

A Control Theory Model of Pricing For a Firm Facing A Stochastic Environment – A Firm's Dynamic Pricing Strategy When Faced With the Threat Of Antitrust Action.

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Abstract: In this paper, a model that has both dynamic and stochastic properties is developed in order to derive an optimal pricing strategy for a firm given potential antitrust action. We find that such a pricing strategy may increase consumer welfare. This sort of model can also be easily generalized to evaluate the effect of exogenous changes in the business environment on firm behavior.

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I. Introduction

In the United States the Sherman Act’s ban on per se pricing is designed to improve consumer welfare by preventing both formal and informal contracts for coordinating prices among firms. The role of the ban on formal price fixing contracts is rarely discussed in the literature. However, it is surprising that even the role of the ban on talking and reaching an informal agreement on prices has not been studied enough by economists (Whinston, 2006: 20). Our paper is an attempt to plug this gap. We show that the mere existence of an enforceable law has significant *dynamic* welfare enhancing effects. In the process we utilize a tool normally used in the literature in finance to model pricing strategy for firms in the face of a stochastic business environment.

Whinston (2006: 21) points out that the industrial organization literature’s approach to understanding the effect of the Sherman Act’s role in banning talk about fixing prices seems to focus on two problem faced by potentially collusive firms. First of all there is a problem in making collusion incentive compatible given an incentive to cheat. However, firms do not need to talk to make collusion incentive compatible – tacit collusion is surprisingly easy in repeated game frameworks. In fact the overabundance of possible equilibria in this context generates the second, coordination, problem. It is difficult for firms to coordinate among many possible incentive compatible equilibria. Thus the difficulty of coordinating among many possible incentive compatible equilibria in the absence of communication enhances consumer welfare. The welfare effect of the

ban on communication is thus an artifact of the Sherman Act. We suggest that the welfare enhancing effect of the Sherman Act operates through another, more mundane, channel – a firm’s desire to avoid even the risk of punishment over time.

Monopolies or the attempt to create a monopolistic outcome through collusive action may elicit prosecutorial action by the anti-trust division of the Justice Department.¹ The rule of reason approach to monopolies and the per se ban on price fixing creates a risk (but not certainty) of prosecution for firms that are perceived to be in monopolistic or oligopolistic settings. Thus, a large firm, or cartel has to toe a fine line. Prices that are “too” high may invite antitrust action. In that case, to maximize current profits, a firm may have excessively reduced future profits such that the total value of the time-adjusted profit stream is lower. If the firm confronting potential antitrust action seeks to maximize discounted profits over time, then it must implement a time optimal pricing policy. Our innovation is in developing a model that has both dynamic and stochastic properties to determine the optimal price for a firm given potential anti-trust action.

Most attempts to understand the reaction of firms to antitrust action take a Beckerian approach. A firm makes a decision to monopolize a market or collude by trading off the gains of this behavior against the expected cost of apprehension by the antitrust agency (Shughart, 1990). Block, Nold, and Sidak (1983), for example, take this approach in a static framework. They model a cartel where firms maximize joint profits given that there is a probability their collusion may be detected and penalties imposed upon conviction by the antitrust enforcer. Our innovation takes this model one step further since we suggest that firms take into account both the current and *future*

probability of antitrust action in order to maximize *dynamic* profits. In doing so the firm sets a price lower than they would otherwise have if there was no chance of antitrust action.

A number of studies suggest that antitrust action does not necessarily produce consumer welfare enhancing price reductions (see for example, Sproul, 1993, Reksulak et al., 2004, Stigler and Kindahl, 1970, Feinberg, 1980). More specifically, Block, Nold, and Sidak (1983) find evidence that firms lower prices when the risk of antitrust action rises – e.g. when there is an increase in the budget of the Anti-Trust Division, an increase in enforcement in neighboring cities, or when there is an increase in enforcement action in a given city. These findings are all consistent with our model. Antitrust action does not lead to significant price reduction because firms try to keep prices low precisely to avoid this action. This view of course begs the question – what then is the basis of antitrust action?

