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# EMPIRICAL EVIDENCE FOR COLLUSION IN THE U.S. AUTO MARKET?

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## ABSTRACT

A supergame theoretic price-setting model of collusion is calibrated to data from the North American passenger car market before, during, and after the voluntary restraint arrangements (VRAs) with Japan. Conclusions about whether the model is consistent with the data from the various regimes depend on assumptions about market structure, demand elasticities, and discount factors. If one believes that the price elasticity of auto demand is about one, for example, then the calibrations suggest that in the pre-VRA and VRA regimes, only General Motors and Ford could conceivably have colluded, and even this limited potential broke down in the post-VRA regime.

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## I. Introduction

This research examines whether conditions consistent with a familiar model of implicit collusion are satisfied in data for the United States passenger car market during each of three regimes. The model is a price-setting supergame with asymmetric capacity constraints, in which excess capacity is taken to "enforce" the collusion. The three regimes are aggregations of years: years prior to the Voluntary Restraint Arrangement (VRA) with Japan; years during the time in which it was binding; and years subsequent to that time.

Our most important conclusion is that whether the model appears broadly consistent with the data depends on what one believes about demand elasticity and on what one believes about cartel membership. If one believes that all three major US firms and all three major Japanese firms colluded, then the model is consistent with the data at very low elasticities of demand (as low as .17, .62, .30 in the respective regimes). These are much lower than generally estimated. Furthermore, the highest of them is suspect since the assertion that Japanese firms in the VRA period were colluding by restricting output below VRA levels contradicts the evidence. If one believes that only the three major US firms colluded, then the model is consistent with the data in a narrow range of elasticities above .64, .70, and .43 in the respective regimes. Finally, if one believes that only General Motors and Ford colluded, a sensible belief if one accepts that Chrysler's poor financial condition made it an untrustworthy conspirator, then elasticities that range up from 1.11, 1.16, and .73 in the respective regimes support the model. Hence, if one believes that elasticities of much less than one are unreasonable, the data are consistent with the story that GM and Ford successfully colluded in the Pre-VRA and VRA regimes but that their ability to collude was undermined in the Post-VRA regime as Japanese firms engaged in significant direct foreign investment.

The methodology of the research is to conduct fairly simple tests of necessary or sufficient conditions from the model in each regime. There are two advantages of conducting the tests for several regimes. Repetition obviously enhances our confidences in the conclusions. Furthermore, it is not unlikely that cartel membership differed across regimes.

The research has two distinctive analytical features relative to the existing literature. One is the asymmetry across firms in capacity and excess capacity. The other is the consideration of "optimal" rules (penal codes) for enforcing collusion.

The research has two distinctive empirical features relative to the existing literature. One is a technique for purging the observations of cyclicality, so as to create a data set relevant for a stationary U.S. auto industry in a sequence of equilibria, punctuated by the beginning and end of the VRA.[1] The other is a technique for blending fragmentary firm-level and industry-level data to infer important, yet unobservable, firm-level variables and parameters.

One of the most important assumptions that we maintain throughout the paper is that the mix of model varieties, and the quality and non-price characteristics of each, are sufficiently similar and stable across the colluding firms during each of the three regimes that they may be aggregated into a single commodity. Empirical acceptance of this assumption may be facilitated by the two-to-four year length of our regimes. That length was dictated by the timing of the VRA and the need to purge the data of cyclicality. All things considered, there may be some tradeoff involved in forcing our chosen regime lengths to reflect three things at once: cyclical stability, trade-policy regime, and comparability of cross-firm product line.

## 2. Maximal Collusion with Capacity Constraints

In his criticism of Cournot's (1838) work, Bertrand (1883) asserted that firms choose prices rather than quantities. In the real world firms usually choose both prices and quantities, as well as qualities and other characteristics of their outputs. To assume less is an abstraction and, as usual, the researcher's problem is to select the most useful abstraction.

To the extent that the level of production capacity is important, the Bertrand price-setting model seems to be a superior analytical tool to the Cournot quantity-setting model.[2] Furthermore, voluntary restraint arrangements, such as those seen in the U.S. automobile market during the 1980's, inhibit the foreign firm's ability to choose quantities, leaving price as their main decision variable over time periods determined by model mix, quality, and other slow-to-change features. For these reasons we find the Bertrand price-setting model a useful abstraction to examine implicit collusion in the U.S. automobile industry, especially in the context of voluntary export restraints.

We model the major automobile manufacturers as engaging in collusion. Much work in game theory has gone into developing formal models of collusion. It demonstrates that players can sustain outcomes that are not consistent with static Nash equilibria by adopting a penal code that instructs them how to behave after any deviation from collusion as well as after any deviation from the behavior specified by the penal code. To be effective a penal code must be credible, that is, at each time period and no matter what has happened in the past, it must be that each player maximizes the present discounted value of his payoffs by obeying the penal code from then on, given that all other players do likewise. One example of a credible penal code is attributed to Friedman (1971). His penal code instructs all players to choose static Nash strategies in all periods following any deviation. The search for optimal penal codes, that is, the credible penal codes which most severely punish deviation and hence can support the maximal possible collusion, was greatly advanced by the work of Abreu (1988). Lambson (1987, 1991) applied Abreu's results to Bertrand games.

The model studied in this paper is one of asymmetric Bertrand oligopoly: although the firms are assumed to have the same marginal cost, c, they have different capacities, with $k_i$ defined as the capacity of firm i. They produce a cross-sectionally homogeneous product--an assumption which requires that the mix of model varieties and the quality of non-price characteristics of each be similar and stable across colluding firms during each of the three periods. To the extent that the firms compete in most of the different product lines, and to the extent that they behave in each product line in a way similar to the behavior postulated below, we might hope that the aggregated markets will also be characterized by that behavior.

