



# **A Varying Parameter Model of Collusion in the Steel Industry**

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## **A Varying Parameter Model of Collusion in the Steel Industry**

### **I. Introduction**

In an earlier study, Lord and Farr (2003) analyzed a strategy that U.S. integrated mill steel firms may have used to mutually enforce collusive behavior during the years 1947 through 1980. They tested two hypotheses arising from a theoretical study by Maksimovic (1988) suggesting that firms in an oligopoly can signal their intention to comply with an implicit cartel arrangement through their choice of capital structure. The first is that leverage should vary positively in response to changes in the price elasticity of demand. The second is that leverage should be a positive function of the number of new equity shares created if holders of convertible bonds exercise all their conversion privileges.

Maksimovic demonstrates that when firms are partially financed with nonconvertible debt there is a discernable ceiling on leverage that is a positive function of price elasticity of demand. This threshold provides a publicly observable indicator that the colluding firms can use to signal their intention to comply with an implicit collusive agreement. Firms that do not exceed the ceiling indicate their intention to abide by the compact. Any firm that exceeds the threshold would send the opposite message, jeopardizing the continuing existence of the cartel.<sup>1</sup>

Lord and Farr extended Maksimovic's model to show that the use of convertible securities in place of nonconvertible debt permits a firm to exceed the industry's debt ceiling and still signal an intention to comply with the agreement. This is possible because the conversion privileges granted to the bondholders allow them to share in the gains that the stockholders would realize by deviating

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<sup>1</sup> Brander and Lewis (1986, 1988) and Stenbacka (1994) develop similar models.

from the collusive arrangement. The extent to which the level of debt can be increased above the ceiling is a positive function of the number of shares of additional common stock the convertible bondholders would possess after exercising their options.

Over the 34-year period that Lord and Farr studied, the integrated mill steel industry in the U.S. experienced dramatic changes. Early in this period, the steel industry was considered a cozy domestic oligopoly where prices were set in an overt scheme known as the basing point pricing system. U.S. Steel published a base price for a variety of steel products in Pittsburgh, and the American Iron & Steel Institute provided a schedule of railway freight rates from Pittsburgh to various locations throughout the country. Other steel producers then set local prices according to these two schedules. However, much changed in the industry by the end of the study period.<sup>2</sup> Around 1960, competition from extremely efficient foreign producers and domestic mini mills drastically transformed the industry. The electric furnace mini mills recast scrap metal, and began to dominate the markets for products such as wire rods, bars, pipes, and structural shapes.<sup>3</sup> Empirical studies by Mancke (1968) and Rippe (1970) found that by 1960 the basing point pricing system was effectively abandoned by the integrated mills, even though the American Iron & Steel Institute continued to publish the prices. However, a Federal Trade Commission Report by Duke, et al. (1977) suggested that collusion continued for some steel products long after the collapse of the overt pricing scheme.

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<sup>2</sup> For excellent and detailed coverage of the transformation of the industry see the books and articles by Adams (1977), Adams and Mueller (1986), Barnett and Crandall (1986), Barnett and Schorsch (1983), Crandall (1981), Hogan (1971, 1987) and Tiffany (1988).

<sup>3</sup> See Barnett and Crandall (1986) and Hogan (1987) for a discussion of the evolution of the product markets controlled by various types of steel mills. In the later years of the study, mini mills effectively stripped away the markets for hot rolled bars, cold finished bars, structural shapes, billots, and wire rods.

Guided by these facts, Lord and Farr collected annual data, from 1947 through 1980, for a sample of integrated mill steel firms that produced mainly heavy, flat steel products. They identified seven publicly traded companies—ARMCO<sup>4</sup>, Bethlehem Steel, Universal Cyclops, Inland Steel, Interlake Iron, Republic Steel, and U.S. Steel—that represent a segment of the steel industry sufficiently concentrated to provide the conditions necessary for collusive behavior. Further, these seven firms present an interesting opportunity to test the hypothesis on convertible securities, since they used a variety of debt securities in their capital structures.

Because of the changes that occurred in the industry, Lord and Farr also test whether the two hypothesized relationships hold throughout the entire study period. To accomplish this, they include a time-based dummy variable and cross product terms between this dummy variable and the independent variables to test the hypotheses in their model. Based on subjective judgments they set the dummy variable to one for all years after 1958 and to zero before 1959. This break point was chosen because 1959 is the year of the great strike that shattered the uneasy peace that had existed between labor and management in the steel industry throughout the 1950s. This date also corresponds nicely with the timeframe suggested by Mancke and Rippe for the demise of the basing point pricing system. As expected, Lord and Farr find that before 1959 there is no evidence that either price elasticity of demand for steel products or the level of convertible security usage are statistically related with the amount of debt in the capital structure for the seven integrated mill steel firms in their sample. However, after 1958 there is clear evidence of the hypothesized positive relationships. Lord and Farr suggest that before 1959 the presence of the overt price fixing mechanism render subtle collusive schemes, such as those suggested by Maksimovic, unnecessary. But after the collapse of formal price leadership, changes in the choice of capital structure among

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<sup>4</sup> Known as American Rolling Mills in the early years of the study.

these firms are consistent with the hypotheses that it may serve as a publicly observable signal of intention to continue collusive pricing and output behavior.

The purpose of the present study is to employ a more objective method to determine the years when these firms displayed behavior consistent with the pattern of collusion documented by Lord and Farr. We chose a switching regression methodology that allows for deterministic switching on the basis of time (Judge, et al, 1985). This means the specified equation is estimated for subsets of observations where the estimated regression coefficients are constant within subsets but vary across subsets.

