ORDER BACKLOGS AND STRATEGIC PRICING: THE CASE OF THE U.S. LARGE TURBINE GENERATOR INDUSTRY

PANKAJ GHEMAWAT* AND ANITA M. McGAHAN

Graduate School of Business Administration, Harvard University, Boston, Massachusetts, U.S.A.

This paper illustrates the usefulness of game theory for strategic management through theoretical and empirical analysis of price competition in the presence of production backlogs. Game-theoretic analysis predicts a different relationship between relative prices and backlog levels than does analysis that ignores the sorts of interactive considerations emphasized by game theory. Empirical analysis based on data for the U.S. market for large turbine generators between 1951 and 1963 corroborates the game-theoretic prediction. The paper concludes with a discussion of the sorts of situations in which game-theoretic reasoning is particularly likely to prove useful. © 1998 John Wiley & Sons, Ltd.

INTRODUCTION

Since the late 1970s, industrial organization economists have devoted much of their attention to the analysis of 'strategic' (i.e., self-consciously interactive) behavior by business rivals. Despite the similarities in nomenclature, however, behavior that is strategic in this sense has traditionally not been a central concern of academics interested in strategic management. Furthermore, there is considerable skepticism within strategic management about the gains from trade with contemporary industrial organization along this dimension.[1]

We are more optimistic: we think that 'strategic' or, to be more precise, game-theoretic, analysis can shed useful and on occasion even counterintuitive light on competitors' interactions. Instead of arguing this point on *a priori* grounds, as is often done, we adduce an example of the utility of game theory through theoretical and empirical analysis of price competition in the presence of production backlogs.

We begin by discussing the general inattention to backlogs (as opposed to inventories, their obverse) in the academic literature despite their overall economic importance. We then present background information on the U.S. large turbine generator industry, a setting in which backlogs were important, and which motivates both our theoretical and empirical analyses. We extend existing models of capacity-constrained pricing to develop theoretical hypotheses about links between the relative prices of duopolists and their backlog levels and find that with strategic behavior, the larger of the two firms will tend to buffer the smaller one. Empirical analysis, based on data for the U.S. market for large turbine generators between 1951 and 1963, corroborates the hypothesis of strategic as opposed to nonstrategic pricing. That leads to discussion of the conditions under which game-theoretic equilibria

[1] As Rumelt, Schendel, and Teece (1991: 20) put it, 'Industrial organization may already have made its most important contributions to strategy'.

are likely to arise in actual markets and to the conclusion.

THE IMPORTANCE OF BACKLOGS

The most direct antecedent of this research is Zarnowitz's (1962) cross-industry analysis of changes in backlogs over the business cycle. Zarnowitz identified three qualitatively distinct variables that capacity-constrained firms might adjust in response to demand fluctuations: prices, inventories, and order backlogs. He also noted that price adjustments were accorded pride of place in economics, that inventory adjustments came second, and that backlog adjustments were largely ignored.

This bias persists. Advances in game theory have led to a number of studies on the optimal adjustment of prices over the business cycle (Green and Porter, 1984; Rotemberg and Saloner, 1986; Dudey, 1992, 1994; Staiger and Wolak, 1992). A few economists have also examined strategic behavior by firms that hold inventories (Arvan, 1985; Ware, 1985; Rotemberg and Saloner, 1989). Academics in strategic management have devoted substantial attention to inventory management as well. But to the best of our knowledge, no one—in either economics or strategic management—has investigated backlogs as a strategic variable. In fact, the index to Tirole's influential 1988 text on industrial organization does not even mention backlogs.

What makes this theoretical bias particularly striking is the empirical fact that backlogs loom larger than finished good inventories in many industries. Zarnowitz (1962) calculated that backlog levels were four times as large as inventory levels in his sample of U.S. manufacturing industries, and eight times as large in the subsample that manufactured durable goods. Given the subsequent emphasis on just-in-time management and inventory reductions, average backlog-to-inventory ratios have likely increased since his study.

The reason backlogs have attracted so little attention is probably related to the common tendency to treat firms as planning their output in anticipation of demand. But in a wide range of manufacturing industries, most production is 'to order' instead of 'to stock': it responds to demand instead of anticipating it. In such settings, back-

logs are apt to be large and inventories small (or zero). The U.S. large turbine generator industry, on which we focus our empirical analysis, is an example.

INDUSTRY BACKGROUND

Our analysis of the U.S. large turbine generator industry spans the period between 1951 and 1963 and is based, in large part, on information assembled by Sultan (1974, 1975). Sultan, in turn, drew heavily on data disclosed in the context of suits filed by the U.S. Department of Justice charging the manufacturers of large turbine generators and their senior executives with conspiring to fix prices in violation of antitrust laws. The issue of how effectively the manufacturers managed to collude as opposed to compete will be revisited toward the end of this section.

Large turbine generators are partially customized units used to convert steam into electrical power. Between 1951 and 1963, they were manufactured in the United States by three companies: General Electric, Westinghouse, and Allis-Chalmers, whose market shares averaged 61 percent, 32 percent, 6 percent, respectively. Sporadic imports accounted for the remaining 1 percent of the U.S. market.

Large turbine generators were produced to order in job shops and took about 2 years to manufacture. Short-run marginal costs were roughly constant up to the point at which capacity constraints—estimated by Sultan to occur at 85 percent utilization—began to pinch, and then increased sharply. If a capacity-constrained manufacturer won an order, it deferred its delivery date and added the order to its backlog. Between 1951 and 1963, deliveries were occasionally deferred for up to 4 years, which was roughly the maximal lead time in adding capacity. Lengthier backlogs occurred only temporarily at Westinghouse during a strike in 1956. Backlogs of 1–3 years were the norm.

Domestic utilities accounted for more than nine-tenths of the demand for large turbine generators manufactured in the United States, and exports and industrial customers for the remainder. There were well over a thousand utilities in the United States. They purchased turbine generators when they forecast that their current capacity would be insufficient to meet consumers'

demand for electricity in forthcoming years. Because the costs of under-provision of electricity were high, orders tended to fluctuate with changes in forecasts about demand, which were often correlated across utilities because of their common dependence on the national economy. As a result, orders sometimes varied by as much as a factor of 10 from year to year. Nonetheless, because of the sizes of individual orders and the purchasing processes that accompanied them, contracts between turbine manufacturers and their customers were struck sequentially rather than simultaneously.