While the stated goal of antitrust is to improve consumer welfare there is a well established literature that suggests this is rarely the basis of action (see for example, Alessi, 1995). We, however, do not address this issue in this paper. Again, our focus is on developing a model that captures a firm’s pricing strategy in the face of possible antitrust action conditioned on some determination of “too” high prices. Further, our model suggests that antitrust agencies may not be able to always find a “smoking gun” of “too” high prices. This may induce the agency to use “other” rationales for antitrust action. It may be interesting to see the effect of these “other” rationales on the credibility of the

¹ We do not make a distinction between a firm and a cartel in this paper. We assume that a cartel will behave exactly like a monopolist. This abstraction away from coordination and incentivisation issues simplifies our model.

agency's threat that "too" high prices are also actionable. We, however, ignore this particular issue in this paper as well.

We believe that the main contribution of our model is that it may provide a means for developing a dynamic model of the firm, especially monopolies and oligopolies, which complements the current dependence on a game theoretic approach. Most game theoretic models predict a large number of possible equilibria suggesting that the main problem for firms liable under the Sherman Act deals with coordination (this is well known but see e.g. Whinston, 2006: 21). Our paper complements this approach by providing a means for modeling the effect of exogenous changes on each possible equilibrium. To this end we have simplified our model by assuming that a firm or a cartel merely tries to maximize profits without worrying about coordination or incentive compatibility issues. This allows us to focus exclusively on the effect of exogenous changes on pricing.

We also note that our approach can be utilized for pricing financial assets. Most current financial models, such as the Capital Asset Pricing Model (CAPM), are equilibrium restricted, i.e., they do not allow for changing market and environmental conditions. The model presented in this paper, however, incorporates both dynamic and stochastic conditions, thus providing a vehicle with which to study the effect of exogenous changes on asset prices as well.

The model to derive optimal pricing strategy is developed in Section II. Final optimality conditions are established in Section III. The implications of the model are explored in Section IV. This section also examines the economic impact of the various

variables. Also, in this section the potential applications of the results are discussed.

Section V concludes.

II. The Model

A firm may be certain about what would ensue if no review for possible antitrust action is undertaken at time t . However, it cannot be sure of the outcome if it is reviewed for such an action at that time. Moreover, if an antitrust action is upheld against the firm, its profits subsequent to such an action would probably be less than what the firm might have earned in the absence of such action, that is $\pi_2 < \pi_1$, where π_1 and π_2 represent the profits earned before and after antitrust action, respectively.

The problem confronting the firm may be stated as follows. If the firm decides to set too high a price, its profits initially are high, but only for a limited time; a high price increases the likelihood of antitrust action brought against the firm at an early stage. If the antitrust action were upheld, the firm would have to be content with lower profits, π_2 , for a longer period of time. On the other hand, should the firm decide to charge a lower price, its current profits are lower, though the firm can forestall or altogether preclude antitrust action. Neither of these schemes is likely to lead to maximization of long-run profits. Optimality would probably be achieved if the firm set some intermediate price. The optimum price would ensure that first-term profits are high enough but not so high as to prompt an antitrust action against the firm too soon.

Assuming a rather simple view of the goals of a firm, we postulate that the firm seeks to maximize the present value of the entire profit stream. The probability of an antitrust action being taken against the firm is a function of its price, $p(t)$, and a

conglomerate of other exogenous factors over which the firm has little control, say $\theta(t)$.² Ceteris paribus, the higher the price the firm charges, the higher the probability that an antitrust action will be initiated against it. Market dominance is often used as indicative of one of the prerequisites of an antitrust action, see Utton (1995), Krouse (1998), which can be defined as the ability of a firm or a group of firms to hold price above long-run average costs without thereby losing so many sales that the price level is unsustainable.

Let $\varphi(t)$ be the probability that an antitrust action has been taken against the firm by time t . Then $[1 - \varphi(t)]$ is the probability that such an action has not been taken by time t . If k is the firm's capitalization rate, that is, the rate required by the investors in the market to invest in a firm with these characteristics. Also, let g be the growth rate, that is, the rate at which the firm's profits are likely to grow. Then the present value of all future profits is given by (1),

$$\int_0^{\infty} \{\pi_1[1 - \varphi(t)] + \pi_2\varphi(t)\} e^{-(k-g)t} dt \quad (1)$$

Also, let $s[p(t), \theta_0]$ be the conditional probability of an antitrust action.

