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Information Sharing and Competition in the Motor Vehicle Industry

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Up to six months ahead of actual production, U.S. automakers announce plans for their monthly domestic production of cars. A leading industry trade journal publishes the initial plans and then a series of revisions leading up to the month in question. We analyze a panel data set spanning the years 1965–95, matching the production forecasts with data for actual monthly production. We show that a firm's plan announcement affects competitors' later revisions of their own plans and eventual production. The interaction appears to be complementary: large plans or upward revisions cause competitors to revise plans upward and increase production. The results are consistent with theoretical models in which firms share information about common demand parameters.

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I. Introduction

Publishing information regarding firms' costs, demand, outputs, prices, or plans for capacity expansion is a common practice in many industries. The information releases may include historical levels or forecasts of future levels and may include industry aggregates or firm-level data. For example, the lumber, coal, and steel industries all have associations that provide information on weekly production for the industry. The motor vehicle and aircraft industries publicly announce schedules of future production. Whether published in the business press or more specialized trade journals, the information releases are often accessible to a firm's investors, employees, and customers. It is of particular interest that the information releases are available to competitors.

The economics literature contains two different views on the motives for information sharing among competitors.[1] One view is that firms faced with demand or cost uncertainty may be better able to tailor their output or pricing decisions to actual market conditions if they have access to competitors' signals as well as their own private signals. In a model proposed by Novshek and Sonnenschein (1982) and analyzed in a score of later papers, information sharing among competitors can be shown to enhance social welfare in a variety of instances. A contrasting view is that information sharing among competitors can facilitate collusion. In the model of Green and Porter (1984), firms cannot distinguish whether a low realized price was due to exogenous demand fluctuations or to a rival's producing more than its collusive output. Information about firms' past actions would allow them to avoid indiscriminate price wars by punishing only if a deviation is observed.

Whether information sharing produces welfare improvements through efficiency gains or welfare losses through anticompetitive coordination is a question of considerable interest to antitrust authorities. Scherer and Ross (1990, pp. 347–52) note that legal precedent in the United States is less than clear, citing the *American Column and Lumber, Maple Flooring,* and *Container Corporation* cases. In an interesting recent case, several airlines were enjoined from issuing price pre-announcements through computer reservation systems as part of the 1994 settlement of *U.S. v. Airline Tariff Publishing Company.*[2]

Given that theory provides competing views of information exchange and given that the issue remains controversial in the realm

[1] See Kühn and Vives (1994) for a survey of the literature.
[2] See Gillespie (1995) for an economic analysis of this case.

of antitrust policy, there has been surprisingly little formal econometric work on information sharing among firms. Genesove and Mullin (1999) provide a case study of the Sugar Institute, a trade association that was found to be in violation of antitrust laws by the Supreme Court in 1936. Using detailed minutes of trade association meetings, they show how the organization of the Sugar Institute facilitated information exchange. Alexander (1988) shows that the formation of the trade association, declared illegal by the Supreme Court in the *American Column and Lumber* case, had no measurable effect on price-cost margins. There are also a number of experimental studies on information sharing and price pre-announcement including Grether and Plott (1984), Cason (1994), and Cason and Davis (1995). To our knowledge, the only paper that provides an econometric analysis of information sharing using industry data is Christensen and Caves (1997). The authors study the announcement of new capacity expansions by pulp and paper firms and the subsequent abandonment of these projects. The likelihood that capacity expansions are abandoned is negatively related to concentration in the submarket, certainty of the project, and internal resources of the firm. They provide some evidence of strategic announcement effects: a rival's subsequent announcement of capacity expansion increases the likelihood that a firm abandons its previously announced project.[3]

The present paper is an empirical examination of information sharing among the major domestic manufacturers of cars in the United States: General Motors (GM), Ford, Chrysler, and American Motors (AMC). We study the motor vehicle industry for several reasons. First, there is an abundance of data published for the industry. Second, the industry's performance has a nontrivial impact on the growth of the national economy. Third, a number of authors, including White (1971, 1982) and Adams and Brock (1995), have argued that U.S. automakers used announcements to facilitate collusion, in particular to bolster GM's leadership position.

We analyze one particular form of information exchange among automakers: the exchange of production plans issued in advance of actual production. From before 1965 to the present, the trade journal *Ward's Automotive Reports* published the firms' announcements of their plans for monthly U.S. production of cars as early as six months before actual production. These plans are subject to continuous revision until the end of the target month. We are interested in understanding why firms issue these announcements and how rivals

[3] This result is true in competitive markets only; the authors find the opposite result in concentrated submarkets.

react to them. Do firms simply disregard rivals' announcements as cheap talk in a babbling equilibrium (see, e.g., Farrell and Rabin 1996)? If firms do respond to rivals' announcements, what is the direction of the response? Determining the direction and pattern of firms' responses will allow us to assess the empirical relevance of a number of theories of oligopoly information sharing. These theories—including the models of Novshek and Sonnenschein (1982) and the subsequent literature, as well as various models of collusion facilitation—are briefly outlined in Section II. Section III describes the data. Section IV presents a detailed discussion of the empirical implications of a representative model from the oligopoly information sharing literature, an extension of Li (1985).

The main empirical results are presented in Sections IV and V. To summarize, we find that automakers' announcements of production plans do affect market outcomes and are therefore not babble. Firms' revisions of their earlier production plans, as well as their actual production, respond to signals from their rivals. Specifically, rival firms tend to adjust their production upward in response to an announcement of aggressive production. Ford and GM respond positively to each other's announcements, as do Ford and Chrysler. We do not observe a relationship between GM and Chrysler on the basis of the signal exchange. In Section V*B,* we examine periods during which an automaker is affected by labor strikes—essentially a firm-specific signal of low production. With this type of signal, rivals produce more aggressively than previously planned, the opposite of what happens when a firm responds to an announcement of a low production plan by a rival. Overall, the results are consistent with the model proposed in Section IV in which plan announcements contain information concerning an uncertain common demand parameter. The evidence is inconsistent with a model of information sharing concerning idiosyncratic cost parameters and is at best mixed regarding theories of collusion-facilitating communication.

II. Hypotheses

The fact that we are focusing on a particular form of information exchange in a particular industry—namely, the publication of production plan announcements by U.S. automakers—limits the set of viable hypotheses explaining why firms share this particular piece of information. For instance, sharing production plans would not aid collusion in a Green and Porter (1984) model since the plans provide no information about firms' past behavior and therefore do not help distinguish between exogenous demand shocks and deviations from collusion. Reliable information on *past* production or *past* sales would aid collusion, and such information is in fact exchanged in many industries, including motor vehicles.[4] Put another way, the theories that suggest that the exchange of *retrospective* information may enhance collusion are not relevant in our context, which involves the exchange of *prospective* information.

We take as the null the hypothesis that firms are nonstrategic in their plan announcements, meaning that firms' plan announcements and production decisions do not respond to rivals' earlier signals. The literature on cheap talk suggests that in cases of information exchange without commitment, babbling is always a possible equilibrium.[5] For example, the firms may not undertake the expense of planning future production when contacted by *Ward's Automotive Reports* or may simply issue a random number in order to keep their plans secret. The cheap talk models generally establish that costless inaccurate announcements will be ignored and have no influence on market outcomes.

Much of the theoretical literature on oligopoly information sharing (Novshek and Sonnenschein [1982] and the later papers) has abstracted from the question of accuracy by assuming that some mechanism exists to certify that the information is truthful, for example an independent auditor. Ziv (1993) points out that, without such mechanisms, information-sharing equilibria are often unstable. In many practical situations, including the announcement of production plans by U.S. automakers, there exists no such certification mechanism. Still, information may be credible if firms strive to maintain reputations for honesty or if there are sunk costs involved in transmitting the information (i.e., talk is not completely cheap).[6] At a fundamental level, then, it remains an empirical question whether the automakers' announcements are regarded as babble or have a real impact on rivals' strategies such as output decisions.

The null hypothesis may hold in another setting as well. Plans may provide truthful information about firms' objectives and actions and thus may not be babble, but they may elicit no response from rivals

[4] Compte (1998) and Kandori and Matsushima (1998) derive folk theorems in a model in which firms communicate private information about their own sales levels. A somewhat counterintuitive result (which also appears in Abreu, Milgrom, and Pearce [1991]) is that *less frequent* information exchange may enhance collusion, making noteworthy the motor vehicle industry's cessation in 1992 of the exchange of 10-day sales data.

[5] The seminal article in the literature on cheap talk is Crawford and Sobel (1982). For a recent survey of the literature, see Farrell and Rabin (1996).

[6] Genesove and Mullin (1999) find that misreporting was not an important issue among members of the Sugar Institute. Klein and Leffler (1981) show that honest behavior can arise in equilibrium of a repeated game. Mailath (1989) provides a model in which firms simultaneously signal their privately known costs with their first-period outputs.

if firms simply are nonstrategic. For example, if the industry is characterized by perfect competition with no uncertainty, firms may ignore rivals' production plans. Firms may still report production plans, perhaps as a means of communication among different units within the firm rather than among different competitors within the industry.

The alternatives to the null involve strategic behavior among firms; that is, competitors take into account rivals' previous announcements when forming their subsequent announcements and production decisions. Whether plan announcements have strategic value will be the subject of empirical study in Section IV. It is noteworthy that *Ward's* itself suggests that the plans may have strategic value: "July–September output planning is too preliminary at this early point to serve as a basis for [solid] projections, but it does provide deep insights into best company thinking at this time and marketing strategy" (*Ward's Automotive Reports,* July 20, 1981).

One set of alternatives is that the production plans allow firms to share information about demand and cost parameters in the spirit of Novshek and Sonnenschein (1982), Clarke (1983), Vives (1984), Gal-Or (1985), Shapiro (1986), and a score of other static models cited in Kühn and Vives (1994). To make the discussion of these models more concrete, assume that firms engage in Cournot (quantity) competition and produce close substitutes. This assumption fits well in the present context since the focus is on automakers' choice of production levels, though the arguments are similar in the case of Bertrand (price) competition.[7] There are three broad effects of information exchange in these models. First, from competitors' reports, firms may learn more about their own uncertain demand and cost parameters. This would be true if there were a correlation among the parameters across firms. Second, firms learn more about their competitors' parameters and thus indirectly about competitors' likely production decisions. Finally, information exchange may increase or decrease the correlation among competitors' production decisions.