Sultan (1975: 46, 55, 62) reported the price elasticity of aggregate demand to be virtually zero in the short-run and −0.11 in the long run. According to testimony by a General Electric executive (cited by Sultan, 1975: 44), the managers of utilities were reluctant to defer orders for new turbines between quarters because of strong incentives to avoid service interruptions. Note that efforts by U.S. manufacturers to take advantage of this price inelasticity by dramatically increasing prices may have been limited by the availability of imports as well as by domestic competition.[2]

The process of purchasing a large turbine generator began when a utility set specifications and invited bids. Government-owned utilities, which accounted for a quarter of the domestic market, purchased from the lowest bidder and posted all bids after the award. Investor-owned utilities, in contrast, negotiated their orders in strict privacy and kept bids secret even after the award. While they weighed several factors in making decisions, including product performance and post-purchase service, relative prices usually proved decisive since large turbine generators cost more than any other electrical equipment in a power plant. A turbine manufacturer scheduled production only after it was awarded an order.

The pricing of large turbine generators was further complicated by meetings among representatives of the three U.S. manufacturers to negotiate the terms of forthcoming bids. We do not attempt to model or test the effects of such preplay communication on the toughness of price competition. One set of reasons is provided by Sultan's (1974:78–83) conclusion that 'the conspiracy in turbine generators was ineffectual'. More specifically the effectiveness of the clandestine meetings among manufacturers of turbine generators was limited by the following considerations.

First, the meetings did not cover many transactions. Even when meetings aimed at fixing prices were most frequent (between 1955 and 1959), competitors discussed fewer than a quarter of all transactions, and only a fraction of the discussions led to agreements on who should underbid whom.

Second, the agreements that were reached by the manufacturers were not contractually enforceable and apparently were not self-enforcing either. Scherer notes that in 1953, for example

> one General Electric executive explained his group's decision to go its own independent way [in the following terms:] 'No one was living up to the agreements and we . . . were being made suckers. On every job someone would cut our throat; we lost confidence in the group.'[3]

This evidence suggests that collusion was not seriously attempted after the early 1950s. On a more systematic plane, Sultan (1975:111) found that after allowing for suitable controls, prices were not significantly higher during the period when meetings to discuss prices were the most frequent.

Third, it should be noted that 88 percent of transactions were consummated at prices lower than the list prices implied by the formulae in turbine manufacturers' price books, and that figure rose to 98 percent for large transactions worth over $3 million apiece. To the extent that aggregate demand was very price-inelastic and that individual customers lacked significant market power, such discounts imply that the attempts to collude were of limited effectiveness.

A different and even more compelling reason for not testing for collusion among turbine generator manufacturers is that we lack the detailed data on absolute prices that are required to distinguish collusive from noncollusive regimes. What we do have are quarterly data on General

---

[2] It is also possible that Sultan underestimated (absolute) price elasticity. His analysis is based on observations about the financial structure of utilities and on a study by Paul MacAvoy (1969). Sultan describes the method as based on 'extremely crude assumptions' (1975:62).

[3] See Scherer (1980: 170).

Electric's average prices (bid over all orders assigned to that quarter, according to Sultan) relative to average prices in the market as a whole. Given this data set, our research strategy is to develop and test game-theoretic predictions about the dependence of the market leader's relative price on backlog levels. In other words, we develop and test a model of backlogs in which noncooperative behavior makes firms 'pull their punches' (in the sense of Tirole, 1988:207), leading to what looks like collusion.

THEORETICAL HYPOTHESES

This section develops both strategic and non-strategic hypotheses about the links between relative prices and backlogs. Finished good inventories, the third mechanism for adjusting to changes in demand identified by Zarnowitz, are omitted from the analysis because no manufacturer of large turbine generators held significant inventory.

In addition to shedding light on the U.S. large turbine generator industry, our analysis of the link between relative prices and backlog levels expands the ways in which price is modeled as having short-run commitment value. Previous work on short-run commitments has often invoked arguably arbitrary lags in changing prices to explain why prices matter intertemporally.[4] We stress, instead, that at least in environments in which production takes time, short-run decisions about prices (or quantities) can have commitment value because they can affect the backlogs with which competitors enter subsequent transactions. In other words, one of the reasons that even pricing decisions may not be perfectly reversible is that they can alter future marketing possibilities by affecting backlog levels.[5]

Our theoretical analysis of prices and backlogs will begin with a consideration of the nonstrategic benchmark: a situation in which competitors ignore interactive effects in relating prices to backlog levels. It will then offer a sharply contrasting hypothesis about the relationship between relative prices and backlogs given strategic behavior.

The nonstrategic and strategic elements of our analysis share several assumptions. Perhaps the most obvious similarity is that both are couched in the operational short run, a period that we define as too short to add production capacity or even complete a production cycle but long enough to write contracts and thereby alter backlog levels. In other words, we will treat our time series of observations on the U.S. large turbine generator industry as a sequence of short-run outcomes given initial backlogs and capacity levels. We will not attempt the much more ambitious task of trying to endogenize firms' capacity strategies, although we will make some remarks about the turbine generator competitors' capacity expansion paths in the course of our statistical analysis.

A second similarity between the nonstrategic and strategic analyses is that they focus on two competitors with identical marginal costs that are, for convenience, normalized to zero. The focus on duopoly is forced by technical complications that arise in solving pricing subgames among more than two asymmetric players that act strategically.[6] While the number of domestic competitors in the U.S. large turbine generator industry was three rather than two, the two largest competitors, General Electric and Westinghouse, accounted for more than 90 percent of the market over the period from 1951 to 1963. The third competitor, Allis-Chalmers, is best considered as a marginal player on the basis of its low capacity share and utilization rates, its high direct costs, its generally negative operating margins, and its decision to exit effective in 1963.

The demand side of the nonstrategic and strategic analyses shares two additional similarities. First, demand is taken to be inelastic throughout: there are Q customers in total, each of which purchases one unit if it achieves positive consumer surplus at the best available terms. At the theoretical level, this assumption obviates the need to postulate a specific rule for rationing customers between manufacturers when their products are available on different terms. Second, the two firms' products are assumed to be physically identical, although they may be dis-

---

[4] The work of Maskin and Tirole (1988), which assumes that duopolists (re)set prices in alternating periods, is an influential and interesting example.
[5] See Dudey (1994) for a model of inventories and pricing behavior.

