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Pre-Emptive Investment Behaviour and Industry Structure

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ABSTRACT

Models of strategic investment behaviour show that an incumbent firm by making pre-emptive capital investments may restrict the entrant's size and increase its market share, or deter entry and limit the number of firms in the industry. The existing empirical literature on testing strategic investment models offers inconclusive evidence. This paper takes a different approach and focuses on the incentives of pre-emptive investments and shows that upward and downward adjustment costs of capital will be important determinants of the desirability and credibility of pre-emptive investments. This in turn posits a link between the upward and downward adjustment costs and industry structure as measured by concentration and the number of firms. While the empirical analysis is best viewed as suggestive and offering an alternative approach to examining strategic investment behaviour, the empirical results, based on a large sample of US manufacturing industries, reveals evidence in favour of such a relationship.

1. Introduction

MODELS OF STRATEGIC INVESTMENT behaviour by Dixit (1980, 1982) and Spence (1977, 1979) show that an incumbent firm by committing to capacity investment in the pre-entry stage may secure greater post-entry output. Thus the incumbent may increase its market share by pre-emptive investments. Alternatively, by engaging in pre-emptive investments, the incumbent may be able to deter entry resulting in a lower number of firms (competitors) in the industry. The hallmark of the above models is that installed capacity should represent a credible commitment (i.e. the rival will buy the threat). With this in mind, these models assume that capital invested is completely irreversible (i.e. totally sunk), signaling credibility. There has been some debate about the rationality and likelihood of pre-emptive investment behaviour. However, evidence presented by Smiley (1988) is revealing. Smiley's analysis, based on a questionnaire survey, shows that for existing mature products 38 percent of the respondents acknowledged using capacity 'occasionally to frequently' as a pre-emptive instrument. The corresponding figure for new products was 42 percent. Smiley's evidence appears to indicate clearly that businesses do in fact attempt to garner market share and/or deter entry by making strategic capital investments. In light of this, and the theoretical results supporting capacity investment as a pre-emptive instrument, it is useful to develop alternative techniques for testing models of pre-emptive investments.

The existing econometric literature on testing strategic investment models is somewhat sparse. Hilke (1984) and Masson and Shaanan (1986) relate industry unutilized capacity to entry. Both find that excess capacity is related to lower entry, but the evidence is weak.[2] Lieberman (1987a, 1987b) examined investment behaviour around points of entry in a sample of chemical processing industries. He found that only in a few instances did incumbent firms hold excess capacity for pre-emptive reasons. Singh *et al.* (1998) note that excess capacity as a strategic instrument is not widely used. These studies offer a contrast to the one by Smiley (1988). In summary, there is mixed evidence on firms using pre-emptive investments to gain market share and deter entry.

Our primary objective in this paper is to outline an alternative methodology for examining strategic investment behaviour and its potential effects. At the heart of the strategy is an attempt to isolate some key parameters that are likely to influence firms' pre-emptive investment behaviour and then link these to observed industry structure variables related to concentration and the number of firms. The capital adjustment cost assumptions in the model by Dixit (1980), and several others, are as follows: downward capital adjustment costs are infinite (i.e., all invested capital is sunk) and upward capital adjustment costs are zero; the only cost for expanding capacity is the linear per unit cost of buying capacity. We note two points. First, whether capacity can added without incurring upward adjustment costs is purely an empirical matter and will depend on industry-specific production technology and the nature of capital markets. Second, contrary to the assumption of Dixit's model, all installed capital may not be sunk. The extent to which capital is sunk will again depend on industry-specific conditions related to production technology and input and capital markets. We argue that if firms operate in an environment where investments are subject to upward adjustment costs, the magnitude of this cost will influence the desirability of acquiring excess or strategic capacity. The higher is this cost, the lower will be the likelihood of pre-emptive investments. On the other side, if installed capital is less sunk implying that incumbents can get rid of capital without incurring much losses, then installed capital will not represent a very credible commitment. So the costs of adjusting capital downwards, or sunk costs, will influence the credibility of installed capital and the likelihood of pre-emptive behaviour. Overall, the likelihood of pre-emptive investments will be determined by the interplay of both desirability (how expensive is installing extra capacity) and credibility (will the rival buy the threat).

