Detecting Cartels*

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Abstract

In reviewing the theoretical and empirical literature on collusion, this paper distills methods for detecting cartels and distinguishing collusion from competition.

1 Introduction

There are two general ways in which cartels are detected: observing the means by which firms coordinate and observing the end result of that coordination. The means of coordination is some form of direct communication and some cartels have been detected by observing that communication. This could entail someone party to the cartel coming forward or an employee who stumbles across evidence or the discovery of documents associated with a tentative merger. Detection by observing the market impact of that coordination refers to suspicions emanating from the pattern of firms' prices or quantities or some other aspect of behavior. Buyers could become suspicious because of a parallel

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movement in prices or an inexplicable increase in prices. A sales representative for a colluding firm may become suspicious because he is instructed not to bid for the business of certain potential customers (as part of a customer allocation scheme) or not to offer reasonable price concessions when business might be lost to other firms.[1]

Though there are then many ways in which cartels can be detected, this chapter is about the role of economic analysis in detection. More specifically, how we can use economic data - prices, quantities, market shares, demand shifters, cost shifters, and the like - and to discriminate between collusion and competition so as to identify episodes of explicit collusion. It is useful to put the problem of detection in the context of a multi-stage process involving screening, verification, and prosecution. The purpose of *screening* is to identify markets where collusion is suspected. It is a form of triage designed to identify industries for closer scrutiny. *Verification* entails systematically trying to exclude competition as an explanation for observed behavior and to provide evidence in support of collusion. Though screening may entail looking at price patterns, verification requires controlling for demand and cost factors and any other variables necessary to distinguish collusion and competition. Finally, the task at the stage of *prosecution* is to develop economic evidence that is sufficient to persuade the courts that there has been a violation of the law. One may interpret this exercise as the same as verification though with a different set of standards. With respect to U. S. case law, economic evidence is not typically sufficient to prove guilt; there must be some evidence of coordination. The focus of this chapter is limited to the role of economic analysis in screening and verification.

The issue of systematically searching for illegal activity is a common one. In identifying fraudulent tax returns, tax authorities - such as the U.S. Internal Revenue Service - are proactive in developing models which flag certain returns as worthy of investigation. In being on the look out for insider trading, securities authorities - such as the U.S. Securities and Exchange Commission - *ex post* monitor volume leading up to a significant announcement. In tracking down fraud, credit card companies use statistical models to identify aberrations in spending patterns. As these cases attest, government agencies and private corporations actively search for illegal activity. However, there are really no analogous policies when it comes to illegal cartels. Though there have been various attempts over time, it is fair to say that economic analysis - whether it occurs in government, academia, or private consulting - has largely been a non-player in the discovery of cartels. Economic analysis can be instrumental in making the prosecutorial case and is essential

[1] A survey of the manner in which some cartels were detected is provided in Hay and Kelley (1974).

in assessing damages but it has not been a standard tool for detecting cartels. The objective of this chapter is to review what methods - theoretical and empirical - are available for engaging in cartel detection and to suggest how economic analysis may play a bigger role. Though it is currently hard to imagine economic analysis alone being used for the discovery and prosecution of cartels, a more active role in identifying industries worthy of closer inspection is certainly within reach.

Section 2 identifies four general methods for detecting collusion and reviews the (small) literature which implements them. Using the theoretical literature on collusive pricing, Section 3 distills collusive markers based on price and market share. Section 4 discusses the issue of how easily a cartel can beat a test for collusion. The possibility of developing a more aggressive screening policy is discussed in Section 5, while Section 6 concludes.

2 Empirical Methods for Detecting Cartels

It is important to be clear as to what it is we are searching for. The objective is not to identify industries with high price-cost margins but rather to uncover prosecutoriable cases of collusion. In light of current antitrust practice, this largely means explicit collusion - where firms have engaged in direct communication and obvious coordination - rather than tacit collusion - where they are able to coordinate through some mutual understanding and without the aid of direct communication. From both a legal and economic perspective, we think of explicit collusion as a discrete event; firms are or are not explicitly colluding. Of course, the impact of collusion, whether explicit or tacit, on price and welfare can be of varying degrees and is certainly pertinent to the calculation of damages and the appropriate enforcement policy. Still, our task is to detect the presence of a cartel in the sense that firms are explicitly coordinating their behavior through illegal means of communication.

In identifying episodes of collusion, verification is a data-intensive and time-intensive process which requires controlling for the many determinants of behavior. It can involve estimating a competitive benchmark and comparing the behavior of suspected colluders to it. It can involve estimating both collusive and competitive models to see which better fits the data. It is not practical to engage in such an exercise except when there are already some suspicions; some evidence that collusion may be afoot in an industry.

It is the role of screening to identify candidates for verification. In most antitrust cases, screening doesn't occur through economic analysis but rather through such avenues as buyer complaints, upset competitors, and the corporate leniency program. Still, economic analysis can serve a screening function. Screening differs from verification in that screening identifies "suspicious" behavior but does not provide "conclusive" evidence of collusion. It may establish that behavior is inconsistent with a class of competitive models though does not address the question of whether it is consistent with some collusive model. It may show that there has been a structural break in behavior while leaving unaddressed whether it is due to the formation of a cartel or some other change. Like verification, screening can be intensive in terms of data, modelling, and estimation. When it is, it is then something that is not practical to use without some other evidence suggesting collusion may be present.

In this section, we will review various empirical methods for detecting collusion. Match a clever economist with a suspected cartel and a unique method of detecting collusion may emerge. Indeed, there are apt to be useful methods hidden in consultants' drawers or buried in court documents. Limiting ourselves to the published literature, we will review four methods for detecting collusion and these methods are based on asking the following questions: A) Is behavior inconsistent with competition?; B) Is there a structural break in behavior?; C) Does the behavior of suspected colluding firms differ from that of competitive firms?; and D) Does a collusive model fit the data better than a competitive model? Methods A and B are generally first-stage methods in that they do not provide evidence of collusion but rather evidence that doesn't sit well with a competitive model. Methods C and D directly speak to contrasting competition and collusion as alternative explanations of firm behavior. A key difference between those two methods is that in Method D the competitive benchmark is estimated using data from suspected colluding firms, while in method C it is done using data from unsuspected firms (or markets). These methods are reviewed in Sections 2.1-2.4 with a critical discussion being provided in Section 2.5.[2]

2.1 Is Firm Behavior Inconsistent with Competition?

The approach here is based on identifying properties of behavior that would always hold under competition - or at least for a wide class of competitive models - and to test whether they are present for a particular industry. The null hypothesis is competition

[2] The term "competition" will mean that firms are not colluding and does not necessarily mean perfect competition. Whether competition includes tacit collusion is left unanswered as the distinction between tacit and explicit collusion is a murky one in the economics literature. We will use "competitive" and "non-collusive" interchangeably.

and the empirical task is to accept or reject that hypothesis. Of course, rejection does not imply collusion; only that behavior is inconsistent with the class of competitive models specified. As we'll see, this approach can be quite complimentary to later ones that test for collusion in that they can be used to identify which firms may be members of a cartel by determining whose behavior is inconsistent with competition. These properties could be how firms' prices are related - for example, are they correlated when they should be independent? - or how a firm's price responds to cost and demand shocks - for example, do prices respond appropriately to cost?

This approach of testing for consistency of behavior with a competitive model is conducted in Porter and Zona (1993, 1999) as well as in Bajari and Ye (2003) who push it further. We'll focus on the latter paper and cover Porter and Zona (1993, 1999) in the context of contrasting the behavior of suspected colluders with a competitive benchmark.

Bajari and Ye (2003) The setting is a first-price sealed bid procurement auction in which the product or service is homogeneous and bidders costs are independent.[3] Bidder i's cost valuation has cdf $F(c_i \mid z_i, \theta) : [\underline{c}, \overline{c}] \rightarrow [0, 1]$ where θ is a vector of parameters common across bidders and z_i is a vector of publicly observed independent variables which, though unique to firm i, may be correlated across firms. The competitive model is based on the unique equilibrium to the following game. Bidder i's expected profit from bidding b_i is

$$(b_i - c_i) \prod_{j \neq i} \left[1 - F_j \left(B_j^{-1}(b_i)\right)\right]$$

which is the gain from winning, $b_i - c_i$, times the probability that bidder i wins where $B_j(\cdot)$ is the bidding function of j. Competitive bids can then be correlated if one fails to control for z_i. But, by controlling for them, costs and thereby bids are independent. Thus, it is a (conditional) independent private values (IPV) setting.

The competitive model predicts that, after controlling for publicly available information $(z_1, \ldots, z_N)$, firms' bids are independent; more specifically, the unexplained part of one firm's bid is independent of the unexplained part of another firm's bid. Secondly, firms' bids are exchangeable: A permutation of the publicly available information analogously permutes the bids. In other words, firms' bidding functions are identical. Note that these properties do not pertain to a firm but rather collections of firms. The competitive theory is being used in terms of what it predicts about the relationship among

[3] For some related work on this method, see Bajari (2001) and, for a more general discussion, Bajari and Summers (2002). Hendricks and Porter (1989) is an early general discussion of detecting collusion at auctions.

firms' bids. For example, it is not being proposed to determine whether a firm's bid is increasing in the distance between its office and the project site (which would be natural as then transportation costs are higher) but rather whether firms' bids respond the same way to distance.

The implementation approach is to estimate a pricing equation for each firm and then test whether independence and exchangeability holds for various (perhaps all) subsets of firms. A test for independence determines whether the unexplained part of each firm's bids are independent. A test for exchangeability determines whether firms' estimated coefficients are the same.

Bajari and Ye (2003) use this approach on procurement auction data for seal coating (which is a highway maintenance process) for projects in Minnesota, North Dakota, and South Dakota during 1994-98. Their data set has 138 projects for which there are eleven main companies. These contracts are awarded through a sealed bid auction with the contract going to the lowest bidder. As they have engineering estimates of the cost of the project, the dependent variable is the ratio of the bid of firm i on project t, $BID_{i,t}$, to the engineering cost estimate for project t, EST_t. The bid equation is:

$$\frac{BID_{i,t}}{EST_t} = \beta_0+\beta_{i1}LDIST_{I,T}+\beta_{i2}CAP_{i,t}+\beta_{i3}MAXP_{i,t}+\beta_{i4}LMDIST_{i,t}+\beta_{i5}CON_{i,t}+\epsilon_{i,t},.$$

$LDIST_{i,t}$ is a measure of the distance between firm i and project t; cost (and thus a competitive firm's bid) is expected to be increasing in it. In procurement auctions, capacity is an important factor in that it can influence production cost - if cost is increasing as capacity tightens - but also opportunity cost as a project won today may prevent the firm from bidding on a potentially more lucrative project tomorrow. $CAP_{i,t}$ is utilized capacity of firm i at the time of project t which is measured as the ratio of the firm's total winning contracts up to the time of auction t to the firm's total of winning contracts in the entire season. $CON_{i,t}$ is the proportion of work done (by dollar volume) by firm i in the state where project t is located and is intended to capture familiarity with local regulators and local material suppliers. Finally, $LMDIST_{i,t}$ measures the minimum distance among rivals and $MAXP_{i,t}$ is maximal free capacity among rivals; both pertain to the competitiveness of firm i's environment in terms of its rivals' cost.

The estimated coefficients are found to be sensible; a firm's bid is increasing (and statistically significant) in the log of distance, used capacity, and minimum distance among rivals and is decreasing in concentration. The estimated coefficient on the maximal free capacity of rivals is not significantly different from zero.

To test for independence, the residuals are calculated for each firm's bid function, $\epsilon_{i,t}$.

