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IDENTIFYING CARTEL POLICING UNDER UNCERTAINTY: THE U.S. STEEL INDUSTRY, 1933–1939*

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THIS article makes inferences about oligopoly behavior from observing an industry's response to unexpected changes in the market price. In particular, the econometric methodology identifies firms that act more competitively following unexpected declines in demand. This behavior is interpreted as reflecting cartel policing in a market in which cooperating firms cannot distinguish between rival cheating and negative-demand shocks.

The econometric methodology is applied to study the U.S. steel industry during the Great Depression. Cartel policing is detected for the period between mid-1935 and mid-1939. In contrast, oligopoly behavior did not vary with unexpected price declines between mid-1933 and mid-1935, when the industry operated under a National Recovery Administration (NRA) Code of Fair Competition. Because collusion was legally enforceable under the code, market punishments were unnecessary.

The empirical analysis is based upon a structural model of industry behavior within which the determinants of the oligopoly supply function can be specified. The model emphasizes that when firms cannot perfectly monitor their competitors, oligopoly behavior and industry supply will be influenced by the inferences about rival behavior that firms make when they observe unexpected fluctuations in the market price.

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I. IDENTIFYING THE DETERMINANTS OF OLIGOPOLY BEHAVIOR

A. Supply and Demand for a Homogeneous Product Oligopoly

An (inverse) market demand curve for a homogeneous product industry is defined in equation (1). Here, P is the market price and Q represents industry output. The vector Y includes those exogenous variables shifting demand that are observable contemporaneously by the firms in the industry. The shock ϵ represents random fluctuations in demand.

$$P = f(Q, Y) + \epsilon. \quad (1)$$

This demand curve defines a marginal-revenue function (2). In equation (2), the notation $f_q(\cdot)$ represents the output derivative of the demand function.

$$MR = f(Q, Y) + Qf_q(Q, Y) + \epsilon. \quad (2)$$

An aggregate-industry supply relation, equation (3), is well defined for a homogeneous-product industry even when firms do not behave competitively. The supply relation generates the model's equilibrium in conjunction with market demand.

$$P = \theta(P - MR) + c(Q, W) + v. \quad (3)$$

The supply relation sums three terms: the short-run marginal cost function $c(Q, W)$, a random cost shock v ,¹ and the $\theta(P - MR)$ term representing oligopoly behavior. The notation W represents a vector of observable, exogenous variables shifting marginal cost. By rewriting the $\theta(P - MR)$ term using equations (1) and (2), the supply relation takes the form

$$P = -\theta Qf_q(Q, Y) + c(Q, W) + v. \quad (4)$$

The markup parameter θ reflects oligopoly behavior.² For example, under perfect competition the industry sets price equal to marginal cost, so θ equals zero. If the industry instead selects the joint-profit-maximizing price, then θ equals one. Other oligopoly models will predict a value for θ between zero and one. In general, θ may be a function of the exogenous variables in the model, including the shocks. This article tests empirically a theory about the effect of demand shocks ϵ on θ .

¹ Equation (3) aggregates individual-firm cost shocks into the scalar industry cost shock v . This substitution is defensible when the firm shocks are highly correlated, as would occur if they largely reflect common input price variation.

² Timothy Bresnahan, *The Oligopoly Solution Concept Is Identified*, 10 *Econ. Letters* 87 (1982).

B. Cartels That Shoot First and Ask Questions Later

Fluctuations in oligopoly behavior are often explained by changes in industry structure. For example, the familiar literatures on "critical concentration ratios" and "practices facilitating collusion" describe how a reduction in the number of sellers or the introduction of practices that increase firm information about rival behavior can cause an oligopoly to switch from a noncooperative equilibrium to a cooperative one. Other structural changes might cause industry behavior to switch from cooperation to competition, as when entry barriers are relaxed.

Some explanations for alteration in oligopoly behavior do not involve changes in industry structure, but share the view of the structural explanation that either competition or cooperation is a dominant strategy for all sellers. For example, large shifts in demand or the introduction of innovative production technologies might cause a cartel to break down by increasing firm incentives to cheat.

In these static models, firms follow pure strategies in equilibrium.³ As a result, these familiar stories have difficulty explaining the behavior of cartels that appear to form again after price wars.⁴ Collusive prices punctuated by competitive episodes have been noted, for example, in the U.S. automobile industry during the 1950s,⁵ in the U.S. railroad industry of the nineteenth century,⁶ and in some international cartels during the 1920s and 1930s.⁷ To address such situations, Green and Porter developed a "trigger price" dynamic oligopoly supgame model.⁸

The Green and Porter model studies firms in an environment of uncertainty. Sellers are unable to distinguish between declines in demand and

³ See George Stigler, *A Theory of Oligopoly*, 72 *J. Pol. Econ.* 432 (1964); Dale Osborne, *Cartel Problems*, 66 *Am. Econ. Rev.* 835 (1976); Michael Spence, *Efficient Collusion and Reaction Functions*, 11 *Can. J. Econ.* 527 (1978); Steven Salop, *Practices That (Credibly) Facilitate Oligopoly Coordination*, in *New Developments in the Analysis of Market Structure* 265 (Joseph Stiglitz & G. Frank Mathewson eds. 1986).

⁴ But see Margaret Slade, *Interfirm Rivalry in a Repeated Game: An Empirical Test of Tacit Collusion*, 35 *J. Indus. Econ.* 499 (1987).

⁵ Timothy Bresnahan, *Competition and Collusion in the American Automobile Industry: The 1955 Price War*, 35 *J. Indus. Econ.* 457 (1987).

⁶ Robert Porter, *On the Incidence and Duration of Price Wars*, 33 *J. Indus. Econ.* 415 (1985); Robert Porter, *A Study of Cartel Stability: The Joint Executive Committee, 1880-1886*, 14 *Bell J. Econ.* 301 (1983).

⁷ Valerie Suslow, *Stability in International Cartels: An Empirical Survey* 13 (Working Paper E-88-7, Hoover Institution 1988).

⁸ Edward Green & Robert Porter, *Non-cooperative Collusion under Imperfect Price Information*, 52 *Econometrica* 87 (1984). For a generalization of the Green and Porter model, see Dilip Abreu, David Pearce, & Ennio Stacchetti, *Optimal Cartel Equilibria with Imperfect Monitoring*, 39 *J. Econ. Theory* 151 (1986).

rival cheating when they attempt to understand observed price declines. Green and Porter demonstrate that long stretches of collusive pricing can occur, so long as all firms respond to large unexpected price declines by competing for a fixed period of time before raising prices back to the cooperative level.⁹ Cheating is discouraged during high price periods because the gains to cheating are limited by the likelihood that such behavior will trigger a price war. In the model's equilibrium, no firm actually cheats but price wars occur whenever demand declines unexpectedly and substantially.

In the Green and Porter model, the dynamic oligopoly equilibrium fluctuates between static cartel behavior and static noncooperative behavior. The timing of these shifts is uncorrelated with movement in observable exogenous demand-shift or supply-shift variables. Porter has supported this theory econometrically by showing that a switching regression model, in which the markup θ takes on either a high or low value, explains the behavior of an express, nineteenth-century railroad industry cartel, the Joint Executive Committee.¹⁰

The trigger-price literature shows how price wars can facilitate substantial periods of cooperative pricing: when firms are unable to distinguish between demand declines and output expansion by a rival, they may enforce collusive pricing through temporary episodes of increased competition. In essence, when monitoring of competitors is not perfect, cartels may "shoot first and ask questions later." Cooperating firms may respond to the possibility of rival cheating by acting more competitively, for a time, before returning to collusive pricing.

This plausible outcome appears likely to generalize beyond the restrictions of the current models.¹¹ In consequence, the econometric technique of this article identifies cartel policing under uncertainty by applying a core insight of the trigger-price literature; the empirical methodology determines whether industry members expand their output in response

⁹ The dynamic equilibrium of the supgame is a noncooperative one. In many periods, however, the noncooperating oligopoly is able to achieve the static collusive price. A contemporaneous observer might describe industry behavior as collusive, but punctuated by periods of competition.

¹⁰ Porter, A Study of Cartel Stability, *supra* note 6. Porter supports his results further by demonstrating that the price-war periods identified endogenously through a maximum-likelihood technique match the price-war periods reported contemporaneously by the trade press.

¹¹ The existing literature selects among multiple equilibria by assuming, implausibly, that oligopolists are able to bargain to reach the most profitable dynamic equilibrium. Carl Shapiro, Theories of Oligopoly Behavior 57 (Discussion Paper No. 126, Discussion Papers in Economics, Woodrow Wilson School, Princeton University, March 1987). Moreover, the punishments specified may not be credible when renegotiation is possible. *Id.* at 58.

