, non-cooperative firms bid according to the bid function

$$\beta^{nc}(x) = \begin{cases} \tilde{\beta}(x), & \text{if } x \leq x^{nc}(k) \\ b^*, & \text{otherwise,} \end{cases}$$

where $\tilde{\beta}(x) \equiv \frac{1}{2(1-x)}\left(2(P_{nc}+k)(1-x^{nc}(k)) + (x^{nc}(k)^2 - x^2)\right)$, which satisfies $\tilde{\beta}(x^{nc}(k)) = P_{nc} + k$. The buyer accepts the lowest bid if it is less than or equal to $P_{nc} + k$ and accepts one of the bids at random if both bids are equal to 1, but otherwise, the buyer invites S_3 to bid. If the buyer observes at least one bid less than 1, the buyer believes that they are in the low-cost state with probability one. If the buyer observes both bids equal to 1, the buyer believes the firms are in a cartel and that they are in the low-cost state with probability $\frac{G(x^C)\rho\xi}{G(x^C)\rho\xi+1-\rho}$. If the buyer observes at least one bid less than or equal to $P_{nc}+k$, the buyer believes that firms are non-cooperative with probability 1. If the buyer observes that both bids are equal to b^*, then the buyer believes firms are in a cartel with probability $\frac{(1-G(x^C))\xi}{(1-G(x^C))\xi+(1-G(x^{nc}))(1-\xi)}$ and non-cooperative with complimentary probability. For other bid combinations, which are off the equilibrium path, the buyer believes firms are non-cooperative with probability 1.

We now show that this is an equilibrium. The buyer's beliefs are consistent with Bayes' rule given the bid strategies. Given the buyer's beliefs, it is a best reply for the buyer to accept bids less than or equal to $P_{nc}+k$ and reject bids between $P_{nc}+k$ and 1. To see that it is a best reply for the buyer to accept a bid of 1, note that the buyer's expected cost if it rejects a bid of 1 is

$$\frac{G(x^C)\rho\xi}{G(x^C)\rho\xi+1-\rho}P_M+1-\frac{G(x^C)\rho\xi}{G(x^C)\rho\xi+1-\rho}+k=1+k-\bar{k}^C,$$

where the equality uses the definition of $\bar{k}^C$ given in (2.6). This expression is greater than or equal to 1 by the assumption that $k\geq\bar{k}^C$. To see that it is a best reply for the cartel to bid according to β^C, note that when the cartel's cost (the lowest of the two firms' costs) is x, the cartel's payoff from a bid of P_M+k is P_M+k-x, the cartel's payoff from a bid greater than P_M+k but less than 1 is π_M, and the cartel's payoff from a bid of 1 is $1-x$. For $x\leq x^C$, by the assumption that $k\leq 1-P_M$, the cartel weakly prefers to bid 1 rather than P_M+k, and by the definition of x^C, the cartel weakly prefers to bid 1 rather than an amount between P_M+k and 1. Similarly, for $x>x^C$, the cartel prefers to bid an amount such as b^* that leads to S_3 being invited rather than a bid of 1, which would be accepted.[1] To see that non-cooperative firm i with cost $x_i\leq x^{nc}(k)$ cannot profitably deviate by bidding 1, note that given equilibrium behavior by the other non-cooperative firm, bidding 1 results in the object either being awarded to the other bidder (if the other bidder has

[1] To see that it is a best reply for non-cooperative firms to bid according to β^{nc}, note that $\widetilde{\beta}(x)$ is the equilibrium bid function for two bidders when there is a reserve price of $P_{nc}+k$ and expected payoff of π_{nc} to each if both bids are above the reserve price. In a standard IPV procurement with a reserve price R, a bidder with cost draw $x_i=R$ bids R and therefore if $x_i\leq R$ the optimal bid $\beta(x_i)=R\frac{1-F(R)}{1-F(x_i)}-\frac{1}{1-F(x_i)}\int_{x_i}^{R}s\ d(1-F(s))$. However in the present case, a noncooperative bidder with cost draw $x_i>x^{nc}(k)$ will bid the "reserve price" $P_{nc}+k$, and therefore for $x_i\leq x^{nc}(k)$, $\widetilde{\beta}(x_i)=(P_{nc}+k)\frac{1-F(P_{nc}+k)}{1-F(x_i)}-\frac{1}{1-F(x_i)}\int_{x_i}^{x^{nc}(k)}s\ d(1-F(s))$. Now using our distributional assumption $F(s)=s$, we obtain the desired expression.

$x \leq x^{nc}(k)$) or S_3 being invited to bid (if the other bidder has $x > x^{nc}(k)$), which weakly decreases the firm's expected payoff relative to following the equilibrium strategy. Q.E.D.

Proof of Proposition 2.4. First consider the case of a cartel. We first prove two lemmas.

Lemma B.1 *Assume $k \leq k^C$. In Stage* 1*, if S_1 and S_2 have formed a cartel, then an equilibrium is as follows: In the high-cost state the firms bid* 1*, and in the low-cost state the firms submit identical bids according to the bid function*

$$\beta^*(\min\{x_1, x_2\}) \equiv \begin{cases} P_M + k, & \text{if } \min\{x_1, x_2\} \leq x^M(k) \\ 1, & \text{otherwise,} \end{cases}$$

where $x^M(k) \equiv P_M + k - \pi_M$. Non-cooperative bidders bid according to β^{nc} defined in the proof of Proposition 2.2*. The buyer accepts one of the bids if both bids are equal to $P_M + k$ and accepts the low bid if at least one bid is less than or equal to $P_{nc} + k$, but otherwise, the buyer invites S_3 to bid. If the buyer observes a bid less than* 1*, the buyer believes that they are in the low-cost state with probability one. If the buyer observes a bid less than or equal to $P_{nc} + k$, the buyer believes it is facing non-cooperative bidders with probability one. If the buyer observes both bids equal to* 1*, the buyer believes they are in the low-cost state with probability $\frac{(1-G(x^M(k)))\rho\xi}{(1-G(x^M(k)))\rho\xi+(1-\rho)}$.*

Proof of Lemma B.1. The buyer's beliefs are consistent with Bayes' rule given the bid strategy. Given the buyer's beliefs, it is a best reply for the buyer to accept one of the bids if both are equal to $P_M + k$ and reject bids between $P_M + k$ and 1. It is a best reply for the buyer to accept the lowest bid if it is less than or equal to $P_{nc} + k$. To see that it is a best reply for the buyer to reject a bid of 1, note that the buyer's expected cost if it rejects a bid of 1 is

$$\frac{(1 - G(x^M(k)))\rho\xi}{(1 - G(x^M(k)))\rho\xi + (1 - \rho)} P_M + 1 - \frac{(1 - G(x^M(k)))\rho\xi}{(1 - G(x^M(k)))\rho\xi + (1 - \rho)} + k = 1 + k - k^C,$$

where the equality uses the definition of k^C given in (2.5). This amount is less than 1 by the assumption that $k < k^C$. To see that it is a best reply for the cartel firms to bid according to β^*, note that when the cartel's cost is x, the cartel's payoff from a bid of P_M+k is P_M+k-x, and the cartel's payoff from a bid greater than P_M+k is π_M. By the definition of $x^M(k)$, for costs less than or equal to $x^M(k)$, it is a best reply for the cartel to bid P_M+k and for costs greater than $x^M(k)$, it is a best reply for the cartel firms to bid 1. Q.E.D.

Lemma B.2 *Assume $k^C < k < \bar{k}^C$. In Stage 1, if S_1 and S_2 have formed a cartel, then an equilibrium is as follows: In the high-cost state the firms bid 1, and in the low-cost state the firms submit identical bids according to the bid function*

$$\beta^{**}(\min\{x_1,x_2\}) \equiv \begin{cases} P_M+k, & \text{if } x \le x^C(k) \\ 1, & \text{if } x^C(k) < x \le 1-\pi_M \\ b^*, & \text{otherwise,} \end{cases}$$

where $b^* \in (P_M+k, 1)$ and $x^C(k) \equiv \frac{P_M+k-\alpha(k)}{1-\alpha(k)} - \pi_M$, where $\alpha(k)$ is implicitly defined by

$$k = \frac{\left(G(1-\pi_M) - G\left(\frac{P_M+k-\alpha(k)}{1-\alpha(k)} - \pi_M\right)\right)\rho\xi}{\left(G(1-\pi_M) - G\left(\frac{P_M+k-\alpha(k)}{1-\alpha(k)} - \pi_M\right)\right)\rho\xi + (1-\rho)}(1-P_M). \tag{B.1}$$

Non-cooperative bidders bid according to β^{nc} defined in the proof of Proposition 2.2. The buyer accepts one of the bids if both bids are equal to P_M+k, or, the low bid if at least one bid is less than or equal to $P_{nc}+k$. The buyer rejects the bids and invites S_3 if the bids are greater than P_M+k but less than 1. If the bids are equal to 1, the buyer accepts the bid with probability $\alpha(k)$ and invites S_3 to bid with probability $1-\alpha(k)$. If the buyer observes a bid less than 1, the buyer believes that they are in the low-cost state with probability one. If the buyer observes a bid less than or equal to $P_{nc}+k$, the buyer believes it is facing non-cooperative bidders with probability one. If the buyer observes both bids equal to 1, the buyer believes they are in the low-cost state with probability $\frac{(G(1-\pi_M)-G(x^C(k)))\rho\xi}{(G(1-\pi_M)-G(x^C(k)))\rho\xi+(1-\rho)}$.