Though there are numerous subcases to consider, some consistent conclusions do emerge in a model of information exchange with Cournot competition. Sharing information about common demand or cost parameters tends to increase the correlation among firms' strategies. If a firm announced a production expansion in this case,

[7] The assumption of Cournot competition is reasonable given Berndt, Friedlaender, and Wang Chiang's (1990) finding that they could not reject Cournot behavior in the motor vehicle industry. For a contrasting view, see Berry, Levinsohn, and Pakes (1999).

we would expect its rivals to follow with their own increases. On the other hand, sharing information concerning idiosyncratic parameters tends to decrease correlation among firms' strategies. If a firm announced a production expansion in this case, it would be an aggressive announcement causing rivals to reduce planned production. In the empirical work, we shall seek to distinguish between these two broad patterns of information exchange. In Section IV, we present a version of these models that aids the interpretation of the empirical results.

Another set of alternatives is that information sharing helps heterogeneous oligopolists, which may prefer different collusive equilibria, collude on a single collusive outcome. The strong form of this hypothesis is that an announcement functions almost as a Stackelberg commitment to a certain output level. The commitment could arise over time as a reputation for honesty is built, could result from the discipline provided by an industry leader, or could stem from the need to signal to other parties simultaneously (parties including, e.g., potential investors; see Gertner, Gibbons, and Scharfstein [1988]).

A weaker form of this hypothesis is that the announcements represent a complex form of communication among firms, reminiscent of (but necessarily cruder than) the airlines' communication via computer reservation systems. In Gertner's (1993) model, two firms with heterogeneous costs engage in a first stage of negotiation before a second stage of price competition. Firms announce successively lower bids (binding commitments to second-stage prices) until no firm chooses to submit a lower bid. Firms end up coordinating on the low-cost firm's monopoly price.

Another possibility is that firms use the announcements to discipline rivals for apparent deviant behavior such as too rapid output expansion. Firms could issue warning signals if they consider competitors' production plans to be too high. Rivals could signal understanding by reducing their production plans in response to the warning.

III. Data

We focus on the major U.S. automakers during the period 1965–95 using data from trade publications. This section presents several tables and figures that highlight the key features of the data. Table 1 provides descriptive statistics for the major U.S. automakers. Monthly industry statistics such as domestic production, domestic sales, and domestic inventories of cars by the major U.S. automakers (the "Big Four") were compiled from *Ward's Automotive Yearbook* and

TABLE 1

Descriptive Statistics for Car Operations of the Big Four, 1965–95

	GM	Ford	Chrysler	AMC*
Monthly production (000s)	326.7	155.2	87.7	18.0
	(110.3)	(50.3)	(35.5)	(9.4)
Monthly production plans (000s)†	338.6	157.5	88.6	18.7
	(107.6)	(47.8)	(35.1)	(9.9)
Monthly sales (000s)	335.4	171.4	89.4	18.4
	(81.9)	(38.4)	(27.8)	(7.9)
Monthly inventories (000s)	737.1	408.8	246.1	55.7
	(165.8)	(80.1)	(68.3)	(19.3)
Market share‡	41.9	21.5	11.2	2.3
	(6.5)	(3.6)	(3.1)	(1.0)
Monthly strike units lost (000s):§				
Unconditional	8.1	2.6	.7	.6
	(44.1)	(18.9)	(4.3)	(5.0)
Conditional on strike	50.1	41.6	17.2	16.5
	(100.3)	(66.0)	(12.7)	(21.8)

Note.—Figures are means. Standard deviations are in parentheses.
* AMC statistics pertain to data through June 1987.
† Statistics for month-ahead production plans.
‡ Market share is a firm's car sales as a percentage of all car sales in the Unites States (both foreign and domestically produced).
§ Strike units lost is *Ward's* report of units of car production lost as a result of strikes. An estimate (described in the text) is used if units lost are not reported.

Ward's AutoInfoBank. Also included in our data is a market share figure, measuring each firm's share of total domestic sales. General Motors is the largest company, with 42 percent of the market. Ford ranks second in market share, Chrysler third, and AMC a distant fourth. The rankings of production, sales, and inventory are identical. Inventory holdings tend to be two to three times the level of production, and the level of production approximately equals the level of sales.[8] The standard deviations, listed below the means, indicate that inventory was more variable than production, which in turn was more variable than sales.[9]

Labor strikes are likely to have dramatic effects on auto production and hence are an important consideration in our study. *Ward's Automotive Reports* provides information on the timing and magnitude of all strikes that may cause a slowdown in auto production, including strikes at assembly plants and strikes affecting suppliers of parts and transportation. *Ward's* reports a strike's beginning and ending dates, whether it was national or local, and whether assembly

[8] The discrepancy between production and sales arises because some cars sold in the United States were produced in other countries (Canada and Mexico) and because of inventory adjustments.

[9] For a model explaining the relative variances of production and sales, see Kahn (1992) and Bresnahan and Ramey (1994).

plants were the direct target. In subsequent analysis, we use *Ward's* estimate of units of production lost because of a strike as a proxy for the strike's magnitude. This datum is reported for a majority of the strikes; in cases in which it was not available, we imputed a value using the procedure described in the Appendix. Table 1 provides descriptive statistics on the resulting strike measure. General Motors lost the most units as a result of strikes in our sample. It lost 8,100 units per month averaged over all months (months with and without strikes); this figure jumps to 50,100 units per month when only those months in which GM was affected by a strike are considered. The standard deviations show that there was a huge variation in the severity of strikes.

The main variable of interest, collected from *Ward's Automotive Reports,* is the announcement of planned production. As much as six months ahead of actual production, *Ward's* publishes each firm's forecast of the number of autos it plans to produce in future months.[10] This is an aggregate number of autos, not broken down by model or platform. Revised announcements are released periodically up to the last day of the production month (in some instances, revisions are issued even after the last day of the production month). The announcements are published in the form of a schedule including each automaker's planned production for the current month and for several months in the future.[11] This schedule is typically updated in the fourth week of the month, though *Ward's* sometimes reports updates to the production schedules more frequently. The production schedules and updates are published for all major automakers simultaneously (i.e., in the same issue of *Ward's Automotive Reports*). To the best of our knowledge, it is not *Ward's* practice to share firms' plans with rivals prior to publication (i.e., during the process of collecting the data).

Since the structure of the data set is slightly complicated, it will prove useful to set out some formal notation for the variables in the data set. Let T be the set of production dates. The total number of production dates is $|T|$, where $|\cdot|$ denotes the number of elements in a set. Let Q_{it} be the actual production of firm i at production date $t \in T$. Let $\tilde{Q}_{it}(\theta)$ be the announcement made by firm i at date θ of its production in the month ending on date $t \in T$. There may be

[10] Whether an announcement is a firm's explicit report or *Ward's* interpretation of an imprecise report, the schedule represents a figure the automaker is willing to release to the public.

[11] The companies sometimes refer to these schedules by various synonyms: ''assembly targets,'' ''assembly schedules,'' ''production plans,'' ''production forecasts,'' etc.

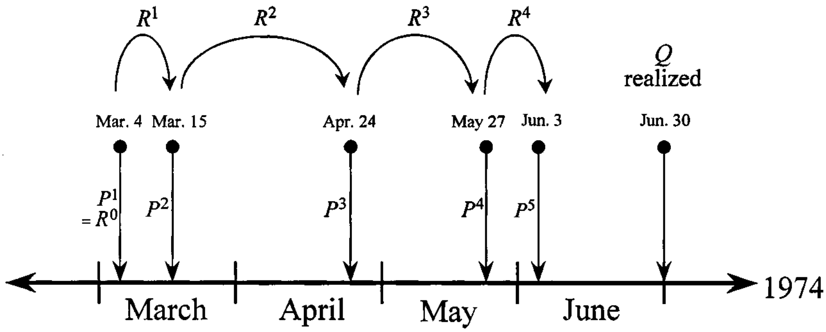

FIG. 1.—Example timeline of plan announcements

several announcement dates associated with any production date. Let $\Theta_t \equiv \{\theta | \tilde{Q}_{it}(\theta) \text{ issued}\}$ denote the set of these announcement dates. In principle, Θ_t could differ across firms, but in practice *Ward's* publishes plan announcements for all firms on the same dates. Let θ_t^k be the kth-lowest element of Θ_t. Define $P_{it}^k \equiv \tilde{Q}_{it}(\theta_t^k)$, the kth announcement issued by firm i for its production in the month ending at date t. In short, P_{it}^k is the kth *production plan* for firm i. Note that there are $|\Theta_t|$ production plans for each production date t. Each plan is associated with a horizon, the elapsed time in days between issuance of the plan and the end of the production month. Let $H_t^k \equiv t - \theta_t^k$ denote the horizon associated with plan P_{it}^k. Let $R_{it}^k \equiv P_{it}^{k+1} - P_{it}^k$ denote the kth revision of firm i's announcement. It will simplify the notation in later sections to define the naught revision to be the first production plan, that is, $R_{it}^0 \equiv P_{it}^1$. Including the naught revision, there are $|\Theta_t|$ revisions for each production date t.

An example may serve to illustrate the structure of the data set. Consider the sequence of production plans for the month of June 1974 (randomly selected from the data set), presented in figure 1. For this particular month, there were five production plan announcements. The first announcement—labeled production plan P^1 or, equivalently, the naught revision R^0—was issued on March 4, four months before total output for the month of June was realized. The last announcement—labeled production plan P^5—was issued on June 3, several days after production had begun in June but before total output was realized. The first revision, R^1, is the difference between the March 15 and the March 4 production plans.

Much of the analysis will focus on systematic deviations of the production plans from actual production, in other words, errors in the production plans. The kth production plan error for firm i

regarding production month t, PPE_{it}^{k}, is measured as a percentage of the average of firm i's actual production in month t and its kth plan:

$$PPE_{it}^{k} \equiv 100\left[\frac{Q_{it} - P_{it}^{k}}{\frac{1}{2}(Q_{it} + P_{it}^{k})}\right].$$

Note the accounting convention that PPE_{it}^{k} is negative if the firm's actual production is less than what was predicted or, in the jargon of the trade press, if the firm ''underbuilds.''