Obviously,

$$s[p(t), \theta_0] = \varphi(t) / [1 - \varphi(t)] \quad (2)$$

where $\theta(t) = \theta_0$ represents the effects of exogenous factors on the probability of an antitrust action. From equations (1) and (2), we derive the state equation,

$$\dot{\varphi}(t) = [1 - \varphi(t)]s(p(t), \theta_0) \quad (3)$$

The initial condition also is not difficult to obtain if we recall that $\varphi(t)$ is the probability that an antitrust action has been taken by time t . That is,

² For example, the political climate may change thus changing the perceived risk of antitrust action. Thus firms may believe that a Republican government in the United States may reduce the risk of antitrust action

$$\varphi(0) = 0 \quad (4)$$

indicating that initially no antitrust action has been initiated against the firm.

Since $s[p(t), \theta_0]$, the conditional probability of entry, is a positive number, equation (3) ensures that $\varphi(t) \rightarrow 1$, as $t \rightarrow \infty$. It is easy to see that $s[p(t), \theta_0]$ being a function of price and time, imparts stochasticity to the problem of determining the optimal pricing policy for the firm. Consideration of legal precedents may be of some aid in deriving the probability function. Also, the functional form of s is influenced by θ , where θ represents all other past and current information affecting s . Since the conditional probability of an antitrust action increases with $p(t)$, we can view s to have the following properties:

$$\frac{\partial s}{\partial p} > 0 \quad \text{and} \quad \frac{\partial^2 s}{\partial p^2} > 0 \quad (5)$$

Also, let ε be a very small quantity. There is, of course, a price p_x which reduces the conditional probability of antitrust action to this small quantity ε . The price p_x can be referred to as the frontier price that keeps the conditional probability of an antitrust action limited at the small quantity ε , as shown in Figure I.³ As will be shown subsequently, however, p_x is not the optimal price for the firm.

Let $q(p)$ have the form of the demand function with the properties $\partial q / \partial p < 0$ and $\partial^2 q / \partial p^2 > 0$. If c is the per unit average cost of production, then the profits of the firm, π_1 , is given by (6),

$$\pi_1 = q(p - c) \quad (6)$$

across the board and price accordingly.

³ See Appendix 1.

π_1 is a concave function of price, implying $\partial^2 \pi_1 / \partial p^2 < 0$, with $\pi_{1 \max}$ occurring at some price, say, p_m . It will be shown that in order to maximize the total time adjusted profits, the firm must charge a price that is lower than p_m to prolong the more profitable pre-antitrust period, sacrificing some immediate profits for long run profits. Thus, $\partial \pi_1 / \partial p$ at the optimal price p^* will be positive rather than zero.

So far as π_2 is concerned, we know only that $\pi_2 < \pi_1(p^*)$. This may be consequence of antitrust penalties or an adverse capital market reaction to the lawsuit.⁴ Of course, there is always the possibility that the antitrust action actually increases competition thus reducing the indicted firm's profitability. Thus, ceteris paribus, the firm is likely to be able to make more profits before rather than after the antitrust action and therefore π_2 is less than π_1 .

In summary, the basic problem the firm faces can be expressed as follows:

$$\text{Max}_{\varphi(t)} \int_0^{\infty} \{ \pi_1 [1 - \varphi(t)] + \pi_2 \varphi(t) \} e^{-(k-g)t} dt \quad (1)$$

under the constraint of the state equation,

$$\dot{\varphi}(t) = [1 - \varphi(t)] s(p(t), \theta_0) \quad (3)$$

and the initial condition,

$$\varphi(0) = 0 \quad (4)$$

III. Optimization

⁴ The adverse capital market reaction could be generated if, for example, investors think that the firm's behavior will be monitored more closely in the future. Thus antitrust action adds a binding constraint (Le Chatelier's principle).

The problem stated in equations (1), (3), and (4) is a typical optimal control problem and can be solved by the application of the Pontryagin's Maximum principle.