Firms are modeled as having an infinite horizon, with the (discrete) time periods being indexed by t. At the beginning of each period firms choose prices for the period simultaneously. After firms announce prices consumers attempt to purchase from firms charging the lowest price. Any unsatisfied demanders then attempt to purchase from firms charging the next lowest price, and so on. If the lowest price firms do not have sufficient capacity to supply the quantity demanded at their price, a rationing rule is required to determine how their output is allocated among consumers. We adopt the Levitan-Shubik (1972) rule which requires that consumers with higher reservation prices be served first. This is the relevant rule if there is a secondary market for the good because low reservation price consumers who acquire the good will in turn sell it to high reservation price consumers. (Alternatively, the Levitan-Shubik rule can be thought of as ignoring aggregate income effects.) Hence, if firm i is the only firm charging the price p then its sales are min $\{k_i, \max [D(p) - \Sigma_{<p} k_j, 0]\}$ where D(p) is total demand when all firms charge p and where $\Sigma_{<p}$ denotes summation over firms charging less than p. If two or more firms charge p then their total sales are min $\{\Sigma_p k_i, \max [D(p) - \Sigma_{<p} k_j, 0]\}$, where $\Sigma_p$ denotes summations over firms charging p. Firms charging the same price must agree on how to divide sales.[3]

Let $P = (p_1, \ldots, p_N)$ be the vector of prices charged by the firms. (It is sometimes convenient to write P in the form $(p_i; P_i)$; the price before the semicolon is firm i's price and the price vector after the semicolon is the vector of other firms' prices.) Then firm i's profit function, $\pi_i(P)$, is simply $(p_i - c)$ times firm i's sales.

Let $p_j(t,i)$ be a price, let $P(t,i) = [p_1(t,i), \ldots, p_N(t,i)]$, define the sequence of price vectors $\tau_i = \{P(t,i)\}_{t=1}^{\infty}$, and define $\tau = (\tau_1, \ldots \tau_N)$. Then $\tau_i$ is a <u>punishment</u> (for player i) and $\tau$ is a (simple) <u>penal code</u>. Firms can agree on a penal code in order to sustain an agreed upon collusive price, say $\tilde{p}$. If any firm, say firm i, charges a price other than $\tilde{p}$

then, in the next period, firms begin to follow the punishment price path described by $\tau_i$. If any firm, say j (perhaps equal to i) deviates from $\tau_i$, then firms begin to follow the punishment path described by $\tau_j$. If a firm deviates from its own punishment path, its punishment path is reimposed from the beginning.

Given a penal code, $\tau$, let $\delta \in (0,1)$ be the firm's discount factor and let $V_j(\tau_i) = \Sigma_{T=1}^{\infty} \delta^{T-1} \pi_j[P(T,i)]$ be the present value of profits to firm j if firm i's punishment path is followed, discounted to the first period of the punishment. $\tau$ is <u>credible</u> if for all i, all j, and all T,

$$(2.1) \quad \pi_j^*[P_j(T,i)] - \pi_j[P(T,i)] \leq \Sigma_{t=T+1}^{\infty} \delta^{t-1} \pi_j[P(t,i)] - \delta V_j(\tau_j)$$

where $\pi_j^*[P_j(T,i)] = \sup_p \pi_j(p;P_j)$ is firm j's <u>deviation profit</u> given $P_j$. In words, in each period every firm prefers to have the punishment continued rather than to optimally deviate and be punished in turn. A penal code is <u>optimal</u> if it minimizes $V_i(\tau_i)$ for each i subject to the constraint that $\tau$ be credible. A price is <u>sustainable</u> (by $\tau$) if there exists a division of the sales such that, for all i,

$$(2.2) \quad \pi_i^*(p,\ldots,p) - \pi_i(p;p,\ldots,p) \leq [\delta/(1-\delta)]\, \pi_i(p;p,\ldots,p) - \delta V_i(\tau_i),$$

that is, if each firm would prefer to have all firms charge p in each period than to deviate from p and be punished.

Let $\bar{P}_i$ minimize $\pi_i^*(P_i)$. $\bar{\pi}_i \equiv \pi_i^*(\bar{P}_i)$ will be called i's <u>one-period security level</u>; no matter what prices other firms charge, firm i can always achieve a profit of at least $\bar{\pi}_i$ in each period. Similarly, firm i can guarantee itself a discounted profit stream worth at least $\bar{V}_i \equiv \bar{\pi}_i/(1-\delta)$ which, accordingly, will be called firm i's security level. If $V_i(\tau_i) = \bar{V}_i$ then $\tau_i$ is a security level punishment. If $\tau_i$ is a security level punishment for all i then $\tau$ is a security level penal code.

Lambson (1987) proved for symmetric Bertrand games (and for a very general class of rationing rules) that if an optional penal code exists then a security level penal code is credible, implying that optimal penal codes are security level penal codes. This result does not hold in all asymmetric Bertrand games, but it is true that the largest firm can always be driven to its security level. Namely, Theorem 2.1 is a special case of a result found in Lambson (1991)[4].

Theorem 2.1: If $\tau$ is an optimal penal code and $k_j = \max_i k_i$ then $V_j(\tau_j) = \bar{V}_j$.

To see why it may not be credible to threaten to drive smaller firms to their security levels, consider a very small firm with a security level close to zero. To hold such a firm to its security level, all firms would have to charge prices close to marginal cost and hence garner profits close to zero. Large firms with high security levels may find it in their best interest to refuse to go through with the punishment.[5] Thus Lambson's (1987) proof that optimal penal codes are security level penal codes does not generalize from symmetric Bertrand games. However, Lambson (1991) establishes that security level penal codes are credible if firms' capacities are not too different. Furthermore, given the Levitan-Shubik mechanism, if

(2.3) $\pi_i^*(c,\ldots,c) \leq \delta\pi_i\ (p;p,\ldots,p)$

for all i and for some p sustainable by a security level penal code, then optimal penal codes are security level penal codes.[6] In any event, since each firm can guarantee itself its security level, security level penal codes provide a bound on the severity of punishments and hence an upper bound on the maximal level of collusion.