A test of independence between firms i and j is testing the hypothesis that the coefficient of correlation for $\epsilon_{i,t}$ and $\epsilon_{j,t}$ is zero. Among the 23 pairs of 11 largest firms that have at least four bids in the same auction, the null hypothesis of independence cannot be rejected at the 5% level in all but four cases. However, of these four pairs, three of them only bid against each other at most two or three times a year which, it is argued, doesn't suggest they interact enough to make collusion worthwhile. This leaves firms 2 and 4 as the lone candidate for being a cartel.

Exchangeability means that the independent variables enter the firm's bid function in a symmetric way so the hypothesis is: $\beta_{ik} = \beta_{jk} \forall i \neq j, \forall k$. They conduct a test for exchangeability among all 11 main firms - thus running a regression that pools all 11 firms - and also test for it for each pair of main firms - pooling only those two firms. The null hypothesis is rejected at the 5% level only for when all 11 main firms are pooled and when firms 2 and 5 are pooled.

In sum, the analysis reveals that all pairs of firms satisfy both the test of independence and exchangeability except for firms 2 and 4 and firms 2 and 5 . Thus, this approach not only suggests that collusion may be present - as some firms act contrary to a competitive model - but also which firms may be colluding. Out of the 11 firms in their data, two candidate cartels are identified: firms 2 and 4 and firms 2 and 5. Given that there are many feasible cartels, this is a highly useful exercise and is complementary to later approaches to be reviewed.[4]

The next natural question is whether the observed departures from competition are consistent with some model of collusion. Consider a collusive model in which the identities of the cartel's members is common knowledge to the other bidders and the cartel bids optimally using the lowest cost among the cartel members. Further suppose that cartel firms are submitting complementary bids that exceed the bid of the designated cartel firm. This could lead to a lack of independence if, for example, complementary bids are some multiple of the designated firm's bid. It could also lead to a failure of exchangeability. If two cartel members don't compete against each other then this could mean that factors affecting the cost of one doesn't affect the bid of the other. This will be discussed in greater depth later. A second question is whether firms could be colluding and still satisfy independence and exchangeability. The answer is clearly "yes" and all they have to do is to proportionately scale their "competitive" bids. This is an important point to

[4] As supporting ancillary evidence, in the late 1980s (prior to this data set), firm 2 received a prison sentence for bid rigging while firms 4 and 5 paid damages for colluding with firm 2.

which we'll return later.

2.2 Has There Been a Structural Break in Firm Behavior?

A second general approach to identifying collusion is to look for a structural break in firm behavior. This could be associated with the formation of a cartel but also with its demise. In both cases there ought to be a discrete change in firms' pricing functions. As opposed to the other methods described in Section 2, this one requires data outside of the time of suspected collusion. While it can be implemented without prior information as to what patterns are consistent with collusion, theory and past evidence on cartels would enhance its power by suggesting what properties to focus upon and what we ought to observe if indeed a cartel has formed.[5] Has average price changed? Has the relationship between a firm's price and cost changed? Has the relationship among firms' prices changed? Has the variance of price and market share changed? Of course, econometric evidence of structural change is not conclusive evidence of collusion as one hasn't distinguished it from other sources of a break. It is then appropriate to think about this method as a screening device which, if indeed a structural break is found in the data, is to be followed with verification methods (which are described later in this section).

In testing for structural change, one can use the classical Chow test *if* there is prior information as to when a cartel may have formed (or when it may have collapsed). However, if observation of, say, a price series is used to identify a possible break in market conduct then the Chow test is inappropriate and can lead to spurious rejection of parameter stability. Thus, the prior information must not be the series for which one will be econometrically testing for a break in the process generating it.

Appropriate events for identifying a candidate breakpoint are those which either are conducive to cartel formation (that is, make collusion easier or more profitable) or are observed along with cartel formation (for example, events that allow the cartel to operate more effectively). It has been documented that trade associations are used as a cover for cartel meetings and, more to the point, trade associations have been created for that express purpose. For example, the Amino Acid Manufacturers International Association was formed by members of the lysine cartel (Connor, 2001) and the Oklahoma Highway Department only started receiving identical bids at procurement auctions some time after the Asphalt Refiners Association was formed (Funderburk, 1974). A test for a break in the relationship among firms' bids around the time of the creation of the association would

[5] Section 3 provides details on what theory suggests to look for.

be useful. Of course, one might expect structural change even if firms are not colluding. For example, the formation of an association could still lead to enhanced correlation of firms' prices because it promotes the exchange of information which homogenizes firms' beliefs. It is not clear, however, that such homogenization would lead to higher average prices. It is then important to consider the various implications of a trade association and identify those which are unique to collusion.[6]

There are other events that could contribute to cartel formation and thus serve as candidate breakpoints but, as above, one must be concerned that there will be structural change even if the event does not trigger collusion. Exit or merger (particularly of a maverick firm) could allow a cartel to form but exit will change the non-collusive solution as well. Though average price is predicted to rise whether or not a cartel forms, there may still be distinguishing effects of collusion; for example, cartel formation might predict more parallel behavior among firms, while non-collusion may have no such prediction. To properly address that question, one must deal with the endogeneity of the event towards understanding the factors behind it. For example, if a firm with an inferior technology exits and, as a result, technology is more uniform among the remaining firms then there might be more correlation among firms' prices because of the greater homogeneity in their cost-generating processes. All this serves as a note of caution but need not rule out using these events as a date for which one tests for structural change in firm behavior.

There are also certain events - such as entry - that provide candidate breakpoints for the collapse of a cartel. As a case in point, the growing expansion of Chinese manufacturers in the market for vitamin C eventually led to the collapse of the cartel in that market (Levenstein and Suslow, 2001). While, even under non-collusion, we expect to see a change in firms' prices in response to the expansion of new competitors, we don't expect to see a discrete change in that pricing relationship *unless* it causes a cartel to dismantle itself.

Though it presumes there is already some suspicions about the presence of a cartel, one can test for structural change at the time at which suspected colluding firms become aware of a government price-fixing investigation or private litigation because such is likely to lead to a collapse of the cartel. Abrantes-Metz, Froeb, and Taylor (2004) use that type of event and find a significant decrease in the price variance. These cartel-destabilizing events could even occur in other (related) markets as long as firms take it as a signal that the authorities might investigate them as well. On this point, Block, Nold, and Sidak (1981) find that a price-fixing case in the bread market for one city reduced the

[6] Kühn (2001) provides a nice discussion about communication practices in connection with collusion.

markups for bread in neighboring cities. While a comparison of prices before and after the launching of an investigation is often used to measure the impact of collusion on price,[7] it can be used to provide evidence of collusion as well.

Though it must be used cautiously, another method is to use one feature of the data to identify a possible breakpoint for structural change in some other feature of the data. For example, one may plot the average price series and "see" a date at which it begins to follow a rising trend. That date could then be used as a breakpoint to test whether there is a break in, say, the correlation between firms' prices. One needs to carefully consider whether this approach is biased towards finding evidence of structural change. It'll very much depend on the class of non-collusive price-generating processes that is specified.

Even if there is not a candidate breakpoint, econometric methods exist for determining whether there is an unknown time at which there is structural change. One approach goes back to Quandt (1960) which is to conduct a test for each possible breakpoint and then use the largest test statistic. The distribution theory for that test statistic has since been developed beginning with Andrews (1993).[8] Once again, finding evidence of structural change must then be followed with an examination of the properties of the change and whether it conforms with our understanding of collusive behavior.

A search for explicit collusion by identifying structural change may be confounded by the breakdown of tacit collusion. For suppose firms are currently tacitly colluding and a persistent demand shock hits that destabilizes the equilibrium. This could induce an abrupt shift to another equilibrium or a period of disequilibrium before a new equilibrium is reached. On this point, it is noteworthy that some cartels were preceded by abnormally low prices; such as the cartels in graphite electrodes (Levenstein and Suslow, 2001) and citric acid (Connor, 2001). One conjectured explanation is that firms were tacitly colluding but collusion fell apart due to some shock. Failure to get the industry back to some tolerable level of prices through tacit means may have induced explicit collusion.

There is another rationale for looking for structural breaks which is that sharp changes in price - inexplicable in light of cost and demand shifts - are consistent with theories of collusive pricing under imperfect monitoring, while not being easily reconcilable within a competitive theory. As originally established by Green and Porter (1984) for a context in which cartel members can only imperfectly monitor the behavior of each other, sustaining collusion may require periodic reversions to low prices as a form of punishment to induce

[7] For an analysis of how this approach - using post-cartel prices to estimate the impact of collusion on price - leads to underestimates of the effect of collusion, see Harrington (2003b).

[8] For a general discussion of econometric methods, see Hansen (2001).

compliance. In contrast to the preceding discussion, this argument provides a basis for looking for structural change even if the data is only available during the collusive regime because the breaks are part of a collusive solution. Such a collusive theory is the basis for an examination of a U.S. railroad cartel in the 1880s (Porter, 1983a). Using an econometric model with regime-switching, there was evidence of ten price wars which could not be adequately explained by cost and demand shocks. Though this approach does entail looking for structural change, it is better thought of as an example of the method described in Section 2.4 in that the model nests competition (the case of no regime switches) and collusion (the case of regime switches) and the issue is which model better fits the data.

Finally, this may be a natural point to discuss the role of estimated price-cost margins in cartel detection. If we use, say, an inexplicable *increase* in the price-cost margin as an indicator of collusion, why not then use a *high* price-cost margin as an indicator? To appreciate the pitfalls with such an approach, a Bayesian perspective is useful. Suppose the empirical frequency or probability of a cartel is α and the density function on the price-cost margin is $f^c(pcm)$ when there is a cartel and $f^{nc}(pcm)$ when there is not a cartel. Conditional on the observed price-cost margin, the posterior probability that there is a cartel is then

$$\frac{\alpha f^c(pcm)}{\alpha f^c(pcm) + (1-\alpha) f^{nc}(pcm)}$$

Even if $f^c(pcm)$ puts much more weight on high price-cost margins than $f^{nc}(pcm)$, this posterior probability is generally going to be small because reasonable estimates of α make it *very* small. Though we don't know what the frequency of cartels is in the economy, we do know the rate of discovered cartels and it is a tiny fraction of all markets. Even if high price-cost margins are associated with collusion, high price-cost margins can be present for many reasons in non-collusive industries - including inelastic firm demand (for example, due to highly differentiated products), patented technology, and high search costs for consumers - and these are much more likely than collusion. Many industries may have high price-cost margins but only a precious few appear to be cartelized. By comparison, sharp changes in the price-cost margin are not so easily rationalized by a non-collusive model. While big changes in demand and cost can do it, such changes ought to be observable and thereby can be taken account of. Screening for abrupt changes in price (or price-cost margins) is then likely to be a more effective screen - in picking up fewer false positives - than looking for high price-cost margins.

2.3 Does the Behavior of Suspected Colluding Firms Differ from that of Competitive Firms?

Firms were suspected of colluding at procurement auctions of asphalt contracts by the Oklahoma Highway Department (OHD) over 1954-65 (Funderburk, 1974). During the time of suspected collusion, bids were identical and, beginning in 1957, were constant at 10.25 cents/gallon. With identical bids, the OHD awarded the contract to the nearest firm to the job site in order to minimize the delivery costs incurred by the state which, it was argued, acted as a market allocation scheme. During the same time period, these suppliers made bids and won contracts in other states at an average price of only 6 cents/gallon and, furthermore, the uniformity in bids in Oklahoma was not observed there. It was estimated that the maximum freight cost for these Oklahoma contracts was 2.48 cents/gallon which meant that any of these firms could have won additional contracts with a price of 10.24 cents/gallon and, even if they absorbed freight costs, would receive a net price of 7.76 cents/gallon; exceeding the price of 6 cents these same firms bid in other states.