FIGURE 1.—Equilibrium with a kinked oligopoly supply function

to unexpected demand declines. The technique first identifies demand shocks, then tests whether the oligopoly markup falls when unexpected demand declines are observed.

C. The Kinked Oligopoly Supply Function

If a cartel responds to negative-demand shocks by acting more competitively for a time, then the supply relation faced by the colluding industry will exhibit a concave kink when demand shifts unexpectedly.¹² This kinked oligopoly supply function is depicted in Figure 1.

The discontinuity arises because the markup parameter θ in the supply relation (3) is affected asymmetrically by negative- and positive-demand shocks. A large unexpected downward shift in industry demand will in-

¹² Appendix B derives the comparative statics of the simultaneous eq. system (1) and (4) in order to demonstrate that demand shocks trace out a function with a concave kink, under the assumption that the markup falls when demand declines unexpectedly.

duce firms to act more competitively (lowering θ) by increasing output as a mechanism of cartel policing. In contrast, positive shocks to demand will not affect θ .

In this story, an asymmetric response is generated solely by random shifts in demand. No kink in the supply relation will be observed if demand shifts as a result of observable changes in the exogenous variables. Moreover, the asymmetry will not arise if the industry acts competitively or if collusion is enforceable without marketplace punishments.

D. The Log-linear Model

In order to identify the cartel response to unexpected demand shifts, a structural supply relation is estimated. The estimation model assumes that market demand has a log-linear functional form, as specified in equation (5). Further, if marginal cost is log-linear, the supply relation (4) can be written as equation (6).

$$\ln P = \alpha_0 + \alpha_1 \ln Q + \alpha_2 \ln Y + \epsilon, \quad (5)$$

$$P = \theta(P - MR) + \exp[\beta_0 + \beta_1 \ln Q + \beta_2 \ln W + v]. \quad (6)$$

In both equations (5) and (6), the vectors of exogenous demand and cost-shift variables have been truncated to include only one variable of each type, with no loss of generality. The two shocks, ϵ and v , are assumed to be independently and identically distributed and to be uncorrelated with each other.¹³

When θ does not vary with Y , the log-linear functional form for demand permits the identification of the supply relation through simple exclusion restrictions. Other functional forms for demand, in contrast, guarantee that the exogenous demand-shift variables will appear in the supply function.¹⁴

¹³ If cheating were actually to occur in any period, as might be permitted in some generalization of the existing models of oligopolistic supergames with imperfect monitoring, such behavior could be interpreted as a negative realization of v indistinguishable econometrically from an unexpected decline in rival marginal cost. (Cartel policing behavior, in contrast, is interpreted as altering the markup parameter.) Although this possibility would imply that v has a negative mean, the parameters of interest would remain identified, because two-stage least squares estimators of the supply relation would continue to generate consistent estimates of all the parameters except the intercept. Finn Førsund, C. A. Knox Lovell, & Peter Schmidt, A Survey of Production Functions and of Their Relationship to Efficiency Measurements, 13 J. Econometrics 5 (1980).

¹⁴ Like the exponential form, however, the linear functional form also permits identification by simple exclusion restrictions. Without such restrictions, identification of the supply relation will turn on the effect of rotations in demand on the equilibrium implied by a variety of solution concepts rather than on the simple instrumental variables techniques applied here. Bresnahan, *supra* note 2.

Equation (6) may be simplified by employing an implication of equation (5),¹⁵ yielding equation (7).

$$\ln P = \beta_0 - \ln(1 + \alpha_1\theta) + \beta_1 \ln Q + \beta_2 \ln W + v. \quad (7)$$

In anticipation of the empirical work, this function is further simplified in equation (8) through application of the approximation $\ln(1 + x) \approx x$.¹⁶

$$\ln P = \beta_0 - \alpha_1\theta + \beta_1 \ln Q + \beta_2 \ln W + v. \quad (8)$$

It is next necessary to specify the determinants of θ , the oligopoly markup parameter. Equation (9) sets forth a simple assumption consistent with the idea that cartels might act more competitively when demand declines unexpectedly.

$$\theta = \theta^* + \gamma(\epsilon). \quad (9)$$

Equation (9) decomposes the markup parameter into the sum of the constant θ^* and a second term γ that depends upon the demand shocks ϵ insofar as they lead to price declines.¹⁷ The assumption that θ^* is constant ignores the possibility that the exogenous variables Y and W affect the markup.¹⁸

With this decomposition, the market-supply equation (8) can be rewritten

$$\begin{aligned} \ln P &= (\beta_0 - \alpha_1\theta^*) - \alpha_1\gamma(\epsilon) + \beta_1 \ln Q + \beta_2 \ln W + v \\ &= \delta_0 - \alpha_1\gamma(\epsilon) + \beta_1 \ln Q + \beta_2 \ln W + v. \end{aligned} \quad (10)$$

In the second step of equation (10), the δ_0 parameter is used to simplify the notation for the intercept.¹⁹

To identify cartel policing under uncertainty, this article seeks to determine whether the supply relation contains a term of the form $\gamma(\epsilon)$ that produces a concave kink in response to demand shocks. This effort is

¹⁵ Equation (5) implies that $P - MR = -\alpha_1 P$.

¹⁶ This approximation is the most reasonable for $x < 1$. Because θ is less than one, the approximation is plausible unless demand is very inelastic (that is, unless $|\alpha_1|$ is large).

¹⁷ Equation (9) presumes that supply shocks v do not affect γ . This assumption is most plausible for a sample period like the Great Depression in which demand fluctuations are the primary source of large price declines. Even if this assumption is incorrect, because supply shocks are large enough also to affect oligopoly behavior, the econometric procedure employed in this article will continue to estimate consistently the effect of unexpected demand declines on the markup. The econometric issues involved are similar to those raised by the possibility of cheating, discussed in note 13 *supra*.

¹⁸ The exclusion of Y is necessary for the structural supply relation to be identified econometrically.

¹⁹ The substitution $\delta_0 = \beta_0 - \alpha_1\theta^*$ emphasizes the difficulty of discriminating between the markup and parameters of the marginal cost function. Bresnahan, *supra* note 2.

complicated by the fact that the demand shocks ϵ are unobservable. Information about those shocks is available, however, from estimating the demand curve (5). In particular, equation (5) can be estimated consistently by single equation methods so long as W , the excluded exogenous variable from the perspective of the system of equations (5) and (10), is employed as an instrument for the endogenous variable Q . The vector of residuals from that regression, denoted DRES, consistently estimates the vector of demand shocks ϵ .

The function connecting DRES and $\gamma(\epsilon)$ is discontinuous under the trigger-price equilibrium story. Demand shocks causing unexpected price declines will not make a cartel act more competitively unless they lead cooperating firms to suspect rival cheating. Hence, only the largest negative values of DRES can be expected to affect oligopoly behavior; firms are unlikely to suspect cheating when unexpected price declines are small or when price rises unexpectedly. Further, once an unexpected price decline is sufficiently large to trigger the suspicion of rival cheating, the cartel's reversionary response to competitive behavior will not necessarily vary with the degree of that unexpected price reduction.²⁰

Because demand shocks likely affect oligopoly behavior in this discontinuous way, most of the variation in industry behavior associated with the suspicion of cheating can be captured by a dummy variable. This variable, denoted DUM, takes on the value of one when the residual from estimating the demand curve (5) is a large negative number. The periods in which DUM is triggered are those in which cartel members facing uncertainty will have the greatest fear of rival cheating and the greatest incentive to police by expanding output. In particular, equation (11) is assumed to hold for some scalar $\gamma^* < 0$.²¹

$$\gamma(\epsilon) = (\gamma^*)\text{DUM}. \quad (11)$$

²⁰ Porter, A Study of Cartel Stability, *supra* note 6, at 310, found no relation between the size of the triggering demand shock and the length of the resulting price war in his railroad cartel data.

²¹ The assumptions (i) that $\gamma(\epsilon)$ does not vary with the size of ϵ once the dummy variable is triggered and (ii) that demand and marginal cost have log-linear functional forms imply that, when $\text{DUM} = 1$, the supply function will fall to a level equal to the fraction $\exp[-\alpha_1\gamma^*]$ of its value when $\text{DUM} = 0$. Hence, the supply relation in the empirical model shifts rather than rotates when demand declines unexpectedly, unlike the behavior depicted in Figure 1.

This result is a special case of a broader set of kinked oligopoly supply functions. With other functional forms for demand, eq. (4) implies that a discontinuous reduction in θ following a negative-demand shock will generate a rotation in the supply function. Alternatively, regardless of the equation for demand, the supply function could rotate if $\gamma(\epsilon)$ (and hence the reduction in θ) is permitted to increase with the absolute value of declines in ϵ .