Proof of Lemma B.2. First note that given $k \in (k^C, \bar{k}^C)$, $\alpha(k) \in (0,1)$ and $x^C(k) < 1-\pi_M$. The buyer's beliefs are derived from Bayes' rule given the bid strategy. Given the buyer's beliefs, it is a best reply for the buyer to accept one of the bids if both are equal to P_M+k, accept the lowest bid if it is less than or equal to $P_{nc}+k$, and reject bids between $P_M + k$ and 1. To see that it is a best reply for the buyer to randomize when it receives a bid of 1, note that the buyer's expected cost if it rejects a bid of 1 is

$$\frac{(G(1-\pi_M)-G(x^C(k)))\rho\xi}{(G(1-\pi_M)-G(x^C(k)))\rho\xi+(1-\rho)}P_M+1-\frac{(G(1-\pi_M)-G(x^C(k)))\rho\xi}{(G(1-\pi_M)-G(x^C(k)))\rho\xi+(1-\rho)}+k$$

which is equal to 1 by the definition of $\alpha(k)$. To see that it is a best reply for the cartel to bid according to β^{**}, note that when the cartel's cost is x, the cartel's payoff from a bid of $P_M + k$ is $P_M + k - x$, the cartel's payoff from a bid greater than $P_M + k$ but less than 1 is π_M, and the cartel's payoff from a bid of 1 is $\alpha(k)(1-x) + (1-\alpha(k))\pi_M$. For costs less than or equal to $x^C(k)$, it is a best reply for the cartel to bid $P_M + k$. For costs less than or equal to $1-\pi_M$ but greater than $x^C(k)$, it is a best reply for the cartel to bid 1, and for costs greater than $1-\pi_M$, it is a best reply for the cartel to bid b^*. Q.E.D.

Continuation of the Proof of Proposition 2.4. Combining Lemmas B.1 and B.2, there exist equilibria in which a cartel with cost draws x_1 and x_2 has expected payoff $\max\{P_M + k - \min\{x_1, x_2\}, \pi_M\}$ when $k \leq k^C$ and greater than or equal to $\max\{P_M + k - \min\{x_1, x_2\}, \pi_M\}$ when $k \in (k^C, \bar{k}^C)$. From Proposition 2.2, we have the result that for $k \geq \bar{k}^C$, the cartel's expected payoff is $\max\{1 - \min\{x_1, x_2\}, \pi_M\}$.

The characterization of equilibria for the merged entity is analogous, with the merged entity having expected payoff of $\max\{P_M + k - \min\{x_1, x_2\}, \pi_M\}$ when $k \leq k^M$, payoff greater than or equal to $\max\{P_M + k - \min\{x_1, x_2\}, \pi_M\}$ when $k \in (k^M, \bar{k}^M)$, and payoff $\max\{1 - \min\{x_1, x_2\}, \pi_M\}$ when $k \geq \bar{k}^M$. Note that for $k \in (k^M, \bar{k}^M)$ the mixing probability in the merger equilibrium is implicitly defined as in (B.1), but with $\xi = 1$, which implies that for a given k, in the merger equilibrium, the buyer accepts a bid of 1 with lower probability than in the no-merger equilibrium. Thus, for parameters such that there is mixing for both a cartel and merged entity, the cartel's expected payoff is greater. Q.E.D.

B.2 Bid rejections and re-bidding in practice

In this appendix, we review public procurements conducted by U.S. cities and towns. 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 B.1, 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.[2]

[2] 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.

Table B.1: Bid rejections and re-bidding[3]

City	Project	Industry	Number of Bidders	Date	Reason for Rejection
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	Ortho Poly Phosphate Blend Delivery	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	6.3.09	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

[3] We refer to the procurements by the name of the city. The full citations are provided at the end of this appendix.

Table B.1: continued

City	Project	Industry	Number of Bidders	Date	Reason for Rejection
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	Fueling	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	Fire Apparatus Manufacturers	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.

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 re-bidding.

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.[4]

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 expectation that additional bids will be received through a future rebid, thereby, reducing the cost of this item."[5] Lacey identified the possibility of seeking more competitive bids as a key reason for re-bidding its contract.[6]

In many of the examples listed in Table B.1, 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."[7] 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."[8] San Rafael rejected all bids because "the lowest bid of $161,232.50 is $36,232.50 more than the Engineer's Estimate."[9] Villa Park rejected all bids due to the high cost of the lowest bid, which was above the engineer's estimate.[10] Woodinville rejected all bids because "the low bid amount for this project exceeded the engineer's estimate by approximately 30%."[11]

In other examples, the stated reason for rejection includes the low bid being above the approved budget for the project.[12]

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

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

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 re-bidding.

References for Appendix B.2

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2. *Belmont-2:* Staff Report to Honorable Mayor and Council Members (September 14, 2004), *available at* http://www.belmont.gov/Upload/Document/D240001279/4H-CC09142004.pdf.

3. *Clinton:* City Council Special Meeting (February 16, 2010), *available at* http://www.cityofclintonnc.com/departments/clerk/board_minutes/2010/02-16-10.pdf.

4. *Des Moines:* Agenda Item Number 45 (October 11, 2010), *available at* http://www.dmgov.org/government/CityCouncil/Resolutions/20101011/45.pdf.

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10. *Piedmont:* City Council Staff Report (July 19, 2004), *available at* http://www.ci.piedmont.ca.us/html/govern/staffreports/7_19_04/dracena.pdf.

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13. *San Rafael:* San Rafael City Council Agenda Report (August 2, 2010), *available at* http://www.cityofsanrafael.org/ccfiles/Meeting%20Reports/2010/08-02-10/City% 20Council/Staff%20Rpts/PW_Santa%20Margarita%20Project %20Reject%20bids.pdf.

14. *Shasta Lake:* Report and Recommendations to City Manager (September 8, 2010), *available at* http://www.ci.shasta-lake.ca.us/Agenda%20Packets/2010/ 09.21.10/7.2.pdf.

15. *Silver City:* Regular Council Meeting (November 10, 2009), *available at* http:// www.townofsilvercity.org/r/legal_notes/2009%2011%2010%20Minutes% 20Regular%20Council.pdf.

16. *Suisun City:* Regular Council Meeting (September 7, 2010), *available at* http://www. suisun.com/Data/CC-RDA/2010/20100907/Item9.pdf.

17. *Tracy:* Agenda Item 1.F (August 5, 2008), *available at* http://www.ci.tracy. ca.us/uploads/fckeditor/File/city_council/agendas/2008/08/05/01f.pdf

18. *Villa Park:* City Council Meeting (december 16, 2008), *available at* http:// www.villapark.org/Agendas-Minutes/2008/121608/16.PDF.

19. *Woodinville:* Resolution No. 299 (June 13, 2005), *available at* http://www. ci.woodinville.wa.us/Documents/CityHall/Resolutions/Resolution%20299.pdf.

20. *Woodinville-2:* Resolution No. 202 (July 2, 2001), *available at* http://www.ci. woodinville.wa.us/Documents/CityHall/Resolutions/Resolution%20202.pdf.

Appendix C

Proofs and numerical examples (Chapter 3)

C.1 Proofs to Chapter 3

Proof of Proposition 3.1. We first prove the following two lemmas.

Lemma C.1 *Suppose it is a common knowledge that $\widehat{\theta}$ is completely informative, i.e. $\widehat{\theta} = \theta$. In equilibrium each noncooperative bidder i bids according to the following bid function*

$$\beta^1_{nc}(\theta, \sigma_i)^* = \begin{cases} \widetilde{\beta}^1_{nc}(\theta, \sigma_i), & \textit{if} \;\; c_i \leq \widetilde{c}(\theta) \\ \theta + \overline{\sigma}\,, & \textit{if} \;\; c_i > \widetilde{c}(\theta) \end{cases}$$

and

$$\beta^2_{nc}(\theta, \sigma_i)^* = \begin{cases} \widetilde{\beta}^2_{nc}(\theta, \sigma_i), & \textit{if} \;\; c_i \leq R^2_{nc}(\theta)^* \\ \theta + \overline{\sigma}, & \textit{if} \;\; c_i > R^2_{nc}(\theta)^* \end{cases}$$

where $\widetilde{c}(\theta) = R^1_{nc}(\theta)^* - \pi^2_{nc}(\theta)$

Proof of Lemma C.1. To see that it is a best response for noncooperative bidders to bid according to $\beta^1_{nc}(\theta, \sigma_i)^*$ and $\beta^2_{nc}(\theta, \sigma_i)^*$, note that the second round is a standard IPV first price procurement with two bidders and a reserve price $R^2_{nc}(\theta)^*$. Therefore, if $c_i \leq R^2_{nc}(\theta)^*$, the optimal bid is given by $\widetilde{\beta}^2_{nc}(\theta, \sigma_i) = \frac{R^2_{nc}(\theta)^*[1-F_\theta(R^2_{nc}(\theta)^*)]}{1-F_\theta(\sigma_i)} + \frac{1}{1-F_\theta(\sigma_i)} \int\limits_{\sigma_i}^{R^2_{nc}(\theta)^*} u dF_\theta(u)$. Since the buyer knows θ, he does not suspend the procurement, so the second round payoffs are not discounted. In the first round, a noncooperative bidder with the cost draw equal to $\widetilde{c}(\theta)$ bids the first round reserve price $R^1_{nc}(\theta)^*$, as he is indifferent between winning the first round at the reserve price and waiting for the second round. Therefore, if $c_i \leq \widetilde{c}(\theta)$, the optimal bid is given by $\widetilde{\beta}^1_{nc}(\theta,\sigma_i) = \frac{R^1_{nc}(\theta)^*[1-F_\theta(R^1_{nc}(\theta)^*)]}{1-F_\theta(\sigma_i)} + \frac{1}{1-F_\theta(\sigma_i)}\int\limits_{\sigma_i}^{\widetilde{c}(\theta)} u dF_\theta(u)$. If $c_i > \widetilde{c}(\theta)$, bidder i prefers to wait for the second round, i.e. the optimal bid is above the reserve price (the upper support). The optimal reserve price in each round is the standard reserve price as in Myerson (1981). *Q. E. D.*

