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How Demand Information Can Destabilize a Cartel

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How Demand Information Can Destabilize a Cartel *

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Abstract

This paper studies a symmetric Bertrand duopoly with imperfect monitoring where firms receive noisy public signals about the state of demand. These signals have two opposite effects on the incentive to collude: avoiding punishment after a low-demand period increases collusive profits, making collusion more attractive, but it also softens the threat of punishment, which increases the temptation to undercut the rival. There are cases where the latter effect dominates, and so the collusive equilibrium does not always exist when it does absent demand information. These findings are related to the Sugar Institute Case studied by Genesove and Mullin (2001).

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1 Introduction

Competition authorities tend to be alarmed when they discover mechanisms or institutions which provide firm-level information on prices or quantities to competitors in oligopolistic industries. Two examples from EU case law are the UK Tractor Case (1992), and the Cement Case (1994). In the UK Tractor Case, the UK trade association of manufacturers and importers of agricultural machinery (Agricultural Engineers Association Ltd) collected information on tractor registration (vehicle licensing) from the Department of Transport and distributed it to its members. This information identified the retail sales and market shares of each of the eight firms on the UK market with detailed breakdowns by product, territory and time periods. The Cement Case differed from the UK Tractor Case insofar as it was price information (not sales) that was communicated by the European Cement Association (Cembureau) to its members (cement manufacturers from 19 European countries).

The European Commission's tough stance in these cases is well-grounded on a body of academic work (discussed in more detail in the next section) studying if and how firms can sustain collusion in an environment where rivals' actions are only imperfectly observable. The conventional wisdom arising from this literature is that, compared to an environment of perfect monitoring, collusion will in general be more difficult to sustain, because deviators are harder to detect and to punish, making the industry more susceptible to cheating.

But can we conclude that market information will always and unambiguously facilitate collusion? The purpose of this paper is to show that there are instances where collusion may actually be easier (not harder) to sustain *without* such information. I analyze a repeated symmetric Bertrand duopoly with uncertain demand, where firms cannot observe the competitor's price, but they receive a noisy public signal about the demand realization. This signal could correspond for instance to the publication of (aggregated or firm-level) sales data for a particular industry. The signal is noisy in both directions: It may erroneously indicate that demand was high when it was in fact low, and vice versa. The noise is crucial in producing the result.

I study the existence of collusive equilibria sustained by optimal collusive strategies where firms coordinate their actions on the public information history. In the benchmark model without signals, whenever at least one firm realized zero profits, optimal punishment requires that firms coordinate on a randomization device, and either jointly stay in the collusive phase or revert to the Bertrand-Nash equilibrium forever. This implies that, along the equilibrium path, collusion is jeopardized every time a low-demand state is realized, even though nobody defected. I first show that if the colluding firms receive public demand information (in addition to their observations on own profits), they will optimally avoid Nash reversion whenever profits are zero and the signal indicates that demand was low. Thus, signals increase collusive profits and hence make collusion more attractive.

However, the contribution of this paper is to show that conditioning on such imperfect signals also has a downside for the firms: Suppose that one firm defected, but the signal (accurately or wrongly) indicates that demand was low. Then, the probability of Nash reversion is zero, i.e. the cheating firm will get away with the defection. This can never happen in an environment without signals, where the probability of Nash reversion is always strictly positive when a defection has occurred. Thus, signals weaken the punishment mechanism, thus undermining compliance with the collusive arrangement. I show that if negative demand shocks are rather unlikely, this second effect dominates the positive effect of transparency which has been stressed in the literature so far. As a result, signals may raise the minimum discount factor required to sustain collusion, so that collusion is less likely to arise.

The paper is organized as follows: Section 2 reviews the related literature. Section 3 introduces the model. Section 4 studies how the introduction of signals into the game affects the existence of collusive equilibria and their properties. Section 5 relates the results to what may be the most prominent example of a collusive trade association in the economic literature, the Sugar Institute Case as studied by Genesove and Mullin (2001), and draws some policy conclusions.

Finally, Section 6 summarizes the main findings and concludes.

2 Related Literature

In his seminal paper of 1964, Stigler was the first to analyze the case of a Bertrand-type oligopoly where each firm's prices are unobservable to its competitors (i.e. each firm can grant secret price cuts to its customers). Stigler (1964) concluded that without observability of prices, collusion will in general be more difficult to sustain, but can still arise if the cartel provides the right incentives.

Following Stigler's (1964) approach, Green and Porter (1984) developed their model to show that given stochastic demand shocks, price wars need not be the result of a collapse of collusion, but should rather be interpreted as part of the firms' equilibrium strategies to ensure tacit collusion in a non-cooperative framework.