A key problem with empirical examination of strategic investment models is that this type of behaviour typically cannot be observed and one has to look for other ways of identifying patterns that may signal such behaviour. The papers by Hilke (1984), Masson and Shannon (1986), Smiley (1988) and Lieberman (1987a, 1987b) take different approaches. The approach is to dwell on some of the key parameters related to upward and downward adjustment costs of capital and link it to the observed industry structure. In section 2 we outline the theory linking adjustment costs to pre-emptive investments and highlight the links to industry structure. In section 3 we measure of adjustment and sunk costs. Section 4 presents the estimation results and section 5 concludes noting some implications and limitations.

2. Theoretical considerations

Our objective is not to propose new theory, but merely to outline some issues that will guide the empirical analysis. We begin by summarizing the basic features of Dixit's (1980) model in section 2.1. In section 2.2 we consider a simple extension incorporating convex capital adjustment costs and highlight the differences between the models. Section 2.3 we outline the empirical predictions and set the stage for measurement and estimation.

2.1 Linear costs

Consider a two-period two-firm model (Dixit, 1980). Capital once installed is assumed to be irreversible; i.e., capital investments represent completely sunk costs. This is needed to signal credibility of capital investments. The market demand schedule is linear

$$p = a - bQ \tag{1}$$

and firms face linear costs given by (to simplify, fixed costs are assumed to be zero)

$$C_i = mq_i + rk_i \tag{2}$$

where 'm' is the constant average variable cost of producing output, and r is the constant unit cost of buying capacity. Without loss of generality we assume $m = 0$. To simplify the algebra and focus on the main issue, let $a\text{-}r = 1$ and $b = 1$. The profit functions for the two firms are

$$\begin{aligned} \pi_1 &= k_1(1 - k_1 - k_2) \\ \pi_2 &= k_2(1 - k_1 - k_2) \end{aligned} \tag{3}$$

In a simultaneous-move Nash equilibrium, the capacities are $k_1 = k_2 = 1/3$. In a sequential-move game where, arbitrarily, firm 1 has the first-mover-advantage, the equilibrium capacities are k_1 = 1/2 and k_2=1/4. This establishes the basic result that if a firm has the first-mover-advantage, then it can restrict the rival's size and gain market share by making 'pre-emptive' investments. For the subsequent discussion, we note the following key features of this model:

(a) capacity expansion costs are linear;

(b) the are no costs of 'adjusting' capacity upwards; and

(c) downward adjustment costs are infinite implying all capital investments are completely sunk.

2.2. A simple extension with convex capital-adjustment costs

There is an extensive literature on capital adjustment costs faced by firms as they expand (contract) capacity. Upward adjustment costs can be significant. In their classic study, Holt *et al.* (1960) provide a suggestive list of adjustment costs that might be incurred. Changes in capacity involve costs related to setting up different shop and machine load schedules, change in controls on stock records, different purchase contracts (possible involving cancellation charges or premiums for expediting special fast deliveries), larger worker training costs, among others. Galeotti (1987), for example, shows that upward adjustment costs are significant and can amount to close to 60 percent of the unit cost of investment. These considerations indicate that when modeling strategic investment, it is important to consider upward adjustment costs. The magnitude of the adjustment costs will depend on the nature of industry-specific capital, technology and potentially other factors related to input and product markets. Below we consider an environment where firms can adjust capacity subject to convex adjustment costs. Holt et al. argue that, in general, convex adjustment costs are a reasonable approximation. The basic purpose is to highlight the effects of upward adjustment costs and derive testable implications.