The pattern of errors in production plans, by company, is shown in figure 2*a*. The errors tend to lie below the horizontal axis, indicating that the plans tend to overestimate actual production. In addition, the errors tend to be more dispersed the farther the plans are made in advance of the production date. Some overestimation would be expected since the auto industry occasionally faces sudden negative shocks to production, including bad weather, shortages of parts, and strikes. The fact that errors appear smaller as the horizon gets shorter suggests that announcements reflect more accurate information as one gets closer to production time. Figure 2*b* pools the data across firms, dividing the data instead by time periods. Similar patterns in the errors are apparent across time periods. One feature of note is that the observations tend to occur in bunches along the horizontal axis in the last subperiod (1985–95), indicating that the announcements of production plans were made at more systematic intervals in the recent past than before.

Table 2 confirms the impressions from figure 2: the means of PPE are negative and become increasingly negative as the horizon increases until the horizon reaches about two months. The standard deviations grow with the horizon as well. The PPE for GM is larger than for any other firm except AMC.[12] As the table shows, there are a large number of observations in each firm/horizon cell and over 1,000 observations per firm, for a total of nearly 7,000 observations of production plan errors (and therefore production plans) in the data set.

[12] With formal statistical tests, it can be shown that the mean PPE is significantly negative for all firms. That for GM is significantly more negative than either Ford's or Chrysler's, though, after one accounts for strikes and the month of August (in which model changeovers occur), the differences shrink, becoming insignificant in the case of Chrysler. General Motors' PPE is significantly less negative than AMC's even after one accounts for strikes and August model changeover effects. The fact that reported production plans are rounded to the nearest thousand, but monthly production figures are not, may inflate AMC's PPE relative to the other firms' since AMC is the smallest firm. Simulations suggested that the impact of such rounding is minor, accounting for at most 2 percent of the standard deviation of AMC's PPE.

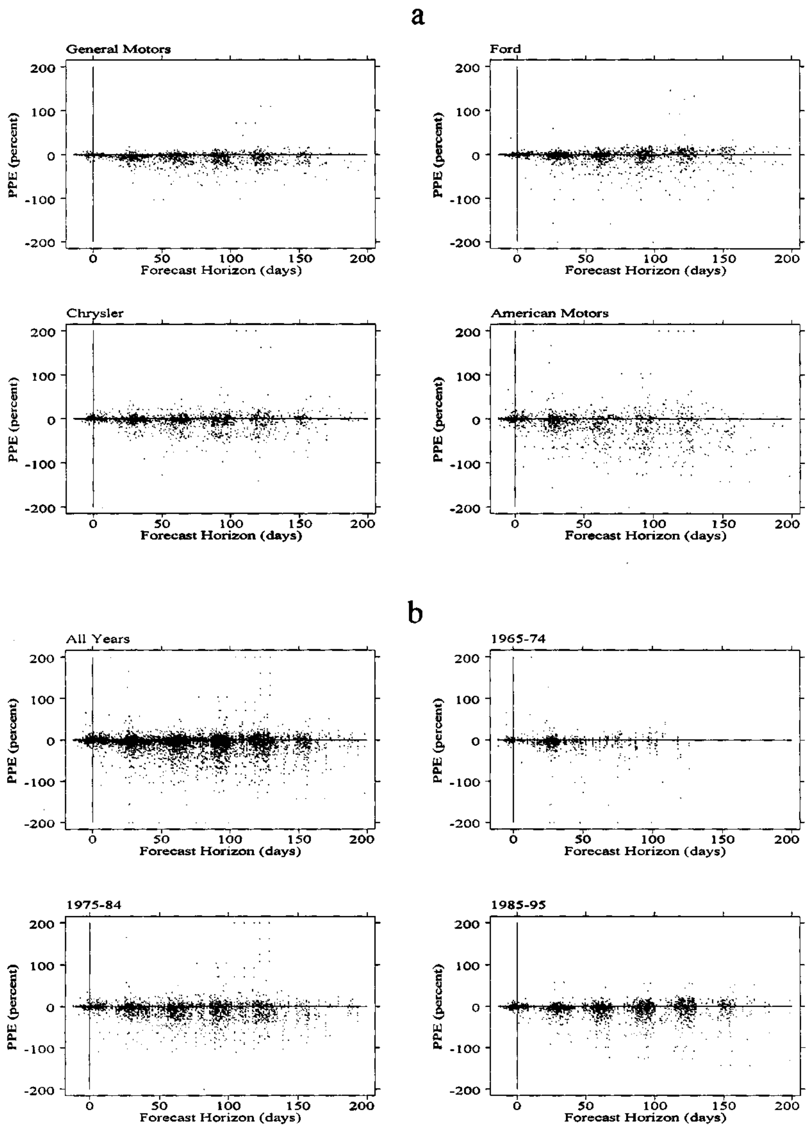

FIG. 2.—Percentage production plan errors (PPE). *a*, By firm, pooling periods. *b*, By period, pooling firms.

TABLE 2

Descriptive Statistics for Percentage Production Plan Errors (PPE)

	Horizon					
	−14–0 Days	1–25 Days	26–39 Days	40–69 Days	70 or More Days	Pooled Horizons
GM:						
μ	−.2	−2.5	−5.1	−7.4	−8.0	−5.5
σ	(3.3)	(4.7)	(13.0)	(12.9)	(18.3)	(13.9)
N	266	240	363	364	653	1,886
Ford:						
μ	.0	−1.8	−4.5	−7.3	−4.8	−4.2
σ	(3.2)	(8.0)	(16.8)	(17.0)	(22.7)	(17.4)
N	265	240	363	364	653	1,885
Chrysler:						
μ	.2	−.1	−2.3	−6.5	−5.7	−3.6
σ	(2.8)	(6.8)	(12.2)	(17.0)	(26.9)	(18.7)
N	266	240	363	364	653	1,886
AMC:						
μ	.5	−3.4	−7.4	−17.0	−19.6	−11.6
σ	(8.5)	(24.3)	(26.1)	(30.3)	(45.8)	(34.1)
N	180	182	258	239	437	1,296
Pooled firms:						
μ	.1	−1.8	−4.6	−8.8	−8.6	−5.8
σ	(4.6)	(12.5)	(17.2)	(19.5)	(29.0)	(21.3)
N	977	902	1,347	1,331	2,396	6,953

Note.—μ is the mean, σ is the standard deviation, and *N* is the number of observations. PPE equals $100(Q_{it} - P_{it})/[\frac{1}{2}(Q_{it} + P_{it})]$, where Q_{it} is actual production and P_{it} is the production plan.

IV. Tests of Information Sharing

In this section, we derive the implications from a model of information sharing concerning a common parameter (e.g., an industry demand intercept). These implications are contrasted with those from a model of information sharing concerning an idiosyncratic parameter (e.g., a firm's marginal cost). We formulate an econometric test of the models' implications; the test is based on the sign of a firm's response to information contained in rivals' earlier production plans.

A. Model

In this subsection, we adapt Li's (1985) model of information sharing to the context of the motor vehicle industry. Suppose that there are n firms that, for simplicity, produce a homogeneous product at marginal cost c. Market demand in a given period t is linear: $p_t(Q_t) = a_t + \gamma_t - b_t Q_t$, where a_t and b_t are positive constants, Q_t is industry output in period t, and γ_t is a mean-zero random variable with density function $g_t(\gamma_t)$. In this model, the only source of uncertainty is a demand intercept, common across firms. Firms engage in simultaneous quantity competition in period t.

Prior to product market competition in period t, each firm i is assumed to obtain a signal, s_{it}, of γ_t, which it may share with competitors. To focus on the consequences of truthful information sharing, we shall assume that firms credibly reveal their signals to each other.[13] In the absence of a mechanism for credible information revelation, we assume that the reputation for honest revelation is sufficiently valuable to maintain honesty. Let τ_i be the precision of s_{it}, that is, $\tau_i \equiv 1/E[\text{var}(s_{it}|\gamma_t)]$.

Under two assumptions—first, that firms' signals are unbiased estimators of γ_t and, second, that firms' expectations of γ_t conditional on $\{s_{it}\}_{i=1}^{n}$ are a linear combination of these signals—it can be shown as a corollary to Li's proposition 1 that the unique Bayesian equilibrium involves the following output for firm i:

$$Q_{it} = \xi_0 + \sum_{j=1}^{n} \xi_{ij} s_{it}, \tag{1}$$

where $\xi_{ij} > 0$ for $j \neq i$. In sum, if firms share information about a common demand parameter, their best-response functions (output as a function of competitors' signals) will be strictly increasing.[14] In general, ξ_{ij}, the partial derivative of firm i's best-response function with respect to firm j's signal, differs across j. It can be shown, for example, that ξ_{ij} increases with τ_j, the precision of j's private signal.

The model needs to be modified in two respects to fit the case of the motor vehicle industry. First, in practice, auto producers announce quantities rather than demand intercepts. To account for this fact, we shall assume that, given a production plan announcement P_{jt} by firm j, all other firms $i \neq j$ can infer the associated private signal for j. That is, there exists a strictly increasing function, $s(P_{jt})$, mapping plan announcements into underlying signals. We assume,

[13] This model is less general than Li's, in which firms are allowed to announce garbled signals of their private information.

[14] Deriving this result from proposition 1 of Li (1985) requires two steps. First, under the assumption maintained here that firms truthfully and completely reveal their private information, it can be shown that the expression labeled δ_i in Li is positive and constant across i. It can then be shown using an expression from Li's proof of proposition 1 that ξ_{ij} has the same sign as $(n + 1)\delta_i - \sum_{j=1}^{n} \delta_j = \delta_i > 0$. One drawback of applying Li's model to the present context is that firms' expected profits fall if they share information. This result disappears if competition occurs in prices (Vives 1984), if marginal costs are increasing (Kirby 1988), if the uncertainty regards the demand slope rather than the intercept (Malueg and Tsutsui 1996), or if shocks to demand intercepts are not perfectly correlated (Novshek and Thoman 1998).

further, that this function is common knowledge, as would be the case if firms' equilibrium strategies were pure strategies.