The approach just described involves comparing the behavior of suspected colluders with some competitive benchmark. In the case of asphalt contracts, the benchmark is comparable markets in which firms are not thought to be colluding; specifically, one has distinct geographic markets for the same product or service and firms are suspected of colluding in some but not all of those markets. Porter and Zona (1999) use this approach in examining collusion in school milk contracts. Alternatively, if there is prior information about the identities of the cartel members and the cartel is not all inclusive, a benchmark can be provided by the behavior of non-colluding firms. Even if there is no prior information, econometric methods such as those used in Bajari and Ye (2003) can identify possible colluders. Their analysis identified three firms among eleven that might be colluding which allows the other eight to serve as a competitive benchmark. A third benchmark is when data contains periods of suspected collusion but also of competition, such as before or after the suspected time of collusion. Data from the time of collusion, when collusion is thought to have temporarily broken down, is more problematic because this could be a price war as part of collusion in which case it need not be an appropriate competitive benchmark.

A common implementation of this approach is to estimate reduced form price equations by regressing price on cost and demand shifters; estimating a price equation for (suspected) cartel members and a price equation for non-colluding firms. One then conducts a test to determine whether they are statistically different. If they are statistically different then one wants to check that the non-colluding firms act in a manner consistent with a competitive model and the colluding firms act in a manner consistent with some model of collusion.

Porter and Zona (1993) The setting is a first-price sealed bid procurement auction as in Bajari and Ye (2003). Bidding behavior is specified to satisfy a log-linear bidding rule, $\log(b_{it}) = \alpha_t + \beta X_{it} + \epsilon_{it}$, where i is the firm and t is the project, α_t is an auction-specific effect, and X_{it} is a vector of observable variables affecting cost and the probability of winning.

The data is from 116 auctions conducted by the New York State Department of Transportation (DOT) for highway construction contracts over 1979-1985. There is prior information about who might be members of the bidding ring. One of the firms was previously convicted for rigging bids on a Long Island highway construction project and four other firms were listed as unindicted conspirators; all of which took place at auctions prior to the data set. This prior information is used to identify a candidate cartel comprised of these five firms. As a reality check, the authors provide some evidence that, in the absence of collusion, the suspected firms would have competed; that is, the set of auctions at which they would have participated significantly intersect. For if that is not the case then there is little reason for them to collude. A maintained hypothesis is that unsuspected firms are acting competitively.

They first consider whether the determination of firms' bid levels differ between cartel firms and competitive firms. To estimate the bid equation, the exogenous variables are: i) the backlog of a firm at the time of an auction as measured by dollar value of contracts won but not yet completed; ii) the capacity of a firm as measured by the maximum backlog (they include capacity squared as well); iii) a firm's capacity utilization rate which is backlog divided by capacity (and capacity utilization squared); and iv) a dummy variable for whether a firm's headquarters is on Long Island (which serves to measure geographic proximity to a job). The bid equation is estimated separately for competitive firms and cartel firms.

The estimated bid function for competitive firms is intuitively sensible with all estimated coefficients being highly significant. A firm's bid is initially decreasing and then increasing in utilization and initially decreasing and then increasing in capacity. In contrast, the estimated bid function for cartel firms tells us that their bids are not statistically significantly related to utilization and is initially increasing and then decreasing in capacity, contrary to that for competitive firms. To test for differences in these estimated coefficients, the bid equation is estimated using all bids. Under the null hypothesis that there is no collusion, the two subsamples - competitive firms and cartel firms - should have the same estimates as those using the entire sample. A Chow test allows that hypothesis to be rejected. The authors conclude that the estimated model fits the bids of competitive firms reasonably well and the bids of cartel firms are statistically different from those of competitive firms.

A more interesting test is conducted on the ranking of bids. Using a multinomial logit (MNL), the likelihood of the observed ranking of bids for auction t is

$$\Pr\left(b_{r_1 t} < \cdots < b_{r_{n_i} t}\right) = \prod_{i=1}^{n_t} \frac{e^{\beta Z_{r_i t}}}{\sum_{j=i}^{n_t} e^{\beta Z_{r_j t}}}$$

where r_m denotes the firm with the m^{th} lowest bid, $Z_{r_m t}$ are exogenous variables, and n_t is the number of bidders at auction t. The crucial property of the MNL is that the model (if correctly specified) can be estimated using any subset of bids. For example, compare using the lowest bid,

$$\prod_{t=1}^{T} \frac{e^{\beta Z_{r_1 t}}}{\sum_{j=1}^{n_t} e^{\beta Z_{r_j t}}}. \tag{1}$$

and the remaining higher bids,

$$\prod_{t=1}^{T} \prod_{i=2}^{n_t} \frac{e^{\beta Z_{r_i t}}}{\sum_{j=i}^{n_t} e^{\beta Z_{r_j t}}}. \tag{2}$$

The authors estimate the model with all ranks, the lowest rank, and the higher ranks. The null hypothesis is that the estimated coefficients are the same and is tested using a likelihood ratio test. Using the bids of competitive bidders, the null hypothesis cannot be rejected; the estimates using the lowest competitive bid and using the higher competitive bids are not statistically different. However, when estimated using the bids of the suspected cartel members, the null hypothesis is soundly rejected.

With this distinguishing empirical property of suspected cartel members, it is now important to show that it is consistent with some model of collusion. Why would collusion result in the process determining the lowest bid differing from that of higher bids? The authors put forth the following collusive scheme. The cartel identifies a firm to submit the lowest bid with the other firms instructed to offer higher bids. The designated firm's bid will be driven by its cost and the desire to trade-off the probability of winning and the surplus it receives if it wins; just as with competitive firms. In contrast, the phantom bids of the other cartel members are only required to be higher and thus need not be generated by an analogous process. Their bids are not set so as to maximize their expected payoff but rather to only give the appearance of competition. Such a collusive model could explain why there would be this disparity between the process generating the lowest cartel member's bid and that of the bids of the other cartel members.

As in the independence and exchangeability tests of Bajari and Ye (2003), testing whether the estimated coefficients for (1) and (2) are the same for suspected colluding firms is a test of competition and can be conducted without a competitive benchmark. Nevertheless, one becomes more confident that a rejection of this test is indeed due to collusion, rather than some other form of misspecification, if the test is not rejected for firms not suspected of colluding.

Porter and Zona (1999) A similar approach is taken in Porter and Zona (1999) in examining collusion at procurement auctions for school milk.[9] A market is a school district where each district awards an annual contract for the supply of school milk. Districts conduct their auctions independently. The analysis focuses on the school districts in the Cincinnati area for which there were three defendants: Coors, Meyer, and Louis Trauth; two of them having confessed to rigging bids. Furthermore, they testified that the cartel used an incumbency scheme whereby a cartel member had served a particular district in the previous year then the other firms were to either not participate or submit high complementary bids.

The approach is of the same vein as in the earlier study. A reduced form model of a firm's bid level is estimated though, in this case, it is done simultaneously with a probit specification for whether a bid was submitted. The strategy is to determine whether there are systematic differences between the estimated bid equations for cartel members and competitive firms and, if so, whether these differences can be explained with a particular model of collusion.

The authors have detailed data on the characteristics of a contract which relate to cost - for example, the distance between the processing plant and the school district (*Distance*) and the size of the school district - and the competitive environment - for example, if a firm is the closest one to the district (and thus has a cost advantage over other bidders). Using data for all competitive firms plus a particular defendant, bids are regressed on various factors (along with estimating the probability that a bit is submitted). This is done assuming the slope coefficients are the same for all firms and when the slope coefficients

[9] For other analyses of collusion in the school milk market, see Lanzilotti (1996) and Scott (2000).

for the defendant are allowed to differ from those of the other firms. In both cases, the intercept is allowed to differ. Under the null hypothesis, the estimated coefficients should be the same for the two estimations and this hypothesis is tested using a likelihood ratio test. This is conducted for each of the three suspected cartel members. It is worth noting that the test is not whether colluders bid more but rather whether their bids are determined differently from that of competitive firms. Higher bids could simply be due to drawing valuations from a different distribution.

For each of these three firms, the null hypothesis is rejected at any conventional significance level which means that suspected colluding firms' bids are determined by a different process than that of unsuspected firms. Furthermore, unsuspected firms' bids respond in a manner consistent with the competitive model; for example, their bids are increasing in *Distance*, while the bids of two colluding firms are *decreasing* in *Distance* (all three colluding firms' bids are decreasing in distance relative to that of the other firms). Using the estimates for the bid submission equation, bids are significantly lower in the distance ranges for which these firms are more likely to bid than competitive firms. This is inconsistent with the competitive model as well. As cost is increasing in distance, a firm's bid should be increasing in distance. Furthermore, if there is a fixed cost to submitting a bid (or there is an opportunity cost to winning a contract), a firm should be more inclined to do so where it thinks it can win with a higher price-cost margin which, controlling for cost factors, suggests that a firm's bid should be relatively *higher* where it is relatively more likely to bid.

If we take unsuspected colluders as the competitive benchmark, it is then clear that suspected colluders' bids systematically departed from the behavior of competitive firms. Of course, collusion is only one possible explanation for this departure and it is not immediately clear that it is a reasonable one. What is needed is a collusive model which predicts the direction of these departures. Before turning to that task, it is useful to consider what was learned from the estimates of the probability of a firm submitting a bid on a contract.

A reduced form probit model was estimated in which the dependent variable takes the value 1 if a firm submitted a bid on a contract. Estimates for competitive firms are generally consistent with competition; for example, they are less likely to submit a bid when *Distance* is greater. Relative to nondefendants' behavior, the three suspected colluders were much more likely to submit bids when *Distance* is 30 miles or less. Furthermore, the decision to submit bids was found not to be independent across colluding firms, which ought to hold for the competitive model after controlling for all public information. Using the estimated probit equation for competitive firms, the residual was calculated for each auction for each of the colluding firms. For each of the three pairs of these firms, the unexplained portion of each firm's submission decision was positively and significantly correlated. That the submission of bids was positively correlated across cartel members suggests parallel behavior. As additional evidence, the authors examined the residuals to the bid level equations and found that they were also positively correlated; a high bid by one of them makes it more likely that the others bid high.

The authors provide a collusive story to explain why bid levels and bid submissions depart from the competitive benchmark. That colluding firms' bids may not be increasing in distance makes sense if more distant school districts are not collusive. There are many firms and districts and, if indeed these firms are coordinating their behavior, it'll be effective only in those markets for which non-colluding firms are neither numerous nor have a significant cost advantage (such as being the closest processors). Firms may then be submitting higher bids in districts for which they have a distance advantage - so collusion works - and, in more distant markets, are forced by competition to submit lower bids (in spite of the higher transportation costs). As to the correlation in the submission of bids, this is consistent with complementary bidding that is intended to give the impression of competition. A cartel member who is not selected to win a contract (say, by the incumbency scheme) submits a higher bid than the incumbent to provide the appearance of competition. Ironically, it is this correlation of the decision to submit a bid which is evidence of collusion!

2.4 Is Firm Behavior More Consistent with Collusion than with Competition?

Now consider an approach which puts collusive and competitive models into a horse race to determine which better fits the data. The general strategy is to specify structural competitive and collusive models of firms' prices or bids and to estimate them using cost and demand shifters. There is evidence of collusion if a collusive model better fits the data. Baldwin, Marshall, and Richard (1997) and Banerji and Meenakshi (2004) use traditional measures to compare models such as the log likelihood, while Bajari and Ye (2003) take a Bayesian approach and derive a posterior probability of a cartel being present.

Baldwin, Marshall, and Richard (1997) The task is to determine whether a cartel was operating at some or all of 108 oral ascending timber auctions in the Pacific

Northwest over 1975-1981. A class of competitive models is specified which includes the maintained hypothesis that, once controlling for publicly observed variables, it is IPV. When a single unit is auctioned, competition results in the winning bid being the second-highest valuation. However, the specified class of competitive models also allows multiple units to be auctioned. If there are m units to be auctioned (and $m < n$ where n is the number of bidders) then, with each bidder bidding for at most one unit, the winning bid is the $m + 1^{st}$-order statistic over n valuations.