Lemma C.2 *Suppose $\widehat{\theta}$ is noisy. If the buyer follows a revealing policy, then the following is PBNE : In the first round the buyer commits to the award rule*

$$R^P_1(\widehat{\theta}, b^1_1, b^1_2) = \begin{cases} R^1_{nc}(\theta_l)^*, & \text{if } \min\{b^1_1, b^1_2\} \leq \theta_l + \overline{\sigma} \\ R^1_{nc}(\theta_h)^*, & \text{if } \min\{b^1_1, b^1_2\} \geq \theta_h + \underline{\sigma} \end{cases}$$

In the first round each noncooperative bidder bids according to the bid function $\beta^1_{nc}(\theta,\sigma_i)^*$ defined in Lemma C.1. If the buyer observes at least one bid less than $\theta_l + \overline{\sigma}$ in the first round, the buyer believes that θ is equal to θ_l with probability one. If the buyer observes both bids greater than $\theta_h + \underline{\sigma}$ in the first round, the buyer believes that θ is equal to θ_h with probability one. If the buyer observes at least one bid less than $\theta_l + \overline{\sigma}$ in the first round, then in the second round he commits to the award rule

$$R_2(b^2_1, b^2_2) = R^2_{nc}(\theta_l)^* \text{ for all } \{b^2_1, b^2_2\}$$

and if the buyer observes both bids greater than $\theta_h + \underline{\sigma}$ in the first round, then in the second round he commits to the award rule

$$R_2(b^2_1, b^2_2) = R^2_{nc}(\theta_h)^* \text{ for all } \{b^2_1, b^2_2\}$$

In the second round each noncooperative bidder bids according to the bid function $\beta^2_{nc}(\theta,\sigma_i)^*$ defined in Lemma C.1.

Proof of Lemma C.2. The buyer's beliefs are consistent with the Bayes' rule given the bid strategies. To see that it is a best reply for a noncooperative bidder i to bid according to the bid functions $\beta^1_{nc}(\theta,\sigma_i)^*$ and $\beta^2_{nc}(\theta,\sigma_i)^*$, note that if $\theta = \theta_l$, in the first round bidder $-i$ bids according to the bid function $\beta^1_{nc}(\theta_l,\sigma_{-i})^*$ which is bounded above by $\theta_l + \overline{\sigma}$. Since bidder $-i$ always bids below $\theta_l + \overline{\sigma}$ in the first round, the buyer rejects the lowest first round bid if it is greater than $R^1_{nc}(\theta_l)^*$ and announces the reserve price equal to $R^2_{nc}(\theta_l)^*$ in the second round. Then, by the definition of $\widetilde{\beta}^2_{nc}(\theta_l, \sigma_i)$, for the costs less than or equal to $R^2_{nc}(\theta_l)^*$, it is a best reply for bidder i to bid $\widetilde{\beta}^2_{nc}(\theta_l, \sigma_i)$ in the second round and for costs greater than $R^2_{nc}(\theta_l)^*$, it is a best reply to bid $\theta_l + \overline{\sigma}$. In the first round, by the definition of $\widetilde{\beta}^1_{nc}(\theta_l, \sigma_i)$, for the costs less than equal to $R^1_{nc}(\theta_l)^* - \pi^2_{nc}(\theta_l)$ it is a best reply for bidder i to bid $\widetilde{\beta}^1_{nc}(\theta_l, \sigma_i)$ and for costs greater than $R^1_{nc}(\theta_l)^* - \pi^2_{nc}(\theta_l)$, it is a best reply to bid $\theta_l + \overline{\sigma}$.

If $\theta = \theta_h$, in the first round bidder $-i$ bids according to the bid function $\beta^1_{nc}(\theta_h, \sigma_{-i})^*$ which is bounded below by $\theta_h + \underline{\sigma}$. If bidder i bids less than $R^1_{nc}(\theta_l)^*$, then the buyer accepts i's bid and i gets a negative payoff. Bidder i's payoff from a bid greater than $R^1_{nc}(\theta_l)^*$, but less than $\theta_l + \overline{\sigma}$ is equal to zero as the buyer rejects both first period bids and announces a reserve price equal to $R^2_{nc}(\theta_l)^*$ in the second round. If bidder i bids above $\theta_h + \underline{\sigma}$, the buyer rejects the lowest first round bid if it is greater than $R^1_{nc}(\theta_h)^*$ and announces the reserve price equal to $R^2_{nc}(\theta_h)^*$ in the second round. Then, by the definition of $\widetilde{\beta}^2_{nc}(\theta_h, \sigma_i)$, for costs less than or equal to $R^2_{nc}(\theta_h)^*$, it is a best reply for bidder i to bid $\widetilde{\beta}^2_{nc}(\theta_h, \sigma_i)$ in the second round, and for costs greater than $R^2_{nc}(\theta_h)^*$ it is a best reply to bid $\theta_h + \overline{\sigma}$. In the first round, by the definition of $\widetilde{\beta}^1_{nc}(\theta_h, \sigma_i)$, for the costs less than or equal to $R^1_{nc}(\theta_h)^* - \pi^2_{nc}(\theta_h)$ it is a best reply for bidder i to bid $\widetilde{\beta}^1_{nc}(\theta_h, \sigma_i)$ and for costs greater than $R^1_{nc}(\theta_h)^* - \pi^2_{nc}(\theta_h)$, it is a best reply to bid $\theta_h + \overline{\sigma}$. It follows then from the definition of $\beta^1_{nc}(\theta, \sigma_i)^*$ and $\beta^2_{nc}(\theta, \sigma_i)^*$ that it is a best reply for bidder i to bid according to the bid functions $\beta^1_{nc}(\theta, \sigma_i)^*$ and $\beta^2_{nc}(\theta, \sigma_i)^*$.

Given the buyer's beliefs, by the definition of $R^2_{nc}(\theta)^*$, it is a best reply for the buyer to set the second round reserve price equal to $R^2_{nc}(\theta_l)^*$ if the lowest first round bid is less than $\theta_l + \overline{\sigma}$ and set the second round reserve price equal to $R^2_{nc}(\theta_h)^*$ if the lowest first round bid is greater than $\theta_h + \underline{\sigma}$.

To show that it is indeed optimal for the buyer to commit to the first round award rule as defined in Lemma C.2, note that the buyer's ex ante expected payoff is $p_l U^1_{nc}(\theta_l)^* + p_h U^1_{nc}(\theta_h)^*$. The buyer can not get a higher payoff by choosing any other award rule $R^P_1(\widehat{\theta}, b^1_1, b^1_2)^{/}$, as the optimal reserve price is $R^1_c(\theta_l)^*$, conditional on $\theta = \theta_l$ and the optimal reserve price is $R^1_c(\theta_h)^*$, conditional on $\theta = \theta_h$.

With exactly the same logic we can argue that the reserve price and noncooperative bid functions defined in Lemma C.2 are mutual best responses when the buyer follows a concealing policy as well. In equilibrium the buyer adopts the award rule that does not depend on the value of $\widehat{\theta}$, so the disclosure policy of the buyer's signal does not affect the noncooperative bid functions. *Q. E. D.*

Continuation of the Proof of Proposition 3.1. Proposition 3.1 follows then by combining Lemmas C.1 and C.2. *Q.E.D.*

Proof of Proposition 3.2. We first prove the following two lemmas.

Lemma C.3 *Suppose it is a common knowledge that $\widehat{\theta}$ is completely informative, i.e. $\widehat{\theta} = \theta$. In equilibrium the buyer adopts a constant award rule $R_1^P(\widehat{\theta}, b_1^1, b_2^1) = R_c^1(\theta)^*$ in the first round, and a constant award rule $R_2(b_1^2, b_2^2) = R_c^2(\theta)^*$ in the second round. The cartel bids according to the following bid functions*

$$\beta_c^1(\theta, \sigma_m)^* = \begin{cases} R_c^1(\theta)^*, \text{ if } c_m \leq R_c^1(\theta)^* - \pi_c^2(\theta) \\ \theta + \overline{\sigma}, \text{ if } c_m > R_c^1(\theta)^* - \pi_c^2(\theta) \end{cases}$$

$$\beta_c^2(\theta, \sigma_m)^* = \begin{cases} R_c^2(\theta)^*, \text{ if } c_m \leq R_c^2(\theta)^* \\ \theta + \overline{\sigma}, \text{ if } c_m > R_c^2(\theta)^* \end{cases}$$

Proof of Lemma C.3. Note that when θ is a common knowledge, the second round is a standard IPV first price procurement with one bidder. Therefore, the optimal award rule in the second round is a constant reserve price (that does not depend on bids).

Given θ, let $R_c^2(\theta)^*$ be the optimal second round reserve price. Then, for the costs less than $R_c^2(\theta)^*$, it is a best reply for the cartel to bid the reserve price and for the costs greater than $R_c^2(\theta)^*$, it is a best reply to bid above the reserve price.

$R_c^2(\theta)^*$is given by

$$R_c^2(\theta)^* = \arg\max_R \{(v_B - R)\, G_\theta(R)\}$$

By assumption, $G_\theta(R)$ has a decreasing reverse hazard rate, so $R_c^2(\theta)^*$ is unique and $R_c^2(\theta)^* \in [\theta + \underline{\sigma}, \theta + \overline{\sigma}]$.