Stigler's (1964) and Green-Porter's (1984) work inspired a growing literature on firm behavior under non-observability of competitors' actions. In particular, Abreu, Pearce and Stacchetti (1986, 1990) analyzed optimal punishment strategies in oligopolies with imperfect monitoring, showing that every symmetric sequential equilibrium payoff in the Green-Porter model can be supported by sequential equilibria having an extremely simple intertemporal structure. Fudenberg, Levine and Maskin (1994) identify conditions for the folk theorem to apply in repeated games in which players observe a public outcome that imperfectly signals the actions played. My paper is most closely related to this literature, both in terms of the structure of the game studied as well as the questions addressed in the analysis.

Note that a public signal serves two distinct purposes in these games: first, it provides information to the agents (which could be achieved by a private signal as well), and second, it also allows firms to coordinate their behavior on the signal's realizations (which is not the case for a (noisy) private signal, as then the state of the world will no longer be common knowledge among the agents). The properties of repeated games with imperfect monitoring and privately observed signals are not yet well understood; one way to resolve the coordination problem in such a model is to allow for communication between players, as shown in Kandori and Matsushima (1998) and Compte (1998).

A different, but related strand of literature studies whether firms find it profitable to share private information with each other. While each firm will always want to learn its rivals' information, it is not clear that the firm will also find it in its interest to voluntarily disclose the information it holds itself. The incentives to share information with rival firms was formally studied by Vives (1984) in a duopoly model with differentiated products where firms have private information about an uncertain linear demand. Vives finds that if the goods are substitutes, it is a dominant strategy for each firm to share information in Bertrand competition, while it is not under Cournot competition. Moreover, the result is reversed if the goods are complements. These findings were generalized by Raith (1996). Experimental evidence on information sharing is provided by Cason and Mason (1999), who found that the information sharing itself did not substantially increase tacit collusion.

The empirical work on collusion with imperfect monitoring generally finds that improving transparency in an industry leads to significant and stable price increases above the competitive level. Well-known examples include the US railroad grain rates in the 1980's (see Fuller et al. (1990)) and the Danish ready-mixed concrete market in the early 1990's (see Albæk et al. (1997)). The striking feature of these two examples is that the relevant market information was not provided by a cartel or trade association, but by government agencies, who were certainly hoping to achieve the opposite effect.

A related problem regards oligopolistic markets where the buyers are the ones who can only imperfectly observe seller's prices (while the sellers can), i.e. the market is not "transparent". One interesting result of this work is that increasing market transparency may not be unambiguously beneficial for consumers (see Nilsson (1999) for a search-cost approach, and Møllgaard and Overgaard (2000) for a product-differentiation approach). If buyers cannot fully observe all prices on the market, it is difficult for firms to steal business from their rivals. This reduces the incentives to cheat, but it also makes it harder to punish a defector. If the latter effect dominates, collusion cannot arise, and so consumers are actually better off than if they could fully observe all prices.

Finally, in an oligopoly with uncertain demand, each firm could choose as its strategy a "supply function" relating its quantity to its price, rather than a fixed price or a fixed quantity. Klemperer and Meyer (1989) give conditions for existence and for uniqueness of a Nash equilibrium in supply functions under uncertainty and compare the equilibrium with the Cournot and Bertrand equilibria when the demand and cost curves, the number of firms, and the form of uncertainty vary. This approach is also taken in Fabra (2003), who compares the level and conduct of collusion under uniform and discriminatory auctions. She finds that uniform auctions facilitate collusion more than discriminatory auctions: the optimal penal code is equally severe under the two formats; but bidders' deviation incentives are weaker in uniform auctions given that the payoff irrelevant bids can be used to relax the enforcement problem.

3 The model

This section builds on Tirole's (1988) illustration of the Green and Porter (1984) model. Consider an infinitely repeated duopoly game where two symmetric firms produce perfect substitutes at constant marginal cost. The firms choose prices every period. Buyers can perfectly observe both prices and will all buy from the low-price firm. Each firm only knows its own price but cannot observe the rival's price. This situation will typically arise in customer markets where the buyers are large firms searching the market for potential input providers; examples would include the Lysine cartel as described in Connor (1999), or the Sugar Institute discussed in more detail in Section 5.[1]

Demand for the product is stochastic; with probability α, demand will be

[1]The assumption that buyers can fully observe prices (while firms cannot) may seem somewhat strong. We make this assumption to isolate the issue of imperfect monitoring among competitors from that of observability by buyers. For a discussion of the literature on limited price observability by buyers, see Section 2.

zero in a given period (the "low-demand state"), and with probability $1-\alpha$, demand will be positive (the "high-demand state"). Realizations are assumed to be iid over time. Firms cannot directly observe the state of demand.