The Hamiltonian H is given by

$$H = \{\pi_1[1 - \varphi(t)] + \pi_2[\varphi(t)]\}e^{-(k-g)t} dt + \lambda[1 - \varphi(t)]s(p(t), \theta_0) \quad (7)$$

where λ is the adjoint variable. The adjoint equation is given by (8),

$$\frac{\partial H}{\partial p} = -\dot{\lambda} = [\pi_2 - \pi_1]e^{-(k-g)t} - \lambda s(p(t), \theta_0)$$

or

$$\dot{\lambda} = [\pi_1 - \pi_2]e^{-(k-g)t} + \lambda s(p(t), \theta_0) \quad (8)$$

with the transversality condition,

$$\lambda(\infty) = 0 \quad (9)$$

For optimal p , the Hamiltonian must be maximized at every point in time. So, for optimality,

$$\frac{\partial H}{\partial p} = 0 = \frac{\partial \pi_1}{\partial p}[1 - \varphi(t)]e^{-(k-g)t} + \lambda[1 - \varphi(t)]\frac{\partial s}{\partial p} \quad (10)$$

It will be shown later that $p(t) = p^*$ for some constant p^* satisfies equation (10) and p^* is unique. Thus, taking $p(t) = p^*$ and $s(p^*, \theta_0) = s^*$, we have from (8),

$$\dot{\lambda} - \lambda s^* = [\pi_1^* - \pi_2]e^{-(k-g)t} \quad (11)$$

where $s^* = s(p^*, \theta_0)$ and $\pi_1^* = \pi_1(p^*)$.

Multiplying (11) by e^{-s^*t} , we obtain

$$e^{-s^*t}\dot{\lambda} - \lambda e^{-s^*t}s^* = [\pi_1^* - \pi_2]e^{-(k-g+s^*)t}$$

or

$$\frac{d}{dt}[e^{-s^*t}\lambda] = [\pi_1^* - \pi_2^*]e^{-(k-g+s^*)t} \quad (12)$$

Integrating (12),

$$e^{-s^*t}\lambda = \frac{\pi_1^* - \pi_2^*}{-[k - g + s^*]} e^{-(k-g+s^*)t} + C$$

$$\lambda(\infty) = 0 \Rightarrow C = 0.$$

Therefore,

$$\lambda(t) = \frac{\pi_1^* - \pi_2^*}{-[k - g + s^*]} e^{-(k-g)t} \quad (13)$$

From equation (3),

$$\dot{\phi}(t) = [1 - \phi(t)]s^*(p^*, \theta_0) \quad (14)$$

Multiplying (14) by e^{s^*t} and rearrange to obtain,

$$e^{s^*t}\dot{\phi}(t) + s^*e^{s^*t}\phi(t) = s^*e^{s^*t}$$

or

$$\frac{d}{dt}[e^{s^*t}\phi(t)] = s^*e^{s^*t}$$

Therefore,

$$e^{s^*t}\phi(t) = e^{s^*t} + C \quad (15)$$

From equation (4),

$$\phi(0) = 0.$$

So from (15) and (4), we have

$$C = -1$$

and

$$\varphi(t) = 1 - e^{-s^* t} \quad (16)$$

Substituting the values of $\varphi(t)$ from (16) and $\lambda(t)$ from (13) into equation (10), we get,

$$\frac{\partial \pi_1}{\partial p} = \frac{\pi_1^* - \pi_2}{k - g + s^*} \frac{\partial s}{\partial p} \quad (17)$$

Equation (17) thus gives the slope $(\partial \pi_1 / \partial p)$ at which the firm must operate for optimality.

Uniqueness of Solution. Before exploring the implication of our results in (17), we first prove that there is just one unique p^* which satisfies (17). Let.

$$F(p) = \frac{\partial \pi_1}{\partial p} (k - g + s(p)) - \frac{\partial s}{\partial p} [\pi_1(p) - \pi_2] \quad (18)$$

The solution of $F(p) = 0$ for p is the same as the solution of p from (17). We now prove that there exists a unique solution of 'p' for $F(p) = 0$ such that $\pi_1(p^*) > \pi_2$. We observe that since $\pi_1(p)$ is concave there will be two values of p satisfying $\pi_1(p) = \pi_2$. Let the smaller solution value be p_1 and the larger value p_2 . Since $\pi_1(p)$ is strictly concave, we have

$$\frac{\partial \pi_1}{\partial p}(p_1) > 0 \quad \text{and} \quad \frac{\partial \pi_1}{\partial p}(p_2) < 0.$$

From equation (18), therefore,

$$F(p) > 0 \quad \text{at} \quad p = p_1$$

$$F(p) < 0 \quad \text{at} \quad p = p_2.$$

Also, $\pi_1(p) > \pi_2$ for $p_1 < p < p_2$.