[6] The upper and lower supports of the pricing strategies may not coincide in games with more than two asymmetric competitors.

tinguished by different delivery dates (i.e., backlog levels), which forces a focus on price competition and its link to backlog levels. This theoretical structure will be elaborated further when we discuss its implications for nonstrategic and strategic behavior.

A nonstrategic benchmark

Following the literature on intertemporal price discrimination (Tirole, 1988:151–152, esp. 36ff.), we assume that once a customer decides to order a product, it prefers early delivery to late delivery. This assumption is also consistent with Zarnowitz's (1962:392–394) analysis and fits with Sultan's (1975) report that when backlogs were high in large turbine generators, customers scrambled to get in line, but that when backlogs were low, customers did not accelerate their purchases to take advantage of low prices.

We represent demand inelastically in terms of the following customer utility function:

$$u - st - p$$

where u is a parameter that captures the willingness to pay for 'immediate' delivery (i.e., delivery subject to only the normal production cycle for products made to order); s is a parameter that captures the time rate of preference; t is a temporal measure of backlogs (i.e., lags in delivery in excess of production cycle time); and p is the price paid for delivery at time t.

It is useful to begin by considering the effect of a prespecified backlog, T, on the pricing decision of a monopolist. The monopolist's optimal price for delivery subject to this backlog is given by:

$$p^* = u - sT$$

and is a decreasing function of T. This relationship should continue to hold even if the monopolist's strategy space is expanded to allow for acceleration of production from a given amount of capacity by incurring higher marginal costs.[7]

Now consider the case of nonstrategic duopoly

and introduce the subscripts 1 and 2 to index the two firms. Then firm 1's pricing decision is subject to a more complicated individual rationality constraint:

$$u - sT_1 - p_1 \geq \max(u - sT_2 - p_2, 0)$$

where the Ts are taken to be parameters and so is p_2 because we are studying nonstrategic behavior. This constraint indicates that the price charged by firm 1 must yield the customer surplus that is at least as great as the surplus it would obtain by purchasing from firm 2 (provided the consumer surplus afforded by firm 2 is greater than zero). If firm 1's price did not meet this condition, then it would never sell any product. Later, when we consider strategic behavior, we modify the assumption that p_2 is a parameter and instead assume that each firm takes its rival's optimal response into account.

In the nonstrategic case, equilibrium requires

$$p_1^* = u - sT_1 - \max(u - sT_2 - p_2, 0)$$

implying that p_1^* is a decreasing function of T_1 and—under the assumption that the rival firm does not set its price, p_2, so high as to imply negative consumer surplus from the purchase of its product—an increasing function of T_2. Similarly, p_2^* is a decreasing function of T_2 and an increasing function of T_1. Nonstrategic considerations therefore lead us to expect that the ratio of p_1^* to p_2^* is a decreasing function of T_1 and an increasing function of T_2. This outcome is nonstrategic in the sense that neither firm takes into account the effect of its own pricing decision on the other firm's optimal response.

As one moves from two players to three, only one of the two individual rationality constraints is likely to be binding, implying that the relative pricing level of the market leader will depend on one but not both of its competitors' backlog levels. We therefore expect that with nonstrategic behavior the ratio of the largest firm's price to the industry's average price will be a decreasing function of the leader's own backlog and an increasing function of at least one of its competitors' backlogs.

A two-period strategic model

Under the hypothesis of strategic behavior, competitors do not treat each others' prices as para-

---

[7] Recall that in the large turbine generator industry, costs were reported to rise above 85 percent capacity utilization, but utilization levels between 85 percent and 100 percent were not infeasible.

metric. Instead, they select prices after considering their rivals' optimal responses. Equilibrium occurs when the optimal responses of the firms are mutually consistent.

Denote the initial capacities for the duopolists as K_1 and K_2 and suppose that $K_1 = 2K_2 = 2K$, so that total industry capacity is $3K$: this simplifies the analysis and approximates structural conditions in the U.S. large turbine generator industry.[8] To capture the idea that production takes time, consider a simple, two-period model in which orders obtained in the first period reduce the amount of capacity left over for the second period. In this model, the accumulation of a backlog is directly associated with the filling of capacity. To illustrate the buffering mechanism in its simplest form (independent of order fluctuations), take demand to be stationary and equal to Q in each of the two periods. Let $\Delta = Q/K$ parameterize the relationship between total demand ($2Q$) and total capacity ($3K$).

To obtain the subgame-perfect equilibrium of this two-period game, we begin with the second period. Ghemawat (1986), building on the methods developed by Kreps and Scheinkman (1983) and Osborne and Pitchik (1986), has characterized the Nash equilibrium in the second-period subgame under the relevant conditions; the proof is available in the preprint version of this paper.[9] Suppose that x_1 and x_2 represent firm 1's and firm 2's residual capacities in the second period. For each firm, residual capacity equals initial capacity less any orders taken in period 1. Denote firm i as the firm with at least as much residual capacity as its rival, i.e., $x_i \geq x_j$. Also suppose that $x_j > 0$; that is, both firms have residual capacity and thus competition occurs in the second period.[10] Then the price announced by the larger firm will stochastically dominate (in a first-order sense) the smaller firm's price. The larger firm in the subgame will be held to its security level, $u.\max(0, Q - x_j)$, and the smaller firm's expected operating profit will equal the

same absolute amount scaled by its relative residual capacity: $(x_j/\min(x_i, Q))$.

With this characterization of the second-period subgame, we can now consider competition at the first period. The possibilities may be partitioned into four different subcases based on the value of the parameter Δ (see Appendix for a sketch of the proof).

If $\Delta \leq 0.5$, demand is so small in relation to capacity that either firm could supply total demand (in both periods) by itself. Since capacity constraints are not binding for either firm, the outcome, as under unconstrained price competition, coincides with perfect competition. Both firms price at 0.