The relation expressed in equation (11) allows equation (10) to be rewritten in the form of equation (12), so that all variables are observable

$$\ln P = \delta_0 - \alpha_1(\gamma^*)DUM + \beta_1 \ln Q + \beta_2 \ln W + v. \quad (12)$$

According to equation (12), when a large negative-demand shock arises—sufficiently large to cause the dummy variable to take on the value of one—the industry responds with increased competition among cartel members, thus lowering the industry price.

The final equation of the empirical model defines when negative-demand shocks are sufficiently large to trigger the dummy variable. Equation (13) sets forth the rule according to which each estimated error of the demand curve e (that is, each element of the vector DRES) is associated with a value of the dummy variable.

$$\begin{aligned} DUM &= 1 && \text{if } e < -Ts \\ &= 0 && \text{if } e \geq -Ts. \end{aligned} \quad (13)$$

Variable DUM is set equal to one if the estimated demand shock is a negative number larger in absolute value than a scalar T times s , the standard error of estimate of the demand curve. The value of T is selected by searching for it (along with the parameters of the supply function) in order to maximize the likelihood of observing the supply relation in the sample.²²

²² Allowing T to enter into the supply relation as an endogenous parameter introduces a large number of discontinuities into the likelihood function for eq. (12). In particular, a discontinuity arises whenever T changes to sweep in or out a demand shock, thereby altering the variable DUM. Moreover, when the likelihood function shifts discontinuously, the maximum-likelihood estimates of the parameters of eq. (12) can change discontinuously. As a result, iterative numerical optimization methods based on the gradient of the likelihood function cannot be employed to search for the parameters that maximize the likelihood function unless the search is conditioned on some value of T .

It may appear at first glance that the likelihood function is not comparable across equations because the definition of one independent variable, DUM, changes. To see why the procedure is, in fact, unobjectionable, consider the dummy variable DUM* that would be created were $T = 0$; this dummy variable is triggered by a negative-demand shock of any magnitude. Next, imagine replacing this dummy variable with a set of dummy variables, by including in the supply function a separate dummy (denoted DUM_{*i*}) for each negative demand shock. Each DUM_{*i*} has only one element with a value of one; this variable identifies the date of the *i*th negative-demand shock. With this substitution, the vector DUM* is replaced with approximately $n/2$ vectors DUM_{*i*} (for a sample of n observations).

From this perspective, eq. (13) requires that the coefficient associated with each DUM_{*i*} in the supply function take on either of two values: the coefficient must be zero, or else it must be identical to the coefficient on every other DUM_{*j*} that also has a nonzero coefficient. In addition, eq. (13) requires that no dummy variable DUM_{*i*} have a zero coefficient unless all other DUM_{*j*} associated with negative-demand shocks smaller in absolute value than the shock associated with DUM_{*i*} also have coefficients of zero. The maximum-likelihood procedure appropriately searches over all permissible values of this constrained coefficient space.

Conditional on estimating the demand function and selecting some value for T , equation (12) can be estimated consistently with single equation methods. Because (12) is one of two equations in a system of demand and supply functions,²³ consistent parameter estimates are derived by employing Y , an excluded exogenous variable, as an instrument for the endogenous output variable.

When estimates of the supply relation are obtained, the hypothesis of cartel policing under uncertainty, which is equivalent to the hypothesis that $\gamma^* < 0$, is examined through a one-tailed test of the null hypothesis that $\gamma^* = 0$. Because α_1 (the elasticity of inverse demand) is known to be nonzero, the hypothesis of interest can be tested by examining whether the coefficient on DUM is negative.²⁴

If the null hypothesis that $\gamma^* = 0$ is accepted, that result provides no basis for discriminating between competitive and collusive explanations for industry behavior. Were the industry behaving competitively, cartel policing under uncertainty would not be detected. Yet $\gamma^* = 0$ will also be observed if cooperation is a dominant strategy for all sellers. In the latter case, all firms recognize that rival cheating is never a rational strategy, cartel policing is never necessary, and the markup does not vary with unexpected reductions in price.

II. THE STEEL INDUSTRY BETWEEN THE WORLD WARS

The model described above is applied to study oligopoly behavior in the U.S. steel industry during the Great Depression. This industry was selected for four reasons. First, business-cycle fluctuations promised substantial demand-side variation, both predictable and random.²⁵ Such

²³ The simultaneous eq. system (5) and (12) estimated in this article is formally equivalent to the system (1) and (2) estimated in Porter, *A Study of Cartel Stability*, *supra* note 6. Porter treats the periods of unexpected demand decline as known (from reading the trade press) or else identifies them as those periods that maximize the likelihood that a switching regression framework describes the data. In this article, in contrast, such periods are inferred from the residuals of the demand curve through the construction of DUM.

²⁴ As the demand elasticity α_1 is negative in eq. (5), the expression $-\alpha_1(\gamma^*)$ will be negative if $\gamma^* < 0$.

²⁵ The magnitude of industry demand shifts is suggested by the monthly variation in capacity utilization between mid-1933 and mid-1939. Investigation of Concentration of Economic Power: Hearings before the Temporary National Economic Committee (Select Committee), Iron and Steel Industry, 76th Cong., 3d Sess., Parts 26–27, at 13858 (1940) (abbreviated hereafter as TNEC Hearings). In July 1933, the steel industry was operating at 55 percent of capacity, the highest rate since mid-1930. The utilization rate fell to 26 percent in November 1933, rose to 59 percent in May 1934, fell to 22 percent in September 1934, and rose to 50 percent by January 1935. During 1935, utilization rates fluctuated between 39 percent and 55 percent. Throughout 1936 and early 1937, the capacity utilization rate rose fairly steadily to a peak of 91 percent in March 1937. The rate stayed above 70 percent

conditions are the most favorable for identifying a supply relation generally and for identifying the influence of demand shocks on the industry markup.

Second, steel sellers apparently interacted under uncertainty, in an environment conducive to the cartel policing behavior embedded in the econometric model. Firms in this industry most likely learned about marketplace behavior primarily through contacts with their customers and suppliers.²⁶ Because this information was limited, the steel producers may well have been unable to distinguish between demand declines and rival cheating if they were colluding.

The strongest evidence that steel producers in the Depression could not monitor their rivals perfectly comes from the provisions of the iron and steel industry's Code of Fair Competition, devised by the industry²⁷ and

through September 1937, then fell precipitously to 26 percent in December. The rate did not climb above 40 percent until August 1938. It peaked at 61 percent in November 1938, then stayed in a range between 49 percent and 57 percent through July 1939. Because industry capacity was stable throughout these years, *id.*, these large utilization fluctuations reflect demand variation.

²⁶ Although the weekly trade publication *Iron Age* attempted to monitor demand fluctuations, the reported information was vague and impressionistic. The analysis of industry trends attempted to control for business-cycle fluctuations and other demand or cost influences, but it is unlikely that these descriptive reports significantly increased the industry demand information available to each firm from its interactions with customers and suppliers.

For example, industry news stories in January and February 1936 focused primarily on trends in steel production relative to orders from the automobile, rail, and heavy industry sectors and on production and distribution problems associated with winter weather. The stories suggested that higher steel demand was commensurate with exogenous increases in industrial production.

On February 27, *Iron Age* first noted the conjunction of increasing production and "weakening" prices that characterized its reports during March. The March 12 issue observed that the decision of a leading producer to publish price lists for the second quarter promised future "price stability." It also emphasized that deviations from the price list could be considered antitrust violations. In the next issue, the publication interpreted an increase in customer orders as reflecting buyer anticipation of price stabilization. By April, news stories were describing the end of the episode of price weakness. According to the April 9 issue, prices rose slightly. On April 16, price pressure was being "firmly resisted."

As described in the trade press, the events of March 1936 appeared to reflect some sort of supply side phenomenon. While these reports were consistent with an episode of increased competition (cartel policing) following a negative-demand shock, the demand shock was not itself described. A demand shock was identified econometrically (see note 67 *infra*) and in consequence likely would have been noted contemporaneously by industry members (although not necessarily distinguished from rival cheating). Thus, in identifying the demand shock, the *Iron Age* reports did not add to the information firms most likely possessed already from their own marketplace contacts.