Let $U_c^2(\theta)^*$ and $\pi_c^2(\theta)$ be the maximum ex ante expected second round payoffs to the buyer and to the cartel.

$$U_c^2(\theta)^* \equiv (v_B - R_c^2(\theta)^*)G_\theta(R_c^2(\theta)^*)$$

$$\pi_c^2(\theta) \equiv E_{\sigma_m}\left[R_c^2(\theta)^* - (\theta + \sigma_m)\right]$$

The first round is also a standard first price procurement with only one bidder where the buyer has an outside option equal to $U_c^2(\theta)^*$ and the cartel has an outside option equal to $\pi_c^2(\theta)$. Therefore, the optimal award rule in the first round is a constant reserve price (that does not depend on bids). Let $R_c^1(\theta)^*$be the optimal first round reserve price. Then, in the first round, the cartel's payoff from a bid equal to the reserve price is $R_c^1(\theta)^* - c_m$ and the cartel's payoff from a bid greater than the reserve price is $\pi_c^2(\theta)$. So, for the costs less than $R_c^1(\theta)^* - \pi_c^2(\theta)$, it is a best reply for the cartel to bid $R_c^1(\theta)^*$ and for the costs greater than $R_c^1(\theta)^* - \pi_c^2(\theta)$, it is a best reply for the cartel to bid $\theta + \overline{\sigma}$.

$R_c^1(\theta_l)^*$ and $R_c^1(\theta_h)^*$ are given by

$$R_c^1(\theta_l)^* \in \arg\max_R \Psi_l(R)$$

$$R_c^1(\theta_h)^* \in \arg\max_R \Psi_h(R)$$

where

$$\Psi_l(R) = (v_B - R)G_l(R - \pi_c^2(\theta_l)) + U_c^2(\theta_l)^*(1 - G_l(R - \pi_c^2(\theta_l)))$$

$$\Psi_h(R) = (v_B - R)G_h(R - \delta\pi_c^2(\theta)) + \delta U_c^2(\theta_h)^*\left(1 - G_h(R - \delta\pi_c^2(\theta_h))\right)$$

By assumption, $G_\theta(R)$ has a decreasing reverse hazard rate, so $R_c^1(\theta_l)^*$ is unique and

$R_c^1(\theta_l)^* \in [\theta_l + \underline{\sigma} + \pi_c^2(\theta_l), \theta_l + \overline{\sigma}]$ and $R_c^1(\theta_h)^*$ is unique and $R_c^1(\theta_h)^* \in [\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h), \theta_h + \overline{\sigma}]$.

Q.E.D.

Let $U_c^2(\theta_l)^*$ and $U_c^2(\theta_h)^*$ be the maximum ex ante expected first round payoffs to the buyer, when $\theta = \theta_l$ and $\theta = \theta_h$, respectively.

$$U_c^1(\theta_l)^* \equiv (v_B - R_c^1(\theta_l)^*)G_l(R_c^1(\theta_l)^* - \pi_c^2(\theta_l)) + U_c^2(\theta_l)^*\left(1 - G_l(R_c^1(\theta_l)^* - \pi_c^2(\theta_l))\right)$$

$$U_c^1(\theta_h)^* \equiv (v_B - R_c^1(\theta_h)^*)G_h(R_c^1(\theta_h)^* - \delta\pi_c^2(\theta_h)) + \delta U_c^2(\theta_h)^* \left(1 - G_h(R_c^1(\theta_h)^* - \delta\pi_c^2(\theta_h))\right)$$

Q.E.D.

Lemma C.4 *Suppose $\widehat{\theta}$ is noisy. If the buyer follows a revealing policy, then in every PBNE, there exists $\widetilde{p} \in (0,1)$ such that in the first round the buyer adopts the following award rule: if $p_{l,\widehat{\theta}} \geq \widetilde{p}$,*

$$R_1^P(\widehat{\theta}, b_c^1) = R_c^1(\theta_l)^*, \text{ for all } b_c^1$$

and if $p_{l,\widehat{\theta}} < \widetilde{p}$,

$$R_1^P(\widehat{\theta}, b_c^1) = \begin{cases} R_c^1(\theta_l)^*, & \text{If } b_c^1 \leq \theta_l + \overline{\sigma} \\ r(p_{l,\widehat{\theta}}), & \text{If } b_c^1 > \theta_l + \overline{\sigma} \end{cases}$$

where $r(\cdot) : [0,1] \to (\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h),\ R_c^1(\theta_h)^*\ ]$. If $\theta = \theta_l$ and the buyer reveals $\widehat{\theta}$ such that $p_{l,\widehat{\theta}} \geq \widetilde{p}$, the cartel bids according to the bid function

$$\beta_c^{1,P}(\theta_l, \sigma_m) = \begin{cases} R_c^1(\theta_l)^*, \text{ if } c_m \leq R_c^1(\theta_l)^* - \pi_c^2(\theta_l) \\ \theta_l + \overline{\sigma}, \text{ if } c_m > R_c^1(\theta_l)^* - \pi_c^2(\theta) \end{cases}$$

If $\theta = \theta_l$ and the buyer reveals $\widehat{\theta}$ such that $p_{l,\widehat{\theta}} < \widetilde{p}$, the cartel bids according to the bid function

$$\beta_c^{1,P}(\theta_l, \sigma_m) = \begin{cases} r(p_{l,\widehat{\theta}}), \text{ if } c_m \leq r(p_{l,\widehat{\theta}}) - \pi_c^2(\theta_l) \\ \theta_l + \overline{\sigma}, \text{ if } c_m > r(p_{l,\widehat{\theta}}) - \pi_c^2(\theta) \end{cases}$$

If $\theta = \theta_h$ and the buyer reveals $\widehat{\theta}$ such that $p_{l,\widehat{\theta}} \geq \widetilde{p}$, the cartel bids $\theta_h + \overline{\sigma}$. If $\theta = \theta_h$ and the buyer reveals $\widehat{\theta}$ such that $p_{l,\widehat{\theta}} < \widetilde{p}$, the cartel bids according to the bid function

$$\beta_c^{1,P}(\theta_h, \sigma_m) = \begin{cases} r(p_{l,\widehat{\theta}}), \text{ if } c_m \leq r(p_{l,\widehat{\theta}}) - \delta\pi_c^2(\theta_h) \\ \theta_h + \overline{\sigma}, \text{ if } c_m > r(p_{l,\widehat{\theta}}) - \delta\pi_c^2(\theta_h) \end{cases}$$

If in the first round the cartel bid is less than or equal to $\theta_l + \overline{\sigma}$, the buyer believes that $\theta = \theta_l$ with probability one. If the first round bid is less than or equal to $\theta_l + \overline{\sigma}$ and is rejected by the buyer, the buyer holds the second round of bidding immediately *after the first round. If in the first round the cartel bid is greater than $\theta_h + \underline{\sigma}$ and is rejected by the buyer, the buyer suspends the procurement and draws an accurate signal $\widehat{\theta}^{acc}$. In the second round, the buyer announces the award rule*

$$R_2(b_c^1) = R_c^2(\theta)^* \text{ for all } b_c^1$$

when $\widehat{\theta}^{acc} = \theta$. The cartel bids according to the following bid function

$$\beta_c^2(\theta, \sigma_m) = \begin{cases} R_c^2(\theta)^*, \text{ if } c_m \leq R_c^2(\theta)^* \\ \theta + \overline{\sigma}, \text{ if } c_m > R_c^2(\theta)^* \end{cases}$$

Proof of Lemma C.4. If the second round is reached, B learns θ with certainty. (Either because the procurement was suspended and B obtained a completely informative signal, or because the first round bid was less than $\theta_l + \overline{\sigma}$, which reveals to the buyer that $\theta = \theta_l$, because in any equilibrium involving non-weakly dominated strategies, the cartel does not bid above $\theta_h + \underline{\sigma}$ when $\theta = \theta_h$). Therefore, the second round is a standard first-price procurement with only one bidder. Then, by the definition of $R_c^2(\theta_l)^*$ and $R_c^2(\theta_h)^*$, it is a best response for the buyer to set the second round reserve price equal to $R_c^2(\theta_l)^*$ if $\theta = \theta_l$ and set the reserve equal to $R_c^2(\theta_h)^*$ if $\theta = \theta_h$, respectively. The ex ante expected second round payoffs to the buyer are given by $U_c^2(\theta_l)^*$ and $U_c^2(\theta_h)^*$ and to the cartel - by $\pi_c^2(\theta_l)$ and $\pi_c^2(\theta_h)$.

Let $R_c^{1,P}(\widehat{\theta})$ denote the maximum price that the buyer accepts in the first round when he observes a signal $\widehat{\theta}$, i.e. $R_c^{1,P}(\widehat{\theta}) \equiv \max_{b_c^1}\{R_c^{1,P}(\widehat{\theta}, b_c^1)\}$.

Given $R_c^{1,P}(\widehat{\theta})$, the cartel's expected payoff from submitting a bid equal to $R_c^{1,P}(\widehat{\theta})$[1] is $R_c^{1,P}(\widehat{\theta}) - c_m$. If $\theta = \theta_l$, the cartel's payoff from submitting a bid greater than $R_c^{1,P}(\widehat{\theta})$ and less than $\theta_l + \overline{\sigma}$ is $\pi_c^2(\theta_l)$. If $\theta = \theta_h$,the cartel's payoff from submitting a bid greater than $R_c^{1,P}(\widehat{\theta})$ and less than $\theta_l + \overline{\sigma}$ is zero (because the buyer rejects the bid and chooses the reserve price equal to $R_c^2(\theta_l)^*$ in the second round). If $\theta = \theta_l$, the cartel's payoff from submitting a bid greater than $\max\{R_c^{1,P}(\widehat{\theta}), \theta_h + \underline{\sigma}\}$ is $\delta\pi_c^2(\theta_l)$. If $\theta = \theta_h$, the cartel's payoff from submitting a bid greater than $\max\{R_c^{1,P}(\widehat{\theta}), \theta_h + \underline{\sigma}\}$ is $\delta\pi_c^2(\theta_h)$ (because the buyer must suspend the procurement and draw a completely informative signal when the first round bid is greater than $\max\{R_c^{1,P}(\widehat{\theta}), \theta_h + \underline{\sigma}\}$).

[1] Clearly, the cartel does not bid below $R_c^{1,P}(\widehat{\theta})$ in equilibrium.