## 3. Empirical Research Strategy

Explicit and implicit in the dynamic collusion that is modeled above are various conditions that can be examined for empirical consistency. Two concern us here:

(1) Each colluding firm must gain more profits from the collusion than it could guarantee for itself in isolation. In other words, each firm's share of collusive profits must exceed its one-period security level. Though this may seem a very weak condition, and thus easily consistent with the data, we found it unsatisfied in some cases for the largest firms under "base-case" parameterization.

(2) Each colluding firm must gain at least as much profit from supporting the collusive pricing continuously than by "defecting" and then being "punished" according to the penal code governing the collusion. In other words, under security-level penal codes, condition (2.2) must hold, in which the left-hand side measures the one-period increment over collusive profits from a firm's defection, and the right-hand side measures the discounted value of the indefinite sacrifice of collusive profits under punishment.

Since the discount factors are not directly observable, these equations can be sized up against the data in two equivalent ways. "Realistic" discount factors can be assumed, and the equations can be examined directly by measuring other variables and parameters as described in Section 4. Or the conditions can be "maintained" as equations and solved for the discount factors that would support such a maintained hypothesis. These implied discount factors can then be evaluated for their realism. One advantage of the second approach is its capacity for meaningful reinterpretation. The model implicitly identifies a "period" with the length of time it takes for rivals to detect a given firm's defection from the collusion;[7] discount factors that seem realistically to be too low correspond precisely to "defection-possibility periods" that seem too long to believe that an auto maker could really hide underpricing and overproduction from its rivals.

Voluntary Restraint Arrangements that constrain the capacity of some firms will reduce both (assuming a fixed collusive price): the temptation of each firm to defect from the collusion and the profits sacrificed under punishment (that is, the punishment cost) that follows defection. In other words, the advent of VRAs, ceteris paribus, will reduce both the left-hand and right-hand sides of condition (2.2); the attenuation of VRAs will raise both sides. Collusive prices will endogenously adjust. An illustration of the component parts of condition (2.2) is given in table 3.1. Even though other things are not equal across regimes, it is interesting that the respective sides of (2.2) change in the implied direction 75 percent of the time for large U.S. firms.

A voluntary restraint arrangement can be interpreted as a policy to reduce the capacity available to the firms which are bound by the arrangement. The effects of imposing a VRA can thus be studied by analyzing the effects of changes in the firms' capacities. Two questions are central. First, how does the arrangement affect the firms' ability to collude? Second, how does the arrangement affect the collusive profits of the various firms?

Consider an arrangement that affects only one firm, say j. Instead of being allowed to sell up to $k_j$, firm j is constrained to sell no more than $v_j < k_j$. This has two effects on collusion. First, the ability of firm j to punish the other firms is reduced; that is, the security levels of the other firms tend to rise. This decreases the right hand side of (2.2) for all $i \neq j$ and a fixed collusive price, p. This effect tends to work <u>against</u> collusion, so only less profitable collusive prices can be sustained. The second effect, on the other hand, words <u>for</u> collusion; firm j finds it less profitable to cheat on a collusive agreement. In the absence of the restraint agreement, firm j would receive $\pi_j^*(p,\ldots p) = (p-c)k_j$ if it deviated optimally from the collusive agreement. With the VRA in place, however, it can only receive $\pi_j^*(p,\ldots,p) = (p-c)v_j$. Hence the demand allocation in collusion can give less output to firm i and more to the other firms. This makes it more attractive to the other firms to abide by the agreement so more profitable collusive prices are sustainable. Nothing can be said about which effect will dominate. [8]

4. <u>Data Description</u>

To calibrate the model and perform the tests described above, we sought three data sets, corresponding to regimes before, during, and after the VRA with Japan. The regimes are distinguished from each other in the model by the way the VRA constrains the capacity of Japanese firms to defect from the collusion and to punish the other defectors. Thus in empirical calibration, we sought a configuration that allowed capacity to differ across regimes, yet that forced other fundamental exogenous variables (demand curves, costs) to remain stationary within regimes. Cyclicality was purged from the data to the degree that stationarity was achieved. This procedure required some creative aggregation over time, since the inner boundaries of the regimes needed also to represent the advent and attenuation of the VRA.

To obtain a "pre-VRA" data set[9], we averaged passenger car figures for 1979, 1980, and 1981I. This had the advantage of combining acknowledged "good" and "bad" periods for the U.S. industry, and of creating a 1979-81I average that was remarkably similar in the aggregate (except capacity) to data for 1981II through 1985, which we used for our "mid-VRA" measures, and to data for 1986 through 1989, which we used for our "post-VRA" measures. The similarity encompassed not only quantities and parameters of the demand curves, but also a form of approximate stationarity for disaggregated prices by firm.[10] The resulting data and parameters are recorded in Table 4.1.