We use the same data set employed in the earlier study by Lord and Farr. The switching regression procedure allocated data between two subsets of observations, the first from 1947 through 1957 and the second from 1958 to 1980. The results are consistent with and similar to the ones found in the original study by Lord and Farr. However, these results were obtained using the more objective procedure to determine if and where significant differences in the structure of the behavior of these firms occurred. In this study we find the expected significant positive relationship of financial leverage with both price elasticity of demand and the level of outstanding options attached to convertible securities for these seven integrated mill steel firms during the years 1958 through 1980, while still finding no similar evidence during the earlier years of the study from 1947 through 1957.

The remainder of the paper is organized as follows. In the following section we develop our hypotheses on the relation between financial leverage, price elasticity of demand, and convertible securities. In Section III we describe the method used to estimate the steel demand function and the annual price elasticities. In Section IV we develop the basic model used to test the hypotheses and further describe the switching regression technique used to find the break point expected in the

behavior of these firms. We then describe the empirical results in Section V and in Section VI provide a summary and conclusion to the paper.

## II. Theoretical Development

In this section, we first present Maksimovic's hypothesized relationship between price elasticity of demand and the threshold level of nonconvertible debt that is consistent with the maintenance of a collusive agreement. Then we outline Lord and Farr's extension suggesting that an individual firm can issue debt above this ceiling by issuing convertible rather than nonconvertible securities.

### A. Maintaining Collusion Among Firms Using Nonconvertible Debt Financing

Assume an oligopolistic industry with  $N$  equal-sized firms. These players face a repeating game where annual profits can be at one of three discrete states depending on the collective or individual actions of the participants. Let  $\pi_i^c$  represent the profit earned by firms from collusion,  $\pi_i^d$  the one-period profit of a single firm that cheats on the collusive arrangement, and  $\pi_i^{nc}$  the profit earned by firms at the non-colluding Nash equilibrium, where we assume that  $\pi_i^d > \pi_i^c > \pi_i^{nc}$ . If the firms in the industry can develop a successful strategy to establish and enforce collusive behavior, they will earn a perpetual stream of  $\pi_i^c$ . On the other hand, if the collusive arrangement collapses, or if it cannot be established in the first place, firms will earn a perpetual stream of  $\pi_i^{nc}$ . If a cartel is ever established and a firm deviates from the collusive agreement to earn the one-time profit of  $\pi_i^d$ , we assume that the cartel collapses in the following period and that cartel participants earn  $\pi_i^{nc}$  in all subsequent time periods. We also assume that all participants know each of the profit states and the motivations of the other firms with perfect certainty.

Further, we assume that all of the firms are corporations with limited liability and that they wish to add the greatest feasible amount of nonconvertible debt into their capital structures, and that the outstanding debt of each firm is publicly observable by the others. We presume that firms choose the maximum level of debt due to tax savings associated with debt relative to equity financing (Miller and Modigliani, 1961, and Stenbacka, 1994). We define the perpetual annual interest obligations incurred by the  $i^{th}$  firm as  $I_i$ . Finally, we assume that all of participants choose a level of debt where  $I_i > \pi_i^{nc}$ . This means that bankruptcy occurs if profits drop to  $\pi_i^{nc}$ . The threat of bankruptcy provides a powerful incentive to maintain collusion that is mutually self-enforcing.<sup>5</sup>

We can now define the equity value of the  $i^{th}$  firm in the three states. The first is where a cartel is successfully established and maintained,

$$V_i^c = (\pi_i^c - I_i) \left( I + \frac{I}{r} \right). \quad (1)$$

Because it is assumed that all firms choose a capital structure where  $I_i > \pi_i^{nc}$ , if the cartel collapses all of the member firms will go bankrupt, thus the value of equity becomes

$$V_i^{nc} = 0. \quad (2)$$

Finally, if one firm deviates from an established collusive arrangement it will collect the corresponding one-time profit and the value of equity becomes

$$V_i^d = (\pi_i^d - I_i). \quad (3)$$

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<sup>5</sup> The case where  $I_i < \pi_i^{nc}$  is of no interest since such a capital structure contributes nothing to the enforcement of collusion since the stockholders are no longer threatened with bankruptcy.

It should be clear that if the value to shareholders from deviation in Equation 3 is higher than the value of maintaining collusion over time in Equation 1, the cartel is doomed to collapse. Therefore, Maksimovic sets Equation 1 greater than Equation 3 and solves for the maximum level of interest obligations consistent with maintenance of the cartel; this interest threshold is,

$$I_i \leq \pi_i^c - r(\pi_i^d - \pi_i^c). \quad (4)$$

As argued above, we assume the tax benefits of debt in capital structure create an incentive for firms to raise  $I_i$  close to  $\pi_i^c - r(\pi_i^d - \pi_i^c)$ . When a firm promises annual interest payments near, but not exceeding this ceiling, it provides evidence to other players that it will not violate the agreement.

Maksimovic then shows that since  $\pi_i^c$  and  $\pi_i^d$  are positively related to a firm's price elasticity of demand, it follows that the debt ceiling also depends on the price elasticity of demand. The combination of the threat of bankruptcy and desire to exploit the tax benefits of debt financing indicates that colluding firms should modify their capital structures positively with fluctuations in the price elasticity of demand. Although it is unlikely that cartel members will have all the necessary information to set and precisely assess the threshold level of debt, it seems likely that the participants would know enough to establish a reasonable level of debt, and to judge if changes in leverage by their rivals are justified or if they should be viewed with suspicion.

Therefore, the first formal hypothesis advanced in the earlier paper by Lord and Farr is,

H<sub>10</sub>: Among members of a cartel, financial leverage is not positively related to a firm's price elasticity of demand.

H<sub>1a</sub>: Among members of a cartel, financial leverage is positively related to a firm's price elasticity of demand.

It is important to understand that this is just one possible solution to the problem of effectively enforcing collusive behavior. Failure to reject the null hypothesis does not mean that collusion is not present, only that capital structure is not supported as the enforcement mechanism.