Differentiating equation (18) with respect to p , we get,

$$\frac{\partial F}{\partial p} = \frac{\partial^2 \pi_1}{\partial p^2} [k - g + s(p)] - \frac{\partial^2 s}{\partial p^2} [\pi_1(p) - \pi_2] \quad (19)$$

From (4) and (5),

$$\partial^2 \pi / \partial p^2 \leq 0 \quad \text{and} \quad \partial^2 s / \partial p^2 \geq 0 \quad .$$

Therefore, from (17), $\partial F / \partial p < 0$ for $p_1 < p < p_2$.

Thus, we have

$$F(p_1) > 0$$

$$F(p_2) < 0$$

$$\partial F / \partial p < 0 \quad \text{for} \quad p_1 < p < p_2.$$

Since $F(p)$ is monotonically decreasing from a positive value at p_1 to a negative value at p_2 , there is a p^* between p_1 and p_2 where $F(p) = 0$.

IV. Implications

The model specified by equation (17) leads to a number of interpretations that may generate testable hypotheses. It's most obvious and direct interpretations are considered first. Next, a few of the more subtle implications of the model are discussed. Finally, the model is examined with regard to its potential applicability to situations that are encountered in business practice. Its actual application, of course, requires that empirical research and analysis be undertaken that is beyond the scope of this paper.

The multiplier term, $(\pi_1^* - \pi_2) / (k - g + s^*)$, provides a direct link between the change in profitability due to a change in price, and a change in the conditional probability function $s(p, \theta)$ due to a change in price. Treating the term as a constant, an

assumption which is relaxed below, attention is focused on the two price derivatives.

Notice that since the multiplicative term is greater than or equal to zero, and

$(\partial s / \partial p) \geq 0$ we have,

$$(\partial \pi_1^* / \partial p) \geq 0 \quad (20)$$

which shows that the optimal price charged by the firm when there is a threat of antitrust action is less than its profit-maximizing price when there is no threat of antitrust action, except for the special case when the equality obtains, i.e.,

$$p^* = p_m$$

only when,

$$\pi_1^* = \pi_2 \quad (21)$$

or,

$$(\partial s / \partial p) = 0 \quad (22)$$

Recall from Figure 1 that conditions (21) and (22) hold only for $p \leq p_x$. Thus, the model implies that p^* is equal to the price that maximizes profits unconstrained by antitrust action if and only if the conditional probability function is zero, i.e., whenever,

$$p = p^* = p_m, \text{ where } p \leq p_x,$$

We have,

$$s(p^* \mid \theta_0) = 0$$

Notice the significance of the latter finding: that is, the effect of θ_0 completely dominates the effect of p . In other words, if θ_0 is such that it rules out the possibility of future antitrust action in time, then the optimal pricing policy for the firm is the same as that of a monopolist without any threat of antitrust action. The situation, of course, could change to the detriment of the firm. For example, changing factors in the firm's

environment could cause an unfavorable shift in the $s(p, \theta)$ function – indicating that the firm must carefully analyze the effects of current pricing policies and future price changes. This would be consistent with the Block, Nold and Sidak (1983) finding that proxies for an increased threat of antitrust action do lead to lower prices.

Whenever $(\partial s / \partial p) > 0$, which is the case for most unregulated monopolistic or oligopolistic firms, the long run optimal price, p^* , is less than the short run profit maximizing price, p_m . The more sensitive s is to p , the lower the optimal price. If $(\partial^2 s / \partial p^2)$ is small, then an increase in p is unlikely to result in antitrust action. On the other hand, as $(\partial^2 s / \partial p^2)$ increases, a rise in the price charged by the firm greatly increases the possibility of antitrust action. Thus, the long run profit-maximizing firm needs an estimate of $s(p, \theta)$ in order to make optimal pricing decisions, i.e., to maximize long run profits.