Thus, if $\theta = \theta_l,$ it is a best reply for the cartel to bid in the first round according to the bid function

$$\beta_c^{1,P}(\theta_l, \sigma_m) = \begin{cases} R_c^{1,P}(\widehat{\theta}), \text{ if } c_m \leq R_c^{1,P}(\widehat{\theta}) - \pi_c^2(\theta_l) \\ \theta_l + \overline{\sigma}, \text{ if } c_m > R_c^{1,P}(\widehat{\theta}) - \pi_c^2(\theta) \end{cases}$$

That is, when $\theta = \theta_l,$ the cartel bids either the maximum price that the buyer accepts $R_c^{1,P}(\widehat{\theta})$, or submits a bid less than or equal to $\theta_l + \overline{\sigma}$ to avoid the delay before the second round.

If $\theta = \theta_h,$ for all costs $c_m,$ it is a best reply for the cartel to bid $\theta_h + \overline{\sigma}$ if $R_c^{1,P}(\widehat{\theta})$ is less than $\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)$. If $R_c^{1,P}(\widehat{\theta})$ is greater than $\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)$, it is a best reply for the cartel to bid according to the bid function

$$\beta_c^{1,P}(\theta_h, \sigma_m) = \begin{cases} R_c^{1,P}(\widehat{\theta}), \text{ if } c_m \leq R_c^{1,P}(\widehat{\theta}) - \delta\pi_c^2(\theta_h) \\ \theta_h + \overline{\sigma}, \text{ if } c_m > R_c^{1,P}(\widehat{\theta}) - \delta\pi_c^2(\theta_h) \end{cases}$$

Given the cartel's equilibrium bid function, the buyer's belief that $\theta = \theta_l$ with probability one when the first round bid is less than or equal to $\theta_l + \overline{\sigma}$ is consistent with the Bayes' rule.

To determine the optimal first round award rule, note that, given the cartel's equilibrium bid function, the buyer's ex ante expected payoff in the first round is given by

$$p_{l,\widehat{l}} \left[\begin{array}{c} \left(\begin{array}{c} (v_B - R_c^{1,P}(\widehat{\theta}_l))G_l(R_c^{1,P}(\widehat{\theta}_l) - \pi_c^2(\theta_l)) + \\ U_c^2(\theta_l)^*(1 - G_l(R_c^{1,P}(\widehat{\theta}_l) - \pi_c^2(\theta_l))) \end{array} \right) 1_{R_c^{1,P}(\widehat{\theta}_l) \leq \theta_l + \overline{\sigma} + \pi_c^2(\theta_l)} + \\ (v_B - R_c^{1,P}(\widehat{\theta}_l)) 1_{R_c^{1,P}(\widehat{\theta}_l) > \theta_l + \overline{\sigma} + \pi_c^2(\theta_l)} \end{array} \right] +$$

$$p_{l,\widehat{h}} \left[\begin{array}{c} \left(\begin{array}{c} (v_B - R_c^{1,P}(\widehat{\theta}_h))G_l(R_c^{1,P}(\widehat{\theta}_h) - \pi_c^2(\theta_l)) + \\ U_c^2(\theta_l)^*(1 - G_l(R_c^{1,P}(\widehat{\theta}_h) - \pi_c^2(\theta_l))) \end{array} \right) 1_{R_c^{1,P}(\widehat{\theta}_h) \leq \theta_l + \overline{\sigma} + \pi_c^2(\theta_l)} + \\ (v_B - R_c^{1,P}(\widehat{\theta}_h)) 1_{R_c^{1,P}(\widehat{\theta}_h) > \theta_l + \overline{\sigma} + \pi_c^2(\theta_l)} \end{array} \right] +$$

$$p_{h,\widehat{l}} \left[\begin{array}{c} (\delta U_c^2(\theta_h)^*) 1_{R_c^{1,P}(\widehat{\theta}_l) \leq \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)} + \\ \left(\begin{array}{c} (v_B - R_c^{1,P}(\widehat{\theta}_l))G_h(R_c^{1,P}(\widehat{\theta}_l) - \delta\pi_c^2(\theta_h)) + \\ \delta U_c^2(\theta_h)^*(1 - G_h(R_c^{1,P}(\widehat{\theta}_l) - \delta\pi_c^2(\theta_h))) \end{array} \right) 1_{R_c^{1,P}(\widehat{\theta}_l) > \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)} \end{array} \right] +$$

$$p_{h,\widehat{h}} \left[\begin{array}{c} (\delta U_c^2(\theta_h)^*) 1_{R_c^{1,P}(\widehat{\theta}_h) \leq \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)} + \\ \left(\begin{array}{c} (v_B - R_c^{1,P}(\widehat{\theta}_h))G_h(R_c^{1,P}(\widehat{\theta}_h) - \delta\pi_c^2(\theta_h)) + \\ \delta U_c^2(\theta_h)^*(1 - G_h(R_c^{1,P}(\widehat{\theta}_h) - \delta\pi_c^2(\theta_h))) \end{array} \right) 1_{R_c^{1,P}(\widehat{\theta}_h) > \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)} \end{array} \right]$$

Introduce the following notation

$$\Psi_l(R) \equiv (v_B - R)G_l(R - \pi_c^2(\theta_l)) + U_c^2(\theta_l)^*(1 - G_l(R - \pi_c^2(\theta_l)))$$

$$\Psi_h(R) \equiv (v_B - R)G_h(R - \delta\pi_c^2(\theta_h)) + \delta U_c^2(\theta_h)^*(1 - G_h(R - \delta\pi_c^2(\theta_h)))$$

By assumption, $G_\theta(R)$ has a decreasing reverse hazard rate which implies that $\Psi_l(R)$ and $\Psi_h(R)$ are st. concave on $[\theta_l+\underline{\sigma}+\pi_c^2(\theta_l), \theta_l+\overline{\sigma}]$ and $[\theta_h+\underline{\sigma}+\delta\pi_c^2(\theta_h), \theta_h+\overline{\sigma}]$, respectively, so the following holds:

$$\left.\frac{d\Psi_l(R)}{dR}\right|_{R=R_c^1(\theta_l)^*} = 0 \text{ and } \left.\frac{d\Psi_h(R)}{dR}\right|_{R=R_c^1(\theta_h)^*} = 0$$

$$\left.\frac{d\Psi_l(R)}{dR}\right|_{R<R_c^1(\theta_l)^*} > 0 \text{ and } \left.\frac{d\Psi_l(R)}{dR}\right|_{R>R_c^1(\theta_l)^*} < 0$$

$$\left.\frac{d\Psi_h(R)}{dR}\right|_{R<R_c^1(\theta_h)^*} > 0 \text{ and } \left.\frac{d\Psi_h(R)}{dR}\right|_{R>R_c^1(\theta_h)^*} < 0$$

Consider the following three cases.

Case 1: $R_c^{1,P}(\widehat{\theta}) \leq \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)$

If in equilibrium the buyer adopts an award rule $R_c^{1,P}(\widehat{\theta}, b_c^1)$ such that $R_c^{1,P}(\widehat{\theta}) \leq \theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h)$, then $R_c^{1,P}(\widehat{\theta})$ must solve the following maximization problem

$$R_c^{1,P}(\widehat{\theta}) \in \arg\max_R \left[(v_B - R)G_l(R - \pi_c^2(\theta_l)) + U_c^2(\theta_l)^*(1 - G_l(R - \pi_c^2(\theta_l)))\right]$$

By the definition of $R_c^1(\theta)^*$, $R_c^{1,P}(\widehat{\theta}) = R_c^1(\theta_l)^*$ in this case.

Case 2: $R_c^{1,P}(\widehat{\theta}) \in (\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h), \theta_h + \underline{\sigma} + \pi_c^2(\theta_l))$

If in equilibrium the buyer adopts an award rule $R_c^{1,P}(\widehat{\theta}, b_c^1)$ such that $R_c^{1,P}(\widehat{\theta}) \in (\theta_h+\underline{\sigma}+\delta\pi_c^2(\theta_h), \theta_h+\underline{\sigma}+\pi_c^2(\theta_l))$, then $R_c^{1,P}(\widehat{\theta})$ must solve the following maximization problem

$$R_c^{1,P}(\widehat{\theta}) \in \arg\max_R \left\{ p_{l,\widehat{\theta}}\Psi_l(R) + (1 - p_{l,\widehat{\theta}})\Psi_h(R)\right\}$$

As $R_c^{1,P}(\widehat{\theta})$ is interior, it should solve the F.O.C.

$$p_{l,\widehat{\theta}}\frac{d\Psi_l(R)}{dR} + (1 - p_{l,\widehat{\theta}})\frac{d\Psi_h(R)}{dR} \equiv 0$$

For given $p_{l,\widehat{\theta}}$, let us denote such interior solution, if it exists, by $m(p_{l,\widehat{\theta}})$

Case 3: $R_c^{1,P}(\widehat{\theta}) \geq \theta_h + \underline{\sigma} + \pi_c^2(\theta_l)$

If the buyer adopts an award rule $R_c^{1,P}(\widehat{\theta}, b_c^1)$ such that $R_c^{1,P}(\widehat{\theta}) \geq \theta_h + \underline{\sigma} + \pi_c^2(\theta_l)$, then $R_c^{1,P}(\widehat{\theta})$ must solve the following maximization problem

$$R_c^{1,P}(\widehat{\theta}) \in \arg\max_R \left\{ p_{l,\widehat{\theta}}(v_B - R) + (1 - p_{l,\widehat{\theta}})\Psi_h(R) \right\}$$

If $R_c^{1,P}(\widehat{\theta})$ is not interior, then $R_c^{1,P}(\widehat{\theta})$ is equal to $\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)$ if

$$-p_{l,\widehat{\theta}} + (1 - p_{l,\widehat{\theta}}) \left. \frac{d\Psi_h(R)}{dR} \right|_{\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)} < 0$$

Since $\left. \frac{d\Psi_h(R)}{dR} \right|_{\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)} > 0$, there exists $\overline{p} \in (0,1)$ such that

$$-p_{l,\widehat{\theta}} + (1 - p_{l,\widehat{\theta}}) \left. \frac{d\Psi_h(R)}{dR} \right|_{\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)} < 0, \text{ if } p_{l,\widehat{\theta}} > \overline{p}$$

and

$$-p_{l,\widehat{\theta}} + (1 - p_{l,\widehat{\theta}}) \left. \frac{d\Psi_h(R)}{dR} \right|_{\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)} > 0, \text{ if } p_{l,\widehat{\theta}} < \overline{p}$$

If $R_c^{1,P}(\widehat{\theta})$ is interior, then $R_c^{1,P}(\widehat{\theta})$ solves the F.O.C.

$$-p_{l,\widehat{\theta}} + (1 - p_{l,\widehat{\theta}}) \frac{d\Psi_h(R)}{dR} \equiv 0$$

Note that for $R_c^{1,P}(\widehat{\theta})$ to satisfy the necessary F.O.C. it must lie in the interval $(\theta_h + \underline{\sigma} + \pi_c^2(\theta_l), R_c^1(\theta_h)^*)$. For given $p_{l,\widehat{\theta}}$, let us denote such interior solution, if it exists, by $z(p_{l,\widehat{\theta}})$.