For the high-demand state, denote the per-period monopoly profits by Π^m. We assume that the two firms share the market equally whenever they charge the same price. Thus, in a period of high demand, each firm's profit under collusion will be $\Pi^m/2$. Next-period's profits are discounted at rate $\delta < 1$.

If a firm realizes profits $\Pi^m/2$, it can perfectly infer the other firm's behavior and vice versa. Then, it is common knowledge that demand was high and both firms set the collusive price. If instead a firm does not sell anything at some date, it does not know *apriori* whether this is due to a low realization of demand or to its competitor charging a lower price. Each firm can however observe its own profits; thus, it is always common knowledge that at least one firm realized zero profits (because then either demand is low, hence the other firm realized zero profits as well, or the other firm undercut).

In addition to their observations of own profits, the firms receive a noisy signal on the demand realization after each period.[2] The signals are iid over time, and can be characterized as follows (see table below): If the actual state of demand was low ($D = 0$), the signal will indicate low demand ($S = 0$) with probability σ_l, and wrongly indicate high demand ($S = 1$) with probability $1 - \sigma_l$. Conversely, if the actual state of demand was high ($D = 1$), the signal will correctly indicate this with probability σ_h, and wrongly indicate low demand with probability $1 - \sigma_h$. Probabilities σ_l and σ_h are known to the firms.

		Signal indicates:	
		low ($S = 0$)	high ($S = 1$)
State of demand:	low ($D = 0$)	σ_l	$1 - \sigma_l$
	high ($D = 1$)	$1 - \sigma_h$	σ_h

Assume that the signal is informative, i.e. $\sigma_l > \frac{1}{2}$ and $\sigma_h > \frac{1}{2}$. Signal precision may vary across demand states, i.e. it could be that $\sigma_l \neq \sigma_h$. The

[2]Firms do not incur any cost to receive this signal, nor do they disclose any information themselves. Think of this signal as being exogenously provided, for instance by a trade association or government agency.

signal is public, so that its realization is common knowledge.

Under the information structure imposed above, play of the infinitely repeated game generates both a private and a public information history. For each firm, the sequence of its prices and sales in each period constitutes its private history. The public history is the sequence of information which both firms observe. In our case, at each stage, it is common knowledge whether or not at least one firm realized zero profits, and whether the signal indicated high or low demand.

We will now study how the firms can collude given the signal extraction problem introduced above. Following the approach of Abreu, Pearce, and Stacchetti (1986), the relevant collusive equilibrium can be characterized as follows: along the collusive path, the two firms charge the collusive price until at least one firm makes zero profit. Both this event and the realization of the demand signal are now public history. If the demand signal indicates that demand was low, the collusive phase optimally continues with probability 1. If instead the signal indicates high demand, optimal punishment requires that firms coordinate on a randomization device, and either jointly stay in the collusive phase or revert to the Bertrand-Nash equilibrium forever.

We restrict attention to symmetric perfect public equilibria (SPPE) in pure strategies. An SPPE is a symmetric strategy profile in which players condition their actions on the public history (not on their private information) at each point in time. Along the lines of Abreu, Pearce, and Stacchetti (1986), we transform the repeated game into an equivalent static game in which the payoffs are decomposed into the sum of a stage game payoff and a continuation value. After the realization of profits and the demand signal, in each period a public random variable is first drawn and then observed by all players. This public randomization device allows the two firms to coordinate on the punishment. Denote by $\underline{v} = 0$ the minmax of the repeated game, and by $\overline{v}(\delta, \alpha, \sigma_l, \sigma_h)$ the ex-ante maximal payoff. Then the set of payoffs supported by SPPE is $E_S(\delta, \alpha) = [\underline{v}, \overline{v}(\delta, \alpha, \sigma_l, \sigma_h)]$, which is compact, non-empty and convex. Moreover, an SPPE that supports the ex-ante maximal payoff $\overline{v}(\delta, \alpha, \sigma_l, \sigma_h)$ always exists. We focus on this optimal SPPE because it is Pareto-dominant from the point of view of the firms.