Collusion is modelled using the collusive auction model of Graham and Marshall (1987) which allows for side payments. There is at most one cartel (which is a maintained assumption) and it contains l members. The cartel elicits members' valuations prior to the auction and a cartel representative submits the highest valuation of the cartel members. For the case of a single unit, if the cartel fails to contain the two highest valuations then the price paid by the winning bidder is, as usual, distributed as a second-order statistic. More generally, if the cartel includes those firms with the highest k values then the price is distributed as a $k + 1^{st}$-order statistic. Thus, under collusion, the price is distributed as a mixture among these order statistics. Finally, they nest the two models by allowing for both the possibility of a bidding ring and multiple units to be auctioned off.

This class of models provides two possible reasons why bidding might be less aggressive - collusion (or a bigger cartel) and a large supply is being auctioned off. The set-up makes these two alternatives quite analogous in that both m and l are presumed to be unobserved and independent across auctions. The independence of the size of the cartel is a bit problematic though the authors argue that it is plausible given the auctions are geographically dispersed and occur over several years. The functional forms for the probability distribution over m and l are identical and allowed to depend on various factors. Though the determination of m and l are reduced form, the bidding models are structural given m and l.

The independent variables influencing the size of the cartel and bidding behavior include the volume of timber offered for sale on a tract, the time over which the timber is required to be cut (that is, the contract length), a measure of logging cost, and a measure of the quality of the timber. The probability of joining the coalition depends on the volume of timber and, so as to control for geographic proximity among bidders, a "bidder proximity dummy" which takes the value 1 when the highest and second-highest bidders are in the same county.

The models are estimated using maximum likelihood. Using the log likelihood criterion, the single-unit collusive model noticeably outperforms the single-unit competitive model.[10] This suggests the competitive model is misspecified though it could be for reasons other than that firms are actually colluding. The authors are able to dismiss one likely alternative which is that the assumption that the distribution on valuations is log-normal is incorrect. Estimating the nested models, performance is not enhanced when multiple supply is added to collusion. The authors conclude that the best model - taking into account performance and parsimony - is the single-unit collusive model.

Banerji and Meenakshi (2004) Comparing the performance of collusive and competitive models is also an approach taken in Banerji and Meenakshi (2004) in examining collusion at oral ascending bid wheat auctions in India. They have prior information that the three largest buyers (with a total market share of about 45%) may be colluding. The competitive model is IPV with asymmetric distributions; the three largest buyers are allowed to draw valuations from different distributions than that of the remaining buyers (all who are assumed to have the same distribution). Based on some prior information, the authors specify the collusive model to be one of bid rotation in which the three buyers randomly decide on the buyer to participate in a particular auction. The winning bid is then the second-order statistic over the valuations of one large buyer and the small buyers. It is assumed that the identity of the participating cartel member is determined prior to observing the specifics of the lot up for auction.

The data they have is for 421 auctions from two months in 1999. It includes some quality variables, the number of bidders who cast bids during the auction, winning price, and identity of winning bidder. This is a structural model which uses a result from Athey and Haile (2002) to identify the latent distributions. Identification only requires the second-order statistic and the identity of the winning bidder. Various criteria are used in comparing the performance of the two models including the log likelihood value and the mean sum of squared residuals. The collusive model fits the data better than the competitive model.

Bajari and Ye (2003) This study also compares structural models of collusion and competition to see which performs better. Recall that their initial tests identified two candidate cartels: firms 2 and 4 and firms 2 and 5. The three candidate models are then a competitive model (where there is no collusion), cartel 24 (where firms 2 and 4 collude and all other firms do not), and cartel 25 (where firms 2 and 5 collude and all other firms

[10] It is also true that the non-collusive model with multiple supply performs significantly better than the single-unit non-collusive model and only marginally worse than the single-unit collusive model.

do not). Their approach is Bayesian as they calculate a posterior probability distribution over these three models based on the observed markups.

The first step is to specify a prior distribution over the three models which is arbitrarily made to be the uniform distribution. The next step is estimation of the likelihood of observing the actual markups given a particular model. Finally, Bayes Rule is used to derive a posterior set of beliefs on the set of models.

To execute this approach, one first needs a measure of actual markups. Specifying a structural model of bidding provides a first-order condition defining a firm's bid which is a function of its cost and the distribution on other firms' bids. By estimating that distribution and using the observed bid, one can backout the firm's cost and thereby get an estimate of the markup. The competitive model is specified to be the IPV model with asymmetric bidder valuation distributions. The cartel model is the competitive model but where the two colluding firms act as a single profit-maximizing bidder with cost equal to their minimum cost (thus presuming they can make side payments). This procedure is done for each of the three models to yield observed markups.

The more challenging task is to estimate the likelihood of these markups for a particular model. Towards this end, structural cost parameter estimates are needed which are derived by eliciting a distribution on markups from industry experts. From this markup distribution, a random draw is made for each bidder for each auction. Using the observed bid, one can infer the latent cost. This latent cost is then regressed on the exogenous factors which yields a set of estimates for the structural model. With these estimates and a model, the likelihood of a particular set of costs is calculated. Simulation methods are used to then calculate an expected likelihood based on an estimated prior distribution over costs and structural parameter values.

The predicted markup at the 50th percentile for the estimated distribution on markups is 3.33% for the competitive model, 4.13% for cartel 24, and 4.47% for cartel 25. As the industry experts put it at 5%, the cartel models fit the median markup better. However, at the 99th percentile, the cartel models predict a markup vastly higher than the 15% predicted by the industry experts. Cartel 24 has it at 33.54% and cartel 25 at 58.26%, while the competitive model is much closer at 23.81%. Due to its poor performance in the tails, the posterior probability that the model is competitive is very close to one.

There are two methodological innovations worth discussing. First, the use of industry experts to provide ancillary information is novel and potentially fruitful but there are concerns. Industry experts might be quite good at predicting median markups but - due to fewer observations - much less effective at extreme markups and it was the poor fit between the experts and the cartel models on extreme markups that allowed the competitive model to be assigned such a high posterior probability. In addition, there is a concern that experts' beliefs are based on what they infer about cost from bids but, if that is the case, then it depends on the model they are using. Did they presume competition? Or did they suspect collusion? If they presume the model is competitive then isn't this approach biased in favor of the competitive model? We need more structure about how experts' beliefs are formed and when they will be reliable.

Second, the Bayesian approach provides an alternative to having two discrete categories: "yes, there is collusion" and "no, there isn't collusion." It would indeed seem more useful to potential plaintiffs and antitrust authorities to be able to assign some (well-defined) strength to the hypothesis of collusion in deciding whether to bring a case. One could also imagine having a more informed prior distribution on there being a cartel by using the empirical frequency of discovered cartels. Though there are sure to be many undiscovered cartels, this would at least provide a lower bound to the prior probability of there being a cartel.

2.5 Discussion

In summary, we reviewed four methods which can be used in connection with detecting collusion: A) determining whether firm behavior is inconsistent with competition; B) determining whether there is a structural break in firm behavior; C) determining whether the behavior of suspected colluding firms differs from that of (presumed) competitive firms; and D) determining whether a collusive model better fits the data than a competitive model.

In their least sophisticated forms, methods A and B provide no direct evidence in support of collusion. Rather, they seek to establish whether observed behavior has a difficult time being explained by competitive models. If a set of firms fail that test - their behavior is inconsistent with competition or there is an inexplicable change in behavior - it is necessary to turn to one of these other methods to assess whether collusion is the most natural explanation.

With regards to method A, the issue is whether the competitive model is misspecified but misspecification may be due to either there being collusion or that the class of competitive models is misspecified in terms of cost and demand assumptions. Misspecification due to omitted variables is particularly a concern here. To confidently reject the competitive model in Bajari and Ye (2003) on the grounds that firms' bids are not independent requires that one has not left out relevant variables which would result in firms' costs being correlated. The authors stress this caveat and note that, for example, if two firms use the same subcontractor in calculating cost and the other firms do not then the bids of those two firms will be positively correlated and thus violate independence without there being collusion. Though it is a tall order to confidently reject the null hypothesis of competition, one is less concerned if such a test is used only as a preliminary diagnostic tool.

Methods C and D allow a researcher to compare collusion and competition though they do this in very different ways; and one method does not dominate the other. Method C requires finding a competitive benchmark; either firms in the market who are not thought to be part of the suspected cartel, a comparable market (such as a different geographic market for the same product or service) that is thought to be competitive, or a time period during which the suspected firms were thought to have been competing. There must then be prior information as which firms may be colluding, in which markets there may be collusion, and over what time there may have been collusion. This method is then not applicable to an all-inclusive global cartel for which data is only available during the time of suspected collusion.

A general concern with Method C has to do with the endogeneity of the competitive benchmark. For example, if the benchmark comes from firms who were not members of the cartel, why weren't they members? It is natural to suppose they are different in some way from the cartel members and then the issue is whether the data one has is adequate to control for those differences. A model of endogenous cartel formation could shed light on how to handle such concerns. Furthermore, there is a presumption that non-colluding firms will act the same in an industry with a cartel as they would without a cartel. It obviously depends on the particular behavioral properties since non-colluding firms will generally produce less when other firms are colluding but their quantities and prices will still be increasing in cost. Nevertheless, it would be interesting to more broadly explore which properties of firm behavior are robust to whether its competitors are (knowingly) colluding and whether it depends on the collusive scheme deployed.

When the competitive benchmark is data from comparable markets for which there is no prior information about collusion, one has to be concerned that collusion might simply be more effective there. For example, suppose firms are able to tacitly collude in market A but not in market B. As a result, firms may resort to explicit collusion in market B and, as a result, collusion is suspected there but not in market A. The "competitive" benchmark is then, unbeknownst to the researcher, not so competitive after all. Failure to find higher prices in market B would then be misleading. Indeed, one could find lower prices in market B. If the inability to tacitly collude in market B is a reflection of the competitiveness of the industry, it is possible that the highest sustainable price is greater in market A where less competitiveness allows tacit collusion to work. That is, there are certain factors which determine whether firms tacitly or explicitly collude (ceteris paribus, firms prefer the former as they are not as much at risk of paying penalties) and these factors might also determine the collusive outcome. Explicit collusion may only occur where collusion is difficult and thus collusive outcomes might be more competitive.[11] But even if the price level is not noticeably different in the two markets, behavior - say in how price responds to cost and demand shifters - might still vary significantly because explicit collusion operates differently from tacit collusion. Unfortunately, theory provides little help here.

After finding there are differences between suspected colluding firms' behavior and some competitive benchmark, there are two follow-up issues. First, the difference could be due to, say, omitted variables and not due to market conduct. Second, any difference must be rationalized with some collusive model. The ultimate objective is not to show that behavior is inconsistent with competition but rather that it is most naturally explained by collusion. Certain collusive models provide predicted directions as to how collusion is apt to depart from competition. For example, Porter and Zona (1999) argue that collusion in markets geographically close to cartel members' plants and competition in more distant markets would make a firm's bid less of an increasing function of distance and perhaps even a decreasing function of distance. Thus, they took the observed empirical departure from the competitive benchmark and offered a collusive equilibrium to rationalize it. An issue is how much discretion a researcher has in terms of various collusive schemes. Providing ancillary evidence in support of a particular collusive scheme is highly useful.