The most difficult challenge was to calibrate firm-by-firm capacity for each of the three regimes. Explicit firm-by-firm data are confidential. Available aggregates for the industry as a whole have conceptual problems (e.g., many measure all motor vehicles, not just passenger cars) and questionable accuracy (e.g., several are simple linked peaks of production series). For the pre-VRA and mid-VRA regimes, we relied instead on USITC (1980, 1985a) for industry-level capacity, K[11], and then allocated K among six U.S. and Japanese "firms":

General Motors (GM)
Ford
Chrysler
Toyota
Nissan
Honda

Production data for the U.S. firms was collected for each of the years 1969 through 1985 from MVMA (1989), Wards (1984, 1986, 1988) and AN (1985). A graphical smoothing method was used to calculate a measure we call "average peak production" for each U.S. firm for each year during the entire period (the measure was always greater than or equal to actual production). By assuming that the ratio of "average peak production" to capacity was identical across U.S. firms[12], we were able to allocate recorded industry capacity among them according to time trends in their peak production figures. For the post-VRA regime we relied on Federal Reserve System (1990) for the growth rates of aggregate capacity for passenger cars and light trucks, applying these rates successively to our 1985 figure for "real" passenger car capacity.

If only large U.S. firms are hypothesized to collude, only data in their capacities are necessary. If, in addition, large Japanese firms are hypothesized to collude then data on their capacities to import are also necessary. Capacity for imports was initially hard to conceive. In an extreme view, all global production could be dumped into the U.S. market--more than 20 million vehicles a year outside the United States. We resolved instead to try something less extreme and consistent with our underlying model. For the pre-VRA period, we assumed that a relevant measure of capacity utilization for the Japanese firms selling imports was an interpolation between capacity utilization rates for American Motors' and Volkswagen's North American operations and for Chrysler, calculated as above. Since Japanese firm sales tended to fall between the two, this reflected a reasonable posture that capacity utilization rates be identical for identically sized firms. For the mid-VRA period, we assumed that Japanese firm import capacity was actual imports, being constrained by the VRA. For the post-VRA regime Japanese firm capacity in the North American market was constructed by summing: (i) published accounts of North American capacity built by Toyota, Nissan, and Honda during 1986-89; and (ii) ongoing VRA allotments for each firm, even when not binding. We emphasize that these calculations of import capacity do not enter our tests of hypothesized collusion among large U.S. firms alone.

Calculated capacities and capacity utilization rates based on these procedures are recorded in Table 4.2.

## 5. Empirical Calibration and Results

All theories of collusion that assume the usual form of individual rationality necessarily require that each firm receive collusive profits that are at least as large as its security level, that is, each firm must receive profits at least as large as the profits that it can guarantee for itself independently of the actions of the other firms. Of course, if punishments are never triggered there is no direct way to observe firms' security levels. If, however, linear demand is assumed and the Levitan-Shubik rationing rule adopted, security levels can be deduced. Specifically, under the Levitan-Shubik rationing rule firm i has a guaranteed residual demand given by

$$(5.1)\quad d_i(p) = \max\,[0, a - bp - K_i]$$

where p is firm i's price and $K_i \equiv \Sigma_{j\neq i} k_j$ represents the capacity of i's competitors. If the firm's own capacity constraint is not binding, then its profit from servicing its residual demand curve can be expressed as

$$(5.2)\quad \hat{\pi}_i(p) = (p-c)\ \max\,[0, (a-bp-K_i)],$$

which, if $a\text{-}bc\text{-}K_j \geq 0$, it maximizes when price is $p^* = (a + bc - K_j)/2b$. If its capacity constraint is binding when it services its residual demand curve by charging $p^*$, that is if $k_i \leq (a - bc - K_j)/2$, then it maximizes profits from its residual demand curve by charging $p^{**} = (a\text{-}k_i\text{-}K_j)/b$, that is, by charging the price such that its capacity is exactly demanded. Thus, firm i's one-period security level is

$$
\begin{aligned}
(5.3) \quad \bar{\pi}_i &= (a\text{-}bc\text{-}K_j)^2/4b && \text{if } k_i \geq (a\text{-}bc\text{-}K_j)/2 \text{ and } a\text{-}bc\text{-}K_j \geq 0 \\
&= 0 && \text{if } k_i \geq (a\text{-}bc\text{-}K_j)/2 \text{ and } a\text{-}bc\text{-}K_j \leq 0 \\
&= (a\text{-}bc\text{-}K_j\text{-}k_i)(k_i/b) && \text{if } k_i \leq (a\text{-}bc\text{-}K_j)/2.
\end{aligned}
$$

As discussed in section 4, each regime is treated separately. The data themselves establish a point on the demand curve. Assuming linearity, the demand curve is then completely determined by its elasticity. The demand curve and the data on firm capacity, in turn, determine the security levels of the firms through (5.3). The data also provide the profits of the firms. The theoretical requirement that all the firms' collusive profits exceed their security levels puts a restriction on which demand elasticities are consistent with both the data and the theory. The ranges of consistent elasticities are in Table 5.1. These ranges depend on very little more than linearity: given linearity, <u>any</u> model satisfying a weak form of individual rationality will imply these restrictions.

Calculations were made for each of the three regimes under three different assumptions pertaining to market structure. The three assumptions were, respectively, (1) that all six of the major automobile corporations were colluding, (2) that all three of the major U.S. automobile corporations were colluding, and (3) that only General

Motors and Ford were colluding. Firms that were assumed not to be colluding were assumed not to be threatening to use any excess capacity in punishing a deviate colluder; hence, the result of dropping a colluder is a reduction in $K_i$ for each remaining colluder.[13] A priori, the case for the first assumption seems strongest in the pre-VRA and post-VRA episodes; during the VRA episode the Japanese firms were constrained by the VRA's and hence had limited ability to expand output to punish deviation (as well as limited ability to expand output to deviate). If one takes the view that the Japanese in the pre-VRA and/or post-VRA period were striving to penetrate the U.S. market, making them unlikely conspirators in any collusive agreement, then assumption 2 might seem most reasonable. Finally, if one believes that the tenuous financial condition of Chrysler during some episodes would have made it an unreliable partner in collusion, assumption 3 might seem most reasonable.