If $0.5 < \Delta \leq 1$, an extreme version of buffering emerges in equilibrium.[11] The larger firm, firm 1, makes sure that the smaller firm, firm 2, is the lower-priced firm in period 1. If, instead, the larger firm were lower-priced in period 1, second-period prices would collapse to 0 because each firm would have sufficient residual capacity ($2K - Q$ and K, respectively) to satisfy second-period demand all by itself. Allowing the smaller firm to sell out in period 1 avoids this dire outcome in period 2.

The precise prices and profits in this subcase can be characterized as follows. Define the price $\underline{p}$ such that firm 1 is indifferent between winning at that price and losing at the price u, i.e.,

$$\underline{p}Q = u(Q - K) + u(Q) \Leftrightarrow \underline{p} = u\frac{2\Delta - 1}{\Delta}$$

Then in the first period, firm 2 prices at $\underline{p}$ and firm 1 employs a mixed strategy over $(\underline{p}, u]$ with a probability distribution function $\Phi(p)$ such that

$$\Phi_1(p) \geq \frac{\Delta^2 p - u(2\Delta - 1)\Delta}{\Delta^2 p + u(2\Delta - 1)(1 - \Delta)} \ \forall p \in (\underline{p}, u]$$

By pricing at $\underline{p}$, firm 2 renders undercutting unattractive for firm 1. Similarly, the strategy used by firm 1 is aggressive enough to deter firm 2 from trying to price above $\underline{p}$ because of the implied probability that firm 2 would lose in period 1 and therefore not make any profit in

---

[8] Over the period from 1951 to 1963, the ratio of General Electric's capacity to Westinghouse's capacity had a mean of 1.95 and a standard deviation of 0.66.

[9] Related characterizations of two-period, capacity-constrained price competition appear in Gal-Or (1984), and Brock and Scheinkman (1985).

[10] If the smaller firm's residual capacity is zero, its equilibrium pricing strategy will not be unique but the larger firm will price at u, i.e., at a level greater on average than the small firm with zero capacity would announce.

[11] Actually, there is a continuum of subgame-perfect Nash equilibria, all of which exhibit buffering. See part (a) of the proof in the Appendix.

period 2 either. These period 1 strategies imply, of course, that firm 2 sells out its capacity in period 1 and that firm 1 monopolizes period 2 demand. In other words, firm 1 buffers firm 2 in the first period to tie up its capacity in the second.

The subcase in which $1 < \Delta < 1.5$ is more complicated in that it involves both firms using mixed strategies over a common support $(\underline{p}, u]$. The infimum, $\underline{p}$, once again makes firm 1 indifferent between winning at that price and naming the price u:[12]

$$\underline{p}Q + u(2Q - 2K)\frac{(2K - Q)}{K}$$

$$= u(Q - K) + u(Q) \Leftrightarrow \underline{p} = \frac{u(2\Delta^2 - 4\Delta + 3)}{\Delta}$$

Note that while this infimum initially decreases as the parameter Δ increases from 1 to 1.22, the two firms' expected profits both increase monotonically with Δ (i.e., with industry capacity utilization).

Starting at this infimum, the two firms name prices no greater than u according to the mixed strategies summarized in the following probability distributions:

$$\Phi_1(p) = \frac{p - \underline{p}}{p - u(2\Delta - 2)}$$

$$\Phi_1(p) = \frac{(p - \underline{p})\Delta}{p - u(2\Delta^2 - 5\Delta + 4)}$$

It is straightforward to check that with $\Delta < 1.5$, $\Phi_2(p) > \Phi_1(p)$ $\forall$ $p \in$ $(\underline{p}, u)$: the larger firm's prices stochastically dominate the smaller firm's in a first-order sense. More often than not, the effect is to exhaust entirely the smaller firm's capacity in the first period. In other words, the larger firm effectively buffers the smaller firm by letting the latter build up a disproportionate backlog (in period 1) before the large firm wins a greater share of orders (in period 2).[13]

---

[12] It is easy to show that this price is greater than the price at which firm 2 would be indifferent between winning in period 1 as opposed to losing with the price u.

[13] We use the term 'buffering' to suggest that the large firm adopts a mixed pricing strategy such that the distribution of its prices stochastically dominates in the first order the distribution adopted by the small firm. Because prices are drawn probabilistically from these distributions, the large firm's

Finally, there is the subcase in which $\Delta \geq 1.5$. Here total demand exceeds total capacity so both firms sell out at the price of u. As in the case of very low demand ($\Delta \leq 0.5$), there is no buffering.

Multiperiod strategic models

Do the strategic buffering effects identified in the two-period model hold up in multiperiod models, i.e., models in which competitors have more than two opportunities to set prices? While a general answer to this question is beyond the scope of this paper, affirmative answers can be given for two special kinds of multiperiod models.

First consider a model similar to the one in the previous subsection except that the $2Q$ customers arrive one by one instead of in two batches. The duopolists bid for the business of each customer as it arrives. This sort of customer-per-period model has been analyzed by Griesmer and Shubik (1963) and Dudey (1992). The state-space equilibria (i.e., the equilibria that arise when firms condition their strategies on state variables such as backlogs or available capacity) involve an extreme version of buffering: the larger firm lets its smaller rival sell out first by winning the first K orders and must be content with the remaining $2Q - K$. Because customers arrive sequentially, each negotiation is a small version of the two-period game described in the prior section. The smaller firm continues to win orders until its residual capacity is exhausted. The large firm then begins to book orders.

The state-space restriction on equilibria may not be reasonable when interactions are repeated; firms may condition their behavior on variables other than backlogs or available capacity. In infinitely repeated games, firms can use rewards and punishments to achieve almost any feasible and individually rational set of payoffs, especially if discount rates are low. Such 'supergames' introduce so many additional equilibria that their analysis tends to focus on stationary structural conditions and stable outcomes. We shall adopt this focus as well. Consider a supergame in which $\Delta = 1$ (a particularly interesting parametric possibility since it demarcates the two qualitatively distinct subcases of buffering identified in the prior subsection. Normalize K so that it equals

---

actual price may not always be higher than that of the small firm.

one as well. Then per-period demand is one unit and the two firms' total capacities are, respectively, two units and one unit.