²⁷ The code was devised through negotiations among the major producers and workers. Workers were represented by officials from the Department of Labor because they were not then unionized.

promulgated by the National Recovery Administration (NRA).²⁸ The steel code was in effect from August 1933 through May 1935.²⁹ Given the opportunity to cooperate legally,³⁰ industry members chose neither to require a common industrywide price schedule nor to insist upon some prespecified division of output.³¹ Rather, in a period in which any express collusive arrangement would be enforceable by law,³² the steel producers chose merely to create a variety of mechanisms for prohibiting secret, selective price cutting. Each seller was required to adhere to the list prices it posted, but each could announce its own price schedule and change prices unilaterally. The industry established a standardized set of product definitions and standardized conduct provisions such as buyer financing terms and the basing point pricing rules for computing shipping costs. In addition, the industry designated as an unfair practice, punishable by law, the substitution of a higher quality product for the product specified in a contract.

The third reason the steel industry during the Depression was chosen for study is that the investigation of industrial concentration by the Tem-

²⁸ See, generally, Carroll Daugherty, Melvin de Chazeau, & Samuel Stratton, *The Economics of the Iron and Steel Industry* (vols. 1 and 2, 1937).

²⁹ On May 27, 1935, the Supreme Court held unconstitutional the act authorizing industry pricing codes.

³⁰ Other industries took advantage of the opportunity created by the NRA to engage in much more explicit price fixing. Some codes provided for setting minimum prices, either as a matter of course or when an "emergency" was declared by virtue of "destructive" pricing in the marketplace. Leverett Lyon *et al.*, *The National Recovery Administration: An Analysis and Appraisal* 578–85, 603–10 (1935). Other codes prohibited sales below cost, typically in combination with devising a standardized accounting system that defined "cost" as incorporating most joint and common costs (including indirect manufacturing expenses, administrative expenses, and selling expenses) in addition to direct labor and material costs. *Id.* at 585–91. Minimum price setting was common among sellers of industrial equipment, while below-cost sale prohibitions were common in the codes promulgated by manufacturing industries and sellers of basic materials. *Id.* at 580–83.

³¹ Although the steel code prohibited the erection of new production capacity, it excepted two areas of ongoing technological progress: new electric furnaces and improvements in steel finishing capacity.

³² The board of directors of the American Iron and Steel Institute, the industry trade association, was empowered to enforce the code by gathering statistics, checking the books of reporting companies, and assessing damages for violations. Firms that did not sign the code were required to comply with its provisions, although it was more difficult to enforce the code with respect to such sellers. While detailed monthly production and capacity data was collected, no statistics were collected on cost variation or the geographic distribution of shipments in order to avoid placing an information-gathering burden on producers.

Although the enforcement of many of the one thousand industry codes was problematic (see, generally, Peter Irons, *The New Deal Lawyers* 35–57 (1982)), the steel code had a strong compliance record because, uniquely among industry codes, all the major steel producers agreed to subject themselves to a contractual enforcement mechanism involving the payment of liquidated damages for violations. Donald Brand, *Corporatism and the Rule of Law: A Study of the National Recovery Administration* 214 (1988).

porary National Economic Committee (TNEC) in 1940 led to the publication of statistical information in monthly time series. Monthly observations provide a plausible approximation to the lag in this industry between firms observing unexpected price declines and their output response. Monthly data also permit a large number of observations from periods of stable industry structure. Finally, as will be described in detail in the remainder of this section, the steel industry during the 1930s was chosen for study because its structure could have been consistent with either competition or collusion.

A. *Structural Case for Collusion*

Many observers have suggested that the U.S. steel industry engaged in cooperative pricing during at least some portion of the 1920s and 1930s.³³ A variety of structural factors are consistent with this view.

Most important, the steel industry was concentrated. The four-firm concentration ratio was around 60 percent during these decades, and the eight-firm concentration ratio rose from two-thirds to more than three-fourths.³⁴ In 1938, the industry Herfindahl-Hirschman index (HHI) based on production capacity was roughly 1620,³⁵ at the high end of the moderately concentrated range defined by the current Department of Justice merger guidelines. United States Steel, the largest firm, typically held a market share in the 35–40 percent range during the 1930s³⁶ and acted as the industry's price leader.³⁷

As a group, these firms were arguably free from competitive discipline. Demand substitutes for steel were limited in most applications,³⁸ imports were a minor concern, and the large sunk costs associated with the introduction of new steelmaking capacity reduced the threat of entry. As a result, industry demand was likely inelastic in the long run³⁹ and the potential gains from collusion were substantial.

³³ Morris Adelman, *Steel, Administered Prices and Inflation*, 75 Q. J. Econ. 16, 35 n.4 (1961); TNEC Hearings, *supra* note 25, at 14232; Leonard Weiss, *Oligopoly—Steel*, in *Case Studies in American Industry* 158, 176–77, 191 (Leonard Weiss ed., 3d ed. 1980).

³⁴ Walter Adams & Hans Muller, *The Steel Industry*, in *The Structure of American Industry* 74, 80 (Walter Adams ed., 7th ed. 1986).

³⁵ TNEC Hearings, *supra* note 25, at 13903.

³⁶ *Id.*, at 13848, 13852.

³⁷ Weiss, *supra* note 33, at 191.

³⁸ In 1938, steel was typically used in the production of auto, rail, and farm equipment, consumer durables, and cans, as well as in construction. TNEC Hearings, *supra* note 25, at 13816.

³⁹ A Depression-era statistical study prepared under the supervision of Theodore O. Yntema concluded that industry demand was highly inelastic, with an elasticity of 0.3 to 0.4.

In addition, a number of industry practices appeared to facilitate collusion. Although the industry moved from a single-basing-point pricing system to multiple basing points in 1924, when the Federal Trade Commission (FTC) outlawed the former practice,⁴⁰ this shift appeared to have little practical effect on pricing.⁴¹ Antitrust enforcers have traditionally been hostile to basing point pricing on the view that it provides a focal point for pricing coordination.⁴² Further, an industry trade group began publishing freight-rate data around 1934, facilitating interfirm monitoring of freight absorption for the remainder of the decade.⁴³

Coordination of a steel cartel appears to have been feasible. The homogeneity of semifinished steel products likely aided firms in their efforts to agree on a collusive price. Also, the industry's experience with express collusion may have improved the prospects for subsequent tacit coordination.⁴⁴ That experience included the infamous "Gary dinners" around 1910⁴⁵ and the industry's adherence to the steel code from mid-1933 through mid-1935.

B. *Structural Case for Competition*

On the other hand, a credible structural argument for competition could be offered.⁴⁶ In 1929, a sizeable disruptive competitor, National Steel,

TNEC Hearings, *supra* note 22, at 13913, 13927. However, Yntema did not correct for the simultaneity of demand with supply. A modern study estimates the elasticity at 0.6 or 0.7, also inelastic. Robert Rogers, *The Behavior of Firms in an Oligopoly Industry: A Study of Conjectural Variations* 151 (unpublished Ph.D. dissertation, George Washington Univ., May 1983).

⁴⁰ The Basing Point Problem, xi (Monograph No. 42, Temporary National Economic Committee, 1941). Multiple basing points were not forbidden until 1948.

⁴¹ Kenneth Warren, *The American Steel Industry 1850-1970: A Geographical Interpretation* 203-04 (1973); Kenneth Mayall, *International Cartels: Economic and Political Aspects* 67-68 (1952).

⁴² Richard Posner, *Antitrust Law: An Economic Perspective* 70-71 (1976); F. Michael Scherer, *Industrial Market Structure and Economic Performance* 329 (2d ed. 1980).

⁴³ TNEC Hearings, *supra* note 25, at 14177-78, 14222-23.

⁴⁴ The U.S. industry also had experience with cooperation in sales abroad. The dozen leading U.S. steel producers organized a Webb-Pomerene Export Association in 1928. The Steel Export Association of America participated actively in international steel commodity cartels from July 1928 through September 1939, and especially beginning in December 1937. These international agreements were suspended by the outbreak of World War II. They expressly excluded the domestic market of the United States. See, generally, Federal Trade Commission, *Report of the Federal Trade Commission on International Steel Cartels*, 3-4, 11-12 (1948); Ervin Hexner, *International Cartels* 203-15 (1945).

⁴⁵ Weiss, *supra* note 33, at 171-72.