Given the ranges of elasticities in Table 5.1, one can use (2.2) to consider whether the data are broadly consistent with security level penal codes. If security level penal codes are employed, then $V_i(\pi_i) = \bar{\pi}_i/(1-\delta)$ where $\bar{\pi}_i$ is defined in (5.3). Deviation from the high collusive price is optimally accomplished by undercutting one's co-conspirators and producing up to capacity; hence $\pi_i^* = (p-c)k_i$. Finally, if firms maximize joint profits subject to (2.2) and if the monopoly price is not sustainable then (2.2) holds with equality, thus determining $\delta$.

The collusive profit $\pi_i(p;p,\ldots,p)$ is, by assumption, what is observed in the data. Hence, assuming that (2.2) holds with equality for each colluding firm (i.e., maintaining that collusion does exist, that it maximizes joint profits, and that security level punishments are credible for all firms) and summing (2.2) over colluding firms, one can solve for the "average" discount factor, $\delta$, implied by the data and the model's assumptions. The discount factors for the extremes of the elasticity ranges for each regime and each market structure assumption are in Table 5.2.

These data-consistent, model-consistent average discount factors seem on balance much too low to be believable. Even the most plausible (that is, the largest) of these discount factors correspond to "defection-possibility periods" that are six to eighteen months in length, depending on firms' rates of time preference. It is hard to believe that auto rivals would remain passive in the face of significantly increased sales by a defector for this long a period before detecting the "infraction" and responding to it. Smaller discount factors, of course, correspond to even longer and more incredible defection periods.

However, these discount factors are derived assuming that all firms can credibly be driven to their security levels. This assumption is not implied by the theory, which only guarantees that the largest firm can be so severely punished and, hence, that (2.2) holds with equality only for GM. Table 5.3 contains the discount factors for GM given the extremes of the elasticity ranges for each regime and each market structure assumption.[14] In every case, GM's implied discount factor approaches one as the elasticity of demand approaches the lower bound of the consistent elasticity ranges exhibited in Table 5.1. Elasticities close to those lower bounds (that is, within about .01) correspond to detection periods of a few months or less with the length of the detection period approaching zero as the elasticity approaches the lower bound. Thus for the reader who accepts the lower elasticity bounds as reasonable (for a market structure assumption that he or she also considers reasonable) the data are broadly consistent with the theory.

## 6. Conclusions

The above model of dynamic imperfect competition in an asymmetric Bertrand oligopoly can be construed as broadly consistent with data on the firms producing passenger cars for the U.S. market between 1979 and 1989. One's conclusions on this point will depend on what he or she believes about automobile demand elasticity and market structure.

Without reference to any particular theory, and requiring only linearity and a minimal notion of individual rationality, the data imply that automobile demand elasticities fell somewhere between 0.17 and 7.05 during the sample period (see Table 5.1). This is, no doubt, a large range. On the other hand, it contains any reasonable a priori opinion on what automobile demand elasticities were without containing numbers above the single digits. The method of data construction in no way required this outcome in advance, so some confidence in this method is justified.

Further restrictions on the demand elasticity imposed by the theory (along with the belief that it would take no more than a few months, at the very most, for firms to detect deviation from collusion) lead one to focus on the lower end of the elasticity ranges implied by linearity and individual rationality. Whether one finds the model consistent with the data then depends on what one believes about demand elasticities and market structure. For example, if one believes that the elasticity of automobile demand is about one, Table 5.1 suggests that in the Pre-VRA and VRA regimes only GM and Ford were able to collude and the collusion broke down in the Post-VRA regime. This is consistent with the story that Chrysler's tenuous financial condition made it an untrustworthy partner throughout the eighties, that Japanese firms eschewed collusion in the Pre-VRA regime as they attempted to penetrate the American market and were prevented from being collusive partners by trade restraints during the VRA regime, and that all firms lost the ability to collude in the competitive environment following the VRA as Japanese capacity in the United States became significant. By contrast, if one is willing to entertain lower automobile demand elasticicities, the data are consistent with even larger automobile cartels.

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TABLE 3.1

CALCULATED COLLUSIVE PROFITS, SECURITY LEVELS, DEFECTION PROFITS, AND PUNISHMENT LOSSES

SIX-FIRM COLLUSION IN PRE AND POST VRA REGIMES
THREE-FIRM COLLUSION IN VRA PERIOD REGIME

Demand price elasticity = 3.00
Cost = Method i calculation

| | Collusive Profits Per Period | Security Profits Per Period | Defection Temptation (One Period) | Punishment Cost Per Period |
|---|---|---|---|---|
| Pre-VRA (1979-81I) | ------ | ------ | ------ | ------ |
| General Motors | 5.307 | 2.361 | 1.243 | 2.946 |
| Ford | 1.927 | 0.467 | 1.059 | 1.460 |
| Chrysler | 0.919 | 0.133 | 0.736 | 0.786 |
| Toyota | 0.627 | 0.079 | 0.669 | 0.548 |
| Nissan | 0.565 | 0.075 | 0.720 | 0.490 |
| Honda | 0.425 | 0.008 | 0.069 | 0.417 |
| Mid-VRA (1981II-85) | | | | |
| General Motors | 6.547 | 4.753 | 1.766 | 1.794 |
| Ford | 2.392 | 1.458 | 0.933 | 0.934 |
| Chrysler | 1.555 | 1.032 | 0.809 | 0.523 |
| Toyota | 0.843 | 0.390 | n.a. | n.a. |
| Nissan | 0.762 | 0.368 | n.a. | n.a. |
| Honda | 0.685 | 0.328 | n.a. | n.a. |

TABLE 3.1,
CONT.