Thus, the equilibrium award rule is such that $R_c^{1,P}(\widehat{\theta}) = R_c^1(\theta_l)^*$ if the following inequalities are satisfied

$$\left[p_{l,\widehat{\theta}}\Psi_l(R) + (1 - p_{l,\widehat{\theta}})\Psi_h(R) \right] \Big|_{m(p_{l,\widehat{\theta}})} > \left[p_{l,\widehat{\theta}} \left[U_c^1(\theta_l)^* \right] + (1 - p_{l,\widehat{\theta}})\delta U_c^2(\theta_h)^* \right]$$

$$\left[p_{l,\widehat{\theta}}(v_B - R) + (1 - p_{l,\widehat{\theta}})\Psi_h(R) \right] \Big|_{\theta_h + \underline{\sigma} + \pi_c^2(\theta_l)} > \left[p_{l,\widehat{\theta}} \left[U_c^1(\theta_l)^* \right] + (1 - p_{l,\widehat{\theta}})\delta U_c^2(\theta_h)^* \right]$$

$$\left[p_{l,\widehat{\theta}}(v_B - R) + (1 - p_{l,\widehat{\theta}})\Psi_h(R) \right] \Big|_{z(p_{l,\widehat{\theta}})} > \left[p_{l,\widehat{\theta}} \left[U_c^1(\theta_l)^* \right] + (1 - p_{l,\widehat{\theta}})\delta U_c^2(\theta_h)^* \right]$$

In the above inequalities the R.H.S. is a linear, st. increasing function of $p_{l,\widehat{\theta}}$ and the L.H.S. is continuous and non-decreasing in $p_{l,\widehat{\theta}}$ (by the Envelope Theorem). Therefore, it must be true that the L.H.S. and the R.H.S. cross only once (these functions cross because L.H.S.<R.H.S. when $p_{l,\widehat{\theta}} \to 1$ and L.H.S.>R.H.S. when $p_{l,\widehat{\theta}} \to 0$). So, there exists $\widetilde{p} \in (0,1)$ such that the above inequalities are satisfied if $p_{l,\widehat{\theta}} > \widetilde{p}$ and at least one of the inequalities is not satisfied if $p_{l,\widehat{\theta}} < \widetilde{p}$.

We can conclude that if $p_{l,\widehat{\theta}} \geq \widetilde{p}$, the optimal first round award rule is given by $R_c^{1,P}(\widehat{\theta}, b_c^1) = R_c^1(\theta_l)^*$ for all b_c^1 and if $p_{l,\widehat{\theta}} < \widetilde{p}$, the optimal first round award rule is given by

$$R_1^P(\widehat{\theta}, b_c^1) = \begin{cases} R_c^1(\theta_l)^*, & \text{If } b_c^1 \leq \theta_l + \overline{\sigma} \\ r(p_{l,\widehat{\theta}})^*, & \text{If } b_c^1 > \theta_l + \overline{\sigma} \end{cases}$$

where $r(p_{l,\widehat{\theta}}) : [0,1] \to (\theta_h + \underline{\sigma} + \delta\pi_c^2(\theta_h),\ R_c^1(\theta_h)^*\ ]$.

Q.E.D.

Continuation of the Proof of Proposition 3.2. It follows from Lemma C.3 and Lemma C.4 that if $p_{l,\widehat{l}} \geq \widetilde{p}$, the buyer's ex ante expected payoff is strictly below $p_l U_c^1(\theta_l)^* + p_h(p_{\widehat{l}|h}\delta U_c^2(\theta_h)^* + p_{\widehat{h}|h} U_c^1(\theta_h)^*)$. *Q.E.D.*

Proof of Proposition 3.3. We first prove the following lemma.

Lemma C.5 *Suppose $\widehat{\theta}$ is noisy. If the buyer follows a concealing policy, then there exists $\widetilde{p}^{NP} \in (0,1)$ such that if $p_{l,\widehat{l}} \geq \widetilde{p}^{NP}$, the following is PBNE. In the first round the buyer adopts the following award rule :*

$$R_c^{1,NP}(\ \widehat{\theta}_l, b_c^1) = R_c^1(\theta_l)^*, \text{ for all } b_c^1$$

$$R_c^{1,NP}(\ \widehat{\theta}_h, b_c^1) = \begin{cases} R_c^1(\theta_l)^*, \text{ if } b_c^1 \leq \theta_l + \overline{\sigma} \\ R_c^1(\theta_h)^*, \text{ if } \ b_c^1 > \theta_l + \overline{\sigma} \end{cases}$$

If $\theta = \theta_l$, the cartel believes with probability $p_{\widehat{l}|l}$ that the award rule is $R_c^{1,NP}(\ \widehat{\theta}_l, b_c^1)$ and believes with probability $p_{\widehat{h}|l}$ that the award rule is $R_c^{1,NP}(\widehat{\theta}_h, b_c^1)$. Given the cartel's beliefs, the cartel bids according to the bid function

$$\beta_c^{1,NP}(\theta_l, \sigma_m) = \begin{cases} R_c^1(\theta_l)^*, \text{ if } c_m \leq R_c^1(\theta_l)^* - \pi_c^2(\theta_l) \\ \theta_l + \overline{\sigma}, \text{ if } c_m > R_c^1(\theta_l)^* - \pi_c^2(\theta_l) \end{cases}$$

If $\theta = \theta_h$, the cartel believes with probability $p_{\widehat{l}|h}$ that the award rule is $R_c^{1,NP}(\ \widehat{\theta}_l, b_c^1)$

and believes with probability $p_{\widehat{h}|h}$ that the award rule is $R_c^{1,NP}(\widehat{\theta}_h, b_c^1)$. Given the cartel's beliefs, the cartel bids according to the bid function

$$\beta_c^{1,NP}(\theta_h, \sigma_m) = \begin{cases} R_c^1(\theta_h)^*, \text{ if } c_m \leq R_c^1(\theta_h)^* - \delta\pi_c^2(\theta_h) \\ \theta_h + \overline{\sigma}, \text{ if } c_m > R_c^1(\theta_h)^* - \delta\pi_c^2(\theta_h) \end{cases}$$

If in the first round the cartel bid is less than or equal to $\theta_l + \overline{\sigma}$, the buyer believes that $\theta = \theta_l$ with probability one. If the first round bid is rejected and is less than $\theta_l + \overline{\sigma}$, the buyer holds the second round of bidding immediately after the first round. If in the first round the cartel bid is rejected and is greater than $\theta_h + \underline{\sigma}$, the buyer suspends the procurement and draws an accurate signal $\widehat{\theta}^{acc}$. In the second round, the buyer announces the award rule

$$R_2(b_c^1) = R_c^2(\theta)^* \text{ for all } b_c^1$$

when $\widehat{\theta}^{acc} = \theta$. The cartel bids according to the following bid function

$$\beta_c^2(\theta, \sigma_m) = \begin{cases} R_c^2(\theta)^*, \text{ if } c_m \leq R_c^2(\theta)^* \\ \theta + \overline{\sigma}, \text{ if } c_m > R_c^2(\theta)^* \end{cases}$$

Proof of Lemma C.5. The outcome of the second round is the same as that under a revealing policy.

Let $R_c^{1,NP}(\widehat{\theta})$ denote the maximum price that the buyer accepts in the first round when he observes a signal $\widehat{\theta}$, i.e. $R_c^{1,NP}(\widehat{\theta}) \equiv \max_{b_c^1}\{R_c^{1,NP}(\widehat{\theta}, b_c^1)\}$. Without loss of generality, assume that $R_c^{1,NP}(\widehat{\theta}_l) < R_c^{1,NP}(\widehat{\theta}_h)$.

Given the true θ, the cartel's beliefs are: $R_c^{1,NP}(\widehat{\theta}) = R_c^{1,NP}(\widehat{\theta}_l)$ with probability $p_{\widehat{l}|\theta}$ and $R_c^{1,NP}(\widehat{\theta}) = R_c^{1,NP}(\widehat{\theta}_h)$ with probability $1 - p_{\widehat{l}|\theta}$. If the cartel bids $R_c^{1,NP}(\widehat{\theta}_l)$, then the cartel believes that the bid will be accepted by the buyer with probability one. If the cartel bids $R_c^{1,NP}(\widehat{\theta}_h)$, then the cartel believes that the bid will be rejected with probability $p_{\widehat{l}|\theta}$ and accepted with probability $(1 - p_{\widehat{l}|\theta})$.