By contrast, method D builds into it both competitive and collusive models. Thus, one can offer criteria for comparing the performance of the two behavioral models. This method is also the most widely applicable in that it can be used even if there is no prior information as to collusion, the cartel is all-inclusive (all firms and all markets), and data is only available during the cartel regime. The major disadvantage is misspecification. In that structural models are being estimated, there is the usual enhanced concern of

[11] One can't help but think of Asch and Seneca (1976) who find that collusive industries are less profitable than non-collusive industries.

misspecification compared to the reduced form price equations of method C. For example, firm symmetry is a maintained hypothesis in Baldwin, Marshall, and Richard (1997) but it is quite possible that the collusive model may outperform because buyers have different distributions over valuations. Misspecification of cost and demand conditions may then cause the competitive model to underperform.

Misspecification is apt to be a more serious concern for the collusive model. Though there is typically a limited number of competitive models and equilibria to them, there are many more collusive equilibria even for a single model; that is, there are many more equilibria for the repeated game than for the static game. Collusive solutions can differ in terms of bid rotation, territorial allocation, side payments, market share allocations, etc. On these grounds, one is more likely to erroneously reject the collusive model than the competitive model. Ancillary evidence as to how firms might be colluding can be useful here. For example, there was evidence that a Florida school milk cartel used side payments and this suggests that market shares could fluctuate over time because contracts could go to the most efficient, with the others receiving transfers as compensation. In contrast, there was no evidence of side payments for a Texas school milk cartel which suggests that collusion may require stable market shares. In both cases, Pesendorfer (2000) finds that the data is consistent with these hypotheses. This highlights how the collusive solutions can vary greatly but also how one can use other evidence to help with the multiplicity problem.

Another source of bias can arise due to mislabelling firms, markets, and periods as being non-collusive when they actually are collusive or vice versa. The former case may be of particular concern in light of the incentives of cartel members to hide evidence. Porter and Zona (1993) recognize this point in noting that some of their "competitive" firms may actually have been part of the cartel. They use past convictions which identifies likely suspects - if they found it profitable to collude once, they may find it profitable again - but then this misses out on firms who previously avoided convictions or have since found it optimal to join the cartel.[12] Similarly, lack of observed interaction among firms - such as not bidding on the same contracts - may lead one to conclude that these firms are not candidates for collusion when in fact their lack of interaction is due to collusion. For consider a collusive scheme in which a designated cartel member submits a bid and

[12] On a related matter, dating of cartels in plea agreements between the U.S. Department of Justice and cartel members are probably an upper bound on the cartel's true start date. The negotiated start date may reflect the earliest date for which there is solid documentation of collusion. Collusion may go back earlier but there is not adequate evidence; either it having been lost or destroyed.

the others do not. There may then be a bias against certain firms being considered as candidate cartels.

3 Collusive Markers

To provide economic evidence of collusion, one needs to know what to look for - what behavioral patterns are indicative of collusion? An important line of work is then to provide collusive markers - behavior that distinguishes collusion from competition. These markers can be developed through theoretical models or by documenting the behavior of price-fixing cartels.[13] In this section, we will review what theory has to offer and, in some cases, provide examples of cartel exhibiting these markers. A more systematic and detailed summary of documented cartel behavioral patterns - along with experimental evidence - will have to await another paper.

Theory has a crucial role to play in providing collusive markers. It is essential if one pursues the empirical method of contrasting the behavior of suspected colluders with that of competitive firms. For if one finds a difference, it is important to know whether these differences are consistent with some collusive theory. If instead the empirical method of detection is to look for structural breaks - perhaps to identify the formation of a cartel - having collusive markers can tell you what kind of change in behavior to look for. These markers are particularly valuable from the perspective of screening where one wants easily measured traits to suggest which industries might have a cartel.[14]

Before embarking on this review, an important disclaimer is that evidence supporting collusion need not imply evidence against competition. The ensuing work will derive distinguishing features of collusion and competition *for a particular class of models.* When we find evidence of collusion, there is always the possibility that there actually is no collusion and the problem is we've misspecified the non-collusive model. Similarly, failure to find evidence of collusion may be due to misspecifying the collusive model; for example, we've focused on the wrong collusive equilibrium. At best, collusive markers can serve to screen industries to determine whether they are worthy of more intense investigation.

Our discussion will focus on what theory has to say about patterns in prices and market

[13] Here I mean industries in which non-economic evidence substantiates collusion. Otherwise one engages in tautological reasoning: Theory says cartels ought to behave this way and if firms behave this way then their behavior tells us how a cartel behaves.

[14] A second role for theory is to provide models of competition and collusion that can be estimated and contrasted. This fits into the empirical method based on finding the model that best fits the data.

shares and how it depends on whether firms are colluding. Theory offers insight into how collusion affects: i) the relationship between a firm's prices and demand movements; ii) the stability of price and market share; and iii) the relationship between firms' prices. A wide array of collusive models will be covered and it is useful to identify five crucial dimensions along which they may differ. First, a collusive model can be static or dynamic. A static approach compares what Nash equilibrium yields and what is gotten from either: i) exogenously imposing some collective preferences (such as joint profit maximization); or ii) an incentive compatible mechanism to which firms are committed (such as firms reporting their private information to a cartel manager and the cartel manager prescribing prices and quantities based on these reports). A dynamic approach is an infinitely repeated setting in which outcomes less competitive than static Nash equilibria are sustained using strategies that punish deviations from the collusive agreement. With this approach, collusion is often distinguished from competition when equilibrium conditions (or incentive compatibility constraints) bind so that collusion is not easy. Second, models differ in terms of the market institution, which is generally either posted price - which characterizes most retail markets - or an auction. Third, models differ in terms of whether the cartel is allowed to make side payments to each other. Indeed, implicit in assuming joint profit maximization is that transfers are allowed for otherwise it is not clear why some firms would go along with such an objective. Fourth, a model may allow firms to send messages to each other prior to choosing price or quantity. Where this is pertinent is when firms have private information about their preferences; such as cost or, in the context of an auction, their valuation. One necessarily thinks of models with direct communication as being associated with explicit rather than tacit collusion. Fifth, most models assume firms are colluding without concern for being detected by the antitrust authorities. There are a few studies, however, for which detection may occur and firms are cognizant of how their behavior can influence detection which then has implications for the price path.

The decision to focus on the unique implications of collusion for price and market share is largely due to the relative ease with which such data is available. There are clearly other identifying markers associated with collusion. For example, unit profit is uncorrelated with firm size under competition but is negatively correlated with firm size under collusion (Osborne and Pitchik, 1987), non-collusive prices depend on whether nearby products are owned by rival firms though that is not true when firms collude and maximize joint profits (Bresnahan, 1987), and there is greater excess capacity under collusion (Benoît and Krishna, 1987; Davidson and Deneckere, 1990). Finally, the theoretical literature on collusive pricing is rich in identifying industry traits which are conducive to collusion.[15] Thus, one can supplement the search for collusive markers with attention to certain industry traits. Research has found that collusion is easier to sustain or is more profitable when concentration is higher, orders are more frequent, firms are more symmetric (Compte, Jenny, and Ray, 2002; Vasconelos, 2003), multi-market contact is greater (Bernheim and Whinston, 1990), and cost is more volatile (Harrington and Chen, 2004).

3.1 Predictions on Price

The basic logic whereby collusion is sustainable as an equilibrium in a repeated game model is predicated upon rewards and punishments.[16] A Nash equilibrium for the static game is one in which each firm's behavior (which is typically either a price, a bid, or a quantity) is optimal given the (correctly anticipated) behavior of other firms. Firms collude for the purpose of raising price above the static Nash equilibrium level so as to yield higher profits. This necessarily means that a firm's behavior doesn't maximize current profit; a firm's collusive quantity is below that which maximizes current profit or its collusive price exceeds that which maximizes current profit. As cheating on the collusive outcome raises current profit, firms can only be deterred from doing so if they experience a future loss. This future loss from cheating comes from an intensification of competition in response to cheating. Thus, if firms act collusively then they continue colluding but if a firm cheats then firms revert to some low-profit punishment path. This may mean going to the static Nash equilibrium for some length of time or an outcome with even lower profits (perhaps pricing below cost) or an asymmetric equilibrium which is particularly detrimental to the firm that deviated (perhaps requiring that the firm produce very little). It follows that a firm which considers deviating from a collusive outcome realizes it would raise current profit but lower its future profit stream. The equilibrium condition or incentive compatibility constraint (ICC) requires that the foregone future profit stream is at least as great as the gain in current from deviating. When the punishment is reversion to the non-collusive outcome for T periods, the ICC is:

$$\sum_{\tau=1}^{T} \delta^{\tau} \left(\pi^{c} - \pi^{nc} \right) \geq \pi^{d} - \pi^{c},$$

[15] A useful reference is Motta (2004).

[16] Standard treatments can be found in Tirole (1988) and Vives (1999).

where π^c, π^{nc}, and π^d is the collusive profit, non-collusive profit, and the (optimal) profit from deviating, respectively. $\delta \in (0,1)$ is the common discount factor across firms. In this simple case, the model is stationary and the solution is symmetric. Deviation yields higher current profit of $\pi^d - \pi^c$ but lower future profit of $\pi^c - \pi^{nc}$ over the next T periods (with firms returning to the collusive outcome thereafter). Equilibrium requires this condition to hold so that abiding by the collusive agreement is optimal for all firms. Since $\pi^c > \pi^{nc}$, this will hold when T is sufficiently high and δ is sufficiently close to one so that firms sufficiently value future profits.

To derive our first collusive marker, let us modify that setting to where the demand curve changes over time. Firms observe the demand shock and then choose prices. At this point, demand could be independently and identically distributed (*iid*) over time or show some persistence or follow some cyclical pattern. Suppose the demand shifts are well-behaved in that "higher demand" corresponds to the demand curve shifting out and both the monopoly price and the static Nash equilibrium price rising.[17] Hence, the static Nash equilibrium price (which we are taking as the non-collusive benchmark) would follow movements in demand - price rises when demand increases - and thus price and quantity are positively correlated over time. These properties also hold under perfect collusion where (symmetric) firms charge the joint profit-maximizing price.

Thus far, the relationship between the price path and demand movements is not distinguishable between competition and collusion. But now suppose that firms are not so patient and thus cannot perfectly collude; that is, firms achieve the collusive outcome which yields the highest profit subject to satisfying the ICCs. This necessarily implies that the ICCs bind which will serve to produce some useful collusive markers. The initial work on this class of models is Rotemberg and Saloner (1986) who considered (observable) *iid* demand shocks. Their result is that, when ICCs bind, price is *lower* when demand is stronger and thus price and quantity are *negatively* correlated. As demand shocks are *iid*, the future loss from cheating is always the same because the expected future foregone collusive profits is independent of the current demand realization. However, the current gain from cheating is higher when demand is stronger since, holding price fixed, the gain in sales from undercutting rival firms' price is greater when demand is stronger. Since the incentive to cheat is then more powerful when demand is greater, cartel stability requires setting a lower collusive price as this weakens the incentive to cheat. Thus, one finds that price can move opposite to demand in a collusive equilibrium, while, for the same demand

[17] This would hold, for example, if demand is linear and "higher demand" means a rise in the intercept.

and cost structures, prices move with demand in a non-collusive equilibrium.[18,19]

Pursuing this idea further, Haltiwanger and Harrington (1991) consider instead a deterministic demand cycle in which demand shifts out then shifts in, with this pattern repeating itself. Such a demand pattern fits seasonal movements in demand which are relatively well anticipated. In contrast to the preceding analysis, the current gain and future loss from cheating both change over time. For consider two points on the cycle where the current demand function is the same but they differ in that one point is during the boom phase - demand is rising (and thus will be higher in the immediately ensuing periods) - and the other is during the bust phase - demand is falling. For the same price, the current gain from cheating is the same at both points because demand is the same. However, the future loss from cheating is higher during the boom because a firm foregoes more profits from competition (compared to collusion) since demand is anticipated to be relatively strong. Thus, contrary to Rotemberg and Saloner (1986), collusion is easier during the boom phase which means firms can set higher prices.[20] Also, compare the peak of the cycle and the period prior to it. The stronger demand at the peak means that the current gain to cheating is higher and, furthermore, foregone future profits are less by cheating at the peak (note, for example, that cheating before the peak means foregoing collusion when demand is strongest). Thus, collusion is more difficult at the peak which requires price to be set lower. This has the implication that the price path will peak prior to demand; the price path will lead the demand cycle. Once again, this is a pricing pattern which runs counter to non-collusive pricing where the price path follows the demand cycle. This relationship between price and demand pattern has been shown to describe retail gasoline markets (Borenstein and Shepard, 1996) though there is no direct evidence of explicit collusion in that market.[21]

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[18] Under certain conditions, these results are robust to when demand shocks are serially correlated (Kandori, 1991).