## B. Maintaining Collusion Among Firms Using Convertible Debt Financing

Lord and Farr extended a suggestion by Maksimovic that the use of convertible debt in place of nonconvertible debt might allow colluding firms to exceed the aforementioned debt ceiling while still sending a signal of compliance with the collusive agreement. This can be seen by first assuming that each limited liability corporation issues a single class of debt securities that can be either convertible or nonconvertible. Again, assume the firms set the annual interest obligations,  $I_i$ , to exceed  $\pi_i^{nc}$ . If a firm issues convertible bonds, assume they all have identical conversion ratios. Next, assume that all of the convertible bondholders behave uniformly and, as above, assume that all participants have perfect knowledge about the potential outcomes and the motivations of others.

The stakeholders now follow a three-step process to determine each firm's capital structure. First, the stockholders select the type and level of debt that then effectively establishes the annual interest payments ( $I_i$ ). For convertible bonds, they also choose a conversion ratio that determines the percentage of new shares of common stock created upon conversion ( $\lambda_i$ ). For instance, if  $\lambda_i = 1$  and all bondholders convert, one new share of stock will be created for each existing share of stock, thus doubling the number of shares. The issuance of nonconvertible debt implies  $\lambda_i = 0$ . In the second step, after the bonds have been issued, the stockholders of each firm decide whether to adhere to the cartel arrangement or to cheat. In the last step, the convertible bondholders decide whether to retain their debt ownership or to exercise their conversion option. For simplicity, assume that all debt holders receive their annual interest payment prior to deciding whether to convert their securities into stock, also allowing them to share in any subsequent distributions to the shareholders. This assumption can be altered slightly, changing the exact nature of the relation, but not its substance.

To protect and preserve the established collusive agreement, the stockholders of each firm must design the convertible debt contracts so that if deviation occurs, the bondholders will convert and capture a substantial portion of the cheating firm's one-time profit. The possibility of conversion by debt holders is, in effect, a self-imposed "tax" on deviating behavior that is publicly observable by other members of the cartel. When all abide by the agreement and the bondholders do not convert, the value of firm equity remains as in Equation 1,  $V_i^c = (\pi_i^c - I_i)(1 + \frac{I}{r})$ . However, if a firm deviates and the debt holders exercise their conversion privilege, the value of equity,  $\ddot{V}_i^d$ , for the original shareholders will now be

$$\ddot{V}_i^d = [(\pi_i^d - I_i) + \frac{\pi_i^{nc}}{r}] [ \frac{I}{1 + \lambda_i} ]. \quad (5)$$

If the bondholders exercise their options, the original stockholders retain only  $\frac{I}{1 + \lambda_i}$  of the cash flows generated while the new stockholders (the former debt holders) receive the remaining  $\frac{\lambda_i}{1 + \lambda_i}$  of the cash flows. Setting  $V_i^c > \ddot{V}_i^d$ , which preserves the incentive to maintain collusion, requires that

$$I_i < \frac{\pi_i^c (1 + r)(1 + \lambda_i) - r \pi_i^d - \pi_i^{nc}}{1 + [\lambda_i (1 + r)]}. \quad (6)$$

In Equation 6,  $I_i$  is a positive function of  $\lambda_i$  under normal conditions where  $\pi_i^d, \pi_i^c, \pi_i^{nc}$ , and  $r$  are nonnegative, and  $\pi_i^d > \pi_i^c > \pi_i^{nc}$ . Further, Equation 6 implies that it would be possible to issue convertible debt at levels higher than implied in Equation 4 and still remain a compliant member of the cartel. By extension, this derivation suggests that colluding firms can use more leverage in their capital structure when convertible debt is added to the mix of debt securities outstanding.

The second hypothesis tested by Lord and Farr can be formally stated as

H<sub>2o</sub>: Among members of a cartel, financial leverage is not positively related to the proportion of new to existing shares created upon conversion of all convertible securities.

H<sub>2a</sub>: Among members of a cartel, financial leverage is positively related to the proportion of new to existing shares created upon conversion of all convertible securities.

### III. Price Elasticity of Demand

To test the first hypothesis requires us to measure the sample firms' price elasticity of demand. Unfortunately, the information necessary to estimate the elasticity for each of the individual integrated mill steel firms is not available. The fact that each of the sample firms produces and sells a number of different steel products provides an additional complication.

As a proxy, we estimate the price elasticity of demand for the product market segment dominated by the firms included in the sample. First, we create a Hicksian (1939) composite commodity that comprises the primary products dominated by the integrated mill steel firms throughout the sample period. These products are plates, hot rolled sheets, cold rolled sheets, galvanized sheets, and tin plates. We measure the output for the sector as the sum of the tons of steel products shipped annually. As a proxy of the price for the product group we use the weighted average of the prices of the steel products included in the composite commodity. The weights are based on the percentage that each item represents in the composite. Fortunately, these weights varied little over the years studied. This weighting scheme follows a procedure similar to that used by Nelson (1994). We obtain the prices

and shipments of each steel product from various issues of the *Annual Statistical Report* of the

American Iron and Steel Institute and *Metal Statistics*.

Using the data for the Hicksian composite commodity, we model demand as:

$$QSTEEL_t = \beta_0 + \beta_1 RSP_t + \beta_2 IP_t + \beta_3 CBOND_t + \beta_4 IER_t + \beta_5 TREND_t + \mu_t, \quad (7)$$

where  $QSTEEL_t$  is total shipments (in tons) of steel products.  $RSP_t$  is the real weighted price of the products. We adjust these prices for price level changes using the metals price index calculated by the Bureau of Labor Statistics (1982=100).  $IP_t$  is the U.S. industrial production index.  $CBOND_t$  is the annual average of monthly yields on *Moody's Seasoned Aaa Corporate Bonds*.  $IER_t$  is the ratio of steel imports to exports.  $TREND_t$  is a time variable starting at one in 1947. Finally,  $\mu_t$  is an additive transitory disturbance term.