⁴⁶ The performance evidence from accounting profits is consistent with the view that the industry was competitive during this period. Steel profits were generally lower than the manufacturing sector average during the 1920s and 1930s and the two profit streams were

was created by merger.⁴⁷ In addition, firms other than the market leaders aggressively adopted new low cost production technologies.⁴⁸ These developments should have increased the difficulty for interfirm cooperation.⁴⁹

Industry capacity utilization was low during the Depression when the durable-goods demand from which steel demand is derived declined precipitously. The industry virtually shut down in December 1932, when the utilization rate fell below 15 percent. The rate stayed below 15 percent in December 1932 and remained below 50 percent from late 1930 to mid-1935 and again from late 1937 through late 1938.⁵⁰ Excess capacity implies that marginal costs were low for steel producers, increasing their incentive to compete.⁵¹

highly correlated. Weiss, *supra* note 33, at 224. However, accounting profits are frequently poor indicators of economic profits because of the accounting treatment of fixed costs. Franklin Fisher & John McGowan, On the Misuse of Accounting Rates of Return to Infer Monopoly Profits, 73 *Amer. Econ. Rev.* 82 (1983). Further, it is often difficult to distinguish profits from rents to low cost factors of production (perhaps plant location in the steel industry) or superior product design.

The accounting evidence on markups, in contrast, suggests less competitive behavior. The Lerner Index for U.S. Steel implied by firm aggregate revenue and marginal cost data developed for the TNEC hearings rose from 0.2 in 1929–31 to 0.3 in 1937 and 0.4 in 1938. TNEC Hearings, *supra* note 25, at 13789–91 (total revenues), 14039 (quantity in weighted tons), 14049 (marginal cost).

⁴⁷ Weiss, *supra* note 33, at 178, 193–94.

⁴⁸ Adams & Mueller, *supra* note 34, at 78–79; Weiss, *supra* note 33, at 191–92; Rogers, *supra* note 39, at 82, 84.

⁴⁹ Further, industry negotiations to create the steel code revealed a divergence of interest between large and small sellers. These differences may have made tacit coordination among those sellers more difficult during years outside the code period. However, intraindustry differences of opinion were significantly more muted in steel than in most industries. Brand, *supra* note 32, at 211.

⁵⁰ TNEC Hearings, *supra* note 25, at 13858.

⁵¹ Some transaction price evidence at first appears consistent with secret price cutting by steel producers during recessions. An index of U.S. Steel's net mill price, which takes into account freight absorption, fell up to 4 percent below a composite price index excluding freight absorption during 1931–33, the first trough of the Depression. A similar discrepancy appeared in 1937–38, the second trough. The maximum discrepancy briefly exceeded 10 percent in 1937. TNEC Hearings, *supra* note 25, at 13810–11. Further, this variation was apparently not a consequence of changes in the product mix associated with the business cycle, as the same pattern was apparent in the pricing of heavy structural shapes. *Id.* at 13796. These price-series differences probably did not reflect secret price cutting through freight absorption, however, because the discrepancy was much higher in the earlier periods of 1912–13, 1916–18, and 1922–23—largely boom years—than during these Depression dates. *Id.* at 13815.

The observed pattern of differences between these price series may instead result from a difference in the quantities measured. Net mill yield includes additional revenues for special finish, quality, size, or heat treatment, while the composite price index is an index of base prices. *Id.* at 13811. The observed pricing pattern could have been caused by shifts in the demand for these extras relative to the demand for steel generally, uncorrelated with the business cycle.

Moreover, the argument for competition contests whether interfirm coordination is feasible by pointing to the extensive differentiation of finished steel products. While base prices apply to a handful of standard sizes and qualities, "producers must be prepared to quote modified base prices on thousands of possible variations."⁵² If the high degree of captive production makes it impossible for firms to monitor semifinished steel prices, colluding firms would find it necessary to coordinate finished steel prices, a far more difficult task than coordinating the prices of semifinished products.⁵³

Finally, multiple basing point pricing need not have been a practice facilitating collusion; it may have been consistent with competition.⁵⁴ The support of some steel buyers for basing point pricing gives added plausibility to the view that this practice reflects competition rather than cooperation;⁵⁵ consumers of steel are unlikely to favor a practice that facilitates collusion among sellers.

III. ESTIMATION RESULTS

This section presents estimates of the demand function and supply relation for the U.S. steel industry during the 1935–39 period in order to test the hypothesis that negative-demand shocks alter industry behavior. The results support the view that unexpected declines in demand cause a temporary change in oligopoly behavior in the direction of increased competition, and thus support the inference that steel firms were colluding under conditions of uncertainty. In contrast, negative-demand shocks had no effect on the oligopoly markup during the 1933–35 period when the NRA steel code was in force, consistent with the view that marketplace punishments were unnecessary when interfirm cooperation was legally enforceable.

⁵² Competition and Monopoly in American Industry 133 (Monograph No. 21, Temporary National Economic Committee, 1940).

⁵³ Consistent with this suggestion, the international steel cartel of the interwar period originally attempted to control semifinished steel prices and outputs but shifted its efforts in 1930 to control finished steel products. The 1933 agreement devised output quotas for both finished and semifinished products. Hexner, *supra* note 44, at 203–12.

⁵⁴ TNEC Hearings, *supra* note 25, at 14619; David Haddock, Basing Point Pricing: Competitive vs. Collusive Theories, 72 Am. Econ. Rev. 289 (1982). If buyers are geographically dispersed, if some spatial locations have production cost advantages, and if there are a large number of sellers at each such location, then in equilibrium the market price at any consumption location will be the delivered price of a marginal producer from a nearby advantageous production location. These competitive prices would mimic a basing point system.

⁵⁵ TNEC Hearings, *supra* note 25, at 14430. However, the large automobile manufacturers opposed the steel basing point system. Brand, *supra* note 32, at 220.

A. Variables and Sample Periods

A glossary of variable names is provided in Appendix A. The price and quantity of semifinished steel were selected for analysis in preference to the comparable data for finished steel because semifinished products are close supply substitutes and therefore can be considered homogeneous goods. Finished steel products are, in contrast, arguably neither substitutes in demand nor substitutes in supply.

Variables reflecting exogenous shifts in demand and supply were limited by the availability of monthly time-series data for the 1930s.⁵⁶ The demand for steel is a derived demand, primarily dependent during that period upon the output of the automobile, rail, and construction sectors of the economy. These sectors produce durable goods, so their demand is heavily influenced by the business cycle. To capture these influences, the regressions include the current level of industrial production and measures of its change over the previous three, twelve, and twenty-four month periods.⁵⁷ To capture the effect of shifts in business-cycle leadership across the auto, rail, and construction sectors, which may use steel in different intensities, quantity variables for the output of the auto and rail car production industries were introduced. Finally, the price of aluminum, which is likely both a demand substitute and a demand complement for steel,⁵⁸ was included in the regressions as a demand-shift variable.

Two supply-shift variables were employed: the price of pig iron and the hourly wage rate for steel industry workers.⁵⁹ The price of scrap steel was not included in the reported regressions. The scrap price is unlikely to affect steel demand,⁶⁰ and its possible role as a supply shift variable is treated in the discussion of specification tests. Capacity utilization rates were not included in the regression equations as variables affecting marginal cost, for two reasons. First, utilization variation over the sample

⁵⁶ The present study of steel demand incorporates exogenous variables roughly representing those suggested by Theodore O. Yntema in 1939. TNEC Hearings, *supra* note 25, at 13921–22.

⁵⁷ These business-cycle variables can be thought of as standing for firm expectations about future demand. The econometric results presented below were robust to an alternative approach to accounting for the intertemporal nature of demand. See note 75 *infra* and accompanying text.

⁵⁸ United Nations Economic and Social Council, Competition Between Steel and Aluminum (prepared by the Industry Division, Economic Commission for Europe, Steel Committee, 1954).

⁵⁹ Unlike the other variables, the wage series was not available before 1934.

⁶⁰ Scrap steel is not a substitute for semifinished or finished steel in most industrial uses. Further, the scrap sector was unimportant empirically in estimating aluminum demand over a similar time period. Valerie Suslow, Estimating Monopoly Behavior with Competitive Recycling: An Application to Alcoa, 17 Rand J. Econ. 389 (1986).

period appears to have been caused almost entirely by business-cycle fluctuation already captured by the industrial production variables, not by the introduction of new capacity with concomitant effect on marginal cost. Second, because output already appears in the supply function, a utilization variable would have the role of capturing the increasing slope of marginal cost when industry production approached capacity. This problem did not arise during the Great Depression. Between 1927 and 1939, capacity utilization rates never exceeded 92 percent other than during a six-month period in 1929.⁶¹

The focus of these regressions is on identifying demand shocks and the output response to them, rather than on estimating the elasticities of the exogenous variables in the demand and supply functions. In consequence, simple time-series predictive mechanisms were incorporated into the equations. A time variable was included in both the supply curve and the demand curve to capture long-term trends in demand, marginal cost, or oligopoly behavior. Further, seasonality in demand⁶² was accounted for by two dummy variables: one for the spring peak months of February and March and one for the winter trough months of November and December. These variables were treated as exogenous sources of demand shifts. Many of the equations were estimated with adjustments for first-order serial correlation of the errors. All variables were measured monthly in order to approximate the length of the detection-and-response lag for firms observing the possibility of rival defection.⁶³

⁶¹ TNEC Hearings, *supra* note 25, at 13858.