This optimal equilibrium can be implemented by randomizing only between the two extremal points of the set $E_S(\delta, \alpha)$. Firms start playing the monopoly price and, depending on the public information, they will stick to that strategy with a certain probability, and move to Nash reversion with the complementary probability. Formally, one of four events, $i = 1, \ldots, 4$, will occur at each stage game, where π_i denotes Event i's probability:

Event i	D	S	Probability π_i
1	1	1	$(1-\alpha)\sigma_h$
2	1	0	$(1-\alpha)(1-\sigma_h)$
3	0	0	$\alpha\sigma_l$
4	0	1	$\alpha(1-\sigma_l)$

If both firms collude, then the public history observed by both firms allows them to distinguish each of the four events. Denoting by β_i the probability of Nash reversion following Event i, the optimal collusive equilibrium can be written as the solution to the following problem:

$$\max_{\{\beta_i\}_{i=1}^4} v = (1-\alpha)\Pi^m/2 + \delta \sum_{i=1}^{4} \pi_i \left[(1-\beta_i)v + \beta_i \underline{v}\right]$$

subject to:

(1) $v \geq (1-\alpha)\Pi^m + \delta\left\{(\pi_2+\pi_3)\left[(1-\beta_3)v + \beta_3\underline{v}\right] + (\pi_1+\pi_4)\left[(1-\beta_4)v + \beta_4\underline{v}\right]\right\}$

(2) $\{\beta_i\}_{i=1}^4 \in [0,1]$

Constraint (1) represents the firms' incentive compatibility constraint: collusion is sustainable if the collusive payoff, v, is at least as high as the payoff from cheating. If a firm cheats while the other continues to collude, it can appropriate the full monopoly profit Π^m, provided demand is high in the period when cheating occurs. In any case, the firm that was cheated on will make zero profits. With the unconditional probability that the signal indicates low demand, $\Pr(S=0) = \pi_2 + \pi_3$, the other firm will believe that Event 3 has occurred, so that Nash reversion will be triggered with probability β_3. Analogously, with probability $\Pr(S=1) = \pi_1 + \pi_4$, the public history is identical to the one that would arise after Event 4, and so Nash reversion will be triggered with probability β_4.

Proposition 1 *If demand signals are available,*

(i) The collusive equilibrium yielding maximal payoff $\overline{v}(\delta, \alpha, \sigma_l, \sigma_h)$ *exists for* δ *arbitrarily close to* 1 *iff* $\alpha < \frac{\sigma_h}{1+\sigma_h-\sigma_l}$.

(ii) The equilibrium strategies are as follows: firms never punish if they both make profits of $\Pi^m/2$*, or if they make zero profits and the demand signal indicates that demand was low, i.e. they optimally set* $\beta_1^* = \beta_2^* = \beta_3^* = 0$*. If they make zero profits and the demand signal indicates that demand was high, they will switch to Nash reversion with probability*

$$\beta_4^* = \frac{1-\delta}{\delta\left[(1-\alpha)\,\sigma_h - \alpha\,(1-\sigma_l)\right]}.$$

Proof: see appendix. □

It is quite intuitive that the firms will not punish if they both make positive profits: if a firm makes profits of $\Pi^m/2$, it can immediately infer that the other firm colluded as well, i.e. there is no inference problem. More interestingly, I show that whenever firms make zero profit, and the demand signal indicates that demand was low, it is optimal not to punish. Given that the signal is imperfect, it is not obvious that it is always optimal to set $\beta_3 = 0$. One could imagine a situation where firms punish with strictly positive (though possibly different) probabilities both when $S = 0$ and when $S = 1$. However, in the proof of Proposition 1, I show that firms can always increase their payoffs if they trade off punishment when $S = 0$ against punishment when $S = 1$. More precisely, v unambiguously increases whenever firms reduce β_3 while increasing β_4 by just enough to keep the incentive constraint unchanged.

The benchmark case without signals Consider now the same situation, but without any demand signals. Then, the only event that firms can condition punishment on is the profit realization.

$\max_{\gamma_1,\gamma_2} v = (1-\alpha)\,\Pi^m/2 + \delta\left\{(1-\alpha)\left[(1-\gamma_1)\,v + \gamma_1 \underline{v}\right] + \alpha\left[(1-\gamma_2)\,v + \gamma_2 \underline{v}\right]\right\}$
subject to:
(1a) $v \geq (1-\alpha)\,\Pi^m + \delta\left[(1-\gamma_2)\,v + \gamma_2 \underline{v}\right]$
(2a) $\gamma_1, \gamma_2 \in [0,1]$

As shown in Amelio and Biancini (2007), firms will never find it optimal to punish when they make positive profits, while punishing with positive probability whenever they realize zero profits. The solution to the optimization problem without demand signals can be characterized as follows (see Amelio and Biancini (2007) for the proof):

(i) The collusive equilibrium yielding maximal payoff $\overline{v}\,(\delta,\alpha)$ *exists for* δ *arbitrarily close to* 1 *iff* $\alpha < \frac{1}{2}$.