Consider first the cartel's problem when $\theta = \theta_l$. If $R_c^{1,NP}(\widehat{\theta}_h)$ is less than $\theta_l + \overline{\sigma}$, then the cartel never bids above $\theta_l + \overline{\sigma}$ in the first round to avoid the delay. If $\pi_c^2(\theta_l) > R_c^{1,NP}(\widehat{\theta}_h) - c_m$, then the cartel prefers to wait for the second round, so it bids the upper support $\theta_l + \overline{\sigma}$. If $\pi_c^2(\theta_l) \leq R_c^{1,NP}(\widehat{\theta}_h) - c_m$, then the cartel prefers to participate in the first round and bids $R_c^{1,NP}(\widehat{\theta}_l)$ if $R_c^{1,NP}(\widehat{\theta}_l) - c_m \geq p_{\widehat{l}|l}\pi_c^2(\theta_l) +$

$(1-p_{\widehat{l}|l})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)$ and bids $R_c^{1,NP}(\widehat{\theta}_h)$ if $R_c^{1,NP}(\widehat{\theta}_l)-c_m < \ p_{\widehat{l}|l}\pi_c^2(\theta_l)+(1-p_{\widehat{l}|l})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)$.

If $R_c^{1,NP}(\widehat{\theta}_h)$ is greater than $\theta_l+\overline{\sigma}$, then if the cartel bids $R_c^{1,NP}(\widehat{\theta}_h)$, the buyer will reject the cartel's bid and suspend the procurement if the buyer's signal is $\widehat{\theta}_l$. If $\pi_c^2(\theta_l) > \max\{R_c^{1,NP}(\widehat{\theta}_l)-c_m,\ p_{\widehat{l}|l}\delta\pi_c^2(\theta_l)+(1-p_{\widehat{l}|l})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)\}$, then the cartel prefers to wait for the second round, so it bids $\theta_l+\overline{\sigma}$ to avoid the delay. The cartel prefers to bid $R_c^{1,NP}(\widehat{\theta}_l)$ if $R_c^{1,NP}(\widehat{\theta}_l)-c_m \geq \max\{\pi_c^2(\theta_l),\ p_{\widehat{l}|l}\delta\pi_c^2(\theta_l)+(1-p_{\widehat{l}|l})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)\}$ and bids $R_c^{1,NP}(\widehat{\theta}_h)$ if $p_{\widehat{l}|l}\delta\pi_c^2(\theta_l)+(1-p_{\widehat{l}|l})(R_c^{1,NP}(\widehat{\theta}_h)-c_m) > \max\{\pi_c^2(\theta_l),\ R_c^{1,NP}(\widehat{\theta}_l)-c_m\}$.

Next consider the cartel's problem when $\theta=\theta_h$. If $R_c^{1,NP}(\widehat{\theta}_h)$ is less than $\theta_h+\underline{\sigma}+\delta\pi_c^2(\theta_h)$, the cartel prefers to wait for the second round for all c_m, so it bids $\theta_h+\overline{\sigma}$. If $R_c^{1,NP}(\widehat{\theta}_h)$ is greater than $\theta_h+\underline{\sigma}+\delta\pi_c^2(\theta_h)$, then the cartel prefers to wait for the second round if $\delta\pi_c^2(\theta_h) > R_c^{1,NP}(\widehat{\theta}_h)-c_m$, so it bids $\theta_h+\overline{\sigma}$. If $\delta\pi_c^2(\theta_h)\leq R_c^{1,NP}(\widehat{\theta}_h)-c_m$, then the cartel prefers to bid $R_c^{1,NP}(\widehat{\theta}_l)$ if $R_c^{1,NP}(\widehat{\theta}_l)-c_m \geq \ p_{\widehat{l}|h}\delta\pi_c^2(\theta_h)+(1-p_{\widehat{l}|h})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)$ and bids $R_c^{1,NP}(\widehat{\theta}_h)$ if $R_c^{1,NP}(\widehat{\theta}_l)-c_m < \ p_{\widehat{l}|h}\delta\pi_c^2(\theta_h)+(1-p_{\widehat{l}|h})(R_c^{1,NP}(\widehat{\theta}_h)-c_m)$.

Let us define the set Σ as follows

$$\begin{aligned}\Sigma \ &\equiv\ \{(\ p_{\widehat{l}|l},\delta)|\ p_{\widehat{l}|l}\in[0,1],\ \delta\in(0,1) \text{ and } p_{\widehat{l}|l}\delta\pi_c^2(\theta_l)+(1-p_{\widehat{l}|l})(R_c^1(\theta_h)^*-c_m)\leq \\ &\leq\ \max\{\pi_c^2(\theta_l),\ R_c^1(\theta_l)^*-c_m\} \text{ for all } c_m\in[\theta_l+\underline{\sigma},\theta_l+\overline{\sigma}]\ \}\end{aligned}$$

If the parameters $(\ p_{\widehat{l}|l},\delta)$ belong to Σ, then if $R_c^{1,NP}(\widehat{\theta}_l)$ is equal to $R_c^1(\theta_l)^*$ and $R_c^{1,NP}(\widehat{\theta}_h)$ is equal to $R_c^1(\theta_h)^*$, the low-cost cartel bids below $\theta_l+\overline{\sigma}$ for all realizations of σ_m. Note that Σ is non-empty for all $\delta\in(0,1)$ if $p_{\widehat{l}|l}$ sufficiently close to 1.

We can now conclude that, given the buyer's award rule in Lemma C.5, it is a best reply for the low cost cartel to bids $R_c^1(\theta_l)^*$, if $c_m\leq R_c^1(\theta_l)^*-\pi_c^2(\theta_l)$, and bid $\theta_l+\overline{\sigma}$ if $c_m > R_c^1(\theta_l)^*-\pi_c^2(\theta_l)$. This follows from the definition of Σ. It is easy to see that for the high cost cartel it is a best reply to bid $R_c^1(\theta_h)^*$ if $c_m\leq R_c^1(\theta_h)^*-\delta\pi_c^2(\theta_h)$ and bid $\theta_h+\overline{\sigma}$ if $c_m > R_c^1(\theta_h)^*-\delta\pi_c^2(\theta_h)$.

Given the cartel's equilibrium bid function, the buyer's belief that $\theta=\theta_l$ with probability one when the first round bid is less than or equal to $\theta_l+\overline{\sigma}$ is consistent with the Bayes' rule.

Finally, we show that it is indeed optimal for the buyer to choose the first round award rule as defined in Lemma C.5.

If the buyer commits to the award rule described in Lemma C.5, then the buyer's ex ante expected payoff is $p_l U_c^1(\theta_l)^* + p_h(p_{\widehat{l}|h}\delta U_c^2(\theta_h)^* + p_{\widehat{h}|h}U_c^1(\theta_h)^*)$.

Consider possible deviations for the buyer. Let us denote by $U_c^1(\theta, R_1^{NP}(\widehat{\theta}, b_c^1))$ the buyer's expected payoff in the first round, conditional on θ and $\widehat{\theta}$, when the buyer's first round award rule is $R_1^{NP}(\widehat{\theta}, b_c^1)$. If the buyer adopts any award rule $R_1^{NP}(\widehat{\theta}, b_c^1)^/$ that is different from the award rule described in Lemma C.5, then the buyer's ex ante expected payoff is

$$
\begin{aligned}
&p_{l,\widehat{l}}U_c^1(\theta_l, R_1(\widehat{\theta}_l, b_c^1)^/) + p_{l,\widehat{h}}U_c^1(\theta_l, R_1(\widehat{\theta}_h, b_c^1)^/) + \\
&p_{h,\widehat{l}}U_c^1(\theta_h, R_1(\widehat{\theta}_l, b_c^1)^/) + p_{h,\widehat{h}}U_c^1(\theta_h, R_1(\widehat{\theta}_h, b_c^1)^/)
\end{aligned}
$$

Because the optimal reserve price is $R_c^1(\theta_l)^*$, conditional on $\theta = \theta_l$ and the optimal reserve price is $R_c^1(\theta_h)^*$, conditional on $\theta = \theta_h$, we have $U_c^1(\theta_l, R_1(\widehat{\theta}_l, b_c^1)^/) < U_c^1(\theta_l)^*$, $U_c^1(\theta_l, R_1(\widehat{\theta}_h, b_c^1)^/) < U_c^1(\theta_l)^*$, and $U_c^1(\theta_h, R_1(\widehat{\theta}_h, b_c^1)^/) < U_c^1(\theta_h)^*$ for all $R_1(\widehat{\theta}, b_c^1)^/$.

The supremum of $U_c^1(\theta_h, R_1(\widehat{\theta}_l, b_c^1)^/)$ is $U_c^1(\theta_h)^*$for all possible $R_1(\widehat{\theta}, b_c^1)^/$.