These results have interesting policy implications. If antitrust agencies are believed to be sensitive to high prices that reduce consumer welfare, then firms will rationally try to keep prices low. Indeed, we show that such behavior is optimal. Thus, the threat of welfare enhancing antitrust indictments may be enough to keep prices low.

The multiplicative term in equation (17) was treated as a constant in order to focus on the price derivatives. Notice, however, that it is both stochastic and dynamic. That is, each of the variables in the term is subject to random events and tends to vary over time. Moreover, changes in any one of the variables will alter the optimal price, p^* . For example, an increase in costs will lower π_1^* , ceteris paribus, and justify a rise in p^* in order to maintain the difference $\pi_1^* - \pi_2$ at a constant level. The firm can take advantage of this, when the market it serves can absorb a price increase, by increasing expenditures

on research and development efforts in an attempt to assure greater long run profitability and growth. This observation may be directly applicable to, and tested in the context of, pharmaceutical companies.

The term's denominator contains three variables, each of which has intuitive applications. For instance, the higher the firm's capitalization rate, k , the lower the value of $(\partial\pi_1^* / \partial p)$, thus inducing the firm to raise p^* . Thus, ceteris paribus, high capitalization rates ought to be associated with higher prices for a given threat of anti-trust action.

The effect of the growth rate variable, g , is just the opposite of k . That is, the higher the growth rate, the higher the value of the multiplier and hence $(\partial\pi_1^* / \partial p)$. This implies that a high growth firm would have a lower optimal p^* than a low growth firm. Again, the result is intuitively appealing because a high growth rate accompanied by a high price is inevitably more likely to invite antitrust action.

The presence of the s^* variable in the denominator of the multiplier represents a 'feedback' effect, which has a destabilizing potential. Its effect is in the same direction as k thus inducing the firm to increase p^* . Increasing p^* , however, further reduces the multiplier and $(\partial\pi_1^* / \partial p)$. But, as $(\partial\pi_1^* / \partial p)$ declines, the firm gains less and risks more by increasing prices. Hence, at some point, the rational firm will establish dynamic equilibrium prices for its products.

The dynamic and stochastic nature of the model cannot be overstressed. All firms face uncertain environments that change over time – sometimes dramatically. Further, as the discussion thus far has shown, the interaction among the variables can be extensive. This makes our model flexible enough for application to actual businesses.

The model divides the probability of antitrust action into two components. The price component is separated from all other facts because the model is specifically concerned with optimal pricing policy. However, to apply the model the major factors that influence the possibility of antitrust action, that is the terms in θ , must be identified and their influence measured. These probability functions can be developed and tested employing publicly available information. In all likelihood, however, serious efforts will be required to develop sufficient information to generate reliable probability functions. One approach to develop and improve the probability estimates is for the researcher to develop Bayesian priors for $\varphi(\pi)$ and $\varphi(p)$; then the objectively determined distributions can be adjusted by the subjectively determined ones to obtain the posterior distributions. Another approach may be to postulate plausible proxies for potential antitrust action like the location of the firm – whether it is in the congressional district of a congressman who has oversight roles over the Anti Trust Division, or proximity to areas with a high frequency of anti trust action etc.

V. Conclusions

In this paper we develop a model that addresses the problem of optimal pricing for a firm confronting possible antitrust action. This stochastic and dynamic model derives the optimal price given the threat of antitrust action. We suggest that this model can also be used to derive optimal pricing strategies when a firm's business environment is uncertain.

Given that a firm wants to maximize the total value of its time adjusted profit stream, the model demonstrates that the optimal price, p^* , lies between the short run monopoly profit maximizing price, p_m , and some very low price, p_x , which guarantees

that no antitrust action will be taken. The three price levels are found to be equivalent only when there is no possibility of antitrust action. When there is a positive probability of antitrust action, the model demonstrates that a firm's profitability is optimally lower in the short run than is otherwise the case. This suggests that the mere threat of antitrust action may have welfare enhancing effects.

This model also shows that the interaction among the variables permits a firm to exchange current profitability for higher growth, thus permitting a firm to adjust its pricing policy to the market it faces. The model also evaluates the impact of numerous other economic variables, such as capitalization rate and business risk, on the optimal pricing. The next step is the empirical research to validate the applicability of the theoretical results obtained here.

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Appendix 1

Figure 1