We assume, *a priori*, that  $RSP_t$ ,  $CBOND_t$ , and  $IER_t$  should negatively affect  $QSTEEL_t$  and that  $IP_t$  should have a positive influence. We include U.S. industrial production to capture changes in the use of steel caused by economic conditions in the economy. The Aaa corporate bond rate is intended to capture the impact of interest rates changes on the demand for steel. To control for the impact of foreign competition on the demand for domestic steel products, we include the ratio of steel imports to steel exports. We use the trend variable ( $TREND_t$ ) to capture general trends in steel usage over the years that could be positive or negative.

Empirical studies typically assume that the structure of behavioral relationships is stable over time and that any variations are transitory in nature. Unfortunately, this restrictive assumption may not be true in many situations, especially when a study covers a lengthy period. The demand functions faced by the integrated mill steel firms are likely to have undergone structural changes over the years. Permanent changes in these demand relationships could have been caused by any number of factors including the post-war recovery and increased competition of foreign steel producers, the closer oversight of this industry by the Justice Department due to its history of

anticompetitive practices, the rise of mini mills that chipped away at the markets formerly dominated by large integrated steel mills, and variations in the relative importance of steel products used in construction and manufacturing.

There are many ways to incorporate structural changes into empirical analysis. One of the more flexible is the Adaptive Regression Model introduced by Cooley and Prescott (1973, 1976).<sup>6</sup> The major advantage of this model is that it requires little prior knowledge about how structures may have changed over time. This variable (random walk) model allows the parameters to vary through time, based on a nonstationary probabilistic scheme with no inherent tendency for them to return to a mean value. The model assumes that the estimated equation parameters are subject to stochastic variation that depends on the sum of both permanent and transitory effects. The permanent effects cause persistent movement in parameter values through time, but the transitory effects are felt only in the current period. This is shown as

$$y_t = x_t' \beta_t \quad t = 1, 2, \dots, T \quad (8)$$

where  $y_t$  is a vector of  $T$  observations of the dependent variable,  $x_t$  is a  $k$  component vector of explanatory variables, and  $\beta_t$  is a  $k$  component vector of parameters subject to sequential variation.

The two sources of variation are incorporated as

$$\beta_t = \beta_t^p + v_t \quad (9)$$

and

$$\beta_t^p = \beta_{t-1}^p + u_t \quad (10)$$

where we denote the permanent component of the parameters with the superscript  $p$ .

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<sup>6</sup> For examples of the use of the adaptive regression model, see McIntosh and Shideed (1989), Parrott and McIntosh (1996), and Rausser and Laumas (1976).

We assume that the stochastic variates  $v_t$  and  $v_t$  are normal, identically, and independently distributed with mean vectors zero and covariance matrices

$$\text{cov}(v_t) = (1 - \gamma) \sigma^2 \Sigma_v \quad (11)$$

and

$$\text{cov}(v_t) = (\gamma) \sigma^2 \Sigma_v \quad (12)$$

where  $\gamma \in [0,1]$ . The parameter  $\gamma$  is the rate at which the  $\beta$ 's adapt to structural change, meaning that as  $\gamma$  approaches one, the effects of the permanent changes increase relative to the transitory ones. The matrices  $\Sigma_v$  and  $\Sigma_v$  provide information concerning the relative variability of the parameters that are assumed to be known up to a scale factor. In addition, we normalize them so that the element corresponding to the intercept is unity. This means that the first explanatory variable is the intercept and its transitory component is captured in the model by the usual additive error term.

Because the process generating the parameters is nonstationary, we cannot specify the likelihood function necessary for parameter estimation. However, Cooley and Prescott (1976) show that a well-defined likelihood function can be constructed by considering specific realizations of the parameter process at a particular point in time. They focus on the value of the parameter process one period ( $T+1$ ) beyond the sample period. By repeated substitution we see that

$$\begin{aligned} \beta_{T+1}^p &= \beta_t^p + v_{T+1} \\ &= \beta_t^p + \sum_{j=t+1}^{T+1} v_j \end{aligned} \quad (13)$$

and by insertion into Equation 9 leads to

$$\beta_t = \beta_{T+1}^p - \sum_{j=t+1}^{T+1} v_j + v_t. \quad (14)$$

Substituting  $\beta_t$  from Equation 14 for  $\beta_t$  in Equation 8 results in

$$y_t = x_t' \beta + \mu_t \quad (15)$$

where  $\beta = \beta_{T+1}^p$ , and  $\mu_t = x_t' v_t - x_t' \sum_{j=t+1}^{T+1} v_j$ .

The random disturbance vector  $\mu$  is normally distributed with mean vector zero and a covariance matrix defined as

$$\text{cov}(\mu) = \sigma^2 [(1-\gamma)R + \gamma Q] = \sigma^2 \Omega_{(\gamma)} \quad (16)$$

where  $R$  is a diagonal matrix with elements  $r_{ii} = x_i' \Sigma_v x_i$  and  $Q$  a  $T \times T$  matrix with elements  $q_{ij} = \min\{|t-i|, |t-j|\} x_i' \Sigma_v x_j$  when both  $i$  and  $j$  are greater than or less than  $t$ , otherwise  $q_{ij} = 0$ . We can now write the full model and the distribution of  $Y$  as

$$Y = X\beta + \mu \quad (17)$$

where  $Y \sim N[X\beta, \sigma^2 \Omega_{(\gamma)}]$ ,  $X$  is a  $T \times k$  matrix and  $\beta$  is a  $k$  component vector.