[19] Recalling our disclaimer, one could also have a non-collusive equilibrium for a different model generating a similar prediction. For example, suppose that when demand increases, firm demand becomes more elastic. Then price competition will intensify when demand is stronger so that price can fall as demand rises even when firms do not collude. Increased firm demand elasticity due to greater consumer search has been used to explain why retail prices are lower for many items during the Christmas season in spite of demand having shifted out.

[20] However, if there are sufficiently tight capacity constraints then price can return to being pro-cyclical (Fabra, 2004).

[21] For further work on demand flucutations, see Bagwell and Staiger (1997) who find that if the demand growth rate is positively correlated over time then the price path is sometimes procyclical but never countercyclical, while if the growth rate is negatively correlated then the price path is sometimes

Another key collusive marker is that price and quantity can be subject to large and persistent changes *in the absence of large demand and cost changes*. This work begins with the seminal paper of Green and Porter (1984) (also see Porter, 1983b). The context is the repeated quantity game but where there is imperfect information. In each period, firms choose quantities and then observe price. Price depends on firms' quantities and an unobserved *iid* demand shock (recall that such shocks were observed in Rotemberg and Saloner, 1986). As a firm's quantity is never observed by other firms, a deviation cannot be directly observed. However, price is observed and, in expectation, a higher quantity will result in a lower price. Of course, since price depends on an unobserved demand shock, a low price could be due to a low demand shock rather than some firm cheating by producing above their collusive quota. There is then imperfect monitoring of collusion by the cartel's members.

An equilibrium is characterized in which, during the collusive phase, firms choose some designated collusive quantity. If the realized price is ever too low (a threshold price is specified as part of the collusive strategy) then firms switch to a punishment phase which is static Nash equilibrium quantities for T periods; after which they return to the collusive phase. A collusive equilibrium quantity is one in which a firm maximizes its payoff taking into account that a higher quantity increases current expected profit but lowers future expected profits by making a punishment more likely (where the probability of a punishment is the probability that the realized price is sufficiently low). Equilibrium then entails stochastic regime switches where a one-time low demand shock triggers a movement from the collusive phase to the punishment phase - associated with is a fall in the average price - and, after T periods, there is a regime switch back to the collusive phase - with a rise in the average price.[22] One then observes abrupt changes in average price which cannot be explained by contemporaneous demand and cost movements. For the railroad cartel of the 1880s, Porter (1983a) and Ellison (1994) do indeed find there are regime switches.[23]

countercyclical but never procyclical.

[22] This equilibrium can be modified to allow T to be randomly selected at the start of each punishment phase so the length of time in the punishment regime is random.

[23] Abreu, Pearce, and Stachetti (1986) considers maximal punishments in this setting and also get regime switches though characterized by a different stochastic process. Like the previous model, movement from the collusive to the punishment regime occurs when price is sufficiently low and thus when the contemporaneous demand shock is low. But in contrast, the punishment phase does not entail static Nash equilibrium but yet higher quantities (and thus lower profits). Firms get out of this punishment phase only when the realized price is sufficiently *low*. There are then regime switches but the process is

Summarizing the above discussion:

Collusive Marker Under certain conditions, price and quantity are negatively correlated, price leads a demand cycle, and the stochastic process on price is subject to regime switches under collusion. Under competition, price and quantity are positively correlated, price follows a demand cycle, and price is not subject to regime switches.

A second collusive marker concerns price stability. Two papers taking very different approaches show that, under certain conditions, prices are more stable under collusion. Consider a setting in which firms choose price and each firm's cost is *iid* over time and across firms and is private information. In each period, colluding firms exchange messages about their costs and then choose price. These messages are not required to be truthful and side payments are not permitted. In characterizing an optimal collusive mechanism, there is a tension between efficiency and the amount of collusion. Given firms have homogeneous products, the unconstrained joint profit-maximizing scheme is to have the firm with the lowest cost in a given period produce all output in that period at its monopoly price. The problem is inducing firms to truthfully reveal their cost since a firm with high cost may want to signal it has low cost in order to be able to produce. So as to induce a high cost firm to provide an accurate cost report, the collusive price may need to be set relatively low when a firm's cost report is low for then a high cost firm would not find it profitable to mimic a low cost firm. Though a mechanism may exist to induce truthful revelation of firms' costs, it may not be optimal for firms to use it because it requires such low prices.

Athey, Bagwell, and Sanchirico (2004) characterize the best strongly symmetric perfect public equilibria in this setting.[24] When firms are sufficiently patient, the collusive equilibrium is to have price and (equal) market shares fixed over time; they do not respond to firms' costs. Inefficiency prevails as it is too costly to induce revelation. Thus, prices are perfectly stable in response to cost fluctuations which also means that price is more stable than in the absence of collusion. When firms are moderately patient, there is partially rigid pricing so the price function is a step function of cost in which case price

always Markovian; the probability distribution on price in a period depends only on the previous period's price and regime (cooperative or punishment).

[24] These equilibria have the property that continuation payoffs are the same for all firms though may vary across histories. Punishment then entails low profits for all firms. This model assumes a continuum of costs and downward sloping demand, while further work - which we review shortly - generally assumes two cost types and perfectly inelastic demand (Athey and Bagwell, 2001, 2004).

is often unchanged but then experiences a large change. This also serves to distinguish collusion from competition.[25]

In all of the models reviewed thus far, firms were not concerned about detection. Suppose instead that buyers may detect collusion from suspicious price changes.[26] In exploring how detection avoidance impacts cartel pricing, Harrington and Chen (2004) do not presume that buyers know how a cartel prices, nor are consciously looking for collusion. Rather, it is assumed that buyers become suspicious when the observed price series is sufficiently anomalous or inexplicable where their beliefs as to what is anomalous depend on the history of prices.

Suppose cost is a random walk with normally distributed shocks. Hence, the non-collusive price is similarly structured. Buyers believe price changes are normally distributed but do not know the moments of the distribution. With bounded memory, they observe price changes and use the sampling moments in their beliefs. This gives buyers a set of beliefs on the current price change. With these beliefs, they can then determine the likelihood of observing the actual price change and in fact do so for a series of price changes. It is assumed that detection is more likely when buyers perceive the most recent price series as being less likely. The cartel is aware of how its price path affects beliefs and thereby the probability of detection. Upon cartel formation, firms inherit the non-collusive price and buyers' beliefs which are predicated upon price changes when firms were not colluding. In a sense, detection occurs when buyers pick up the "break" in the pricing function associated with cartel formation. Ideally, a cartel would like to raise price fast and have it adjust quickly to cost shocks but it must temper any such price movements in light of the prospect of detection.

The optimal cartel price path is found to have a transition phase - in which price rises largely irrespective of cost - and a stationary phase - in which price is responsive to cost. While price is sensitive to cost in the stationary phase, it is much less variable than either cost, the non-collusive price, or the simple monopoly price. Intuitively, though the cartel might want to raise price considerably in response to a series of large positive cost shocks, such a price series may be perceived as unlikely by buyers and thus induce an investigation. To avoid triggering detection, the cartel doesn't respond commensurately

[25] As described later, in other circumstances collusive prices and market shares can be sensitive to firms' costs for this class of models.

[26] In many price-fixing cases, these are industrial buyers such as with vitamins, lysine, and graphite electrodes. Generally, the antitrust authorities do not actively engage in detection but rather respond to complaints (McAnney, 1991).

to large cost shocks. Relative to non-collusive pricing, the impact of cost shocks on price is muted and takes a longer time to pass through. Thus, the variance of price is lower with collusion. Examining collusion at auctions of frozen perch, Abrantes-Metz, Froeb, and Taylor (2004) find that the price variance during collusion is indeed distinctly lower then what is observed after the cartel was discovered (excluding the transition from collusion to non-collusion).

Collusive Marker Under certain conditions, the variance of price is lower under collusion.

The last set of collusive price markers concerns the relationship between firms' prices. Indeed, there is a common wisdom that parallel price movements are a collusive marker. Though there is a fair amount of documentation of identical bids at auctions - see, for example, Mund (1960), Joint Executive Committee (1961), and Comanor and Schankerman (1976) - in very few cases has collusion been found. More broadly, evidence that parallel pricing is a feature of collusion is ambiguous.

Let us first consider this issue in the context of an auction so the issue is how bids are related. McAfee and McMillan (1992) consider a symmetric IPV first-price sealed bid auction. The model is static with the objective being to characterize the best collusive mechanism (with the presumption that repetition can make any such mechanism an equilibrium if the bidders are sufficiently patient). A mechanism takes bidders' reports as to their valuations and then assigns bids (and possibly side payments) for the ring members. The mechanism is required to be incentive compatible so that reports are truthful.

If side payments are not allowed, the optimal mechanism is one in which all bidders report their valuation to the "cartel manager" prior to the auction and those whose valuation exceeds the auction's reserve price are supposed to submit a bit equal to the reserve price. As the cartel includes all bidders, the auctioneer is forced to randomly select a winner from among those submitting the reserve price. This is incentive compatible and in understanding why, first note that all that matters is that a firm truthfully report that its valuation is either above or below the reserve price. If its valuation is above the reserve price, truthfully saying so gives it a chance to win the item at a price below its valuation and saying otherwise foregoes that profitable opportunity. A bidder whose valuation is below the reserve price will not want to say it is above it as it could end up winning the item and paying a price above its valuation. Furthermore, if the mechanism was such that a bidder's report (above the reserve price) influenced its chances of being the winning bidder, they would have an incentive to report that their valuation is higher than it actually is. Thus, the cartel can do no better than this scheme even though it is inefficient since the bidder with the highest valuation does not win for sure. The notable property is that all bidders bid the same price (which is the reserve price). Thus, one gets a strong prediction of parallel pricing behavior.[27]

Two points are worth adding. In the context of a series of auctions, an equivalent mechanism is bid rotation where one selected bidder (whose report exceeds the reserve price) bids the reserve price and all others do not. We will return to bid rotation below when we discuss collusive markers based on market share. Second, if the cartel can engage in side payments then the optimal mechanism is efficient as the bidder with the highest valuation wins as long as its value exceeds the reserve price. One such mechanism is for the cartel members to hold their own first-price sealed bid auction prior to the actual auction. If the highest bid exceeds the reserve price then that bidder bids the reserve price (all others don't bid or bid less) and pays each of the other bidders an equal share of the difference between his bid in the first auction and the reserve price.[28]

An important caveat to this prediction of identical bids is provided in Marshall and Marx (2004). They consider a first-price sealed bid auction with heterogeneous IPV. Cartel members commit to a mechanism which is of the class mentioned above but with side payments being allowed. Thus, bidders are induced to truthfully reveal their valuations and, in response to these reports, the cartel manager prescribes bids for all cartel members. There are two important distinctions from McAfee and McMillan (1992). First, no ex post information is provided regarding the identity of the winning bidder and their bid. Second, the cartel is not all-inclusive; some bidders are not members of the cartel. The situation is then one of imperfect monitoring; the cartel member who was designated to submit the highest bid cannot distinguish failing to win the item because a non-cartel member outbid him or another cartel member cheated and outbid him.