(ii) The equilibrium strategies are as follows: firms never punish if they both make profits of $\Pi^m/2$*, i.e. they optimally set* $\gamma_1^* = 0$*. If they make zero profits, they will switch to Nash reversion with probability*

$$\gamma_2^* = \frac{1-\delta}{\delta\,(1-2\alpha)}.$$

I fist inspection of the two maximization problems shows that the introduction of signals has two distinct effects:

(i) The value of collusion increases when signals are available: If the signal correctly indicates low demand, punishment will be avoided, which increases the probability of continuing the collusive phase next period.

(ii) The value of defection changes as well (in fact, it increases) because a defecting firm now has a higher probability of getting away with the defection: If demand was high, but the signal wrongly indicates low demand, or instead demand was low, and the signal correctly indicates low demand, punishment will not be triggered.

The two effects therefore work in opposite directions: they make both compliance and defection more attractive, and it is not obvious which of these effects will dominate.

4 Equilibria with and without signals

We will now study how the introduction of signals into the game affects the existence of collusive SPPEs and their properties.

We argued above that if δ can be arbitrarily close to 1, the collusive equilibrium will exist

(i) with signals: iff $\alpha < \frac{\sigma_h}{1+\sigma_h-\sigma_l} \equiv \alpha_S$

(ii) without signals: iff $\alpha < \frac{1}{2} \equiv \alpha_{noS}$

Comparing the two upper bounds on α, we find the following:

Proposition 2 *For δ arbitrarily close to 1, the range of values of α compatible with collusion is larger when demand signals are available, i.e. $\alpha_S > \alpha_{noS}$. If signals are sufficiently accurate, collusion can be sustained for any $\alpha \in [0, 1)$.*

Proof: We claim that

$$\frac{\sigma_h}{1+\sigma_h-\sigma_l} > \frac{1}{2}$$

This expression simplifies to

$$\sigma_h + \sigma_l > 1$$

which always holds by our assumption that the signals are informative, i.e. $\sigma_l > \frac{1}{2}$ and $\sigma_h > \frac{1}{2}$. Note that as $\sigma_l \to 1$, we have that $\alpha_S \to 1$, which concludes the proof of Proposition2. $\square$

Let us now turn to the minimum discount factors required to sustain collusion with and without signals. Recall that we must have $\beta_4^* \leq 1$. This condition can be rearranged to read

$$\delta \geq \frac{1}{1+(1-\alpha)\,\sigma_h - \alpha\,(1-\sigma_l)} \equiv \delta_S$$

where δ_S is the lower bound on δ for collusion to be sustainable when signals are available.

The corresponding expression for the game without signals derives from $\gamma_2^* \leq 1$, and reads

$$\delta \geq \frac{1}{2\,(1-\alpha)} \equiv \delta_{noS}$$

Comparing the two lower bounds on δ, we find that signals have an ambiguous impact on the minimum discount factor: For low levels of α, firms will have to be more patient under signals than without signals:

Proposition 3 *Signals will raise the minimum discount factor required to sustain collusion whenever*

$$\alpha < \frac{1-\sigma_h}{1-\sigma_h+\sigma_l}$$

and will reduce the minimum discount factor otherwise.

Proof: Rearranging the inequality

$$\delta_S = \frac{1}{1+(1-\alpha)\,\sigma_h - \alpha\,(1-\sigma_l)} > \frac{1}{2\,(1-\alpha)} = \delta_{noS}$$

we obtain the condition on α as stated in Proposition 3. $\square$

We can now state the main result of our analysis:

Proposition 4

(i) If $\alpha \geq \frac{\sigma_h}{1+\sigma_h-\sigma_l}$, collusive equilibria do not exist even if demand signals are available.

(ii) If $\alpha \in \left[\frac{1}{2}, \frac{\sigma_h}{1+\sigma_h-\sigma_l}\right)$, demand signals allow for collusion to be sustained where this is not possible without signals.

(iii) If $\alpha \in \left[\frac{1-\sigma_h}{1-\sigma_h+\sigma_l}, \frac{1}{2}\right)$, collusion can be sustained with or without signals, but signals facilitate collusion by reducing the minimum discount factor required to sustain collusion.

(iv) If $\alpha < \frac{1-\sigma_h}{1-\sigma_h+\sigma_l}$, collusion can be sustained with or without signals, but signals raise the minimum discount factor required to sustain collusion.