| | | | | |
|---|---|---|---|---|
| Post VRA (1986-89) | | | | |
| General Motors | 5.962 | 3.918 | 2.644 | 2.044 |
| Ford | 2.924 | 1.328 | 1.251 | 1.596 |
| Chrysler | 1.814 | 0.740 | 0.796 | 1.074 |
| Toyota | 1.017 | 0.299 | 0.576 | 0.718 |
| Nissan | 0.779 | 0.299 | 0.295 | 0.480 |
| Honda | 0.982 | 0.311 | 0.134 | 0.671 |

TABLE 4.1

DATA AND PARAMETERS

| | Pre VRA (1979-81I) | Mid VRA (1981II-85) | Post-VRA (1986-89) |
|---|---|---|---|
| Quantity (D( ))[1] | 9.714 | 9.667 | 10.999 |
| Price (p)[2] | $9045 | $10269 | $10307[3] |
| Cost (c),[4] method i | $7880 | $8743 | $8775[3] |
| Cost (c),[6] method ii | $4734 | $5090 | $5109[3] |
| Base-case market elasticity of demand for autos ..[7] | 1.00 | 1.00 | 1.00 |
| ...implied demand-curve intercept (a) | 19.43 | 19.33 | 21.997 |
| ...implied demand-curve slope (b times $10^4$) | -10.74 | -9.41 | -10.67 |

[1] Annual average of U.S. and Canadian production for the U.S. market and U.S. retail sales of import models. For details see separate appendix available from the authors.

[2] Average consumer expenditure per new car from MVMA (1986, p. 38), adjusted for changes in the overall consumer price index between 1982 and year t -- hence in "1982 purchasing power."

[3] Approximation based on col. 2 times relative CPI of new autos to all items.

[4] Estimated materials and payroll costs from USITC (1985a, pp. 39-40) and U.S. Department of Commerce (1986, p. 769), also adjusted for changes in the overall consumer price index between 1982 and year t -- hence in 1982 purchasing power. For details see separate appendix available from the authors.

[6] Cost estimate based on the assumption that lowest-price models were priced at marginal cost (c); lowest-price-model data from USITC (1985b), also adjusted for changes in the overall consumer price index between 1982 and year t--hence in "1982 purchasing power." For details see separate appendix available from the authors.

[7] Experiments with alternative values of the elasticity were performed, and are described in Section 5. These alternatives imply of course, corresponding values of intercept (a) and slope (b).

TABLE 4.2

CAPACITY AND CAPACITY UTILIZATION

| | Capacity (Units) | Capacity Utilization (%) |
|---|---|---|
| Pre-VRA (1979-81I) | | |
| GM | 5,626,600 | 80.96 |
| Ford | 2,563,300 | 64.53 |
| Chrysler | 1,420,800 | 55.52 |
| Toyota | 1,112,100 | 48.38 |
| Nissan | 1,103,000 | 43.95 |
| Honda | 424,300 | 86.04 |
| Mid-VRA (1981II-85) | | |
| GM | 5,447,500 | 78.76 |
| Ford | 2,178,800 | 71.93 |
| Chrysler | 1,549,400 | 65.77 |
| Post-VRA (1986-89) | | |
| GM | 5,617,100 | 69.28 |
| Ford | 2,725,100 | 70.03 |
| Chrysler | 1,703,600 | 69.50 |
| Toyota | 700,000[1] | 94.80 |
| Nissan | 701,000[1] | 72.52 |
| Honda | 728,000[1] | 88.02 |

[1] Average North American capacity plus VRA allottment. See text.

TABLE 5.1

DATA-CONSISTENT RANGE OF
DEMAND PRICE ELASTICITIES
GIVEN LINEAR DEMAND
AND INDIVIDUAL RATIONALITY

| | |
|---|---|
| Pre-VRA (1979-81I) | |
| Six-firm collusion | 0.17 to 5.51 |
| U.S. big-three collusion | 0.64 to 4.69 |
| U.S. big-two collusion | 1.11 to 4.46 |
| Mid-VRA (1981II-85) | |
| Six-firm collusion | 0.62 to 4.94 |
| U.S. big three collusion | 0.70 to 4.68 |
| U.S. big-two collusion | 1.15 to 4.39 |
| Post-VRA (1986-89) | |
| Six-firm collusion | 0.30 to 7.05 |
| U.S. big-three collusion | 0.43 to 6.39 |
| U.S. big-two collusion | 0.73 to 5.30 |

TABLE 5.2

DATA-CONSISTENT, MODEL-CONSISTENT AVERAGE DISCOUNT FACTORS AT EXTREME CONSISTENT ELASTICITIES

| | |
|---|---|
| Pre-VRA (1979-81I) | |
| Six-firm collusion | 0.50 and 0.58 |
| U.S. big-three collusion | 0.54 and 0.65 |
| U.S. big-two collusion | 0.68 and 0.73 |
| Mid-VRA (1981II-85) | |
| Six-firm collusion | 0.40 and 0.66 |
| U.S. big-three collusion | 0.49 and 0.74 |
| U.S. big-two collusion | 0.66 and 0.84 |
| Post-VRA (1986-89) | |
| Six-firm collusion | 0.29 and 0.79 |
| U.S. big-three collusion | 0.43 and 0.86 |
| U.S. big-two collusion | 0.58 and 0.83 |

TABLE 5.3

DATA-CONSISTENT, MODEL-CONSISTENT DISCOUNT FACTORS FOR GM AT EXTREME CONSISTENT ELASTICITIES

| | |
|---|---|
| Pre-VRA (1979-81I) | |
| Six-firm collusion | 0.37 and 1.0 |
| U.S. big-three collusion | 0.47 and 1.0 |
| U.S. big-two collusion | 0.59 and 1.0 |
| Mid-VRA (1981II-85) | |
| Six-firm collusion | 0.63 and 1.0 |
| U.S. big-three collusion | 0.63 and 1.0 |
| U.S. big-two collusion | 0.77 and 1.0 |
| Post-VRA (1986-89) | |
| Six-firm collusion | 1.0 and 1.0 |
| U.S. big-three collusion | 1.0 and 1.0 |
| U.S. big-two collusion | 1.0 and 1.0 |

## FOOTNOTES

1. This sets our research apart from the several papers on how the incentives for and stability of implicit collusion vary over cyclical peaks and troughs. See, for example, Rotemberg and Saloner (1986, 1989a), Domowitz, Hubbard, and Petersen (1987), and Iwand and Rosenbaum (1988).