Then, there exists a value $\widetilde{p}_{h,\widehat{l}}$, such that for all $p_{h,\widehat{l}} < \widetilde{p}_{h,\widehat{l}}$, the following inequality holds

$$
\begin{aligned}
&p_{l,\widehat{l}}U_c^1(\theta_l, R_1(\widehat{\theta}_l, b_c^1)^/) + p_{l,\widehat{h}}U_c^1(\theta_l, R_1(\widehat{\theta}_h, b_c^1)^/) + \\
&p_{h,\widehat{l}}U_c^1(\theta_h)^* + p_{h,\widehat{h}}U_c^1(\theta_h, R_1(\widehat{\theta}_h, b_c^1)^/) < \\
&p_l U_c^1(\theta_l)^* + p_{h,\widehat{l}}\delta U_c^2(\theta_h)^* + p_{h,\widehat{h}}U_c^1(\theta_h)^*
\end{aligned}
$$

Let, $\widetilde{p}_{l,\widehat{l}} \equiv 1 - \widetilde{p}_{h,\widehat{l}}$. Let use define $\widetilde{p}^{NP}$ to be the value in $(0,1)$ such that if $p_{l,\widehat{l}} \geq \widetilde{p}^{NP}$, then $p_{l,\widehat{l}} \geq \widetilde{p}_{l,\widehat{l}}$ and ($p_{\widehat{l}|l}, \delta) \in \Sigma$. We can conclude that if $p_{l,\widehat{l}} \geq \widetilde{p}^{NP}$, it is optimal for the buyer to commit to the award rule as described in Lemma C.5. *Q.E.D.*

Continuation of the Proof of Proposition 3.3. Proposition 3.3 follows from Lemma C.5. *Q.E.D.*

Proof of Proposition 3.5. Let us define $R_\lambda^1(\theta, b_1^1, b_2^1)^*$ and $R_\lambda^2(b_1^2, b_2^2)^*$ to be the buyer's optimal award rules when it is a common knowledge that $\widehat{\theta} = \theta$ and the buyer believes with probability λ that sellers are noncooperative and believes with probability $1 - \lambda$ that sellers are collusive. Using similar arguments as in the proofs of Propositions 3.2 and 3.3, one can show that when the buyer follows a concealing policy, for any $\lambda < 1$, there exists $\widetilde{p}_{\lambda}^{NP} \in (0,1)$ such that if $p_{l,\widehat{l}} \geq \widetilde{p}_{\lambda}^{NP}$, the low signal buyer chooses the first round award rule $R_{\lambda}^{1,NP}(\widehat{\theta}_l, b_1^1, b_2^1)$ such that $R_{\lambda}^{1,NP}(\widehat{\theta}_l, b_1^1, b_2^1) = R_{\lambda}^1(\theta_l, b_1^1, b_2^1)^*$ and the high signal buyer chooses the award rule $R_{\lambda}^{1,NP}(\widehat{\theta}_h, b_1^1, b_2^1)$ such that

$$R_{\lambda}^{1,NP}(\widehat{\theta}_h, b_1^1, b_2^1) = \begin{cases} R_{\lambda}^1(\theta_l, b_1^1, b_2^1)^*, \text{ if } \min\{b_1^1, b_2^1\} \leq \theta_l + \overline{\sigma} \\ R_{\lambda}^1(\theta_h, b_1^1, b_2^1)^*, \text{ if } \min\{b_1^1, b_2^1\} > \theta_l + \overline{\sigma} \end{cases}$$

and both noncooperative and collusive sellers bid as if θ were known to the buyer and the award rules were given by $R_{\lambda}^1(\theta, b_1^1, b_2^1)^*$ and $R_{\lambda}^2(b_1^2, b_2^2)^*$. When the buyer follows a revealing policy, one can show that for any $\lambda < 1$, there exists $\widetilde{p}_{\lambda} \in (0,1)$ such that if $p_{l,\widehat{l}} \geq \widetilde{p}_{\lambda}$, the low signal buyer chooses the first round award rule $R_{\lambda}^{1,P}(\widehat{\theta}_l, b_1^1, b_2^1) = R_{\lambda}^1(\theta_l, b_1^1, b_2^1)^*$ and the high signal buyer chooses the award rule $R_{\lambda}^{1,P}(\widehat{\theta}_h, b_1^1, b_2^1)$ such that $R_{\lambda}^{1,P}(\widehat{\theta}_h, b_1^1, b_2^1) \neq R_{\lambda}^{1,NP}(\widehat{\theta}_h, b_1^1, b_2^1)$. We can conclude that for a given λ, if $p_{l,\widehat{l}} \geq \max\left\{\widetilde{p}_{\lambda}, \widetilde{p}_{\lambda}^{NP}\right\}$, then the buyer's ex ante expected payoff is higher under the concealing policy. *Q.E.D.*

C.2 Numerical examples for Chapter 3

Table C.1 reports the percent differences between the buyer's expected payoff under the concealing policy and the buyer's expected payoff under the revealing policy, normalized by the difference between the buyer's expected payoff when $\widehat{\theta}$ is completely informative and the buyer's expected payoff when $\widehat{\theta}$ is completely informative. (A positive/negative entry indicates that the buyer's payoff under the concealing policy is higher/lower).

Table C.1: Buyer's expected payoff under concealing policy relative to revealing policy

	δ=0.6	δ=0.7	δ=0.8	δ=0.9
p=0.95	15.9%	17.4%	19.3%	3.4%
p=0.90	31.3%	33.6%	4.6%	-16.4%
p=0.85	30.4%	5.2%	-15.3%	-18.3%
p=0.80	5.3%	-11.2%	-6.1%	0.0%
p=0.75	-0.5%	0.0%	0.0%	0.0%
p=0.70	0.0%	0.0%	0.0%	0.0%
p=0.65	0.0%	0.0%	0.0%	0.0%
p=0.60	0.0%	0.0%	0.0%	0.0%
p=0.55	0.0%	0.0%	0.0%	0.0%
p=0.50	0.0%	0.0%	0.0%	0.0%

Table C. 2 reports the buyer's expected payoff under the revealing and concealing policies.

Table C.2: Buyer's expected payoff under concealing and revealing policies

	δ=0.6		δ=0.7		δ=0.8		δ=0.9	
	Concealing	**Revealing**	**Concealing**	**Revealing**	**Concealing**	**Revealing**	**Concealing**	**Revealing**
p=1.00	4. 1371	4. 1371	4. 1553	4. 1553	4. 1775	4. 1775	4. 2048	4. 2048
p=0.95	4. 1126	4. 0349	4. 133	4. 0558	4. 1577	4. 081	4. 1233	4. 1116
p=0.90	4. 0881	3. 9348	4. 1076	3. 9584	4. 005	3. 9866	3. 9636	4. 0204
p=0.85	3. 9855	3. 8369	3. 8865	3. 8633	3. 8338	3. 8945	3. 8682	3. 9314
p=0.80	3. 7679	3. 7418	3. 7212	3. 7709	3. 7807	3. 8050	3. 8585	3. 8585
p=0.75	3. 6475	3. 6498	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585
p=0.70	3. 6475	3. 6475	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585
p=0.65	3. 6475	3. 6475	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585
p=0.60	3. 6475	3. 6475	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585
p=0.55	3. 6475	3. 6475	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585
p=0.50	3. 6475	3. 6475	3. 7106	3. 7106	3. 7807	3. 7807	3. 8585	3. 8585

Table C. 3 reports the highest acceptable price by the low/high signal buyer in the initial round of bidding when the buyer follows a revealing policy.

Table C.3: Highest acceptable price under revealing policy

	δ=0.6		δ=0.7		δ=0.8		δ=0.9	
	$R_l^{1,P}(\theta_l{}^\wedge)$	$R_l^{1,P}(\theta_h{}^\wedge)$	$R_l^{1,P}(\theta_l{}^\wedge)$	$R_l^{1,P}(\theta_h{}^\wedge)$	$R_l^{1,P}(\theta_l{}^\wedge)$	$R_l^{1,P}(\theta_h{}^\wedge)$	$R_l^{1,P}(\theta_l{}^\wedge)$	$R_l^{1,P}(\theta_h{}^\wedge)$
p=0.95	2. 97	6.92	2. 97	6. 89	2. 97	6. 87	2. 97	6. 84
p=0.90	2. 97	6.83	2. 97	6.81	2. 97	6. 79	2. 97	6. 76
p=0.85	2. 97	6.74	2. 97	6.73	2. 97	6. 70	2. 97	6. 66
p=0.80	2. 97	6.65	2. 97	6.63	2. 97	6. 61	2. 97	2. 97
p=0.75	2. 97	6.54	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.70	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.65	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.60	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.55	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.50	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97

Table C. 4 reports the highest acceptable price by the low/high signal buyer in the initial round of bidding when the buyer follows a concealing policy.

Table C.4: Highest acceptable price under concealing policy

	δ=0.6		δ=0.7		δ=0.8		δ=0.9	
	$R_l^{1,NP}(\theta_l{}^\wedge)$	$R_l^{1,NP}(\theta_h{}^\wedge)$	$R_l^{1,NP}(\theta_l{}^\wedge)$	$R_l^{1,NP}(\theta_h{}^\wedge)$	$R_l^{1,NP}(\theta_l{}^\wedge)$	$R_l^{1,NP}(\theta_h{}^\wedge)$	$R_l^{1,NP}(\theta_l{}^\wedge)$	$R_l^{1,NP}(\theta_h{}^\wedge)$
p=0.95	2. 97	6. 98	2. 97	6. 96	2. 97	6. 94	3. 26	6. 67
p=0.90	2. 97	6. 98	3. 06	6. 86	3. 50	6. 49	3. 44	6. 67
p=0.85	3. 46	6. 49	3. 70	6. 34	3. 67	6. 49	3. 61	6. 61
p=0.80	3. 87	6. 19	3. 86	6. 33	2. 97	2. 97	2. 97	2. 97
p=0.75	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.70	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.65	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.60	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.55	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97
p=0.50	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97	2. 97

C.3 Disclosure policy of the engineer's estimate

Table C.5 summarizes the current disclosure policy of the engineer's estimate for the US Departments of Transportation.[2]

Table C.5: State DOT's Policies on EE release

EE Policy	**State**
No release before the bid letting - EE release after	AK, AZ, CO, DE, GA, ID, IN, KY, ME, MN, NM, OH, SC, TN, WV
No release before or after the bid letting	AR, IL, IA, KS, MD, NE, VT, VA
Release of a range of values before no release after	AL, NJ, MO, WI
Release of a range of values before EE release after	CT, HI, MS, MT, NY, ND, OR, WA, WY, PA
Release of a budgeted estimate before EE release after	CA, FL, SD, NC
Release of a budgeted estimate before no EE release after	RI
EE release before	LA, MA, MI, NV, OK, TX, UT, NH

[2] Table C.5 is from De silva, et al (2005).

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