If  $\gamma$  is known, we can apply generalized least squares to obtain the parameter estimates, since all the other factors are observed exogenous variables. However, since  $\gamma$  will not be known in most instances, we can write the log likelihood function of the observations specified at a particular realization as

$$\begin{aligned} L(Y; \beta, \sigma^2, \gamma, X) = & -\frac{T}{2} \ln 2\pi - \frac{T}{2} \ln \sigma^2 - \frac{1}{2} |\Omega_{(\gamma)}| \\ & - \frac{1}{2\sigma^2} (y - X\beta)' \Omega_{(\gamma)}^{-1} (y - X\beta). \end{aligned} \quad (18)$$

Maximizing Equation 18 with respect to  $\beta$  and  $\sigma^2$  yields estimators conditional on  $\gamma$  as

$$\hat{\beta}_{(\gamma)} = [X' \Omega_{(\gamma)}^{-1} X]^{-1} X' \Omega_{(\gamma)}^{-1} y \quad (19)$$

and

$$\hat{\sigma}_{(\gamma)}^2 = \frac{1}{T} [y - X \hat{\beta}_{(\gamma)}]' \Omega_{(\gamma)}^{-1} [y - X \hat{\beta}_{(\gamma)}]. \quad (20)$$

Substituting these estimators into Equation 18 yields the concentrated log likelihood function

$$L_c(Y; \gamma) = -\frac{T}{2} (\ln 2\pi + 1) - \frac{T}{2} \ln \hat{\sigma}_{(\gamma)}^2 - \frac{1}{2} \ln |\Omega_{(\gamma)}|. \quad (21)$$

Maximizing the concentrated likelihood function for  $\gamma \in [0,1]$  is equivalent to maximizing the log likelihood equation. We can then insert the value of  $\gamma$  that maximizes the conditional log likelihood function (say  $\gamma^*$ ) into Equations 19 and 20 to obtain estimates of  $\beta$  and  $\sigma^2$  that are asymptotically efficient (Cooley and Prescott, 1973, 1976).

Without prior knowledge that some other specification is superior, Cooley and Prescott (1973) suggest that it is appropriate to set the relative importance of the permanent and transitory changes equal to each other for all random parameters. This assumption suggests that  $\Sigma_v$  and  $\Sigma_\nu$  are equal. Further, if we have no reason to suspect that the random parameters are correlated with each other over time, we can assume the matrices to be diagonal. Given these assumptions, the only requisite is the specification of the relative variability of the different parameters. Cooley and Prescott (1976) indicate that the loss in estimation efficiency is comparatively small even for sizeable errors in specifying the diagonal elements. In this study, we use the standard errors of the parameters that we obtain by using a maximum likelihood estimator that assumes constant parameters. We use these standard errors as the diagonal elements of  $\Sigma_v$  and  $\Sigma_\nu$  as a proxy for the relative variability of the parameters. In addition, we scale the diagonal elements so that the first element is equal to one.

We calculate the estimated price elasticities by using each annual  $\beta_{1t}$ , the coefficient on real steel prices ( $RSP_t$ ), and the corresponding price and quantity data over the entire dataset. We show this as



$$\hat{\beta}_{1t} = \frac{\partial QSTEEL_t}{\partial RSP_t} \times \frac{RSP_t}{QSTEEL_t}, \quad (22)$$

where  $\hat{\beta}_{1t}$  from Equation 7 is  $\partial(QSTEEL_t)/\partial(RSP_t)$ . Panel A of Table I shows the annual estimates of the parameters in Equation 7,  $\gamma$  (the permanent components of  $\beta$ ), and the asymptotic standard errors of  $\beta$ . Panel B contains the annual estimates of the price elasticity of demand.

## IV. The Model

In this section we will first specify the fundamental model that is employed to test the two hypotheses. Then we describe the switching regression methodology used to find any potential variations in structural behavior of the firms over the study period.

### A. The Fundamental Model

We specify the following model to test the two hypotheses presented by Lord and Farr that among cartel members, financial leverage is positively related to both price elasticity of demand and the number of new shares created if the bondholders were to exercise all outstanding convertible securities.

$$\begin{aligned} LEV_{t,i} = & \alpha + \psi_1 LEVBMAN_t + \psi_2 SIGMA_{t,i} + \psi_3 MB_{t,i} + \psi_4 CBOND_t + \psi_5 PROFIT_{t,i} \\ & + \theta_1 PED_t + \theta_2 LAMBDA_{t,i} + \phi_1 SIGLAM_{t,i} + \phi_2 MBLAM_{t,i} + \phi_3 CBONDLAM_{t,i} + \mu_{t,i} \end{aligned} \quad (23)$$