A second modification is needed because, in practice, auto producers share multiple production plan announcements for any given production month t rather than just one announcement. We model the motive for multiple announcements as stemming from gradual learning about the state of demand. More formally, rather than receiving a single signal s_{it} of γ_t, firm i may receive a sequence of signals $\{s_{it}^k\}_{k=1}^{|\Theta_t|}$, which it shares with competitors before production in month t. (Recall that $|\Theta_t|$ is the number of plan announcements associated with production in month t.) During each stage of the revision process, a firm incorporates any new information into its new production plan announcement. As before, let P_{it}^k be firm i's kth production plan for month t. Firm i's revised production plan is given by

$$P_{it}^{k+1} = f_i(P_{it}^k, \{s_{jt}^k\}_{j\neq i}, s_{it}^{k+1}, u_{it}^{k+1}). \tag{2}$$

The revised production plan depends on firm i's previous plan, P_{it}^k, which incorporates information before the kth announcement, in addition to information firm i obtains between its kth and $(k + 1)$st announcements. This new information includes two pieces: rivals' signals, $\{s_{jt}^k\}_{j\neq i}$, inferred from their kth production plan announcements, and firm i's new private signal, s_{it}^{k+1}. The signals $\{s_{jt}^k\}_{j\neq i}$ are indeed new information to be incorporated into P_{it}^{k+1} since firm i does not observe rivals' kth production plan announcements until after it announces P_{it}^k. The last term, u_{it}^{k+1}, is an error term, picking up unmodeled shocks to the firm's response function.

With multiple production plan announcements, the specification of inference functions s^k must be generalized:

$$s_{jt}^k = s^k(R_{jt}^{k-1}, \{s_{lt}^{k-1}\}_{l\neq j}), \tag{3}$$

defined for $k > 1$. That is, rivals draw inferences about j's new private information from the revision in j's production plans, $R_{jt}^{k-1} \equiv P_{it}^k - P_{it}^{k-1}$, rather than the level P_{jt}^k. However, R_{jt}^{k-1} alone is not sufficient for rivals to infer the exact value of j's signal s_{it}^k. To illustrate this point, consider an example in which GM tries to infer Ford's private information from Ford's previous revision. Ford's previous plan may reflect private information; it may also be that Ford has received no new private information but simply has revised its production plan in response to yet earlier revisions by its rivals (Chrysler, AMC, or GM itself). General Motors needs to use twice-lagged information to interpret the signal embodied in Ford's previous revision. Thus the inference function in (3) has been generalized to include prior information $\{s_{lt}^{k-1}\}_{l\neq j}$ as an argument. For $k = 1$, the only information available about j's signal is j's first plan, P_{jt}^{1} (equivalently, its naught revision R_{jt}^{0}); so we can write the inference function for $k = 1$ simply as $s_{jt}^{1} = s^{1}(R_{jt}^{0})$. Using this equation and noting that equation (3) has a recursive structure, we can rewrite (3) without loss of generality as

$$s_{jt}^{k} = s^{k}(R_{jt}^{k-1}, \{R_{lt}^{m}\}_{l=1,\ldots,n}^{m=0,\ldots,k-2}). \tag{4}$$

Using the identity linking revisions and production plans, we can show that (4) is equivalent to

$$s_{jt}^{k} = s^{k}(P_{jt}^{k}, \{P_{lt}^{m}\}_{l=1,\ldots,n}^{m=1,\ldots,k-1}). \tag{5}$$

We have abused notation slightly by letting s^{k} represent the three inference functions in (3), (4), and (5). We assume that, with all other variables held constant (including, importantly, the firm's lagged production plan), a higher production plan implies a higher private signal for a firm, that is, $\partial s_{jt}^{k}/\partial P_{jt}^{k} > 0$. This is equivalent to the assumption that a higher revision in (3) implies a higher private signal, ceteris paribus.

Substituting (5) into (2) and taking a first-order Taylor approximation gives the following linearized form for the best-response function:

$$P_{it}^{k+1} = \alpha_{i}\mathbf{1}_{i} + \beta_{i}P_{it}^{k} + \sum_{j\neq i}\delta_{ij}P_{jt}^{k} + \sum_{j=1}^{n}\sum_{m=1}^{k-1}\mu_{ij}^{m}P_{jt}^{m} + \theta_{i}s_{it}^{k+1} + u_{it}^{k+1}, \tag{6}$$

where $\mathbf{1}_{i}$ is an indicator function for firm i, and $\delta_{ij} = (\partial f_{i}/\partial s_{jt}^{k})(\partial s_{jt}^{k}/\partial P_{jt}^{k})$. Similarly to the argument above that ξ_{ij} in equation (1) is positive, it can be argued that $\partial f_{i}/\partial s_{jt}^{k} > 0$. Further, according to the formalization above, $\partial s_{jt}^{k}/\partial P_{jt}^{k} > 0$. Hence, $\delta_{ij} > 0$ when firms share information about a common demand parameter.

The dependent variable in (6), P_{it}^{k+1}, has three indexes: i for firms, t for production months, and k for the sequence of plan announcements associated with each production month. This third dimension, k, in addition to the usual two in panel data sets, i and t, presents a problem for the estimation of (6) but simultaneously permits a solution to the problem. Pooling across both t and k would allow us to increase the power of our tests; however, it is impossible to pool across k using standard methods since the number of terms on the right-hand side of (6) varies with k. In particular, the number of terms in $\sum_{j=1}^{n}\sum_{m=1}^{k-1}\mu_{ij}^{m}P_{jt}^{m}$ is increasing in k. The sum $\sum_{j=1}^{n}\sum_{m=1}^{k-1}\mu_{ij}^{m}P_{jt}^{m}$ represents the history of information released by firms prior to announcing the right-hand-side variables of interest in our study (the once-lagged plans $\{P_{it}^{k}\}_{j=1}^{n}$). As k increases, this history—knowledge of which is required to make correct inferences from later announcements—grows. Though the sum $\sum_{j=1}^{n}\sum_{m=1}^{k-1}\mu_{ij}^{m}P_{jt}^{m}$ is not of direct interest, as noted in the discussion following equation (3), it must be included in the estimation or else the coefficients $\{\beta_i, \delta_{ij}\}_{i=1,\ldots,n}^{j\neq 1}$ on the variables of direct interest will be biased. We proceed by dividing the data into subsamples indexed by k and then partialing out the variables $\{P_{jt}^{m}\}_{j=1,\ldots,n}^{m=1,\ldots,k-1}$ from both sides of equation (6) for each k. After we partial them out, the set of remaining right-hand-side variables is the same for all k, allowing us to run a regression pooled across both t and k with these modified data.

To describe the partialing-out process more formally, some notation is in order. Let $r^k[X]$ denote the residual from the regression of an arbitrary variable X on $\{P_{jt}^{m}\}_{j=1,\ldots,n}^{m=1,\ldots,k-1}$. For all (i, k) pairs, we regress the dependent variable (P_{it}^{k-1}) and each independent variable ($\mathbf{1}_i$, P_{it}^{k}, and $\{P_{jt}^{k}\}_{j\neq i}$) on $\{P_{jt}^{m}\}_{j=1,\ldots,n}^{m=1,\ldots,k-1}$ and compute the residuals from these regressions (respectively, $r^k[P_{it}^{k-1}]$, $r^k[\mathbf{1}_i]$, $r^k[P_{it}^{k}]$, and $\{r^k[P_{jt}^{k}]\}_{j\neq i}$). The three-dimensional nature of our data set allows us to run these regressions since, for each (i, k) pair, we have a time series of observations indexed by t. We then run a regression of "residuals on residuals":

$$r^k[P_{it}^{k+1}] = \alpha_i r^k[\mathbf{1}_i] + \beta_i r^k[P_{it}^{k}] + \sum_{j\neq i}\delta_{ij} r^k[P_{jt}^{k}] + \theta_i s_{it}^{k+1} + u_{it}^{k+1}. \quad (7)$$

The ordinary least squares (OLS) estimates of α_i, β_i, and $\{\delta_{ij}\}_{j\neq i}$ in (7) are numerically identical to those in (6) (see Greene 1990, pp. 181–82). The advantage of (7) over (6) is that it has the same right-hand-side variables for each k; so it is possible to pool across k with specification (7). The drawback is that the parameters $\{\mu_{ij}^{m}\}_{j=1,\ldots,n}^{m=1,\ldots,k-1}$ are not estimable in (7), but this is not a serious loss since they are essentially nuisance parameters.

It may aid intuition to note, as an aside, that equation (7) can be expressed in terms of revisions rather than production plans. To see this, observe first that $r^k[R_{jt}^{k-1}] = r^k[P_{jt}^{k}]$ and second that $r^k[R_{it}^{k}] = r^k[P_{it}^{k+1}] - r^k[P_{it}^{k}]$.[15] Then (7) can be written equivalently as

$$\begin{aligned} r^k[R_{it}^{k}] = {} & \alpha_i r^k[\mathbf{1}_i] + \beta_i' r^k[R_{it}^{k-1}] \\ & + \sum_{j\neq i}\delta_{ij} r^k[R_{jt}^{k-1}] + \theta_i s_{it}^{k+1} + u_{it}^{k+1}. \end{aligned} \quad (8)$$

The coefficients in (8) are identical to those in (7) except for β_i', which equals $1 - \beta_i$. Hence, we can determine the nature of firms'

[15] That is, $r^k[R_{jt}^{k-1}] = r^k[P_{jt}^{k}] - r^k[P_{jt}^{k-1}] = r^k[P_{jt}^{k}]$, where the first equality holds since $r^k[\cdot]$ is a linear operator and the second equality holds since P_{jt}^{k-1} is one of the regressors involved in computing the residuals $r^k[\cdot]$, implying $r^k[P_{jt}^{k-1}] = 0$. The fact that $r^k[\cdot]$ is a linear operator also implies $r^k[R_{it}^{k}] = r^k[P_{it}^{k+1}] - r^k[P_{it}^{k}]$.

responses to rivals' information either by regressing a firm's production plans on rivals' lagged plans or by regressing a firm's revisions on rivals' lagged revisions.