⁶² See *Id.*

⁶³ If the lag were actually shorter than one month, then price may have returned to the cooperative level before each observation period ended. Average monthly prices would then understate the price reduction that results from cartel policing following a demand shock, and the coefficient on DUM would be biased toward zero. Nevertheless, some decline most likely would be detectable econometrically.

If the lag were longer than one month, the estimate of the coefficient of DUM would not be affected in a large sample. The dummy variable in effect removes from the sample output observations that arise simultaneously with a negative price shock. If firms respond to the threat of rival cheating by increasing output for more than one month, then the sample will contain some high output observations reflecting cartel policing behavior not removed by the dummy variable. These observations can be thought of as negative realizations of v , the supply-shock variable, uncorrelated with any other variable in the supply curve. The constant term in the estimated supply relation will be biased because the presence of such observations implies that v has a negative mean. But all other coefficients, including the coefficient of the dummy variable, will continue to be estimated consistently for reasons similar to those discussed at note 13 *supra*.

If price was typically last more than one month, their average length can be inferred by adding to the regression function dummy variables lagged one or more periods from the date of the negative-demand shock. Additional lags would be introduced so long as they enter with a negative coefficient (expected to equal the coefficient on DUM) rather than with a

TABLE 1
EMPIRICAL RESULTS

Function	Demand from August 1935 to July 1939*	Supply from September 1935 to July 1939*	Supply from September 1933 to June 1935*
C	-1.00 (1.3)	-.06 (.7)	-.60 (3.0)
LQ	-.08 (1.3)	-.02 (1.3)	.04 (5.0)
TIME	.01 (15.5)	.01 (4.3)	.00 (.5)
LRIRP	...	.37 (4.9)	1.70 (12.4)
LRWAGE	...	-.05 (.5)	...
DUM	...	-.01 (3.2)	.00 (.3)
LRALP	-.49 (2.6)	...	...
SP	-.00 (.1)	...	...
WN	-.00 (.7)	...	...
LCAR	.02 (2.9)	...	...
LRAIL	-.01 (1.6)	...	...
LRV	.07 (.4)	...	...
LRDY3	.02 (.3)	...	...
LRDY12	-.17 (3.8)	...	...
LRDY24	.13 (2.5)	...	...
RHO	.26 (1.6)	.92 (17.3)	...
T	...	.48	.50
Statistics:			
R^2	.96	.95	.95
Durbin-Watson	1.90	1.88	1.76
N	48	47	22

NOTE.—*t*-statistics are given in parentheses.

* LRP is the dependent variable in each equation.

The empirical study primarily concerns the monthly observations from July 1935 to July 1939. This sample period commences at the end of the NRA-code period and lasts until monthly data were no longer available from the TNEC hearings. For comparison, the empirical methodology is also applied to observations from August 1933 to June 1935, the period in which the steel code was in force. Collusion was presumably a dominant strategy for all producers under the NRA, so a cartel policing response to unexpected demand declines should not be detected.

B. Estimation Results

Results for the 1935–39 sample period are presented in the first two columns of Table 1. The first column exhibits the preferred specification

coefficient of zero. When the loss of a few degrees of freedom is unimportant, this procedure would also reduce the standard error of estimate in the supply relation regression if price wars last longer than one period. The application of this procedure is discussed at note 69 *infra*.

of the demand curve. To identify the demand curve, the exogenous cost-shift variables were instrumented for output.⁶⁴ The equation was estimated with a procedure correcting for first-order serial correlation in the errors, resulting in the loss of an observation from the sample.

The estimated own-price elasticity of demand is high; an elasticity of -12 is implied by the point estimate of the inverse elasticity. While empirical studies involving yearly observations have concluded that the demand for steel was inelastic,⁶⁵ demand was likely far more elastic with respect to monthly fluctuations in price or output because buyers could build or draw down inventories inexpensively for short periods. In consequence, an elastic short-run demand curve does not imply the absence of large gains to cooperative behavior.

Although the seasonal dummy variables and some of the industrial production and sectoral demand shift variables are insignificant, all were included in the preferred specification because they were suggested by theory and correlated with industry output. The residuals from the estimated demand function were used to construct the dummy variable DUM employed in estimating the supply function. The likelihood function was maximized by triggering the dummy variable when demand fell randomly by more than 0.48 times the standard error of estimate.⁶⁶ This occurred in twelve of the forty-eight periods covered by the 1935–39 sample.⁶⁷

The second column of Table 1 shows the preferred specification of the supply relation. In estimating this equation, excluded exogenous demand-shift variables were used as instruments for quantity and a correction for first-order serial correlation was employed. The estimated supply function is essentially horizontal, likely reflecting excess production capacity in the industry.⁶⁸ The price of iron, the most important physical input, enters significantly and positively. It is surprising that wages have no effect on marginal cost, although the estimated standard error implies that

⁶⁴ Single equation estimation methods were employed. It is difficult to estimate the system of demand and supply functions simultaneously because the errors in the demand curve are used to create the variable DUM employed in estimating the supply relation.

⁶⁵ See note 39 *supra*.

⁶⁶ An unexpected demand decline reducing price by 8 percent lowered the estimated demand function by one standard error of estimate. Hence, with T approximately equal to one half, DUM was triggered by unexpected declines in price of 4 percent or more.

⁶⁷ For the 1935–39 regressions reported in Table 1, large negative-demand shocks caused DUM to take on the value of one in the following periods: October 1935, March 1936, June 1936, August 1936, November 1936, December 1936, February 1937, June 1937, July 1937, July 1938, May 1939, and July 1939.

⁶⁸ In the log-linear functional form of eq. (12), parameters associated with the markup shift the constant term rather than the slope of the supply relation. Hence, the slope parameter of the supply relation is interpreted as reflecting the slope of marginal cost.

the coefficient on the wage variable could be consistent with a substantial positive elasticity.

The hypothesis that unexpected declines in demand lead to more competitive behavior is tested by the coefficient on the dummy variable. This coefficient is negative and significant, consistent with the existence of cartel policing under uncertainty. Thus, this equation supports the hypothesis that steel producers were colluding during the late 1930s.

While the coefficient on the dummy variable is significant, its magnitude is small. The low point estimate is not troublesome for two reasons. First, as indicated in equation (12), γ^* must be inferred by dividing the coefficient of the dummy variable by the inverse-demand elasticity. Because the point estimate of the demand elasticity is small and imperfectly estimated, a wide range of values of γ^* , including very large values, is consistent with the coefficient reported in Table 1. Second, even if γ^* is small, collusion in the steel industry may be supportable by shallow episodes of increased competition, particularly if information lags are brief.⁶⁹

The model was also estimated over the period when the NRA steel code was in effect, from mid-1933 to mid-1935. To identify the demand shocks arising during the small NRA sample, the demand curve was assumed to be a stable function from mid-1933 through mid-1939.⁷⁰ In contrast, the

⁶⁹ In order to achieve the best high-price equilibrium in a trigger-price model, reversion to the worst low price equilibrium is generally required. However, some other collusive price is typically supportable by reversion to a low price equilibrium that is not the worst possible. See, generally, Shapiro, *supra* note 11, at 53–58. Moreover, reducing the lag with which firms receive information about their rivals' actions typically increases the efficacy of collusion. *Id.* at 55–56.

The data permits an estimate of the joint detection and response lag. When a dummy variable lagged one month was introduced into the supply relation (see note 63 *supra*), it had a positive coefficient insignificant from zero, while the coefficient on DUM remained significant and negative. In consequence, the detection lag and response lag individually are each likely no longer than one month. (The theoretical significance of a short response lag is unclear. Frequent moves in a repeated game setting may make collusion more effective—by increasing punishments—or less effective—by increasing the scope of detection. Shapiro, *supra* note 11, at 55–56.)

⁷⁰ When the demand function was estimated over the 1933–39 period, the slope coefficient was estimated as a small positive number. This troubling result, suggesting the possibility of specification error, would normally call into question whether the dummy variable identifies periods of large negative-demand shocks. In this particular case, however, the identification of the shocks is fairly trustworthy because the residuals for the 1935–39 period generated by the demand curve estimated from 1933–39 and the resulting dummy variable are similar to the residuals and dummy variable generated by the demand function limited to the 1935–39 sample.