With production taking one period, the larger firm will get to employ at least one unit of capacity over any two successive periods; the question is whether it should try to employ both. Under the assumption of stationarity, the answer is negative because a strategy by the larger firm of consistently employing both units induces the smaller firm to price at its marginal cost (i.e., 0). In contrast, a strategy of allowing the smaller firm to win whenever it has available capacity allows the larger firm to keep a unit of capacity employed at a price of *u*. In terms of backlogs, the larger firm optimally prices to lose whenever the smaller firm's order backlog is zero. The larger firm prices to win whenever the smaller firm's order backlog is one period long.

To summarize, the two-period model, the customer-per-period model, and (under auxiliary assumptions) the infinitely repeated model suggest that with strategic behavior the difference between the market leader's price and the industry average price should be negatively related to the smaller firm's backlog. This hypothesis can be tested against the nonstrategic hypothesis that the leader's price premium will be negatively related to the leader's own backlog level and positively related to at least one of its competitors' backlog levels.

EMPIRICAL ANALYSIS

The idea that the larger competitor will buffer the industry can be formalized in the context of the large turbine generator industry in terms of the following equation:

$$p_{GE} - p_{IND} = \beta_1 + \beta_2 \text{BACKLOG}_{GE}$$
$$+ \beta_3 \text{BACKLOG}_{WH} + \beta_4 \text{BACKLOG}_{AC} \quad (1)$$

where $p_{GE} - p_{IND}$ is the difference between General Electric's average price and the industry average price in the quarter; BACKLOG_{GE} is General Electric's backlog in the quarter, BACKLOG$_{WH}$ is Westinghouse's backlog, and BACKLOG$_{AC}$ is Allis-Chalmers' backlog.

The hypothesis that the firms acted strategically implies the following inequalities: $\beta_2 \geq 0$, $\beta_3 \leq 0$,

and $\beta_4 \leq 0$. This is tested against the null hypothesis that the firms did not act strategically: $\beta_2 < 0$, $\beta_3 > 0$, and $\beta_4 > 0$.

The data used to test these hypotheses are drawn from Sultan (1975:232, chart 13.2), which is reproduced here, and Sultan (1974:282, chart 9.1). We deplotted these figures after unsuccessfully attempting to obtain the original data from Sultan himself, the courts, and the companies involved in the suits. In order to minimize the effects of measurement error, we prefer to use a logit specification in which the dependent variable is a dummy equal to 1 if General Electric charged a premium over its competitors and zero otherwise.

The results reported for the logit specification in the first column of Table 1 indicate that General Electric buffered Westinghouse when Westinghouse's backlog was relatively low; this pattern is consistent with the hypothesis of strategic as opposed to nonstrategic behavior. The same estimate yields signs on the coefficients for General Electric's backlog and Allis-Chalmers' backlog that are insignificant, indicating that General Electric may have keyed its pricing strategy on Westinghouse's backlog, in a way consistent with the theory developed in the previous section. An analysis that excludes Allis-Chalmers (in column 2) suggests that Westinghouse's strategy may have been influenced to a greater extent by the presence of Allis-Chalmers: the coefficient on Westinghouse's backlog retains its sign but changes in value when Allis-Chalmers is omitted from the analysis.[14]

We also conducted generalized-least-squares analysis of Equation 1 with the level of GE's price premium as the dependent variable. (This analysis is the OLS estimate corrected for serial correlation.) Although theory suggests that the extent of General Electric's price premium would not affect the outcome of bidding situations, we ran the tests under the assumption that a greater price premium might contain information about the extent to which General Electric and its rivals wanted to avoid mistakes that might arise if their bids were not ranked in the

---

[14] As noted earlier, Allis-Chalmers exited the industry during the period under study. Westinghouse's pricing strategy with respect to Allis-Chalmers may have been affected on the margin by this change in structure.
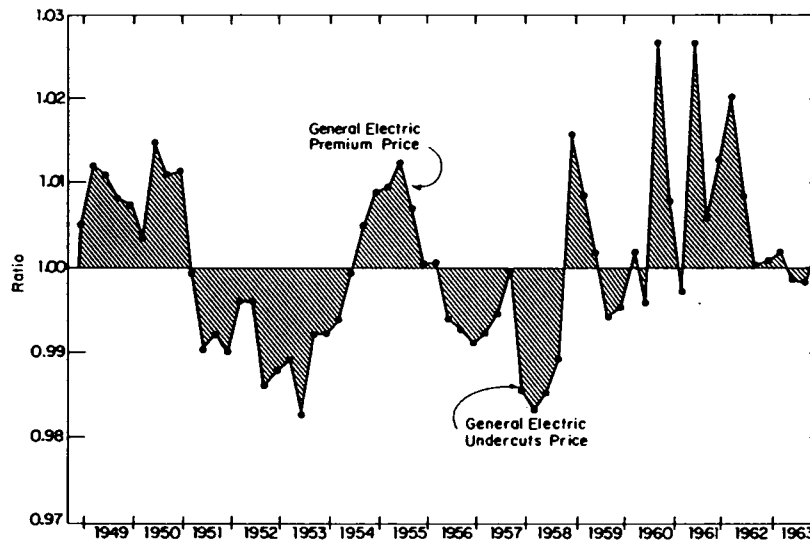
Figure 1. General Electric's price relative to industry average price, 1948–63. Reprinted by permission of Harvard Business School Press from *Pricing in the Electrical Oligopoly*, Vol. 2, by Ralph G. M. Sultan. Boston: 1975, p. 232. Copyright © 1975 by the President and Fellows of Harvard College

Table 1. Impact of relative prices on backlogs

	(1)	(2)
BACKLOG$_{GE}$	−0.2090	−0.2531
	(0.189)*	(0.085)
BACKLOG$_{WH}$	−0.8692	−0.5566
	(0.007)	(0.043)
BACKLOG$_{AC}$	1.182	
	(0.022)	
cons	8.997	9.194
	(0.002)	(0.002)
Number obs.	52	52
Prob $> X^2$	0.0000	0.0000

*Prob $> |t|$ in parentheses.

Table 2. Supplementary GLS analysis of the impact of relative prices on backlogs

	(1)	(2)
BACKLOG$_{GE}$	0.1827	0.1057
	(0.751)*	(0.856)
BACKLOG$_{WH}$	−2.802	−2.389
	(0.009)	(0.014)
BACKLOG$_{AC}$	1.062	
	(0.416)	
cons	14.294	
	(0.006)	
Number obs.	51	51
R^2	0.235	0.210

*Prob $> |t|$ in parentheses.

intended order.[15] The GLS regressions corresponding to Equation 1 are reported in columns (1) and (2) of Table 2. This test provides strong corroborating evidence that General Electric buffered Westinghouse, as game theory suggests.