Assume investment costs are strictly convex in the rate of investment. As before, for simplicity we assume m = 0. The cost function incorporating quadratic adjustment costs is

$$C_i = rk_i + \phi k_i^2/2 \tag{4}$$

where ϕ (with $0 \leq \phi \leq 1$) is the adjustment cost parameter and r is the fixed unit cost of buying capacity. Here, higher values of ϕ signal higher adjustment costs. Due to the quadratic nature of the cost function, ϕ is the adjustment cost parameter for both upward and downward adjustment. As before, assuming a-r=1, and b=1, the profit functions are

$$\begin{aligned} \pi_1 &= k_1[1 - k_1(1+\phi) - k_2] \\ \pi_1 &= k_1[1 - k_1(1+\phi) - k_2] \end{aligned} \tag{5}$$

In a sequential-move game where firm 1 has the first-mover advantage, the equilibrium capacities are

$$k_1 = (1+2\phi)\{4(1+\phi)^2 - 2\}^{-1}$$
$$k_2 = [2(1+\phi)]^{-1}[1- (1+2\phi)\{4(1+\phi)^2 - 2)\}^{-1}] \tag{6}$$

From the expression for k_1 we get

$$\delta k_1/\phi = - \{4+8\phi+16\phi^2\}/\{4(1+\phi)^2 - 2\}^2 < 0 \tag{7}$$

When ϕ=0 the capacities are the same as in the linear case: k_1=0.5 and k_2 =0.25. Thus the market shares of firms 1 and 2 are 66 per cent and 33 per cent, respectively. Now consider increasing ϕ from 0 to 1. The absolute capacities decline for both firms. But, in the limiting case, the market shares of firms 1 and 2 are now 52 percent and 48 percent, respectively. Thus higher upward adjustment costs of capital ϕ lower the incentive to install additional pre-emptive capacity by firm 1, leaving a relatively greater share for firm 2. One way to think about this outcome is to say that lower pre-emptive capacity installed by the incumbent (or the dominant firm) leaves open 'relatively' more space in the market for the follower firm or the potential entrant(s).

While the above model is written in terms of two firms — a leader and a follower in the sequential move game, we can conceptualize the problem in several alternative ways. First, one can add more firms in the above setup and the results go through.[4] The key requirement is the presence of an incumbent leader who has the first-mover advantage. Second, the problem can be thought of in terms of an incumbent and a potential entrant (or multiple entrants), i.e. entry deterrence. The above results and intuition go through.[5] Overall, we are able to generate predictions about market shares (or industry concentration) and the number of firms, which we discuss later.

2.3. Desirability versus credibility of strategic investments

The desirability of strategic investments is conditioned on costs. In Dixit's linear model with no upward adjustment costs, if the per unit capacity cost '*r*' rises, then the desirability of pre-emptive investment falls. In the extension with adjustment costs, ϕ provides an important disincentive. In short, the desirability of strategic investment is a *decreasing* function of ϕ; in industries where ϕ is high, the incentive to engage in pre-emptive behaviour is likely to be lower.

As an alternative to Dixit's model, we assumed that adjustment costs are convex and symmetric in both upward and downward adjustment. Therefore low (high) values of the parameter ϕ indicate low (high) downward adjustment costs of capital. If ϕ is low then capacity is relatively easily reversible and installed capacity will not serve as a credible commitment. If capacity investment is not credible, the incumbent firm will have less incentive to install strategic capacity.[6] On the other hand a high value of f implies that installed capacity is largely irreversible and therefore capacity will serve as a credible commitment. In short, the credibility of installed capacity is an *increasing* function of ϕ. The likelihood of pre-emptive investments will be determined by both desirability (how expensive is installing extra capacity) and credibility (will the rival buy the threat).

2.4 *Industry structure*

In the empirical analysis, we obtain industry-specific estimates of the adjustment cost parameter ϕ and obtain proxies for downward adjustment costs, which represent the extent to which capital stock are sunk. We begin by noting a practical issue. The sample contains 267 US manufacturing industries with annual observations on capital stock and related variables over the period 1958-1994. This gives us a total (panel) of 9,879 observations. We examined the capital stock series to tally the number of observations when the industry capital stock increased or decreased, i.e. ΔK^{+} and ΔK^{-} . Roughly 73 per cent of the observations were ΔK^{+} and 27 per cent ΔK^{-} . In addition, for a large number of industries, we did not have any ΔK^{-} observation. All of this implies that the estimate of ϕ will realistically capture the upward adjustment cost of capital.