**Table I. Demand Equation Parameter and Elasticity Estimates**

Panel A. Equation 7 Parameter Estimates							
Year	Gamma ( $\hat{\gamma}_t$ )	Intercept <sub>t</sub> (\$ <sub>0t</sub> )	RSP <sub>t</sub> (\$ <sub>1t</sub> )	IP <sub>t</sub> (\$ <sub>2t</sub> )	CBOND <sub>t</sub> (\$ <sub>3t</sub> )	IER <sub>t</sub> (\$ <sub>4t</sub> )	TREND <sub>t</sub> (\$ <sub>5t</sub> )
1947	0.00	46,963.93 (11,251)*	-95.06 (33.97)*	520.00 (120.7)*	-3,781.21 (375.9)*	-862.67 (243.8)*	718.86 (312.3)**
1959	0.12	48,482.23 (13,266)*	-112.45 (39.96)*	682.10 (124.8)*	-3,106.23 (475.0)*	-780.63 (260.7)*	286.09 (334.3)
1960	0.22	44,014.20 (13,073)*	-101.74 (39.13)**	761.35 (127.8)*	-2,770.16 (519.0)*	-779.16 (254.2)*	-5.11 (355.0)
1961	0.10	43,396.78 (12,126)*	-95.39 (36.24)**	701.96 (127.1)*	-3,028.46 (469.9)*	-875.77 (240.6)*	153.38 (350.6)
1962	0.10	39,334.08 (11,460)*	-81.01 (33.93)**	716.53 (127.6)*	-3,004.70 (475.9)*	-916.60 (235.9)*	68.93 (361.2)
1963	0.08	39,271.42 (11,104)*	-77.79 (32.76)**	706.76 (127.4)*	-2,996.53 (477.5)*	-909.05 (236.7)*	52.85 (368.6)
1964	0.12	37,939.28 (10,761)*	-70.48 (31.57)**	707.31 (126.7)*	-2,707.69 (508.2)*	-858.43 (241.3)*	-69.09 (381.6)
1965	0.12	33,846.39 (10,933)*	-56.11 (32.34)**	727.34 (128.2)*	-2,712.15 (514.9)*	-847.84 (245.9)*	-171.03 (395.4)
1966	0.20	29,344.07 (11,205)**	-44.07 (33.48)	783.77 (132.1)*	-2,484.58 (531.2)*	-807.11 (255.8)*	-440.76 (424.4)
1967	0.16	34,115.11 (12,129)*	-56.86 (37.15)	720.92 (136.0)*	-2,554.01 (532.2)*	-700.02 (275.9)*	-300.91 (448.5)
1968	0.30	41,134.52 (12,665)*	-77.12 (39.85)**	719.34 (136.8)*	-2,339.77 (543.5)*	-440.87 (283.5)	-449.64 (483.6)
1969	0.64	38,253.84 (10,829)*	-66.74 (34.14)**	830.65 (114.8)*	-1,766.74 (528.9)*	-323.97 (225.9)	-1,063.27 (457.2)**
1973	0.72	55,760.95 (9,650)*	-123.02 (36.86)*	874.63 (119.4)*	-3,028.15 (409.4)*	-624.07 (161.5)*	-655.77 (437.3)

\* Significant at the 0.01 level    \*\* Significant at the 0.05 level    \*\*\* Significant at the 0.10 level

**Panel B. Price Elasticity of Demand Estimates (Equation 22)**

Year	Elasticity ( $\epsilon_t$ )	Year	Elasticity ( $\epsilon_t$ )	Year	Elasticity ( $\epsilon_t$ )	Year	Elasticity ( $\epsilon_t$ )
1947	1.028	1956	0.730	1965	0.370	1974	0.477
1948	0.921	1957	0.791	1966	0.298	1975	0.738
1949	1.132	1958	1.044	1967	0.414	1976	0.611
1950	0.911	1959	1.028	1968	0.499	1977	0.645
1951	0.810	1960	0.866	1969	0.419	1978	0.625
1952	1.001	1961	0.893	1970	0.632	1979	0.592
1953	0.826	1962	0.708	1971	0.656	1980	0.731
1954	1.047	1963	0.650	1972	0.646		
1955	0.718	1964	0.521	1973	0.629		

—Data from 1947-1985 are used to estimate the demand function. The results shown in both panels are truncated in 1980 to be consistent with other data available for the integrated mill steel firms.

—Gamma represents the rate at which the  $\beta$ 's adapt to structural change in the adaptive regression model.

—Maximum likelihood estimation is used given  $0 \leq \hat{\gamma}_t < 1$  in increments of 0.02. When gamma equals one, the variance-covariance matrix is singular which prevents parameter estimation.

—Parameter estimates and standard errors are unchanged when  $\hat{\gamma}_t = 0$ . This happened in 1947-58, 1970-72, and 1974-80, hence only the estimates

for 1947 are shown to save space.  
—Asymptotic standard errors are reported in parentheses.

The equation is estimated using the data set from Lord and Farr, which includes observations from 1947 to 1980 for seven domestic integrated mill steel firms. We define each of the variables below and provide justification for the control factors that we add to more adequately specify the model.

The dependent variable,  $LEV_{t,i}$ , is the proxy for financial leverage. For the  $i^{th}$  firm in year  $t$ , we calculate a ratio where the numerator is the book value of long-term debt and the denominator is the sum of the book values of long-term debt and preferred stock and the market value of common equity. We obtain the book values and number of outstanding shares from various issues of the *Moody's Industrial Manual* and end-of-year stock prices from the CRSP tape.

The first five explanatory variables are general controls that we include in the model to capture the effects of additional factors that potentially influence the choice of financial leverage. The first,  $LEVBMAN_t$ , measures the average ratio of the book values of long-term debt to the book values of long-term liabilities and equity for U.S. manufacturing firms in the  $t^{th}$  year. We obtain this data from Taggart (1985) who provides information from the IRS publication *Statistics of Income*. We include this term to control for systemic changes in financial leverage that are caused by fluctuations in macroeconomic conditions, such as changes in tax and inflation rates, that affect all manufacturing firms in a uniform fashion. It should be positively related to financial leverage. The second control variable,  $SIGMA_{t,i}$ , is a proxy for firm risk. It is the annual standard deviation of monthly stock returns for the  $i^{th}$  firm in year  $t$  using CRSP data. The empirical evidence on the *relation* between risks, measured by the volatility of either earnings or stock returns, and financial leverage has been mixed and provides little guidance.<sup>7</sup> Therefore, we have no *a priori* expectation concerning the direction of the impact of this risk measure on leverage. The third control variable,

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<sup>7</sup> See Lord and Farr (2003) for a thorough review of earlier empirical tests.

$MB_{t,i}$ , measures the market-to-book ratio for the  $i^{th}$  firm in year  $t$ . The data necessary to compute this ratio are taken from various issues of the *Moody's Industrial Manual* and the CRSP tape. Many earlier studies, most notably Titman and Wessels (1988), document a significant negative relation between financial leverage and the market-to-book ratio. The fourth variable,  $CBOND_t$ , is the annual average of monthly yields on Moody's Seasoned Aaa Corporate Bonds. The effect of this variable on a market-based measure of financial leverage is also difficult to predict. On the one hand, an increase in rates might decrease the value of equity, thus increasing  $LEV_{t,i}$ . On the other hand, many studies suggest that when rates are high, firms tend to shy away from long-term debt financing in favor of raising marginal capital in the form of equity. Previous empirical evidence on the relationship between financial leverage and interest rates has been mixed. The final general control variable is,  $PROFIT_{t,i}$ , a proxy for firm profitability. Titman and Wessels (1988) show that there is a significant negative relation between leverage and profitability. This variable is the ratio of gross profits (sales minus cost-of-goods-sold) to sales revenue of the  $i^{th}$  firm in the  $t^{th}$  year. Again, the necessary data is collected from various issues of *Moody's Industrial Manual*.