[15] Such mistakes might arise because firms had different interpretations of the technical requirements for a turbine, for example. Also note that the theory stipulates that General Electric pricing strategy dominates Westinghouse's pricing strategy in the first order. The data here describe relative prices on average over quarterly intervals. Thus, the data on the relationships between pricing strategies may be interpreted in terms of tendencies to buffer in prices.

DISCUSSION

We have established that strategic analysis—that is, a self-consciously interactive and 'conservative' pricing strategy for the market leader—has greater explanatory power than non-strategic analysis with respect to the dependence of relative prices on backlog levels in the U.S. large turbine generator industry between 1951 and 1963. Our conclusion rests, as does almost all of strategic analysis, on the concept of game-theoretic equilibrium. This style of explanation is based on the presumption that equilibrium-related reasoning

has a discernible influence on the outcomes observed in actual markets. It raises a question about game theory that is of central interest to strategic management: under what conditions is equilibrium actually likely to arise (see Camerer, 1991)?

By way of addressing this question, we should note that the large turbine generator case was not randomly selected. We picked it because we thought that it displayed some of the attributes that are most likely to increase the payoff to self-consciously interactive reasoning and strategy selection. In other words, we think that students of other cases can improve their assessments of how much game-theoretic analysis contributes to their case studies by comparing them with large turbine generators along the following indicators that affect one or both of the two possible routes to equilibrium, introspection and learning.

1. *Concentrated competition.* The two largest manufacturers of large turbine generators controlled more than 90 percent of the U.S. market, with a third competitor—who seems to have been 'straitjacketed' since it exited in 1962 after years of operating losses— accounting for nearly all of the remainder. Such concentration is likely to amplify the marginal effects of one rival's choices on another's payoffs, increasing the importance of careful competitive analysis. Additional significance might be attached to the inference that there were only two competitors with the large turbine generator industry with significant (nonstraitjacketed) stategic discretion: there is a sense in which the conditions required for the realization of an equilibrium via player-by-player introspection are weaker in two-player games than in general *n*-player games (e.g., Aumann and Brandenburger, 1995). It is probably no accident that many of the teaching cases currently being used to acquaint strategy practitioners or apprentices with game theory feature (near) duopolies: 'Polaroid–Kodak' (Merry, 1976), 'British Satellite Broadcasting versus Sky Television' (Ghemawat, 1993), 'Bitter Competition: Holland Sweetener Company versus NutraSweet' (Brandenburger, 1993), and, of course, 'General Electric vs. Westinghouse in Large Turbine Generators' (Porter and Ghemawat, 1980).

2. *Mutual familiarity.* The competitors in large turbine generators, particularly GE and Westinghouse, were familiar with each other in the sense that they had decades of experience competing with each other in the turbine market and in several other electrical products. While this description of mutual familiarity is loose, it has affinities with the more stringent restriction of mutual knowledge of strategies that is required to ensure equilibrium through introspection (Aumann and Brandenburger, 1995). Note that the gap between mutual familiarity and mutual knowledge of strategies was likely to have been narrowed, in this particular case, by preplay communication and by the distinct but consistent strategic roles selected by General Electric and Westinghouse. In addition, it is plausible to think that mutual familiarity increases the likelihood and speed of convergence of adaptive, dynamic processes of learning by competitors to reach an equilibrium.

3. *Repeated interaction.* There were at least two distinct senses in which the pricing interactions among the competitors in large turbine generators were repeated. First, short-run pricing decisions recur with more frequency than most other types of commitment decisions (which has the useful side effect of facilitating statistical testing). Second, the multimarket contact between General Electric and Westinghouse can be seen as further increasing the number of pairwise interactions. Such repetition coupled with structural stability increases the likelihood that competitors will learn to play a particular equilibrium as a result of an adaptive, dynamic process of learning—even if they start without mutual knowledge of each other's strategies. Put differently, equilibrium is a more plausible outcome in repeated interactions than in one-shot interactions. In addition, repetition typically expands the set of pay-off vectors that are sustainable in equilibrium and thereby effectively decreases the likelihood of observing out-of-equilibrium behavior.

Having cited these three rather general influences on the likelihood and speed of convergence to equilibrium, we should add that the outcomes of actual market games may be heavily influenced by idiosyncratic, case-specific circumstances. In

large turbine generators, for instance, much of the decline in pricing discipline that accompanied declining capacity utilization in the late 1950s and early 1960s seems attributable to informational imperfections: uncontrollable errors—due to customized, complex product specifications—in calculating book prices (and their discounted levels) and imperfect information about the prices negotiated by rivals with investor-owned utilities.

The importance of informational considerations is corroborated by developments subsequent to the period studied in this paper. In 1963, General Electric changed its pricing policy to adhere strictly to the levels published in a simplified price book adjusted by a prespecified multiplier. After a period of learning that lasted about 1 year, the book prices and multipliers for both General Electric and Westinghouse (Allis-Chalmers had exited) came to coincide, and remained the same until the early 1970s, when the two were challenged with another antitrust suit. In the context of our models, it is tantalizing to conjecture that the new pricing policy permitted the large turbine generator manufacturers to exploit more effectively the possibility of tacit collusion via 'noncooperative' strategies that were identified by the customer-per-period model.

CONCLUSIONS

The theoretical and empirical analysis in this paper has made a number of contributions. First, it has highlighted the role that backlogs can play in affecting competitive behavior. And it has done so in a way that illustrates the potential pay-offs to conjoining theoretical and empirical analysis: looking at the real world can suggest additional variables that are worth analyzing theoretically.[16] Given the empirical salience of backlogs, however, the present analysis can only be billed as being exploratory. Two particularly promising avenues for further research involve additional modeling (under a wider range of assumptions) of the effects of backlogs on incentives to compete and additional studies of industries in which backlogs are important.

Second, our analysis has emphasized the fact that even pricing decisions, which are often treated as being easily reversible, can have significant short-run commitment value. This is consistent with, and a contribution to, recent empirical work in industrial organization that highlights price-related rigidities (e.g., Carlton, 1989). It also reinforces an emerging theme in strategic management: that it is important to attend to the commitment or irreversibility that is integral to most competitively significant moves (Caves, 1984; Ghemawat, 1991).