Proof: follows from Propositions 2 and 3, where $\frac{1-\sigma_h}{1-\sigma_h+\sigma_l} < \frac{1}{2}$ is implied by our assumption that the signals are informative, i.e. $\sigma_l > \frac{1}{2}$ and $\sigma_h > \frac{1}{2}$.$\square$

The last part of Proposition 4 is the key result of this paper. Intuitively, the availability of signals affects the minimum discount factor in two ways: First, signals reduce δ_S by allowing firms to reduce the probability of Nash reversion when a negative demand shock occurred in a collusive period. Second, signals increase δ_S because a firm which undercuts has a higher chance to get away with it, and so the temptation to defect increases. Now, for low levels of α, this second (negative) effect will dominate the first (positive) effect, leading to an overall increase in δ_S.

Figure 1 illustrates Proposition 4 graphically for the case where $\sigma_h = \sigma_l$ (i.e. signal precision is the same for both demand states). This assumption reduces the relevant parameter space to two dimensions and hence facilitates graphical representation.[3] Condition $\alpha < \frac{\sigma_h}{1+\sigma_h-\sigma_l}$ then simplifies to $\alpha < \sigma_h$, while condition $\alpha < \frac{1-\sigma_h}{1-\sigma_h+\sigma_l}$ simplifies to $\alpha < 1-\sigma_h$.

INSERT FIGURE 1 HERE

Finally, let us compare the expected discounted present value of collusion with and without signals.

Proposition 5 *The expected discounted present value of collusion is always higher with signals than without signals.*

Proof: Inserting the optimal probabilities $\beta_1^* = \beta_2^* = \beta_3^* = 0$ and β_4^* from Proposition 1 into the objective function, we obtain the maximal payoff when signals are available as

$$\overline{v}\left(\delta, \alpha, \sigma_l, \sigma_h\right) = \frac{\Pi^m}{2} \frac{\left(1-\alpha\right)\sigma_h - \alpha\left(1-\sigma_l\right)}{\sigma_h\left(1-\delta\right)}$$

while the maximal payoff without signals is

$$\overline{v}\left(\delta, \alpha\right) = \frac{\Pi^m}{2} \frac{1-2\alpha}{1-\delta}$$

The inequality $\overline{v}\left(\delta, \alpha, \sigma_l, \sigma_h\right) > \overline{v}\left(\delta, \alpha\right)$ reduces to $\sigma_l + \sigma_h > 1$, which holds by our assumption that the signals are informative, i.e. $\sigma_l > \frac{1}{2}$ and $\sigma_h > \frac{1}{2}$.$\square$

5 Discussion

A canonical example of a trade association helping in enforcing a collusive arrangement is the Sugar Institute analyzed by Genesove and Mullin (2001). This

[3] For general values of σ_h and σ_l, these conditions are not linear in signal precision. Thus, the four regions into which Proposition 4 divides the parameter space will not generally be of equal size.

trade association was formed by 14 firms comprising nearly all the cane sugar refining capacity in the United States, and operated from December 1927 until 1936. Among other things, it collected information on its members' business conduct through its own investigators, and if it found indications of cheating, provided a forum for accusation and rebuttal.

One interesting analogy to our model is that the reported information was not fully reliable:

> The accusation could be factually wrong: a concession on one barrel of caked sugar was wrongly reported as a concession on a much larger amount of powdered sugar by a Sugar Institute investigator. Or a firm employee or direct broker may simply have made an error in invoicing or shipping. (p. 389)

Most significantly, the punishment mechanism of the cartel differed markedly from the predictions of collusion theory in that retaliation was not immediate; instead, "the Sugar Institute served as a court", providing a mechanism "by which firms can first judge whether cheating has in fact occurred before taking action." (p. 389) In other words, punishment was conditioned on "additional evidence" that went well beyond a first suspicion: "Market share is a noisy indicator of cheating; and with direct evidence available, the refiners evidently preferred to rely on that instead." (p. 394)

The authors argue that this approach "delayed, and perhaps restricted, retaliation against violations of the agreement" (p. 387). They quote several instances where deviators got away with what was very likely an attempt to cheat. "...Firms accept some cheating so as not to punish inappropriately." (p. 393) While it remains mysterious how cheating can actually occur along the collusive path, the model we analyzed above stresses precisely this trade-off between Type I and Type II error, and how signals tilt the trade-off in favor of less punishment, at the risk of letting deviators get away with it.