The next two explanatory variables,  $PED_t$  and  $LAMBDA_{t,i}$ , test the two hypotheses developed by Maksimovic and Lord and Farr. The first,  $PED_t$ , measures the price elasticity of demand of the industry sector dominated by the integrated mill steel firms in the  $t^{th}$  year. Panel B of Table I, shown in the previous section, contains the annual price elasticity estimates. Maksimovic hypothesizes that price elasticity of demand should be positively related to financial leverage. The second variable,  $LAMBDA_{t,i}$ , ( $\lambda_{t,i}$ ) measures the number of new shares created if all outstanding convertible bonds and preferred stocks of the  $i^{th}$  firm are exercised at time  $t$ . We obtain the number of outstanding shares and convertibility options from the *Moody's Industrial Manuals*. Lord and Farr

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hypothesize that the number of outstanding convertibility options is positively related to financial leverage.

The final three variables,  $SIGLAM_{t,i}$ ,  $MBLAM_{t,i}$ , and  $CBONDLAM_{t,i}$ , are cross-product terms to control for the fact that the decision to issue convertible securities can also be influenced by several exogenous factors. To date, four cogent arguments have been advanced to explain why firms issue convertible securities. They are high interest rates, undervalued firm equity, volatility of firm returns, and the presence of asymmetrical information possessed by the manager concerning future firm performance.<sup>8</sup> These factors must be controlled for in the model in order to examine if convertible securities allow firms to use more debt in their capital structure than would be allowed within the collusive arrangement with straight debt alone. The control variables  $SIGMA_{t,i}$  and  $CBOND_{t,i}$  provide readily available proxies for firm risk and the level of interest rates, respectively. In addition, previous studies have used the market-to-book ratio,  $MB_{t,i}$ , as a proxy for both under-valuation of equity and the existence of high levels of asymmetrical information. Therefore, we incorporate the interaction of these factors with the levels of convertible debt outstanding by introducing the cross-product terms  $SIGLAM_{t,i}$ ,  $MBLAM_{t,i}$ , and  $CBONDLAM_{t,i}$ , which are the products of  $LAMBDA_{t,i}$  with  $SIGMA_{t,i}$ ,  $MB_{t,i}$ , and  $CBOND_{t,i}$ , respectively. The coefficients on these variables describe the impact of the interaction of these factors on financial leverage. We have no *a priori* expectation on how these interaction terms will affect leverage.

## B. The Switching Regression Methodology

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<sup>8</sup> See Billingsley and Smith (1996) for a brief review of the factors that might explain convertible security issuance.

The primary purpose of this paper is to employ a switching regression procedure that allows for deterministic switching on the basis of time (Judge, et al, 1985) to objectively determine when the behavior of integrated mill steel firms may have changed over the years studied.<sup>9</sup> This procedure calls for the fundamental model specified in Equation 23 to be estimated for subsets of observations where the estimated regression coefficients are constant within subsets but vary across subsets.

Using this procedure, Equation 23 is rewritten as

$$\begin{aligned} \text{LEV}_{t,i} = & \alpha + \psi_1 \text{LEVBMAN}_t + \psi_2 \text{SIGMA}_{t,i} + \psi_3 \text{MB}_{t,i} + \psi_4 \text{CBOND}_t + \psi_5 \text{PROFIT}_{t,i} \\ & + \theta_1 \text{PED}_t + \theta_2 \text{LAMBDA}_{t,i} + \phi_1 \text{SIGLAM}_{t,i} + \phi_2 \text{MBLAM}_{t,i} + \phi_3 \text{CBONDLAM}_{t,i} + \mu_{t,i} \end{aligned} \quad (24)$$

when  $t \leq t_0$  and

$$\begin{aligned} \text{LEV}_{t,i} = & \alpha^* + \psi_1^* \text{LEVBMAN}_t + \psi_2^* \text{SIGMA}_{t,i} + \psi_3^* \text{MB}_{t,i} + \psi_4^* \text{CBOND}_t + \psi_5^* \text{PROFIT}_{t,i} \\ & + \theta_1^* \text{PED}_t + \theta_2^* \text{LAMBDA}_{t,i} + \phi_1^* \text{SIGLAM}_{t,i} + \phi_2^* \text{MBLAM}_{t,i} + \phi_3^* \text{CBONDLAM}_{t,i} + \mu_{t,i} \end{aligned} \quad (25)$$

when  $t > t_0$ .

The procedure allocates observations to each subset based on an unknown switching point at time  $t_0$ .

The time ( $t_0$ ) when the switch occurs is estimated by choosing the value that maximizes the log-likelihood function. The log-likelihood function conditional on  $t_0$  is shown as

$$L(\beta_1, \sigma_1^2, \beta_2, \sigma_2^2) = (-T/2) * (2\pi) - (t_0 * \sigma_1) - ((T-t_0) * \sigma_2) - (1/(2 * \sigma_1^2)) * \text{SSE}_1 - (1/(2 * \sigma_2^2)) * \text{SSE}_2 \quad (26)$$

Once the switching point is found, a likelihood ratio test is conducted to determine if the two regressions estimated using the switching regression technique explain behavior better than a single regression obtained using all observations in the dataset.

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<sup>9</sup> For a thorough discussion of the switching regression methodology see Goldfeld and Quandt (1976).