In summary, we derived several empirical implications from a model in which firms share information over a period of time concerning a common demand parameter. Firms' behavior can be captured by a sequence of best-response functions exhibiting strategic complementarity: firms tend to revise their plans upward if rivals' previous announcements or revisions were high. The partial derivatives of the best-response functions depend on competitor-specific variables, including, for example, the perceived precision of their signals. In practice, since the motor vehicle industry involves differentiated rather than homogeneous products, the partial derivatives may also depend on the closeness of firms' output in the product space.

It is instructive to compare the results in a model with uncertainty about a common demand parameter to those from a model with uncertainty about idiosyncratic costs. Consider, therefore, an alternative model in which each firm i has private information about the level of its constant marginal cost, c_i. As in the derivation of equation (1), it can be shown (see Li 1985, proposition 6) that firm i's equilibrium output is increasing in competitors' signals of their own costs. Since auto producers share production plan announcements rather than directly sharing signals of their marginal costs, to adapt the model to the motor vehicle industry, the next step is to consider how competitors may deduce firm i's signal about its uncertain marginal cost from i's production plan announcement. As before, we shall assume that there is a monotonic mapping from production plans to signals. In contrast to the model with common demand uncertainty, in the model with idiosyncratic cost uncertainty, this mapping is strictly decreasing. That is, a high–production plan announcement is correlated with a *high* demand intercept in the presence of common demand uncertainty but is correlated with a *low* marginal cost in the presence of idiosyncratic cost uncertainty.

Thus the implications for the partial derivatives of a best-response function such as (7) with respect to competitors' announcements differ depending on the source of the uncertainty. Common demand uncertainty implies a strategic complementarity; idiosyncratic cost uncertainty implies a strategic substitutability.

B. Empirical Results

In this subsection, we present empirical estimates of the best-response function in equation (7). Table 3 presents regressions of firms' second production plans P^2_{it} on rivals' initial production plans

TABLE 3

RESPONSE OF SECOND PRODUCTION PLAN TO FIRMS' INITIAL PLANS

	GM		Ford		Chrysler		
	Including AMC	Excluding AMC	Including AMC	Excluding AMC	Including AMC	Excluding AMC	AMC
Rival initial plan:							
GM	. . .	. . .	.032**	.016	−.007	−.001	.005
			(.019)	(.011)	(.016)	(.008)	(.004)
Ford	.196**	.134**	. . .	. . .	.039	.040*	−.013*
	(.063)	(.046)			(.029)	(.024)	(.008)
Chrysler	.002	−.004	.086**	.073**	. . .	. . .	.003
	(.086)	(.068)	(.041)	(.029)			(.010)
AMC	−.339	. . .	−.123	. . .	−.017	. . .	. . .
	(.234)		(.107)		(.118)		
Own initial plan	.888**	.942**	.911**	.882**	.944**	.952**	1.034**
	(.045)	(.025)	(.029)	(.029)	(.054)	(.037)	(.023)
Horizon	.040	.071	.013	−.001	.035	.043*	.003
	(.065)	(.052)	(.027)	(.025)	(.022)	(.018)	(.012)
Constant	9.31	−11.62	5.31	3.69	−5.57	−8.87**	−1.14
	(15.73)	(8.23)	(8.05)	(4.58)	(7.42)	(3.68)	(2.47)
Observations	210	308	210	308	210	308	210
R^2	.997	.997	.996	.996	.991	.991	.982
Monthly dummies†	1.09	1.37	2.33**	2.77**	1.85**	2.19**	1.69*

NOTE.—The OLS method is used since the independent variables are identical across firms, and so SUR is identical to OLS. The regressions including AMC use data from the beginning of the sample through 1987, when AMC exited; the regressions excluding AMC use data through December 1995. The dependent variable, a firm's second production plan, equals P_{it}^2; initial production plans equal $\{P_{jt}^1\}_{j=1}^n$. Horizon equals H_t^1. White (1980) heteroskedasticity-consistent standard errors are in parentheses.

† F-statistics for the exclusion of the monthly dummies.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

$\{P^1_{jt}\}_{j\neq i}$ and other controls. Table 4 presents regressions of firms' third and later production plans $\{P^k_{it}\}_{k>2}$ on rivals' lagged production plans $\{P^{k-1}_{jt}\}^{j\neq i}_{k>2}$ and other controls. Although the specification of equation (7) suggests that the data used in the two sets of regressions can be pooled, we ran separate regressions for two reasons. First, reporting the results separately serves as a check that partialing out the twice-lagged information set does not generate spurious results. Since the twice-lagged information set is the empty set for the data in table 3, no partialing out needs to be performed. Second, reporting the results separately serves to verify that the sign of the best-response function does not change with k, that is, does not change as firms progress from the early to later production plan announcements within a production month.

The results in table 3 indicate how a given firm first revises its production plan in response to information contained in competitors' first production plan announcements. For each of the Big Three (GM, Ford, and Chrysler), we run two specifications, one including and one excluding AMC. We run a specification without AMC in order to use a longer time series since the inclusion of AMC limits the span of the study to the mid 1980s, after which AMC exited the sample. We allow coefficients to vary across firms. Since the set of regressors is the same for all firms, the seemingly unrelated regressions (SUR) method is identical to OLS. We control for seasonal variation with monthly dummies and also add a control for horizon length, H^k_t. We report White (1980) heteroskedasticity-consistent standard errors throughout.

The coefficients on rivals' initial production plans (estimates of δ_{ij} in eq. [7]) are consistent with the model of information sharing about a common demand parameter and inconsistent with the model of information sharing about idiosyncratic costs. Those coefficients that are significantly different from zero are positive, indicating that firms' first revisions seem to move in a complementary direction with rivals' initial production plans. In particular, GM responds positively to Ford's plans, Ford responds positively to both GM's and Chrysler's, and Chrysler responds positively to Ford's. If firms were sharing information about idiosyncratic costs, we would expect to see negative coefficients. The one anomaly is AMC's negative response to Ford's production plans, though the effect is only marginally significant and its sign is reversed in table 4.

To interpret the magnitudes of the coefficients, consider the coefficient for Ford's initial production plan in GM's regression including AMC, .196. This number implies that an increase in Ford's initial production plan of 1,000 cars causes GM to revise its plan upward by 196 cars. As a rough rule of thumb, the coefficients can be con-

TABLE 4

RESPONSE OF THIRD AND GREATER PRODUCTION PLANS TO FIRMS' LAGGED PLANS

	GM		Ford		Chrysler		
	Including AMC	Excluding AMC	Including AMC	Excluding AMC	Including AMC	Excluding AMC	AMC
Rival lagged plan:							
GM	. . .	. . .	.053**	.046**	−.010	.018	.006
			(.025)	(.021)	(.024)	(.024)	(.006)
Ford	.414**	.319**	. . .	. . .	.203**	.166**	.040*
	(.199)	(.161)			(.069)	(.057)	(.023)
Chrysler	−.078	−.048	.104*	.113*	. . .	. . .	−.015
	(.098)	(.080)	(.056)	(.047)			(.014)
AMC	−.134	. . .	−.035	. . .	−.071	. . .	. . .
	(.432)		(.157)		(.179)		
Own lagged plan	.919**	.938**	.835**	.866**	.868**	.881**	.733**
	(.050)	(.040)	(.056)	(.040)	(.061)	(.049)	(.082)
Horizon	.032	.042**	.026*	.031**	.034**	.037**	.002
	(.027)	(.019)	(.015)	(.010)	(.016)	(.011)	(.003)
Constant	8.16	−.70	3.72	.15	−1.25	−3.90*	−1.83
	(10.84)	(4.22)	(7.43)	(2.92)	(5.18)	(2.15)	(1.08)
Observations	650	945	650	945	650	945	650
R^2	.585	.552	.529	.531	.484	.501	.418
Monthly dummies[†]	1.68*	1.53	2.20**	2.30**	.81	1.65*	1.97**

NOTE.—Regressions in which nuisance variables are partialed out as described in Sec. IV. The second-stage OLS results are reported (OLS is used since the independent variables are identical across firms, and so SUR is identical to OLS). The regressions including AMC use data from the beginning of the sample through 1987, when AMC exited; the regressions excluding AMC use data through December 1995. The dependent variable, a firm's production plan, equals P_{it}^{k+1}; lagged production plans equal $\{P_{jt}^{k}\}_{j=1}^{n}$. Horizon equals H_t^k. The reported R^2 is taken from the second-stage regressions. White (1980) heteroskedasticity-consistent standard errors are in parentheses.

[†] F-statistics for the exclusion of the monthly dummies.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

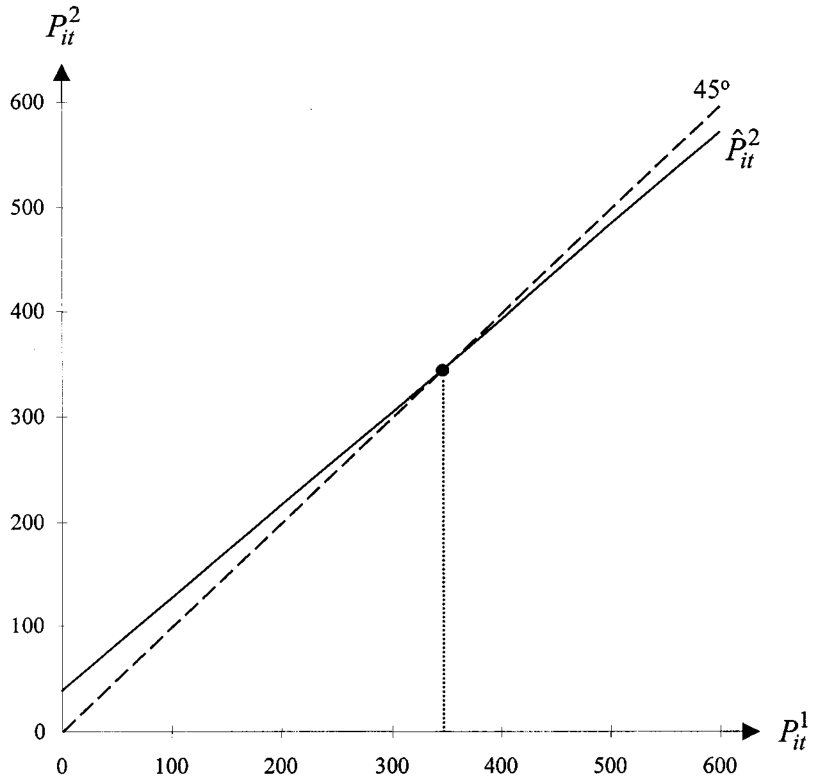

FIG. 3.—Example of regression toward the mean for General Motors

verted into elasticities by multiplying them by the ratio of the rival's to the firm's size ("size" measured in the usual ways: output, sales, etc.). For example, with any measure from table 1, Ford is about half of GM's size, so the elasticity corresponding to the .196 estimate would be approximately .1. Notice that the coefficient on AMC's initial plan in GM's regression, −.339, is apparently large in absolute value; but this translates into a small elasticity (approximately −.02) since AMC is only one-sixteenth the size of GM.