Attempts to estimate the model over two earlier sample periods, January 1927 to May 1930, and June 1930 to July 1933, were also beset by the difficulty of estimating a downward sloping demand function. The econometric problem in all these cases appears to be that demand shocks are large relative to observable shifts in supply. In a small sample, the noise from random demand variation can readily lead to estimates with the wrong slope.

estimated supply relation was limited to the brief sample period in which the steel code was in force to allow the parameters of the marginal cost function and the average markup to vary from their values in the later period.⁷¹

The estimated supply function of the steel code sample period, shown in the third column of Table 1, exhibits sensible coefficient estimates other than the high reported elasticity of marginal cost with respect to the price of iron, which may reflect specification bias associated with the omission of other cost-shift variables. The coefficient on the dummy variable was estimated as a small positive number, indistinguishable from zero. This result is consistent with the view that the steel code made collusion a dominant strategy for all sellers, so industry members never interpreted price declines as rival cheating and never increased output in response.⁷²

C. Specification Tests

Several specification tests were employed to confirm the cartel policing response to unexpected demand declines observed in the estimated supply function for the 1935–39 sample period. Two tests investigated whether the model is robust to alternative functional forms. The first estimated a linear version of the structural model.⁷³ The supply relation for this model confirmed the log-linear results: periods of negative-demand shocks led to significant reductions in markup.⁷⁴ The second test addressed the possibility that the dummy variable was picking up a curvature of the structural supply curve not already controlled for by the log-linear functional form. To confirm that a negative coefficient on DUM reflected a response to unexpected demand declines rather than the effect of large residuals of either sign, a new variable was introduced into the supply relation equal to the square of the residual of the demand function. Although the new variable entered significantly, the coefficient on the dummy variable remained negative and significant, and its point estimate

⁷¹ The supply relation regressions for the NRA sample period also differ from the regressions for the 1935–39 period because the wage rate was omitted as an exogenous variable. See note 59 *supra*.

⁷² The statistical results showing an absence of cartel policing are also consistent with the implausible alternative hypothesis that the industry equilibrium was a noncooperative one while the steel code was in effect.

⁷³ When demand and marginal cost are linear, the oligopoly markup affects the slope of the supply relation rather than the intercept. Hence, the dummy variable enters into the linear supply function interacted with output.

⁷⁴ These estimates were less satisfactory than those obtained from the log-linear model because the residual plots suggested that the linear equation was misspecified.

doubled in magnitude. Hence, this robustness test also confirms the results obtained from the log-linear specification.

Another specification test involved an alternative treatment of the business cycle in the demand function. Instead of capturing intertemporal demand shifts through lagged industrial production variables, this test employed industrial production measured one year in the future as a proxy for current expectations.⁷⁵ As before, the residuals from the demand equation were used to create a dummy variable employed in estimating the supply relation. The resulting supply-function estimates were similar to those reported in Table 1, and the coefficient on the dummy variable remained negative and significant.

One robustness test explored the significance of the omission of the price of scrap steel from the supply function. Scrap is the largest physical input into semifinished steel production after pig iron,⁷⁶ so its factor price would likely affect marginal cost. However, the greater part of the scrap employed in producing semifinished steel comes directly from the production of semifinished steel rather than from the spot market; the two goods are to a large extent complements in supply.⁷⁷ In consequence, the equilibrium price of scrap steel is determined simultaneously with the equilibrium price and output of semifinished steel.

The price of scrap steel was omitted from the reported supply-function regressions because no instruments were available to correct for its simultaneity with output. This omission could bias the coefficient of the dummy variable in the direction of a large negative number—leading an observer to mistakenly identify cartel policing—if lower scrap prices both reduce demand (creating the appearance of a random demand decline) and increase supply (by lowering marginal costs). To confirm that scrap prices did not have this effect on the estimated regression equation, the scrap price was included in the supply function (without an instrument). The coefficient of DUM did not change markedly and the regression as a whole deviated little from the equation reported in Table 1.⁷⁸ Hence, it is unlikely that omitting the exogenous component of the scrap-price variable created the mistaken appearance of cartel policing.

⁷⁵ Ex post realizations measure ex ante expectations with random forecast error. Lagged industrial production was employed as an instrument to correct for this errors-in-variables problem.

⁷⁶ TNEC Hearings, *supra* note 25, at 10392.

⁷⁷ *Id.*; Lyon et al., *supra* note 30, at 333, 364.

⁷⁸ The log deflated scrap price entered positively in the 1935–39 equation with a coefficient of 0.04 and a *t*-statistic of 1.1. The dummy variable coefficient rose in absolute value to -0.02 , and its *t*-statistic was 3.0. When the price of scrap steel was included in the supply function regression for the NRA period, the results were also similar to those reported in Table 1.

Two robustness tests were suggested by problems associated with the use of semifinished steel prices as the dependent variable.⁷⁹ First, the reported price of semifinished steel may not be a market price because most industry production of semifinished steel (90 percent in 1929) was transferred captively within integrated producers.⁸⁰ In particular, some industry participants during the 1930s believed that integrated firms seeking to deter unintegrated producers of semifinished steel from entering into finished steel production kept the semifinished price artificially high.⁸¹ Under this story, colluding downstream producers in effect shared their cartel profits with the unintegrated upstream sector, in exchange for the unintegrated semifinished sector's forbearance from new entry downstream.⁸²

To show that semifinished prices in fact represent the market price of semifinished products, the demand and supply functions for semifinished steel were reestimated over the 1935–39 sample period while substituting a finished steel transaction price series for the semifinished price series.⁸³ For the purpose of interpreting this regression, the finished price series can be thought of as a noisy proxy for the unobservable semifinished price, with a mean value in excess of the mean semifinished price by the average costs of conversion. In the estimated supply relation, all variables had an appropriate sign. The coefficient on the dummy variable did not change significantly from the previously reported supply function, al-

⁷⁹ In addition to the two problems discussed in the text, reported semifinished steel prices may not reflect true transactions prices. George Stigler, *The Kinky Oligopoly Demand Curve and Rigid Prices*, 55 J. Pol. Econ. 432 (1947). For example, selective seller discounting or freight absorption may have lowered transaction prices, or unanticipated buyer shortages may have raised prices. Even if this hypothesis is correct, however, the reported prices appear to be unbiased proxies for the true prices for two reasons. First, the evidence from finished steel products shows that reported prices generally moved in tandem with U.S. Steel's composite mill net yield, a transactions price series, throughout the 1935 to 1939 sample period. The lone exception was a rapid increase in the reported price in early 1937 not reflected in the transaction price. TNEC Hearings, *supra* note 25, at 13815. Second, one robustness test reported in the text, in which the finished steel transactions price is employed as a proxy for the semifinished price, can be interpreted as showing that this potential difficulty did not affect the regression results.

⁸⁰ Daugherty, de Chazeau, & Stratton, *supra* note 28, at 21.

⁸¹ *Id.*, at 580, 601–10.

⁸² In addition to the econometric evidence discussed in the text, the theory founders on the evidence that the spread between the prices of various finished steel products and the semifinished product from which they were made widened under the NRA steel code. Daugherty, de Chazeau, & Stratton, *supra* note 28, at 601. The entry deterrence theory has trouble explaining this observation because there is no reason to believe that the threat of vertical integration by semifinished producers was reduced by the provisions of the Code.

⁸³ The finished transaction price series employed measured the mill-net yields for steel products shipped domestically by U.S. Steel subsidiaries. TNEC Hearings, *supra* note 25, at 14103.

though its standard error grew in consequence of the added noise. The coefficient on the dummy variable remained significant at a 10 percent level.

Second, the semifinished price series exhibits apparent nominal rigidities, especially during the NRA period.⁸⁴ This observation suggests the possibility that larger than expected price declines associated with large negative-demand shocks reflect "menu costs" prohibiting price adjustment when demand shocks are small, rather than cartel policing. To evaluate this theory, the supply model for the 1935–39 sample period was fitted to a subsample of observations consisting of those periods in which a nominal price change occurred.⁸⁵ Despite the loss of degrees of freedom, the results remained robust to this alternative specification; the coefficient of the dummy variable remained negative and significant.

IV. CONCLUSION: THE STEEL INDUSTRY IN THE 1930S

The empirical evidence presented in this article suggests that during some or all of the period from July 1935 through July 1939, the U.S. steel producers were supporting cooperation with marketplace punishments as predicted by the trigger-price models. In contrast, no marketplace punishments were detected for the NRA period. The latter finding suggests that the steel code successfully facilitated collusion by ensuring that cooperation was a dominant strategy for all producers.

Perhaps the most interesting interpretation of these results is contingent upon the assumption that competition was a dominant strategy for steel manufacturers in 1933.⁸⁶ Then the NRA steel code provides a structural

⁸⁴ Daugherty, de Chazeau, & Stratton, *supra* note 30, at 1107.