The interesting prediction is that, for some valuations, two cartel members' bids are clustered. Using the (truthful) reports of their valuations at the pre-auction meeting, the cartel selects the bidder with the highest report - let us refer to him as the cartel

[27] LaCasse (1995) considers this setting but where the antitrust authority actively engages in detection and the bidders, who might form a cartel, are cognizant of this fact. The challenge from the authority's standpoint is that a low winning bid might be due to the existence of a cartel or instead that all bidders have low valuations. Equilibrium entails bidders using a mixed strategy to determine whether to form a cartel and the authority randomizing in their decision to perform an investigation with that probability decreasing in the winning bid.

[28] Also see Graham and Marshall (1987) and Mailath and Zemsky (1991) for analyses of collusion at second-price auctions.

representative (at the auction) - to bid at a certain level with all other cartel members told to bid less. Absent ICCs, the cartel representative would bid optimally in light of his valuation and the distribution on non-cartel members' bids. The problem, however, is that if that results in a bid which is too low, another cartel member may cheat by outbidding the cartel representative's bid. To avoid that from occurring, the cartel representative must set a higher bid so that the other cartel members don't want to outbid it and are content to set a lesser bid. Now suppose these other cartel members all set very low bids. The problem that emerges is that the cartel representative would have an incentive to bid a bit lower since he is only bidding high in order to discourage cheating. In order to keep him from doing that, one of the other cartel members must set a bid a little below the cartel representative's bid; it'll keep the cartel representative from cheating without affecting whether the cartel representative wins. That bids are clustered in this way is unique to when bidders collude.[29] Note that clustered bidding would not emerge with an all-inclusive auction as then monitoring is perfect; if the cartel representative doesn't win then someone must have cheated. There is then no need to set a higher price as cheating can be deterred in other ways.

Collusive Marker Under certain conditions, firms' prices are more strongly positively correlated under collusion.

In a standard static oligopoly model, some recent work has considered whether parallel pricing is more common under collusion. Buccirossi (2002) considers a static setting with stochastic cost and demand shocks and compares Nash equilibrium prices with joint profit-maximizing prices. It is shown that it is generally not true that there is more parallel behavior under collusion. Though non-collusive prices are more correlated when there are independent demand shocks, they are *less* correlated under independent cost shocks. At the Nash equilibrium, a firm's price is increasing in both firms' costs which induces some correlation even if shocks are independent. Interestingly, the joint profit-maximizing price of a firm depends only on its own cost so firms' prices are independent.[30]

One final result is worth mentioning. Blair and Romano (1989) offer a simple test for identifying who and who is not a member of a cartel. Upon cartel formation, cartel

[29] The authors note that at a (non-collusive) equilibrium for a complete information auction setting, the bidder with the highest valuation bids at the second highest valuation and the second highest bid mixes just below his valuation. Though there is clustered bidding there as well, it is necessarily among the two highest bids while that needn't be the case in Marshall and Marx (2004).

[30] Smith (2003) derives a similar result in a setting with cost shocks and firms choosing quantities.

members will generally lower their quantities. The aggregate supply of cartel members must decline[31] though individual firms' supply need not when firms have different costs. But what is true for standard oligopoly models is that non-members will always *raise* their quantity as they take advantage of the cartel reducing their supply. A firm reducing its quantity then identifies it as a cartel member, while a firm raising its quantity suggests it is not a member of the cartel. While this does not provide a marker for collusion, it does offer a way in which to identify a cartel's members.

3.2 Predictions on Market Share

How does collusion affect the stability of market share? Let us return to the Bertrand price setting when firms' costs are stochastic and private information. Cartel members can convey messages about their costs prior to setting price and quantity. As mentioned earlier, an optimal equilibrium can have firms keeping prices and market shares fixed so there is indeed stable market shares. This was mentioned for when costs are *iid* across firms and over time but it also holds when firms' costs are persistent over time (Athey and Bagwell, 2004). More generally, firms settle on a collusive outcome with stable market shares when cost persistence is sufficiently high relative to firms' patience.

To see the logic underlying this result, note that when cost persistence increases, it becomes more valuable to a firm to signal that it has low cost as it influences not only current beliefs (and potentially the current collusive output quotas) but also future beliefs on cost and thus can enhance a firm's future market share. Given this augmented incentive for a firm to report its cost is low (even when its cost is high), inducing truthful revelation either requires firms to be more patient - so they are content to wait for higher market share in the more distant future when they may truly have low cost - or to set lower prices (thus reducing the gain in current profit from reporting a low cost). When firms are not very patient, the preference is to forego efficiency in order to support higher collusive prices. Market shares are then more stable over time under collusion.

Collusive Marker Under certain conditions, market share is more stable under collusion.

When instead patience is high relative to persistence, the best collusive equilibrium may have market shares moving over time as firms achieve a more efficient mechanism in which a firm with lower cost has a higher market share (Athey and Bagwell, 2001, 2004).

[31] This is proven in Farrell and Shapiro (1990) for a joint profit-maximizing cartel.

This is shown in a simple situation where cost is high or low. The way the mechanism works is to engage in intertemporal market share favors. A firm that announces low cost and receives a high market share in the current period can expect a lower market share in the next period. This induces the firm to truthfully reveal. For if it is high cost and announces low cost, it sacrifices future market share when indeed it might truly be low cost. (Note that market share is especially valuable to a firm when it has low cost.) Thus, market shares are predicted to change over time (with firms' costs) and, furthermore, a firm's market share is negatively correlated over time. This is a history-dependent modification of a bid rotation scheme. Note that with this cost structure, market share would be *iid* over time in the absence of collusion.[32]

Similar results of intertemporal market sharing arises in models of repeated auctions which, contrary to the preceding model, do not allow messages to be sent and assumes prices are private information. The solution is a history-dependent bid rotation scheme; the probability of winning is decreasing in the frequency with which a bidder has won in the past. Thus, firms are favored who have tended to lose recent auctions (Blume and Heidhues, 2003; Skrzypacz and Hopenhayn, 2004).[33]

Collusive Marker Under certain conditions, a firm's market share is negatively correlated over time under collusion and is independent over time under competition.

Several recent price-fixing cartels engaged in various forms of intertemporal market sharing including the citric acid cartel of 1991-95 (Connor, 2001), the graphite electrodes cartel of 1992-97 (Levenstein, Suslow, and Oswald, 2004), and the vitamins cartel, in particular vitamins A and E over 1989-99 (European Commission, 2003).

3.3 Discussion

Though the collusive pricing literature is rich and offers some behavioral patterns that could help us to distinguish collusion from competition, it is deficient in some serious ways.

[32] This analysis assumes firms' costs are independent. Aoyagi (2002) considers when firms' costs are correlated and also finds collusion entails an intertemporal market sharing scheme.

[33] One problem with a collusive marker of negatively correlated market shares is that such a prediction would seem consistent with a non-collusive model in which firms have capacity constraints which apply over multiple periods. For example, a firm that wins a large contract in the current procurement auction may not have the capacity left to bid for contracts in the next period or, even if it does, there is an opportunity cost to using up capacity. A firm with little capacity ought to bid less aggressively knowing that if it wins then it'll have no capacity for the next auction which might involve a particularly profitable contract being auctioned off.

Ideally, we would want markers that are fairly universal and require minimal data. None of the markers just mentioned quite satisfy both criteria. While some markers require only price data - such as the collusive marker of lower price variance - others require ancillary information - for example, controlling for demand movements - which makes an intensive investigation necessary. Regardless of the data requirements, these markers are far from universal. Distinguishing features of collusion may only emerge when collusion is sufficiently imperfect so that ICCs bind. Thus, strong cartels may not be identified by some of these markers. But the problem is well-known to be much more severe in that there are many collusive equilibria and a particular marker may be peculiar to a particular equilibrium selection. Of particular concern is that collusion may be present but a marker is not satisfied.[34]

Collusive theory is, in addition, beset by two methodological weaknesses. With a few rare exceptions, existing models do not distinguish between tacit and explicit collusion. Yet, the objective is to have markers of explicit collusion. It is not just to distinguish collusion from competition but also explicit collusion from tacit collusion. Features unique to explicit collusion include communication among firms and side payments. As communication is a defining feature of explicit collusion, research which encompasses it is particularly valuable and includes McAfee and McMillan (1992), Athey and Bagwell (2001, 2004), Athey, Bagwell, and Sanchirico (2004), and Marshall and Marx (2004). In spite of this work, a major lacuna exists in both our understanding of when firms explicitly collude and what are its distinguishing features. In that tacit collusion is generally not subject to antitrust penalties, that firms explicitly collude either means: i) they were unable to tacitly collude; or ii) the incremental profit from colluding explicitly rather than tacitly exceeds the expected penalties. Yet, there is really no research that addresses these two questions. For example, research which characterizes industry traits conducive to collusion do not distinguish between explicit and tacit collusion. But what are the traits that would result in explicit collusion rather than tacit collusion? There is then the second issue about how the operating practices of an explicit cartel differs from that of firms who are tacitly colluding. This speaks directly to identifying markers of explicit collusion.

A second methodological problem is that most theories presume cartel members are ignorant of detection.[35] Firm behavior is then not designed to avoid creating suspicions

[34] But one should not fault theory too much in that these collusive theories were not typically derived for the purpose of identifying collusive markers that could be useful in detection. If theorists model with that as an objective, much better markers could emerge.

[35] Exceptions include Besanko and Spulber (1989, 1990), LaCasse (1995), Cyrenne (1999), Harrington

among buyers, competitors outside of the cartel, and the antitrust authorities. This results in a failure to address two critical issues. First, the properties of the cartel price path during the transition from the inherited non-collusive price to some stationary collusive outcome. In essence, most theories characterize the stationary phase even though the transition may offer the greatest hope for detecting cartels. It is then important to develop theories which tell us what to look for during that transition. Second, to what extent can a cartel avoid "failing" a test for collusion by acting strategically. This deals both with whether it is feasible for the cartel to do so but also, even if it is feasible, whether it is costly to do so in which case they may still leave a trail that might lead to detection.

4 Beating a Test for Collusion

An important issue about any detection method is: Can a cartel easily beat the test? In Bajari and Ye (2003), firms' bids are independent under the competitive model and lack of independence is taken as evidence consistent with collusion. However, as the authors note, this test can be beat by the cartel members appropriately scaling their "competitive bids" (which would mean scaling up in the case of a procurement auction). As the competitive bids are independent, an affine transformation of them will also be independent and thus would be consistent with competition. The same is true for the bid ranking test of Porter and Zona (1993). Similarly, exchangeability can be beat with such a transformation of competitive bids. Though colluding firms' bid functions may then be different, one could not distinguish it from a non-collusive solution in which their valuations are drawn from a different distribution. The ability of colluding firms in an auction to beat such tests is nicely shown in LaCasse (1995). The model is one in which bidders at an auction decide whether to collude and the antitrust authority decides whether to pursue an investigation based upon the observed bids. At a Bayes-Nash equilibrium, the posterior probability that a cartel has formed depends only on the winning bid and is independent of all other bids because they are strategically chosen to be uninformative.

Though a cartel *could* beat these tests, there is the empirical issue as to whether they do. In fact, Porter and Zona (1993) and Bajari and Ye (2003) do reject independence of firms' bids so, if firms are not colluding, they are not being very smart about it. Bajari and Summers (2002, p. 145) note that: "... in all case studies of collusion of which we are aware, failures of conditional independence and exhangeability accompanied

(2003, 2004), and Harrington and Chen (2004).

collusion." However, one can either infer that cartels are not being smart - which may indeed be the case - or instead that this is evidence *against* collusion because a smart cartel would not behave in this manner. It is certainly evidence against the collusive model of LaCasse (1995). One would instead infer that there is misspecification in cost and demand conditions. A troubling element here is the dependence of inferences on the specification of the collusive model and the selection of an equilibrium. The modeller has a lot of discretion and whether one assumes a smart or naive cartel makes a big difference.