## V. Results

The empirical estimates of Equations 23 through 25 are shown in Table II. The results for Equation 23, estimated with all available observations, partially meet *a priori* expectations. Two of the five control variables have the anticipated sign and are statistically significant and two of the interaction terms are significant. However, of the two variables, PED and LAMBDA, included to test the fundamental hypotheses, only LAMBDA is statistically significant. The lack of statistical significance for the variable PED fails to provide support for the major proposition that these firms used financial leverage to signal compliance with a collusive agreement. Even though LAMBDA is significant, failure to reject the null hypothesis with regards to PED indicates that LAMBDA loses its meaning in this context, that it allows firms to use debt levels higher than the ceiling implied in Equation 4 while still remaining a compliant member of the cartel.

The results for Equation 24, using observations only from 1947 through 1957, are similar to those for Equation 23, but here neither PED, nor LAMBDA, is statistically significant. Significantly, Equation 25, using only observations from 1958 through 1980, generally yields results completely in agreement with *a priori* expectations. Only the interaction term between firm risk (SIGMA) and the number of outstanding convertibility options (LAMBDA) is not statistically significant, which was also the case in the estimation of Equations 23 and 24.

Collectively, these results provide support for the argument that the firms analyzed in this study behaved consistently with expectations regarding the defined collusive behavior during the years 1958 through 1980. This is seen by the positive and statistically significant results on the parameters associated with PED and LAMBDA in Equation 25. Further, the results from Equation 24 also support the expectation that during the early years of the study (1947-1957) the overt basing point



pricing system likely rendered subtle collusive arrangements, as defined here, unnecessary.

**Table II: Regression Results for Equations 23, 24, & 25**

Parameter	Variables	Parameter Estimates (all years) (Equation 23)	Parameter Estimates (years 1947-1957) (Equation 24)	Parameter Estimates (years 1958-1980) (Equation 25)
"	INTERCEPT	0.0882 (.0574)	0.1703 (.1522)	0.1666 (.0552)*
$R_1$	LEVBMAN	1.3189 (.3585)*	1.7382 (.8399)**	1.0424 (.3258)*
$R_2$	SIGMA	-0.3994 (.2865)	0.0584 (.4289)	-0.5512 (.2448)**
$R_3$	MB	-0.1509 (.0189)*	-0.1369 (.0364)*	-0.2054 (.0226)*
$R_4$	CBOND	0.0126 (.0081)	-0.0337 (.0473)	0.0152 (.0066)**
$R_5$	PROFIT	-0.1712 (.1289)	0.1674 (.2539)	-0.3084 (.1169)*
$Z_1$	PED	0.0459 (.0313)	-0.0337 (.0779)	0.1212 (.0275)*
$Z_2$	LAMBDA	1.7448 (.4606)*	4.6206 (2.516)	2.4386 (.6021)*
$N_1$	SIGLAM	4.0559 (3.145)	-2.5348 (9.237)	3.2002 (2.355)
$N_2$	MBLAM	-0.9885 (.3560)*	-1.1763 (.4590)**	-1.2861 (.3930)*
$N_3$	CBONDLAM	-0.1896 (.0461)*	-0.9580 (.0301)*	-0.2908 (.0653)*
$R^2$		0.793	0.799	0.895
N		238	77	161
Log (L)		288.51	380.79 ←	→ 380.79
* Significant at the 0.01 level.		** Significant at the 0.05 level.		

—Standard errors are shown in parentheses.

—Dummy variables are included in each equation to capture base level differences in capital structure across firms, however, to conserve space the cross-sectional intercept-shifting parameter estimates are not shown but are available from the authors on request.

—An F-test confirms the joint hypothesis of significant differences in base level capital structures across the sample firms for all regression equations.

—An F-test confirms that the parameter estimate of LEVBMAN is not significantly different from one in any of the regression equations.

## **VI. Summary and Conclusion**

In this paper we attempt to replicate an earlier study by Lord and Farr (2003) to explore whether firms in the integrated mill steel industry may have employed the components of their capital structures to publicly demonstrate an intention to comply with a collusive agreement. The fundamental hypotheses are based on theories developed by Maksimovic (1988) and Lord and Farr suggesting that the amount of financial leverage used by oligopolists should be positively correlated with both the price elasticity of demand and the number of new shares created if convertible security holders exercised all of their options. Lord and Farr found that such positive relationships prevailed among a sample of seven integrated mill steel firms during the period from 1959 to 1980, but found no evidence of similar relationships in the period from 1947 through 1958.

Lord and Farr selected a break point in the data between 1958 and 1959 based on subjective analysis of various factors likely to have changed the nature of collusion among these steel firms, such as, the great steel strike in 1959 and the assertions by Mancke (1968) and Rippe (1970) that the integrated mills had effectively abandoned the basing point pricing system by 1960. In this study, we use a switching regression procedure on the same data set employed by Lord and Farr and allow the data itself to determine the actual point in time where a change in behavior occurred among these firms. The procedure indicates that significantly better results are obtained when the data set is broken into two subsets of observations, the first from 1947 through 1957 and the second from 1958 to 1980. This division of observations is very close to the arbitrary break point used in the original study by Lord and Farr, but this result is obtained using an objective procedure determined by the data itself. The results for the two primary hypotheses tested in the paper are similar to those found in the earlier study by Lord and Farr where both price elasticity of demand and the level of outstanding options attached to convertible bonds are positively related to the level of debt in capital

structure in the second subset of observations (1958 through 1980), while no such evidence was found in the earlier years (1947 through 1957).

Our results shed further light on the behavior of the firms in this fascinating industry during the period after World War II. The study by Duke et. al. (1977) indicates a persistent interest in how American integrated mill steel firms maintained a structured pricing system even after the collapse of basing point pricing. Our results add further strength to Lord and Farr's assertion that capital structure arrangements may have served as publicly observable signals to maintain cartel behavior in these markets even after the demise of the overt basing point pricing scheme.

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