Third, our analysis has indicated the importance of recognizing that competition among firms occurs across multiple variables, which may have varying characteristics. This is an important theme in strategic management that has received little empirical attention.[17] The advantages of looking at buffering over both backlogs and capacities in order to understand the pattern of interactions in the large turbine generator industry illustrates its importance.

Fourth, this case study has illustrated the pay-offs to allowing for strategic (i.e., self-consciously interactive) behavior. While game-theoretic analysis entails significant complexity, it can also deliver significant benefits. The benefits of such analysis are particularly likely to exceed the costs in cases that share some of the features of the large turbine generator industry: concentrated competition, mutual familiarity, and repeated interaction.

REFERENCES

Arvan, L. (1985). 'Some examples of dynamic Cournot duopoly with inventory', *RAND Journal of Economics*, **16**(4), pp. 569–578.

---

[16] These and other benefits of the detailed, longitudinal study of cases of competitive interaction are discussed in more detail in Ghemawat (1997).

[17] For exceptions, see Sutton (1991), Gasmi, Laffont, and Vuong (1992), and McGahan (1995).

Aumann, R. and A. Brandenburger (September 1995). 'Epistemic conditions for Nash equilibrium', *Econometrica*, **63**, pp. 1161–1180.

Brandenburger, A. (1993). 'Bitter competition: The Holland Sweetener Company versus NutraSweet', Harvard Business School Case Services #794-079 to 794-085.

Brock, W. A. and J. A. Scheinkman (July 1985). 'Price setting supergames with capacity constraints', *Review of Economic Studies*, **52**, pp. 371–382.

Camerer, C. F. (1991). 'Does strategy research need game theory?' *Strategic Management Journal*, Winter Special Issue, **12**, pp. 137–152.

Carlton, D. W. (1989). 'The theory and the facts of how markets clear: Is industrial organization valuable for understanding macroeconomics?' In R. Schmalansee and R. Willig (eds), *Handbook of Industrial Organization* North-Holland, New York, pp. 909–946.

Caves, R. E. (May 1984). 'Economic analysis and the quest for competitive advantage', *American Economic Review*, **74**, pp. 127–132.

Dudey, M. (November 1992). 'Dynamic Edgeworth–Bertrand competition', *Quarterly Journal of Economics*, **107**, pp. 1461–1477.

Dudey, M. (1994). 'Inventory dynamics and price wars', Rice University working paper (December, rev. 9/96).

Gal-Or, E. (1984). 'Price dispersion with uncertain demand', *International Economic Review*, **25**(2), pp. 441–458.

Gasmi, F., J-J. Laffont and Q. Vuong (1992). 'Economic analysis of collusive behavior in a soft drink market', *Journal of Economics and Management Strategy*, **1** (Summer), pp. 277–311.

Ghemawat, P. (1986). 'Capacities and prices: A model with applications', Harvard Business School working paper.

Ghemawat, P. (1991). *Commitment: The Dynamic of Strategy*. Free Press, New York.

Ghemawat, P. (1993). 'British Satellite Broadcasting versus Sky Television', Harvard Business School Case Services #9-794-031.

Ghemawat, P. (1997). *Games Businesses Play: Cases and Models*. MIT Press, Cambridge, MA.

Green, E. J. and R. H. Porter (January 1984). 'Non-cooperative collusion under imperfect price information', *Econometrica*, **52**, pp. 87–100.

Griesmer, J. H. and M. Shubik (June 1963). 'Toward a study of bidding processes, Part II: Games with capacity limitations', *Naval Research Logistics Quarterly* **10**, pp. 151–173.

Kreps, D. and J. A. Scheinkman (1983). 'Quantity precommitment and Bertrand competition yield Cournot outcomes', *Bell Journal of Economics*, **14** (Autumn), pp. 326–337.

MacAvoy, P. (1969). *Economic Strategy for Developing Nuclear Breeder Reactors*. MIT Press, Cambridge, MA.

Maskin, E. and J. Tirole (May 1988). 'A theory of Dynamic Oligopoly II: Price competition, kinked demand curves, and Edgeworth cycles', *Econometrica*, **56**, pp. 571–590.

McGahan, A. M. (October 1995). 'Cooperation in prices and capacities: Trade associations in brewing after repeal', *Journal of Law and Economics*, **38**, pp. 521–559.

Merry, G. W. (1976). 'Polaroid–Kodak', Harvard Business School Case Services #376-266.

Osborne, M. J. and C. Pitchik (April 1986). 'Price competition in a capacity constrained duopoly', *Journal of Economic Theory*, **38**, pp. 238–260.

Porter, M. E. and P. Ghemawat (1980). 'General Electric vs. Westinghouse in large turbine generators (A)', Harvard Business School Case Services #9-380-128.

Rotemberg, J. J. and G. Saloner (1986). 'A supergame-theoretic model of price wars during booms', *American Economic Review*, **76**, pp. 390–407.

Rotemberg, J. J. and G. Saloner (1989). 'The cyclical behavior of strategic inventories', *Quarterly Journal of Economics*, **104**, pp. 73–97.

Rumelt, R. P., D. Schendel and D. J. Teece (1991). 'Strategic management and economics', *Strategic Management Journal*, Winter Special Issue, **12**, pp. 5–29.

Scherer, F. M. (1980). *Industrial Market Structure and Economic Performance*. Rand McNally College Publishing, Chicago, IL.

Staiger, R. and F. Wolak (1992). 'Collusive pricing with capacity constraints in the presence of demand uncertainty', *RAND Journal of Economics*, **23**, pp. 203–220.

Sultan, R. (1974). *Pricing in the Electrical Oligopoly*, Vol. 1. Division of Research, Graduate School of Business Administration, Harvard University, Boston, MA.

Sultan, R. (1975). *Pricing in the Electrical Oligopoly*, Vol. 2. Division of Research, Graduate School of Business Administration, Harvard University, Boston, MA.

Sutton, J. (1991). *Sunk Costs and Market Structure*. MIT Press, Cambridge, MA.

Tirole, J. (1988). *The Theory of Industrial Organization*. MIT Press, Cambridge, MA.