2. See Davidson and Deneckere (1984).

3. In the collusive equilibria described below, any firm deviating from agreed upon behavior does so by charging a price different from that charged by any other firm. Thus it is unnecessary to specify how cooperating firms divide sales with an uncooperative firm charging the same price. See Lambson (1991).

4. The model explored in Lambson (1991) is more general than the model applied here.

5. This model may be one way to formalize the notion of a small number of dominant firms that share the market with a "competitive fringe," the members of which are too small for the large firms to bother with.

6. Construct $\bar{\pi}_i$ by having all firms but firm i charge c for one period while firm i charges the price (less than or equal to c) such that, given the (sustainable) price and division of sales following the first period of the punishment, firm i's discounted payoff equals $\bar{V}_i$. It is easily verified, recalling $\pi_i(c;c,\ldots,c)= 0$ and $\bar{V}_i = \pi_i^*(c,\ldots,c)/(1-\delta)$, that this is a credible, security level penal code.

7. See, for example, Tirole (1989, pp, 248, 251-252) for this interpretation of what a period <u>must</u> mean, given the model.

8. Brock and Scheinkman (1985) show that when firms' capacities are constrained to be identical the effects of capacity changes on the sustainability of collusion are nonmonotonic.

9. Details of the steps described in the remainder of Section 4 are available from the authors in a separate data appendix.

10. To be specific, each regime's distribution of prices across firms was quite stable from year to year, consistent with our assumption that automobiles are a cross-sectionally homogeneous good (see introduction).

11. Such data were supplied by U.S. firms as part of an investigation by the International Trade Commission, on condition that they be kept confidential. The Commission published only the aggregate figures for all U.S. firms.

12. This assumption would make sense if peaks represented surges of aggregate demand that took all colluding producers by surprise, and allowed all to produce temporarily at levels comparably close to full capacity.

13. $K_i$ was calculated as the sum of the capacities of the colluders and the sales of the noncolluders.

14. GM's discount factor is a U-shaped function of the elasticity. Changing the elasticity means rotating the demand curve through the observed (collusive) point. Increasing elasticity thus reduces (increases) profitability to the left (right) of the observed point. At low (high) elasticities optimal deviation from marginal cost pricing occurs at prices above (below) the observed point so at low (high) elasticities the security level falls (rises) as elasticity increases. The result is a U-shaped function with the maximum security level (and hence the maximum discount factor) in the consistent range occurring at one (or both) of the end points.

Data Appendix

Empirical Evidence for Collusion
In the U.S. Auto Market

Val Eugene Lambson
J. David Richardson

(1) Table 4.1, Row 1.

$D(\ ) = S_{US} + S_J$, where

$S_{US} = s_{GM} + s_F + s_C + s_{r1}$ = estimated North American passenger car production (units) by U.S. firms for the U.S. market (plus North American production of Volkswagen);

$S_J = s_T + s_N + s_H + s_{r2}$ = U.S. passenger car production (units) by Japanese firms for the U.S. market plus retail sales (units) of imported passenger cars in the U.S. market by non-U.S. firms;

and where

$s_{GM}, s_F, s_C, s_{r1}$ = estimated North American passenger car production (units) by General Motors (GM), Ford (F), Chrysler (C), and residual North American resident, non-Japanese suppliers; each in turn equal to "scaled" measured production, defined as

$$\begin{bmatrix}\text{scaling}\\ \text{factor}\end{bmatrix} \cdot \begin{bmatrix}\text{measured}\\ \text{production}\end{bmatrix}$$

$$= [(S_{US}' + M - X)/S_{US}'] \cdot s_i';$$

where

$$S_{US}' = \sum_{i=1}^{4} s_i';$$

$s_i'$ = annual measured U.S. production by GM, F, C, and residual suppliers, from 1984, 1986, and 1988 versions of Ward's Automotive Yearbook, and from The Wall Street Journal of 3/10/89 (A2), 9/18/89 (A6), 11/20/89 (A2), 2/9/90 (A2), 6/15/90 (C9), and 9/24/90 (B10);

M - X = net U.S. imports (units) by U.S. firms from Canadian affiliates: 1978-84 figures from USITC (1985b, table 28, p. 46); 1985-88 figures from 1987, 1988, 1989, and 1990 editions of Motor Vehicles Manufacturers Association (MVMA), World Motor Vehicle Data, and from MVMA Facts and Figures 1986;

and where

$s_T$, $s_N$, $s_H$ = U.S. passenger car production (units) plus retail sales (units) of imported passenger cars in the U.S. market by Toyota (T), Nissan (N), and Honda (H); 1978-85 figures from USITC (1985b, pp. 11-14) plus N and H production from 1986 version of Ward's Automotive Yearbook; 1986-88 figures from 1990 edition of MVMA World Motor Vehicle Data, passenger car retail sales of U.S.-built units plus imported units by T, N, and H; 1989 figure from scaling 1988 figure by 1988-89 growth rate of sales of Japanese passenger cars and light trucks from Wall Street Journal, 4/24/90 (A1);

$s_{r2}$ = retail sales of imported passenger cars by "residual" foreign suppliers, where "residual" excludes T, N, and H, and where "foreign" excludes sales of imported units by GM, F, and C; 1978-85 figures from USITC (1985b, pp. 11-14); 1986-88 figures from 1990 edition of MVMA World Motor Vehicle Data; 1989 figure set equal to the arithmetic average for 1986-88.