The results are consistent with plan announcements' exhibiting "regression toward the mean"; that is, firms tend to revise downward plans that are greater than average and revise upward plans that are less than average. This proposition is illustrated in figure 3, which graphs $\hat{P}_{it}^2$, the expected value of GM's second production plan announcement, as a function of P_{it}^1, its first production plan announcement. We use the coefficient estimates from GM's regression including AMC and set variables other than P_{it}^1 equal to their mean values in the sample. Graphically, plan announcements exhibit regression toward the mean if the plotted line is a clockwise rotation of the 45-degree line through the mean of P^1_{it}. For the case under consideration, the $\hat{P}^2_{it}$ line has a smaller slope than the 45-degree line (.888 to be precise) and intersects the 45-degree line at 340,000 cars, statistically indistinguishable from the mean of P^1_{it} for GM, 347,000 cars.[16]

Other controls included in the regression, the horizon and a constant, are generally not significant. The fact that horizons do not vary greatly across observations included in the regression (they are all first revisions, which were often issued a set amount of time before actual production) would explain the lack of significance in the horizon coefficient. The included monthly dummies (whose coefficients are not reported) are jointly significant in general, though their exclusion does not substantially affect the coefficients of interest.

The results carry over to the regressions involving plans later than the second, reported in table 4. The results are broadly consistent with the proposition that firms' best-response functions exhibit a strategic complementarity. Automakers revise their plans upward in response to the new information embodied in rivals' past revisions. The pattern of response is similar to that in table 3: GM responds positively to Ford's revision, Ford to GM's and Chrysler's, Chrysler to Ford's, and AMC to Ford's. Those estimated coefficients that are statistically significant in table 4 are larger and have a higher significance level than in table 3.

Though the horizon variable is generally positive in both tables 3 and 4, the standard errors are smaller in table 4, and thus horizon is generally significant, whereas it is insignificant in table 3. The reason is that there is less variation in horizon if we use data only on the second production plan (as in table 3) than if we use data for third and later production plans. The positive coefficient on horizon is consistent with the idea that the realization of negative shocks causes later announcements (with shorter horizons) to be less optimistic than early announcements.

[16] The fact that the coefficient on own lagged plan is significantly less than one in most cases could be symptomatic of reporting errors in firms' plans. This would not only bias the coefficients on own plans downward but could also bias the other coefficients (either upward or downward). To check that our results on the coefficients of interest (rivals' lagged plans) were not due to this bias, we ran the regressions in tables 3 and 4 constraining the coefficient on own lagged plan to be one. The coefficients of interest were still positive and significant. We are grateful to Robert Topel for this suggestion.

In interpreting the results of tables 3 and 4, we should note that there is the theoretical possibility of omitted-variable bias in the estimation of equation (7) since we do not have data on s_{it}^{k+1} and thus simply fold it into the error term. It is conceivable that s_{it}^{k+1}, the most recent private signal, is correlated with the right-hand-side variables $\{P_{jt}^{k}\}_{j\neq i}$: such correlation would arise if the information contained in firm j's announcement were revealed privately to firm i in the interval between dates θ_t^k and θ_t^{k+1}. For example, suppose that all firms receive the same information about the state of demand, but GM incorporates the new information into its production plan faster than its rivals. There would then be a positive correlation between rivals' plans and GM's lagged plans, a correlation that would be mistakenly interpreted as rivals' learning from GM's announcements. This scenario is contradicted by our finding that firms' responses to rivals' lagged announcements often work in two directions simultaneously: GM responds to Ford and vice versa; Ford responds to Chrysler and vice versa. Thus it does not appear that one firm is more efficient than rivals at incorporating new information into its plans.

V. Extensions of the Empirical Analysis

In this section we examine several extensions of the empirical analysis. Our main goal is to determine whether the interaction among firms during the revision process is merely part of a babbling equilibrium or whether rivals' announced signals translate into tangible changes in a firm's output. Our test involves regressing output on rivals' lagged production plans. The results are presented in subsection *A*. In these regressions, it is important to control for the effect of strikes (both own and rivals') on output. The strike variables—particularly the effect of rivals' strikes on a firm's output—will be interesting in their own right since we shall interpret a strike as an observable signal of a firm's production costs. It will be shown that the pattern of firms' responses to such cost signals is quite different from the responses to signals embodied in rivals' production plans. The discussion of the strike results is deferred to subsection *B*.

A. Production Plans and Output

The results in tables 3 and 4 indicate how one firm's announcements concerning its anticipated production level vary with competitors' earlier announcements. The question remains whether a firm's actual production also responds to competitors' announcements such as postulated in equation (1). To address this question, we estimate regressions of the following general form:

$$r^k[Q_{it}] = \alpha_i r^k[\mathbf{1}_i] + \beta_i r^k[P_{it}^k] + \sum_{j\neq i} \delta_{ij} r^k[P_{jt}^k] + \theta_i s_{it}^{k+1} + u_{it}^{k+1}. \quad (9)$$

The logic behind (9) is that output Q_{it} can be regarded as the last public announcement issued by firm i for production month t. Thus the theory behind equation (7) can also be applied here. The main difference between (7) and (9) is that Q_{it} is a real quantity, whereas P_{it}^{k+1} is purely informational. We have abused notation slightly by using the same notation for the coefficients and the error term in (7) as in (9): we do not impose such a restriction in the estimation.

Two other differences from the methodology used to estimate (7) are that we account for strikes and serial correlation. In considering actual as opposed to planned production, we need to control for strikes because they are an important, observable component of the term s_{it}^{k+1} in equation (9). We control for strikes by adding the term

$$\lambda_i r^k[\mathrm{STR}_{it}] + \sum_{j\neq i} \lambda_{ij} r^k[\ln(1 + \mathrm{STR}_{jt})]$$

to (9), where λ_i and λ_{ij} are coefficients to be estimated, $r^k[\cdot]$ is the partialing-out operator, and STR_{jt} is firm j's units of production lost because of strikes in month t (described in Sec. III). The hybrid specification—linear in own strikes and concave in rivals' strikes (in particular, a log specification for rivals' strikes)—proved to produce a better fit than a purely linear or purely concave specification, but the qualitative results were unaffected by the choice of specification.

Serial correlation was not an issue in the estimation of (7) since the dependent variable (production plan) does not form an ordered time series with a consistent interval between observations. The dependent variable in (9) *is* a standard time series. Durbin-Watson (1951) tests indicated that the errors exhibit significant serial correlation in several cases. We thus use the Prais-Winsten (1954) estimator, which is asymptotically efficient in the presence of serial correlation, to estimate (9).[17] In all other respects, our estimation methodology is the same as before: we allow coefficients to vary across firms, include a variable for horizon length, control for seasonal variation with monthly dummies, and report White (1980) heteroskedasticity-consistent standard errors.

The estimates of β_i will provide some indication of the

[17] We quasi-difference the data only once rather than iterating to convergence; either method is asymptotically efficient.

''cheapness'' of firms' production plan announcements. If the production plan announcements are part of a babbling equilibrium, then we would expect $\hat{\beta}_i$ to be zero. We would also expect automakers to ignore rivals' signals, and consequently, we would expect $\hat{\delta}_{ij}$ to be zero. Positive values for $\hat{\delta}_{ij}$ are consistent with the model of information sharing concerning a common demand parameter; negative values are consistent with information sharing concerning idiosyncratic cost parameters.

Two sets of regressions are presented. Table 5 examines the relationship between production and month-ahead production plans. Month-ahead plans are defined as P^k_{it} with k selected so that H^k_t, the associated horizon, is as close as possible to one month. Month-ahead plans are interesting because they are the last announcements made before production begins, so firms still retain a degree of flexibility in adjusting their output. As equation (9) indicates with the use of the operator $r^k[\cdot]$, we partial out the lagged information set $\{P^m_{jt}\}^{m=1,\ldots,k-1}_{j=1,\ldots,n}$ before performing the regression. We then examine the relationship between production and initial plans, with the results presented in table 6. We have two motives for restricting attention to initial plans. First, it will reveal whether early announcements are babble (independent of the findings from table 5 about the relevance of later announcements). Second, there is no information set to partial out, so a two-stage regression is not required.

Consider the results in table 5. As can be seen from the parameter estimates for the firm's own production plan, each company's production is highly correlated with its respective month-ahead announcements and is significantly different from zero. Despite the fact that production plans have no commitment value, they do not appear to be simply cheap talk. Thus information sharing in the auto industry is not a babbling equilibrium. In fact, GM's production rises about one for one with plans: an F-test cannot reject that the estimate of β_i equals one for GM. For the other companies, the estimates for β_i are significantly less than one, though still positive and significant.