Ware, R. (February 1985). 'Inventory holding as a strategic weapon to deter entry', *Economica*, **52**, pp. 93–101.

Zarnowitz, V. (November 1962). 'Unfilled orders, price changes, and business fluctuations', *Review of Economics and Statistics*, **44**, pp. 367–394.

APPENDIX

The characterization of the equilibrium outcomes to competition in the first period is similar to, as well as built on, the characterization of the second-period subgame in Ghemawat (1986). Therefore the proof will only be sketched here and will focus on the intermediate levels of capacity utilization $(0.5 < \Delta < 1.5)$ in which mixed strategy equilibria arise. Split this range

up into the two subcases identified in the text:

(a) $0.5 < \Delta \leq 1$

In this subcase if firm 1 wins in period 1 with price p, it meets all the demand in that period, and enters the second period with residual capacity of $2K - Q$, compared to a capacity of K for firm 2. Since each firm has enough capacity to serve second-period demand all by itself, operating profits for each firm in period 2 will be zero, implying total operating profits, summed across the two periods of pQ and 0 respectively for the two firms.

In contrast, if firm 2 wins in period 1 with price p, it meets all the demand in that period and enters the second period with residual capacity of $K - Q$, which is less than second-period demand as well as firm 1's capacity of $2K$. As a result, positive operating profits are expected by both competitors in the second period: according to the characterization in Ghemawat (1986), they equal $u(2Q - K)$ and $u(2Q - K)(K - Q)/Q$ for firms 1 and 2 respectively (in addition to the pQ that firm 2 earns in period 1).

Given this characterization, the minimum price at which firm 1 is willing to bid to win in the first period as opposed to naming u, $\underline{p}_1$, is given by

$$\underline{p}_1 Q = u(2Q - K) \Rightarrow \underline{p}_1 = \frac{u(2\Delta - 1)}{\Delta}$$

Firm 2, in contrast, makes nothing if it loses in the first period, so it is willing to go as far down in price as 0 in order to win.

It proves impossible to use the methods developed by Kreps and Scheinkman (1983) to derive properly mixed equilibrium pricing strategies for both firms: such strategies would leave both firms with a positive probability of undercutting the other, whereas being undercut in period 1 would be devastating for firm 2 and, because of interactive effects, a Pyrrhic victory for firm 1. To avoid this outcome, firm 2 employs the pure strategy of naming a price, $\underline{p} \in (0, \underline{p}_1)$ with probability 1. And firm 1 checks firm 2's temptation to try naming a price higher than $\underline{p}$ by adopting a (possibly) properly mixed pricing strategy at least as aggressive (in the sense of first-order stochastic dominance) as the one derived below.

To be precise, firm 1's pricing strategy should be at least as aggressive as the one that will shrink the incremental pay-offs to firm 2 from naming prices higher than $\underline{p}$ down to zero. It must therefore be the case that

$$(1 - \Phi_1(p)) \left[pQ + u(2Q - K) \left(\frac{K - Q}{Q} \right) \right]$$

$$\leq \underline{p}Q + u(2Q - K) \left(\frac{K - Q}{Q} \right)$$

$$\Rightarrow \Phi_1(p) \geq \frac{(p - \underline{p})Q}{pQ + u(2Q - K) \dfrac{K - Q}{Q}} \forall p > \underline{p}$$

Any strategy that is this aggressive will do the job, although the extreme case in which firm 1 also names $\underline{p}$ with positive probability requires additional tie-breaking rules.

Note that there is a continuum of equilibria in period 1, a fact which one of the referees called to our attention (also see Dudey, 1994). However, each of them involves the larger firm buffering its smaller rival with probability 1.

(b) $1 < \Delta < 1.5$

In this subcase, if firm 1 wins in period 1, it meets all the demand in that period and enters period 2 with a residual capacity of $2K - Q$, which is smaller than firm 2's capacity of K. Given the proof in Ghemawat (1986), the two firms' expected operating profits in the second period subgame are given, respectively, by $u(2Q - 2K) \left(\dfrac{2K - Q}{K} \right)$ and $u(2Q - 2K)$.

In contrast, if firm 2 wins in period 1, it sells out in that period, and firm 1 has a monopoly in period 2, off which it earns uQ.

We advance the analysis by calculating the minimum prices that the two competitors anticipating these pay-offs in period 2 are willing to bid to win in period 1. For firm 1,

$$\underline{p}_1 Q + u(2Q - 2K) \frac{2K - Q}{K} = u(2Q - K) \Rightarrow \underline{p}_1$$

$$= \frac{u(2\Delta^2 - 4\Delta + 3)}{\Delta}$$

And for firm 2,

$$\underline{p}_2 K = u(2Q - 2K) \Rightarrow \underline{p}_2 = u(2\Delta - 2)$$

For $1 < \Delta < 1.5$, $\underline{p}_1 > \underline{p}_2$, implying that the common infimum is given by

$$\underline{p} = \max(\underline{p}_1, \underline{p}_2) = \frac{u(2\Delta^2 - 4\Delta + 3)}{\Delta}$$

It is now easy to construct the properly mixed equilibrium pricing strategies for both firms. Firm 2 should, by naming any price, p, in the interval $(\underline{p}, u)$, expect to make exactly as much as it does by naming $\underline{p}$:

$$\Phi_1(p)u(2Q - 2K) + (1 - \Phi_1(p))pK$$
$$= \underline{p}K \Rightarrow \Phi_1(p) = \frac{p - \underline{p}}{p - u(2\Delta - 2)}$$

From firm 1's perspective, it should expect to make as much by announcing any price p as it does by naming u:

$$\Phi_2(p)[p(Q - K) + uQ]$$
$$+ (1 - \Phi_2(p))\left[pQ + u(2Q - 2K)\frac{2K - Q}{K} \right]$$
$$= u(2Q - K)$$
$$\Rightarrow \Phi_2(p) = \frac{u(2\Delta^2 - 4\Delta + 3) - p\Delta}{u(2\Delta^2 - 5\Delta + 4) - p}$$
$$= \frac{(p - \underline{p})\Delta}{p - u(2\Delta^2 - 5\Delta + 4)}$$

It is easy to check that $\Phi_2(p) > \Phi_1(p) \forall p \in (\underline{p}, u)$ Q.E.D.