Fortunately, there are other tests of collusion for which it is not costless for firms to beat. In Porter and Zona (1999), an unconstrained cartel finds it optimal to bid high in nearby collusive markets but bid low in more distant competitive markets. This resulted in bids being decreasing in distance which was taken as evidence of collusion. Cartel members could avoid failing this test by making their bids increasing in distance but it would require lowering their bids in collusive markets - which means earning less profit on contracts won - and/or raising their bids in competitive markets - which means reducing the chance of winning those contracts. In choosing their bids, a smart cartel would trade-off cartel profit with the probability of detection. A smart cartel may reduce the power of a test but may not eliminate it entirely.

It may also be difficult for cartel members to beat some tests based on identifying a structural break (the method described in Section 2.2). Since collusion must mean a change in the process generating price - for that is the express purpose of forming a cartel - in principle one should be able to pick up a break by monitoring the average price change. Once again the cartel can reduce the power of this test by manipulating price changes - for example, making them modest and including price decreases amongst price increases - but it foregoes profit in doing so. More generally, it would seem that the transition from the non-collusive outcome to the collusive stationary path - as opposed to the collusive stationary path - may be particularly fruitful for detection because mimicking competition is especially costly in terms of profit given that the cartel inherits a price well-below where it would like it to be. Ironically, almost all theoretical work implicitly focuses on the stationary phase and leaves unanswered what the transitional path looks like.[36]

As the above discussion reveals, some tests of collusion have power even with smart cartels because it means lower profit from circumventing them.[37] A second reason that

[36] Exceptions are Harrington (2003, 2004) and Harrington and Chen (2004) who show that the cartel price path is comprised of a transition phase and a stationary phase.

[37] An insightful discussion on this issue is provided in Porter (2004) who poses five problems that a cartel must solve to be effective and how, in solving those problems, they might reveal that a cartel

tests may have power comes from the need to maintain cartel stability. Ensuing that a price path respects ICCs may restrict the feasibility of looking "competitive." In Marshall and Marx (2004), the cartel needs to cluster bids to avoid cheating. In Rotemberg and Saloner (1986), the cartel needs to lower prices during times of strong demand. Alternatively, they could have price move with demand but it would require yet lower prices. The cartel may prefer to have higher counter-cyclical pricing and trade-off higher profit with a higher chance of detection. The feasibility in beating a test for collusion may be further exacerbated when firms are heterogeneous as then the cartel must balance diverse preferences. For example, in Harrington (1989), less patient firms must be given higher market shares to stabilize the cartel. More generally, it is the firm that has the greatest incentive to deviate which limits the set of feasible policies and thus makes it harder to both maintain cartel stability and avoid detection. And all this may be even more acute when there is imperfect monitoring. Periodic reversion to lower prices may be required to maintain collusion but the resulting structural break could trigger detection. Can a cartel design a policy that deters cheating without inducing rejection of the null hypothesis of no structural change? Or is there a fundamental tension between practices that promote compliance and those which avoid detection?

5 Screening for Price-Fixing

Screening refers to a cost-effective method for identifying industries whose behavior is sufficiently suggestive of collusion so as to warrant verification; that is, an intense investigation that directly contrasts collusion and competition as competing explanations of market behavior. Though the antitrust authorities do not currently screen for price-fixing, history is scattered with attempts. Going back to at least the 1950s, the U. S. Department of Justice would collect reports of identical bids at government procurement auctions (Joint Executive Committee, 1961). More than 25 years ago, Joseph Gallo proposed a computer program to identify collusion at sealed-bid auctions (Gallo, 1977). A more recent attempt is the work of Abrantes-Metz, Froeb, and Taylor (2004) where it is notable that Luke Froeb is currently Director of the Bureau of Economics at the Federal Trade Commission. The question is - Can we effectively screen for price-fixing and, if so, what will it take to make it work?

There are three criteria we lay out for systematic and ubiquitous screening. First,

exists.

evidence of collusion (preferably explicit collusion) must be discernible by just looking at prices, market shares, or other easily available data. Second, the test to be conducted should be routinizable so that it can be conducted with minimal human input. These first two criteria indicate that one is imagining an empirical exercise far removed from the typical industry analysis which involves collecting data on price, quantity, and cost and demand shifters and then performing many modifications to a sophisticated econometric model. The third criterion is that the screen should be costly for the cartel to beat.

The objective is to screen industries as a matter of course; even where there is no hint of collusion. To be practical, screening must then rely on easily available data which, in many cases, will mean exclusively using price data. However, in some instances, quantity and some cost or demand shifters may also be accessible at low cost. Consider a product with a primary input which trades on commodity markets; for example, raw sugar used in the production of refined sugar (Genesove and Mullin, 1998). If cartel members manufacture in one country and sell in another - such as with the vitamins cartel - then exchange rate fluctuations provide an easily available cost shifter.

Though high frequency price data is not often easily available, there is a growing number of possibilities. The government has access to bid data from auctions for which it is involved; ranging from defense procurement to Treasury bills. Online price data is another source. There is a growing amount of online retailing and many scholars have already "scraped" data off of web pages. Shopbots are present to perform some of this work. Furthermore, some web sites are beginning to collect price data from conventional retailers. This is currently being done with gasoline prices[38] though the voluntary nature of reports makes the data sketchy. Then some markets - like financial markets, electric power, and some commodity markets - offer high-frequency data that, at a price, is available.

With this data, the empirical exercise must be simple enough to be largely automated. One possibility is looking for certain collusive markers such as low price variance, low market share variance, high correlation in bids at an auction, negative correlation in market shares, negative correlation in price and quantity, and so forth. For example, Abrantes-Metz, Froeb, and Taylor (2004) make progress in developing a screen for a low price variance.

A second approach is to identify structural breaks in the stochastic process producing prices or some other measure of firm behavior. As new data arrives, a test for a structural break is conducted. The problem with using, say, a Chow test is that one can expect to

[38] For example, `www.gaspricewatch.com`

eventually reject the hypothesis of parameter stability even if the model is stable. Fortunately, Chu, Stinchcombe, and White (1996) provide appropriate tests for conducting continual monitoring for structural breaks. Examination of spreads for certain Nasdaq securities show a very quick switch from quoting all eighths to avoiding odd-eighths and this is reflected in a sharp and quick doubling of the spread (see Figure 1 from Christie and Schultz, 1999). A monitoring of structural change would have probably picked it up. Likely structural breaks to look for include an increase in average price changes, a fall in the price variance, and an enhanced correlation among firms' prices.

Another possibility is to develop software that picks up anomalies. By an anomaly is meant, for example, the avoidance of odd-eighth quotes in Nasdaq markets and the inclusion of cents on a multi-million dollar bid which, in the case of the FCC spectrum auctions, acted as a signal between bidders (Cramton and Schwartz, 2000). An empirical regularity known as Benford's Law (Hill, 1995) could be useful here. This refers to the property of many data series whereby the first significant digit, the second significant digit, and so forth has a particular distribution which is not uniform but rather logarithmic. The probability distribution on the first k digits is specified to be

$$\log_{10}\left[1+\left(\sum_{i=1}^{k} d_i \times 10^{k-i}\right)^{-1}\right]$$

where $d_i \in \{0,1,\ldots,9\}$ is the i^{th} digit. For example, the frequency with which the first digit is 1 is about 30%, is 2 is about 18%, and so forth. Another useful property to test for is that digits are not independent so that the unconditional distribution on the second digit differs from the distribution on the second digit conditional on the first digit. This regularity has been used in uncovering tax fraud in that "artificially created" numbers don't typically satisfy Benford's Law while "naturally created" numbers often do (Geyer and Williamson, 2004).

Ideally, any data screen should also satisfy the property that it is costly for the cartel to beat the test. A screen that became sufficiently successful and could be costlessly beat may ultimately be beaten by firms. This is not entirely obvious, however, because new cartels are continually born and some could be naive if information about detection methods doesn't easily spread across industries. Furthermore, a firm's management that learns about how detection is being conducted may learn too late if they learn by being caught colluding. The point is that the learning environment - in terms of the extent of learning from others and the opportunities for experiential learning - may be such that the learning process does not converge to where all or even most prospective cartels know how authorities detect. Nevertheless, it is certainly a desirable property for a test to be costly to beat as then it'll have power even against smart cartels.

Screening appears to be effectively used in a wide variety of contexts including insider trading, credit card fraud, and tax evasion. What allows them to do this is an ample supply of data - whether it is hourly trading volume and bid and ask prices for a security, daily credit card purchases, or annual tax returns. This serves two key purposes. First, the data is available to be screened. Second, it allows them to empirically identify what fraud looks like since they have many *ex post* verifiable cases. Two general methods are deployed in utilizing this data. Supervised methods involve the development of canonical models of fraudulent and nonfraudulent behavior using samples of such behavior. A particular case is then classified into one of those two categories. In contrast, unsupervised methods look for deviations from some benchmark; searching for anomalies or outliers.

How could we implement screening as part of an activist policy? First, building a library of cartels which will allow us to empirically identify markers to look for in the data. The antitrust authorities could be of great assistance here if they were to establish a policy that, as part of a plea agreement with colluding firms, all data is made public. Second, developing high-frequency price data series for more markets. Perhaps the government could induce buyers to provide this data under the condition of privacy, especially as there is a potential benefit to them from doing so. Third, refining existing empirical methods for picking up structural change and statistical anomalies. This may be the most robust method for identifying suspicious industries.

6 Concluding Remarks

The challenges to using economic analysis in the detection of cartels are complex and numerous but the currently weak state of the discipline may well be attributed to lack of attention. Though the literature on collusion is immense, very little of it was conducted with the intent of developing theoretical and empirical tools for uncovering collusion. And almost none tries to identify markers of explicit collusion as opposed to tacit collusion. On top of the lack of methods is a lack of knowledge about what cartel behavior actually looks like. There is a wealth of cases but not much has been done to distill behavioral patterns from them. Such an analysis will produce collusive markers and provide a set of empirical facts to which a theory of cartel formation and pricing must conform. Hopefully, any new theory will also suggest other collusive markers that we may not have yet looked for in the data.

Is all this a pipe dream? Can, say, the U.S. Department of Justice or the DG Competition European Commission be more pro-active in detecting cartels? Addressing this question more broadly, there has indeed been advances in this regard. Though corporate leniency programs have been most useful in providing evidence to aid in prosecuting suspected cartels, the Omnibus question has led to the discovery of cartels in industries heretofore not suspected. An individual who is granted amnesty under the U.S. Corporate Leniency Program is asked, at the conclusion of their examination, whether they know of illegal collusion in any other market. She must answer the question and, if she is shown to have provided false statements, she loses amnesty as well as being subject to perjury. This has led to fresh discoveries. There is other evidence of a more aggressive policy (Spratling, 2001):

> At the Advanced International Cartel Workshop, the Department of Justice's Antitrust Division revealed, for the first time publicly, that the enforcement agency has proactive efforts underway to detect international cartels. The proactive efforts are a targeted and focused undertaking, directed at markets in industries where the Division has information that collusion has occurred or where the Division has had leads or prosecution in adjacent industries.

Furthermore, there are academic discussions about promoting discovery by offering colluding firms rewards, not just relief from penalties, under the corporate leniency program (see, in particular, Spagnolo, 2000). The real issue is whether economic analysis can also be part of a more aggressive policy. For that to occur will require significant theoretical and econometric advancements. The greatness of the challenge is matched by its worthiness.

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