Given this, for upward adjustment costs we will have an estimate of ϕ. Let Ω be a proxy for downward adjustment costs or the extent of sunk costs. Thus the desirability of strategic investment is influenced by ϕ and the credibility by Ω. The desirability and credibility in turn affect the likelihood of strategic investment, which in turn affects the observed industry structure represented by the industry concentration (CONC) and the number of firms (FIRMS). We get two relationships:

$$\begin{gathered} \mathrm{CONC}_i = \mathrm{f}(\phi_i, \Omega_i, Z_i) \text{ and} \\ \mathrm{FIRMS}_i = \mathrm{g}(\phi_i, \Omega_i, Z_i) \end{gathered} \tag{8}$$

where Z is a vector of other variables that determine CONC and FIRMS. From the discussion of the theory, we have $f_\phi<0$, $f_\Omega>0$, $g_\phi>0$, $g_\Omega<0$. In the section 3 we obtain industry-specific estimates of ϕ, proxies for Ω and the other control variables Z.

3. Measurement

The data appendix provides the details regarding the sample and variables. The dependent variables are given in equation (8): the industry concentration ratio (CONC) and the total number of firms (FIRMS). These data are available for the 5-yearly Census of Manufactures. Thus, we have seven observations for each industry. Since we are interested in the longer-run industry characteristics, for the estimation we use the industry average CONC and FIRMS over the seven years as the dependent variable. Table 1 provides the cross-industry summary statistics, indicating wide cross-industry variation in CONC and FIRMS.

Table 1: Summary statistics

	mean	*std. dev.*
CONC	38.87	20.00
FIRMS	557.85	834.74
$(1-\lambda^{EQP})$	0.9125	0.1172
$(1-\lambda^{CAP})$	0.9116	0.1087
Ω(W)	32.51	29.54
Ω(RENT)	90.14	94.46
Ω(USED)	21.41	37.74
Ω(DEPR)	18.49	4.94
Ω(EK)	0.0093	0.0353
R&D	0.0104	0.0109
ADVT	0.0184	0.0245
GROW	0.0198	0.0250

Industry variable definitions.

CONC:	Four-firm concentration ratio
FIRMS:	Number of firms
$(1-\lambda^{EQP})$:	Estimated equipment-capital adjustment cost parameter
$(1-\lambda^{CAP})$:	Estimated total-capital adjustment cost parameter
Ω(W):	Sunk costs; weighted index
Ω(RENT):	Sunk costs; rental-capital intensity
Ω(USED):	Sunk costs; used-capital intensity
Ω(DEPR):	Sunk costs; depreciation rate
Ω(EK):	Sunk costs; median entry-capital requirement
R&D:	R&D intensity
ADVT:	Advertising intensity
GROW:	Mean rate of industry sales growth

3.1 Adjustment costs

There is a substantial econometric literature on the estimation of factor demand under adjustment costs, see Hendry *et al.* (1983) and Jorgenson (1986). We use a partial-adjustment framework to obtain estimates of the adjustment cost parameter ϕ. The partial-adjustment model is based on quadratic cost minimization where firms, when making their optimal input adjustment decisions, aim to minimize disequilibrium costs and adjustment costs. The disequilibrium costs arise due to lost output and revenue from having input stocks that are sub-optimal. The adjustment costs are incurred when the firm attempts to align actual input stocks to the desired or optimal stocks. The papers by Kennan (1979) and Hendry *et al.* (1983), for example, discuss the theoretical underpinnings and econometric specification of these models. The partial capital adjustment model is given by

$$K_{i,t} - K_{i,t-1} = \lambda(K_{i,t}^{*} - K_{i,t-1}) \qquad 0 \leq \lambda \leq 1 \tag{9}$$

where i and t denote industry and time, K^* the equilibrium (or desired) capital stock, and λ the adjustment cost parameter. High (low) values of λ imply low (high) adjustment costs. From equation (9), the actual adjustment of the capital stock is some fraction λ of the desired adjustment due to the presence of adjustment costs. K^* is not observed and has to be modeled as a function of the relevant driving variables. The accelerator model has been widely used in modeling capital-stock dynamics. We model capital stock adjustments as being primarily driven by firms' expected output trajectory. We utilize a modified accelerator model to proxy K^*. If Q denotes industry output, the desired K^* is a function of future expectations of Q_t^e; the intuition being that if expected output is increasing, firms will have to adjust their capital stock upwards. If Q follows an AR(n) process, then Q_t^e can be replaced by lagged values of Q: $Q_t^e = \Sigma_k \gamma_k Q_{t-k}$, where $k=0,1,2,\ldots,n$.