Additionally, the results of table 5 illustrate some of the effects of information sharing: firms tend to produce more when their rivals' plans are high. General Motors' production responds positively to Ford's month-ahead plans and vice versa; Ford responds positively to Chrysler's month-ahead plans and vice versa. The effects of GM's plans on Ford's output and Ford's plans on Chrysler's output are significant at the 5 percent level. Again, this supports the notion that automakers do not interpret their rivals' announcements as cheap talk. The interpretation of the coefficients δ_{ij} is similar to that in tables 3 and 4. For example, the .086 coefficient on GM's month-

TABLE 5

RESPONSE OF PRODUCTION TO FIRMS' MONTH-AHEAD PRODUCTION PLANS

	GM		FORD		CHRYSLER		
	Including AMC	Excluding AMC	Including AMC	Excluding AMC	Including AMC	Excluding AMC	AMC
Rival month-ahead plan:							
GM	. . .	. . .	.086**	.083**	−.006	−.007	.007
			(.022)	(.019)	(.016)	(.015)	(.005)
Ford	.131	.082	. . .	. . .	.211**	.197**	.011
	(.094)	(.091)			(.093)	(.090)	(.013)
Chrysler	.099	.081	.141	.149	. . .	. . .	−.001
	(.096)	(.089)	(.125)	(.113)			(.014)
AMC	.013	. . .	.117	. . .	−.103	. . .	. . .
	(.274)		(.122)		(.116)		
Rival strike:							
GM	. . .	. . .	.99*	1.12**	−.38	−.47	.49**
			(.52)	(.47)	(.58)	(.51)	(.18)
Ford	4.44**	5.07**	. . .	. . .	.82	.98*	−.09
	(1.18)	(1.34)			(.60)	(.55)	(.19)

Chrysler	.38	.20	.11	−.01	. . .	. . .	−.43
	(2.00)	(1.87)	(1.16)	(.95)			(.34)
AMC	5.67*	. . .	−.37	. . .	−1.11	. . .	. . .
	(3.42)		(1.04)		(1.12)		
Own month-ahead plan	.923**	.933**	.732**	.747**	.656**	.682**	.699**
	(.054)	(.052)	(.082)	(.074)	(.145)	(.141)	(.069)
Own strike	−.781**	−.774**	−.938**	−.931**	−.520**	−.526**	−.215
	(.035)	(.036)	(.074)	(.082)	(.257)	(.207)	(.139)
Horizon	−.158**	−.125**	−.059*	−.038	.013	−.001	−.019**
	(.052)	(.042)	(.033)	(.024)	(.032)	(.021)	(.008)
Constant	−7.28	−.39	−1.19	−2.40	−3.44	−3.32	1.62
	(10.92)	(6.26)	(6.70)	(3.52)	(7.21)	(3.39)	(1.55)
Observations	256	356	256	356	256	356	256
R^2	.988	.982	.986	.980	.972	.969	.938
Monthly dummies†	2.02**	2.50**	1.14	1.50	2.57**	3.12**	2.79**

Note.—Regressions in which nuisance variables are partialed out as described in Sec. IV. OLS is used since the independent variables are identical across firms, and so SUR is identical to OLS. The regressions including AMC use data from the beginning of the sample through June 1987, when AMC exited; the regressions excluding AMC use data through December 1995. The dependent variable is monthly production, Q_{it}; horizon equals H_t^k; and production plans are P_{it}^k, where the k is chosen so that H_t^k is the horizon closest to one month. The strike variable is the measure of units of production lost described in Sec. IV; it enters in linear form for own strike and log form, $\ln(1 + STR_{it})$, for rival strike. The two-step Prais-Winsten (1954) estimator is asymptotically efficient in the presence of autocorrelation. White (1980) heteroskedasticity-consistent standard errors are in parentheses. Since the constant is quasi-differenced in the Prais-Winsten procedure, the reported R^2 (from the second step of the procedure) is not bounded between zero and one.

† F-statistics for the exclusion of the monthly dummies.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

TABLE 6

Response of Production to Firms' Initial Production Plans

	GM		Ford		Chrysler		
	Including AMC	Excluding AMC	Including AMC	Excluding AMC	Including AMC	Excluding AMC	AMC
Rival initial plan:							
GM	...	...	.035	.043**	−.021	.003	−.003
			(.027)	(.020)	(.014)	(.012)	(.004)
Ford	.207*	.190*	...	...	.019	.010	.009
	(.120)	(.109)			(.037)	(.033)	(.010)
Chrysler	.002	.175	.108	.104**	...	...	−.016
	(.158)	(.133)	(.078)	(.063)			(.015)
AMC	−.104	...	−.114	...	−.110	...	...
	(.412)		(.218)		(.154)		
Rival strike:							
GM	...	...	2.14**	2.48**	−.11	−.09	.65**
			(.79)	(.77)	(.82)	(.74)	(.20)
Ford	7.12**	7.21**	...	...	1.45	1.41	−.13
	(2.19)	(1.95)			(1.06)	(1.00)	(.26)

Chrysler	3.30	3.53	−.34	−.13	. . .	. . .	−.16
	(3.28)	(2.88)	(1.33)	(1.31)			(.43)
AMC	1.55	. . .	−.63	. . .	−1.87	. . .	. . .
	(5.37)		(1.69)		(2.02)		
Own initial plan	.611**	.688**	.777**	.708**	.822**	.840**	.783**
	(.101)	(.081)	(.057)	(.058)	(.056)	(.044)	(.044)
Own strike	−.474**	−.442**	−.831**	−.824**	−.418*	−.461**	−.165
	(.176)	(.195)	(.079)	(.074)	(.209)	(.195)	(.129)
Horizon	−.170*	−.092	−.036	−.038	−.058**	−.043*	−.028**
	(.097)	(.074)	(.040)	(.032)	(.027)	(.022)	(.008)
Constant	106.77**	49.54**	12.57	18.78*	20.24**	8.23	5.09*
	(42.37)	(24.91)	(15.97)	(10.05)	(9.85)	(6.24)	(2.86)
Observations	268	370	268	370	268	370	268
R^2	.967	.966	.974	.967	.954	.948	.942
Monthly dummies†	3.52**	3.69**	2.44**	2.73**	2.18**	2.73**	3.04**

NOTE.—OLS is used since the independent variables are identical across firms, and so SUR is identical to OLS. The regressions including AMC use data from the beginning of the sample through June 1987, when AMC exited; the regressions excluding AMC use data through December 1995. The dependent variable is monthly production, Q_{it}; horizon equals H_t^k; and initial production plans equal P_{it}^1. The strike variable is the measure of units of production lost described in Sec. IV; it enters in linear form for own strike and in log form, $\ln(1 + STR_{it})$, for rival strike. The two-step Prais-Winsten (1954) estimator is asymptotically efficient in the presence of autocorrelation. White (1980) heteroskedasticity-consistent standard errors are in parentheses. Since the constant is quasi-differenced in the Prais-Winsten procedure, the reported R^2 (from the second step of the procedure) is not bounded between zero and one.

† F-statistics for the exclusion of the monthly dummies.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

ahead plan in Ford's regression implies that a 1,000-car increase in GM's plan, with earlier plans held constant, leads to an increase in Ford's output by 86 cars.

Turning to table 6, we see a similar pattern of responses of firms' output to initial production plans. The responses of GM to Ford and of Ford to both GM and Chrysler are positive in both the regressions excluding AMC and including AMC and are significant at least at the 10 percent level in the regression excluding AMC. This implies that a firm's early announcements, like later announcements, are not babble but are correlated with the firm's own output and influence rivals' output. Thus the results from tables 5 and 6 are broadly consistent with findings from tables 3 and 4, which in turn are consistent with a model in which firms share information concerning a common demand parameter. We conjecture that two factors determine the magnitude of firms' responses to rivals' plans. First, firms may respond more to larger competitors, which may expend a greater absolute amount on forecasting and thus may announce signals of greater precision. Second, in a market with differentiated products, firms may respond more to competitors closer to themselves in the product space since the signals of closer competitors have more relevance. If Chrysler's product line is closer to Ford's, this second factor may explain why Chrysler would respond to Ford's announcements but not to GM's.

B. Production and Signals of Idiosyncratic Costs

In this subsection, we consider the coefficients λ_i and $\{\lambda_{ij}\}_{j\neq i}$ on the strike variables from tables 5 and 6. Up to now, we have examined the response of automakers to signals in the form of announced production plans. The results have suggested that these announcements are signals of a common demand parameter. In this subsection, we examine a signal that is known to be firm-specific: labor strikes. We consider a strike to be a signal that the affected firm is temporarily experiencing a production setback that is analogous to extremely high costs of production. In the case of a complete shutdown, costs could be considered infinite. A firm may not want to send a signal that it is in a high-cost phase because of a strike, but the publicity of a strike is unavoidable.

The estimates, $\hat{\lambda}_i$, for "own strike" reported in the tables demonstrate that strike activity effectively cuts production relative to the company's plan. The coefficients are negative in all cases and significant in all cases except for the regressions for AMC. Table 5 shows that for every 1,000 units of production lost because of a strike, GM fell short of its month-ahead production plans by about 780 cars, Ford by about 930, and Chrysler by about 520. The effects of ''own strikes'' on the discrepancy between output and initial plans, reported in table 6, have similar, though slightly smaller, magnitudes.

The general tenor of the results from tables 5 and 6 is that a firm produces more than planned when a rival is hindered by a strike. The findings suggest that a firm boosts production when it observes a rival's production setback. Ford and AMC produce more when GM is affected by a strike; GM also takes advantage of Ford when Ford is struck. In all regressions, Chrysler responds positively to a strike affecting Ford, and this effect is significantly positive in one case. The effect of Chrysler's strikes on rivals is insignificant in all cases. The large standard errors on this coefficient are symptomatic of the relatively small variation in STR_{it} for Chrysler. Indeed, table 1 shows that Chrysler did not experience as many or as severe strikes as its rivals.

The log specification makes it difficult to determine the magnitude of the strike effects directly from tables 5 and 6. To aid interpretation, in figure 4 we graph the effect on GM's output of units lost because of strikes. The figure is based on the coefficients from GM's regression including AMC in table 6. As illustrated in the figure, if Ford faced a strike causing it to lose 100,000 units of production in a month, this would cause GM's output to rise by about 33,000 units. The curve representing Ford's strike effect flattens out for high strike losses: if Ford lost 275,000 units in a month because of strikes, around the maximum for Ford's monthly production in our sample, GM's output would rise by about 40,000 units. The curves for both Chrysler and AMC are also graphed so that they terminate at the maximum monthly production for the respective firms. The curve representing GM's own strike effect shows that GM's actual production declined by 500 cars for every 1,000 units of reported strike losses. That the slope of this line is not minus one suggests that GM is often able to compensate for strike losses by increasing production between the end of the strike and the end of the month.