Finally, it is noteworthy that the Sugar Institute ceased to operate in 1936, when the Supreme Court ruled its practices illegal. However, judging from the

Figures provided on p. 382, the Lerner Index did not change significantly in subsequent years (and it certainly did not return to the low levels preceding the formation of the Sugar Institute). One interpretation could be that the collusive equilibrium remained sustainable even though the industry was deprived of the "services" provided by its trade association.

The most important implication of our analysis for antitrust policy is therefore that removing a monitoring device may not be sufficient to put an end to collusion in an industry. Without any accompanying measures, collusion may in fact continue even after such an intervention. Collusion will certainly be less profitable than before (demand information unambiguously raises the net present value of collusion), but ironically, collusion may actually become easier (and not harder) to sustain. Thus, a harsh stance against information exchange among firms is important, but must be complemented by further policies to make sure that cartels cease to operate.

6 Conclusion

We analyzed a symmetric Bertrand duopoly model with uncertain demand, where one firm's prices are unobservable to its competitor, but firms receive noisy public signals about the state of demand. First, I show that the optimal collusive strategy is as follows: Firms never punish if they both make positive profits, or if they make zero profits and the demand signal indicates that demand was low; if they make zero profits and the demand signal indicates that demand was high, they will switch to Nash reversion with strictly positive probability.

Next, I studied the existence of such collusive equilibria compared to the benchmark case without demand signals. I found that for a discount factor arbitrarily close to 1, these signals allow for tacit collusion to be sustainable if the probability of low-demand states is high, i.e. in cases where collusion would have been impossible absent signals.

On the other hand, if the probability of negative demand shocks is low, there are actually cases where tacit collusion will be more difficult to sustain with signals (in the sense that firms will have to be more patient) than without signals. The reason is that in order to take advantage of the information that becomes available, firms need to soften the threat of punishment, which may increase the temptation to undercut the rival, thus creating severe incentive problems.

Nonetheless, the expected discounted present value of collusion is always higher with signals than without signals.

Revisiting the Sugar Institute Case studied in Genesove and Mullin (2001), we saw that the enforcement problems that this particular cartel seems to have faced strikingly recall the ones studied in this paper. We concluded that a policy which fights monitoring devices will always reduce the profitability of collusion, but may not always be successful in breaking collusion; on the contrary, collusion may actually be facilitated by the removal of demand information.

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7 Appendix

Proof of Proposition 1:

We start with part (ii) of Proposition 1. Observe that $\underline{v} = 0$. Simplify and rearrange the objective function,

$$v = (1-\alpha)\,\Pi^m/2 + \delta \sum_{i=1}^{4} \pi_i \left[(1-\beta_i)\,v + \beta_i \underline{v}\right]$$

to read

$$v_{OF} = \frac{(1-\alpha)\,\Pi^m/2}{1-\delta \sum_{i=1}^{4} \pi_i\,(1-\beta_i)}$$

(the subscript OF will help us to distinguish the objective function from the incentive constraint, IC).

The value of collusion, v, is strictly decreasing in β_1 and β_2:

$$\frac{\partial v_{OF}}{\partial \beta_i} = -\frac{(1-\alpha)\,\Pi^m/2}{\left[1-\delta\sum_{i=1}^{4}\pi_i\,(1-\beta_i)\right]^2}\delta\pi_i < 0 \text{ for } \beta_i \in \{\beta_i\}_{i=1}^4$$

Likewise, rearrange the incentive constraint (1) to read

$$v \geq \frac{(1-\alpha)\,\Pi^m}{1-\delta\,\{(\pi_2+\pi_3)\,(1-\beta_3)+(\pi_1+\pi_4)\,(1-\beta_4)\}}$$

We see that β_1 and β_2 enter the incentive constraint only on the left-hand side, through v, while they do not affect the value of defection, i.e. the right-hand side of (1). Hence, reducing β_1 and β_2 both increases the objective function and relaxes the incentive constraint. Therefore, it must be optimal to set β_1 and β_2 to their lowest possible value, i.e. $\beta_1^* = \beta_2^* = 0$.