⁸⁵ The number of observations fell dramatically. To conserve degrees of freedom, only one exogenous cost-shift variable, the price of iron, was employed. Because the method of sample construction led to a large number of missing observations, the possibility of autocorrelated disturbances was taken into account by including a lagged dependent variable in the regression, thereby altering the implicit assumption about the time series process followed by the errors.

⁸⁶ Although the structural evidence could be consistent with either competitive or cooperative behavior during the early 1930s, this assumption implicitly weights heavily the competitive pressure created by the massive levels of industry excess capacity during the Depression. See text accompanying notes 50–51 *supra*; Brand, *supra* note 32, at 211.

The view that cooperation replaced competition as a dominant strategy when the NRA steel code was in effect, and that the industry cooperated under uncertainty after the NRA was abolished, is consistent with recent macroeconomic estimates showing that the NRA industry codes in aggregate increased the economy-wide price level by 14 percent per year, while nullification of the codes decreased prices at only half that rate, 7 percent per year. Michael Weinstein, *Some Macroeconomic Impacts of the National Industrial Recovery Act, 1933–1935*, in *The Great Depression* 262, 267 (Karl Brunner ed. 1981).

Moreover, a recent study of conjectural variations in the steel industry is consistent with

explanation for the industry's shift to cooperation in 1935. The experience with collusion, the existence of a model for future cooperation in the form of steel code provisions, and the publication of freight-rate data beginning during the code period likely reduced the costs of future interfirm cooperation. Hence, as was recognized contemporaneously by the Federal Trade Commission, the NRA code provisions effectively continued in force after the code was abolished.⁸⁷ Only the enforcement mechanism changed, from legal coercion to marketplace punishments. In sum, under this interpretation of the empirical results, the NRA taught the steel producers how to collude.⁸⁸

the view that firm behavior was more competitive from 1931–33 than it was from 1935–39. Rogers, *supra* note 39, at 219–33. Average conjectures—each firm's view of the average output response of its rivals to its own output change—rose from the earlier period to the later one for all but one of the eight leading firms in the industry, and the average conjecture for the lone exception remained unchanged. (Because trigger-price models imply that firms sometimes act cooperatively and other times act more competitively, average conjectures should increase if cooperation under uncertainty replaces competition.)

⁸⁷ TNEC Hearings, *supra* note 25, at 14232. Two anecdotes support this view. First, less than ten days following the Supreme Court's decision holding the NRA unconstitutional, the iron and steel industry's trade association membership unanimously adopted a resolution declaring the "voluntary" intention of individual members to continue to abide by the provisions of the steel code. *Id.* at 14434–35. Second, a schedule of industrywide adjustments to base prices for nonstandard variations in steel products was arrived at cooperatively through discussions among competitors for years following the official end of the NRA. Competition and Monopoly in American Industry, *supra* note 52, at 133.

⁸⁸ By the standards of the mid-1930s, this result would have been counted a policy success. One goal of the NRA was to stop price deflation through fostering interfirm cooperation. By the time of the TNEC hearings, in contrast, the output and employment reduction harms associated with collusion were considered to outweigh any price stability benefits. Kenneth Roose, *The Economics of Recession and Revival: An Interpretation of 1937–38*, at 142–43 (1954). Today collusion is considered harmful because supracompetitive pricing creates an allocative efficiency loss and a wealth transfer from consumers to producers.

APPENDIX A

TABLE A1

GLOSSARY OF TERMS

Variable Names	Meaning
Roots:	
<i>P</i>	Wholesale price of semifinished steel billets
<i>C</i>	Constant
<i>Q</i>	Aggregate production of semifinished steel
TIME	Months since start of sample
IRP	Composite pig iron prices
WAGE	Hourly earnings of workers in U.S. Steel's manufacturing subsidiaries
DUM	Dummy variable taking on the value of one when the residual from the estimated demand curve is smaller than $-T$ times the standard error of estimate of the demand equation (see eq. [13])
ALP	Aluminum prices
SP	Dummy variable for February and March
WN	Dummy variable for November and December
CAR	U.S. production of passenger cars
RAIL	Quantity of rail freight cars shipped
<i>Y</i>	Industrial production index
DY _{<i>n</i>}	Change in <i>Y</i> over the past <i>n</i> months (<i>n</i> = 3, 12, 24)
RHO	First-order autocorrelation of the residuals
<i>T</i>	Minimal size of negative-demand shocks triggering DUM as a fraction of the standard error of estimate of the demand equation (see eq. [13])
WPI	Wholesale price index
Prefixes:	
<i>L</i>	Logged values
<i>R</i>	Dollar values expressed in real terms (divided by WPI)

SOURCES.—Data on the wholesale price of semifinished steel billets, the wholesale price index, composite pig iron prices, the quantity of rail freight cars shipped, U.S. production of passenger cars, and the industrial production index were taken from *Survey of Current Business* (1933–39). Aluminum prices were found in *Metal Statistics* (1942). Scrap steel prices were reported by *Iron Age* (July 1933–September 1939). Semifinished steel production data and the hourly earnings of workers in U.S. Steel's manufacturing subsidiaries were taken from exhibits submitted during the Temporary National Economic Committee Hearings (1940).

NOTE.—Other abbreviations include DRES, the vector of residuals from the estimated demand curve; R^2 , the multiple correlation coefficient; and *N*, or the number of observations.

APPENDIX B

COMPARATIVE STATICS OF INDUSTRY EQUILIBRIUM

The comparative statics of equations (1) and (4) with respect to demand and supply shocks are presented in matrix equation (B1). These equations can be solved to confirm the intuition of Figure 1, that a demand shift traces out a more steeply sloping function when demand declines unexpectedly than when demand rises unexpectedly because the markup parameter varies with negative-demand shocks but not with positive shocks.

Equation (B1) holds constant the exogenous variables *Y* and *W*. The notations θ_e

and θ_v refer to the partial derivatives of θ with respect to the demand and supply shocks, and functions subscripted q are partial derivatives with respect to quantity.

$$\begin{vmatrix} 1 & -f_q \\ 1 & \theta(f_q + Qf_{qq}) - c_q \end{vmatrix} \begin{vmatrix} dP \\ dQ \end{vmatrix} = \begin{vmatrix} 1 & 0 \\ \theta_\epsilon(-Qf_q) & \theta_v(-Qf_q) + 1 \end{vmatrix} \begin{vmatrix} d\epsilon \\ dv \end{vmatrix}. \quad (B1)$$

A random demand shift traces out the slope of the supply curve if the markup parameter does not vary.⁸⁹ This result, derived from equation (B1), is presented in equation (B2). For $\theta_\epsilon = 0$,

$$(dP/d\epsilon)/(dQ/d\epsilon) = c_q - \theta(f_q + Qf_{qq}). \quad (B2)$$

The right-hand expression in (B2) is the partial derivative of the supply relation (4) with respect to output, under the assumption that θ is a constant. The slope of the supply relation equals the slope of the marginal cost function plus the slope of the markup function $\theta(P - MR)$.⁹⁰

If instead θ varies with ϵ , a shift in ϵ traces out a more steeply sloped function because the demand shock causes both demand and supply to shift. For $\theta_\epsilon \neq 0$,

$$(dP/d\epsilon)/(dQ/d\epsilon) = \{[c_q - \theta(f_q + Qf_{qq})] + f_q^2 \theta_\epsilon Q\} / \{1 + [Qf_q \theta_\epsilon]\}. \quad (B3)$$

If a cartel employs marketplace punishments to support periods of collusive pricing, then negative-demand shocks will lead to a lower markup, so that $\theta_\epsilon > 0$. Hence, the additional addend in the numerator of (B3) is positive, while the additional addend in the denominator is negative. Assuming that $[1 + Qf_q \theta_\epsilon]$ is greater than zero, it is evident that the derivative $(dP/d\epsilon)/(dQ/d\epsilon)$ in (B3) is a larger positive number than the corresponding derivative in (B2).

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⁸⁹ Similarly, when a random cost-shift occurs, supply curve fluctuations will trace out a demand curve. The following equation, derived from (B1), shows that this conceptual experiment results in a function with the same slope as demand: $(dP/dv)/(dQ/dv) = f_q$.

⁹⁰ In general, the supply relation can be expected to slope upward. The expression for the slope of the markup function, $-\theta(f_q + Qf_{qq})$, is likely a positive number, although it could be negative if demand is a convex function (if $f_{qq} \gg 0$). Even then the slope of the supply relation will remain positive unless the markup term swamps the marginal cost term in eq. (B2).

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