The results from tables 5 and 6 show that firms expand output when they receive a signal about a rival—such as a strike—indicating that the rival will likely cut back production. This pattern of responses is exactly what is predicted by the model of information sharing concerning idiosyncratic cost parameters. This pattern of responses is the opposite of that embodied in the estimated effects of rivals' production plans in tables 3–6: low–production plan announcements by a firm tend to cause rivals to contract rather than expand output. Hence, firms are not likely to be sharing information about idiosyncratic costs through their production plan announce-

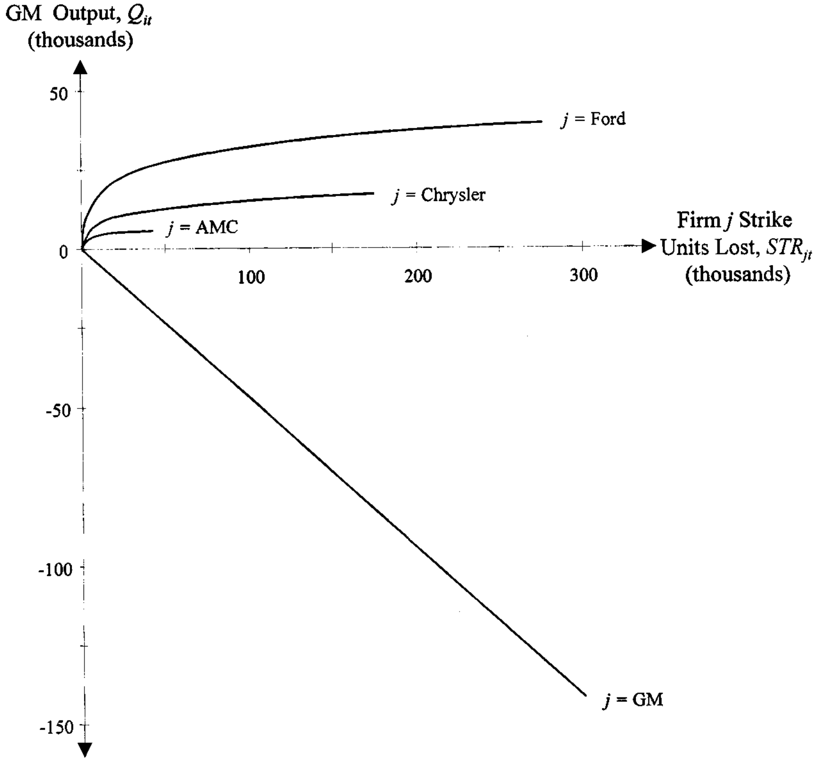

FIG. 4.—Example of strike effects for General Motors

ments, lending further support to the notion that they are sharing information about common demand parameters.

VI. Conclusion

The results strongly reject the hypothesis that production plan announcements by the Big Four (and by the Big Three after the exit of AMC) have no information content. The results also reject the hypothesis that there is no strategic response by firms to the announcements. Among the remaining alternatives, it is difficult to separate benign motives from collusive ones. The results reveal a strong complementarity exhibited by firms' responses to rivals' announcements: firms react to larger than average plans of competitors by revising their own plans upward and by increasing their production relative to initial plans. This complementarity supports the hypothesis that production plan announcements contain information about common demand parameters. It is evidence against the hypothesis that the announcements contain information about idiosyncratic cost parameters. One implication of our findings is that firms have little incentive to overstate their intended production levels in their plans, for this will induce rivals to produce more rather than contract their output. Thus it would be futile for a firm to use its production plans to behave like a Stackelberg leader, announcing a high plan to induce rivals to cut back their output: rivals would respond in the opposite direction.

Our results do not allow us to reject the hypothesis of a collusive auto industry. Our underlying model posits information sharing among Cournot competitors; an alternative model with information sharing among joint profit maximizers would have similar implications for the response of rivals to a firm's announcements. Though we cannot uniquely identify the mode of competition underlying the industry—Cournot, joint profit maximization, and so forth—we can rule out some modes. It is unlikely that the underlying mode of competition is standard leadership by GM: GM responds to Ford as much as Ford responds to GM; Chrysler responds more to Ford than to GM. Communication appears to be more mutual than in the standard leadership model. Even authors who view GM as a price leader allow for the possibility of mutual communication. For example, in White's (1971) study, GM is not usually the first to announce price: ''In the fall of 1956 and again in the fall of 1966, 1967, and 1968, price differences appeared initially in published prices. Ford or Chrysler appeared with its prices first. General Motors followed with prices that, except for 1956, were lower. Within a week, the other two had closed whatever gap existed between their prices and General Motors' for comparable models'' (p. 112). Our results would be consistent with the notion that, even though Ford and Chrysler eventually fall in line with GM's announcement, GM's announcement is conditioned on the information contained in Ford's or Chrysler's initial announcements.

Furthermore, it is unlikely that GM announces high production plans in order to warn the smaller firms whose production plans may have diverged from acceptable levels; if such warnings were effective, smaller firms would respond negatively rather than positively to GM's announcements. It is unlikely that communication works as modeled in Gertner (1993). In Gertner's model, firms start out with high prices and bid down to the low-cost firm's optimal price. In terms of quantities, this would mean that firms announce higher and higher quantities. By contrast, the data suggest that there is substantial overstatement of production the earlier the announcement.

In the interpretation of our results, one caveat is that the automakers produce lines of differentiated products rather than a homogeneous ''car,'' as the plans would indicate. Such aggregation would seem to reduce the value of the announcements relative to their value if they were disaggregated into more narrow categories. The results suggest that there is still information content even to these aggregate announcements.

Another caveat is that production plans represent only a small part of the total information flow among automakers. During the period studied, firms exchanged information on plant operations, 10-day sales, product improvements, prices, and so forth. There may be motives for the broad sweep of information exchange that are not revealed in the analysis of any one piece. For example, in addition to sharing production plans, firms exchanged price information perhaps for strategic reasons, as suggested by the quote from White (1971) above. Production plans and price announcements may simply be complementary signals of a common demand parameter: if a firm receives a private signal that industry demand is high, it tends to announce high production plans and high list prices; the opposite if industry demand is low. Alternatively, the interaction between production plans and price announcements may be more complicated. If, contrary to the assumptions of our basic model, there are several major sources of asymmetric information, say concerning common demand and idiosyncratic cost parameters simultaneously, price announcements might alter the inferences drawn from production plans. By itself, a high production plan might be consistent with both a high common demand intercept and a low idiosyncratic marginal cost. Coupled with a high-price announcement, the high production plan may be an unambiguous signal of a high common demand parameter; coupled with a low-price announcement, it may be an unambiguous signal of a low idiosyncratic cost parameter. One argument against the complicated interaction between production plans and price announcements is that the announcement of prices is much less frequent and systematic than of production plans. If price announcements were necessary to draw inferences from the plans, we would expect that the two would usually be announced together in the same trade journal.

There are a number of further questions that could be answered using the data set. Do firms establish reputations for honesty over time that they ''harvest'' when strategically beneficial? Such behavior would be in evidence if rivals' strategic responses to a given firm's revisions are less pronounced the larger the firm's recent production plan errors. Do firms respond symmetrically to positive and negative revisions of competitors? Do other audiences, such as the stock market, respond to the announcements? Besides answering questions of interest to corporate strategists, identifying stable patterns in firms' production announcements would aid in forecasting trends in auto production, an important component of cyclical movements in the overall economy. Work along these lines was pursued by Krane and Reifschneider (1987) with production plan announcements aggregated across automakers. Improvements to the forecasts could come from disaggregating the plan announcements and taking into account firms' strategic responses to competitors' plans.

Appendix

In this Appendix, we construct a model that can be used to impute units of production lost by firm i in month t as a result of strike activity, STR_{it}. For approximately three-quarters of the strikes, this measure was reported by *Ward's*. For the remaining quarter, this measure was not reported, and the missing value needs to be imputed. For the 77 observations in which the datum was available, we ran a fixed-effects regression on STR_{it} on a constant, the number of days that the strike covered during the month, a dummy for assembly strikes (as opposed to strikes affecting suppliers of parts or transportation), a dummy for national United Auto Workers strikes (as opposed to local strikes), a time trend, a squared time trend, and monthly dummies. The dependent variable (STR_{it}) enters the equation in log form, ensuring that the predicted values from the model are positive. Duration also enters in log form.

The results are reported in table A1. The coefficients are generally sig-

TABLE A1

MODEL OF PRODUCTION UNITS LOST BECAUSE OF STRIKES

Variable	Coefficient Estimate	Standard Error
Constant	−16.5*	9.63
Duration (natural log)	.544**	.123
Assembly strike dummy	−.620	.506
National UAW strike dummy	2.211**	.397
Time trend	.585**	.282
Squared time trend ($\times 10^{-2}$)	−.360**	.165
Firm dummies:		
GM	1.979**	.433
Ford	1.079**	.431
Chrysler	1.574**	.475
Observations	77	
R^2	.750	
Monthly dummies†	.88	

NOTE.—The dependent variable is the natural log of STR_{it}, a firm's units of monthly car production lost because of a strike, as reported by *Ward's Automotive Reports*. For strikes spanning multiple months, we apportion a fraction of the units lost equal to the fraction of the strike's duration during the month. Standard errors are White (1980) heteroskedasticity-consistent.

† F-statistics for the exclusion of the monthly dummies.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

nificant and have the expected sign. The assembly strike dummy is insignificant, suggesting that strikes affecting suppliers of parts and transportation may slow production as much as or more than strikes against assembly plants directly. The fit of the model is quite good, with an R^2 of .75.

Letting $\mathbf{x}_{it}$ be a row vector of the right-hand-side variables in table A1 for an observation *it* for which STR_{it} is missing and letting $\hat{\boldsymbol{\beta}}$ be the column vector of coefficient estimates from the table, we impute a value using the formula

$$\widehat{\text{STR}}_{it} = \exp(\mathbf{x}_{it}\hat{\boldsymbol{\beta}}) \exp\left(\frac{\hat{\sigma}^2}{2}\right),$$

where $\hat{\sigma}$ is the estimated variance of the errors from the regression reported in table A1. The second factor, $\exp(\hat{\sigma}^2/2)$, adjusts for the fact that we take the expectation of a nonlinear function in computing $\widehat{\text{STR}}_{it}$ (see Greene 1990, p. 158).

We ran the regressions in tables 5 and 6 with alternative strike measures that are less precise proxies of a strike's magnitude but did not require imputation, including strike duration and a simple strike dummy. The qualitative results were unchanged with these alternatives.

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