We will now show that $\beta_3^* = 0$. Setting $\beta_1^* = \beta_2^* = 0$ and inserting for $\{\pi_i\}_{i=1}^4$, the objective function simplifies to

$$v_{OF} = \frac{(1-\alpha)\,\Pi^m/2}{1-\delta\,(1-\alpha)-\delta\alpha\sigma_l\,(1-\beta_3)-\delta\alpha\,(1-\sigma_l)\,(1-\beta_4)}$$

Given that $\frac{\partial v_{OF}}{\partial \beta_i} < 0$ for β_3 and β_4, the incentive constraint will be binding under any solution of our maximization problem. Rewrite the incentive constraint (1) as

$$v_{IC} = \frac{(1-\alpha)\,\Pi^m}{1-\delta\,\{[(1-\alpha)\,(1-\sigma_h)+\alpha\sigma_l]\,(1-\beta_3)+[(1-\alpha)\,\sigma_h+\alpha\,(1-\sigma_l)]\,(1-\beta_4)\}}$$

Now, take the total differential of the incentive constraint:

$$dv_{IC} = \frac{\partial v_{IC}}{\partial \beta_3}d\beta_3 + \frac{\partial v_{IC}}{\partial \beta_4}d\beta_4 = 0$$

to solve for the marginal rate of substitution between β_3 and β_4:

$$\begin{aligned}\frac{d\beta_3}{d\beta_4} &= -\frac{\partial v_{IC}/\partial \beta_4}{\partial v_{IC}/\partial \beta_3} \\ &= -\frac{(1-\alpha)\,\sigma_h+\alpha\,(1-\sigma_l)}{(1-\alpha)\,(1-\sigma_h)+\alpha\sigma_l} < 0\end{aligned}$$

Next, evaluate the total change in the objective function when β_3 and β_4 are traded off against each other according to this marginal rate of substitution:

$$\begin{aligned} dv_{OF} &= \frac{\partial v_{OF}}{\partial \beta_3} d\beta_3 + \frac{\partial v_{OF}}{\partial \beta_4} d\beta_4 \\ &= \frac{\partial v_{OF}}{\partial \beta_3} \left(-\frac{(1-\alpha)\sigma_h + \alpha(1-\sigma_l)}{(1-\alpha)(1-\sigma_h) + \alpha\sigma_l} d\beta_4 \right) + \frac{\partial v_{OF}}{\partial \beta_4} d\beta_4 \\ &= \frac{(1-\alpha)\Pi^m/2}{[D]^2} \delta\alpha d\beta_4 \left[\sigma_l \frac{(1-\alpha)\sigma_h + \alpha(1-\sigma_l)}{(1-\alpha)(1-\sigma_h) + \alpha\sigma_l} - (1-\sigma_l) \right] \end{aligned}$$

where D denotes the denominator of v_{OF}. Now, our assumptions on parameters imply that

$$\frac{(1-\alpha)\Pi^m/2}{[D]^2} \delta\alpha > 0$$

and that

$$\sigma_l \frac{(1-\alpha)\sigma_h + \alpha(1-\sigma_l)}{(1-\alpha)(1-\sigma_h) + \alpha\sigma_l} - (1-\sigma_l) > 0$$

(the latter reduces to $(1-\alpha)(\sigma_h + \sigma_l - 1) > 0$, which is indeed satisfied by our assumption that the signals are informative, $\sigma_l > \frac{1}{2}$ and $\sigma_h > \frac{1}{2}$.)

Hence, we can conclude that

$$sign(dv_{OF}) = sign(d\beta_4)$$

i.e. a reduction in β_3, matched by an increase in β_4 just sufficient for the incentive constraint to remain binding, will unambiguously increase the objective function. Therefore, it must be optimal to set β_3 to its lowest possible value, i.e. $\beta_3^* = 0$.

It remains to show the solution for β_4^*. Insert $\beta_3^* = 0$ into v_{OF} and v_{IC}, and equate the two to solve for β_4^* as

$$\beta_4^* = \frac{1-\delta}{\delta[(1-\alpha)\sigma_h - \alpha(1-\sigma_l)]}$$

Let us now turn to part (i) of Proposition 1. For the expression above to be a valid solution, we must have $\beta_4^* \in (0,1]$. Recall that $\delta \in (0,1)$, so that $(1-\delta)/\delta > 0$. Thus, for $\beta_4^* > 0$ to be satisfied, we must have that

$$(1-\alpha)\sigma_h - \alpha(1-\sigma_l) > 0$$

This expression can be rearranged to read

$$\alpha < \frac{\sigma_h}{1 + \sigma_h - \sigma_l}$$

as stated in Proposition 1. Now, we must also have $\beta_4^* \leq 1$. This condition can be rearranged to read

$$\delta \geq \frac{1}{1 + (1-\alpha)\,\sigma_h - \alpha\,(1-\sigma_l)}$$

Given that $(1-\alpha)\,\sigma_h - \alpha\,(1-\sigma_l) > 0$, the right-hand side of this expression is strictly smaller than 1. Thus, if δ can be arbitrarily close to 1, the condition $\beta_4^* \leq 1$ will always be satisfied. This concludes the proof of Proposition 1.$\square$