(2) Table 4.1, Row 2.

$P = P_t' \cdot (CPI_{82}/CPI_t)$, where

$P_t'$ = average consumer expenditure per new passenger car; 1978-85 figures from MVMA Facts and Figures '86; 1986-89 figure from scaling 1981III-85 average by the rate of inflation in the consumer price index for new autos between the 1986-89 period and the 1981III-85 period;

$CPI_{82}$, $CPI_t$ = consumer price index for all items in 1982 and year t, respectively, from various issues of the Economic Report of the President.

(3) Table 4.1, Row 3.

$c_1 = c_{t1}' \cdot (c_{t1}''/c_{t1}') \cdot (CPI_{82}/CPI_t)$

where

$c_{t1}''$ = payroll plus cost of materials for motor vehicles and car body equipment industry; 1978-83 figures from U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States 1986, Table 1382, p. 769, drawn from earlier Census... and Annual Survey of Manufactures; 1984-85 figures, see below; 1986-89 figure from scaling 1981III-85 average by the rate of inflation in the consumer price index for new autos between the 1986-89 period and the 1981III-85 period;

$c_{t1}''/c_{t1}'$ = ratio of $c_{t1}''$ from above to "cost of goods sold" by U.S. operations of GM, F, C, American Motors Corporation, Volkswagen, and Honda; 1978-84 figures for $c_{t1}'$ from USITC (1985a, pp. 39-40); 1985 figure for $c_{t1}'$ scaled up from 1984 figure by 1984-85 rate of increase in net sales; 1984-89 ratio of $c_{t1}''/c_t'$ assumed equal to 1983 ratio;

$CPI_{82}$, $CPI_t$ = see above under (2).

(4) Table 4.1, Row 4.

$c_2 = c''_{t2} \cdot (CPI_{82}/CPI_t)$,

where

$c''_{t2}$ = sales-weighted average across six firms of the suggested retail price for the lowest-priced model produced by GM, F, C, T, N, and H; 1978-85 figures from USITC (1985b, pp. 22-25); 1986-89 figure from scaling the 1981III-85 average by the rate of inflation in the consumer price index for new autos between the 1986-89 period and the 1981III-85 period;

$CPI_{82}$, $CPI_t$ = see above under (2).

(5) Table 4.2, "Capacity" column.

$k_i$ for i = GM, F, C = $(K_{US}/\bar{S}_{US}) \cdot \bar{s}_i$

where

$K_{US}$ = passenger car production capacity (units) for the North American market by North-American-resident, non-Japanese suppliers

= $\dot{S}_{US}/CU_{US}$ for 1978-85, where

$\dot{S}_{US}$ = see above under (1);

$CU_{US}$ = aggregate capacity utilization rate for U.S. producers; 1978 figure from USITC (1980, p. A-31); 1979-84 figures from USITC (1985a, p. 44); 1985 data from USITC;

and for 1986-89 = arithmetic average of $K_{US}$ for 1986, 1987, 1988, 1989, where each was 1985 $K_{US}$ scaled by the rate of growth in industrial capacity for autos and light trucks from Board of Governors of the Federal Reserve System, Federal Statistical Release, G.17 (419), Table 4;

and where

$$\bar{S}_{US} = \sum_{i=GM,F,C} \bar{s}_i;$$

and where

$\bar{s}_i$ for i = GM,F,C = each firm's average peak production = the sum of each year's four quarters of linearly interpolated production ($s_i'$, see above for definition and source) between "peaks"; peaks were determined graphically, with each firm having obvious peaks around 1978 and 1984; therafter, a succession of declining peaks for GM and C and mildly rising peaks for F; graphs are available on request from the authors;

$k_i$ for i = T, N...

...for 1978 - 1981 II = average of linear interpolation of 1975-76 capacity of American Motors Corporation (AMC, roughly the same size supplier as T,N at that time) and C capacity in 1981 (roughly the same supplier size as T,N at that time), where capacity for AMC was determined analogously to GM, F, and C above;

...for 1981 III - 1985 = actual $s_i$ = voluntary restraint quantity determined by government of Japan from Wall Street Journal, 4/14/88.

...for 1986-89 = sum of voluntary restraint quantity determined by government of Japan (see immediately above) and average annual U.S. production capacity determined from reports in Wall Street Journal, 3/9/87 (p.10) and 4/20/90 (A5), and in the Economist, 4/18/89, with linear interpolation for unpredicted years between 1986 and 1992. (Nummi production capacity allocated ½ to T).

$k_i$ for i = H ...

...for 1978-1981 II = AMC capacity plus Volkswagen North American capacity (H was roughly the same size supplier as AMC plus Volkswagen during this period), where capacity for AMC and Volkswagen were determined analogously to GM, F, and C above;

for 1981 III - 1985 = see T, N above for import share of H capacity plus North American production for H, from Wall Street Journal, 2/24/84 (p.2), 5/14/84 (p.10), 2/14/86 (p.1);

...for 1986-89, see method above for T, N.

(6) Table 4.2, "Capacity Utilization" column.

$cu_i$ = capacity utilization rates for each firm in respective periods = $(s_i/k_i)\cdot 100$, where for

$s_i$, see above under (1).

$k_i$, see immediately above.

Raw numerical data are available from the authors upon request.

## DATA APPENDIX REFERENCES

USITC (1980), Certain Motor Vehicles and Certain Chassis Thereof, Publication 1110 of the United States International Trade Commission, Washington, December.

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