We augment the basic accelerator model by incorporating additional variables that are likely to affect capacity decisions. In particular, we focus on two variables: the federal funds rate (FFR) and energy prices (ENER). It is well known that various key interest rates are co-integrated with FFR. We use this as a rough proxy for the cost of capital. Since we estimate the partial adjustment model for each industry, the estimated coefficients of FFR are allowed to vary across industries capturing potentially different sensitivity of capital adjustment decisions to FFR. The ideal solution would be to obtain industry-specific time-series on cost-of-capital, but this is beyond the scope of the present paper. Regarding ENER, rising or falling energy prices by driving obsolescence or movements towards machines with different energy-intensities can act as a key driver for capital augmentation or modification decisions. Thus the augmented accelerator model assumes

$$K_{i,t}^{*} = \mathrm{f}(Q_{i,t}^{e}, \mathrm{FFR}_t^{e}, \mathrm{ENER}_t^{e}) \tag{10}$$

Similar to output, assuming that FFR and ENER follow AR(.) processes, we can replace the expected terms by lagged values of FFR and ENER to get

$$K_{i,t}^{*} = \Sigma_k \alpha_k Q_{i,t-k} + \Sigma_l \beta_l \mathrm{FFR}_{t-l} + \Sigma_m \lambda_m \mathrm{ENER}_{t-m} \tag{11}$$

where k, l and m are the appropriate lag lengths. The partial-adjustment model (9) becomes

$$K_{i,t} = (1-\lambda) K_{i,t-1} + \Sigma_k \xi_k Q_{i,t-k} + \Sigma_l \psi_l \mathrm{FFR}_{t-l} + \Sigma_m \tau_m \mathrm{ENER}_{t-m} + \varepsilon_{i,t} \tag{12}$$

where the coefficients on *Q*, FFR and ENER are combinations of the parameters in (11) and the adjustment cost parameter λ. Linking it to the theory discussion, from equations (4) and (12) we have $\phi=(1-\lambda)$; low λ implies high ϕ representing higher adjustment costs. The sample contains 267 SIC 4-digit manufacturing industries and for each industry we have annual time-series data on industry real capital stock and output over the period 1958-1994. We combine this with the aggregate data on FFR and ENER. This allows us to estimate equation (12) for each 4-digit industry. If a particular industry's estimated $(1-\lambda)$ is low (high) - implying that λ is high (low) - then the cost of adjusting capital is low (high).

We estimated equation (12) for the 267 industries using data on industry real equipment-capital stocks as well as real total-capital stock. The experimentation showed that at most two lags of *Q*, FFR and ENER were significant and for several industries, one lag was sufficient. Thus, for parsimony, for each of the 267 industries, we estimated equation (12) with two lags of *Q*, FFR and ENER. Equipment can be highly specialized and often are the key driver of adjustment costs as well as sunk costs. Given this, we obtain two estimates of upward adjustment costs:

(1) $(1-\lambda^{EQP})$ for equipment capital; and
(2) $(1-\lambda^{CAP})$ for total capital.

We took a close look at the standard errors and point estimates of the adjustment cost parameters. In terms of the absolute value of the parameter estimate, for $(1-\lambda^{EQP})$ a total of 47 (out of the 267 estimates) were outside the parameter bounds (all greater than one). But given the standard errors on these estimated coefficients, only 7 were statistically different from one. So we set all these values equal to one in the empirical work. For the 7 that were statistically greater than one, we considered three options:

(a) assume they were equal to one in the subsequent estimation;
(b) drop these industries from the final estimation sample; and
(c) keep the estimated values as they are in the estimation.

As it turns out, the final results were not affected quantitatively or qualitatively across these three options. Similarly, we examined the values for $(1-\lambda^{CAP})$; there were 8 that were statistically greater than one. We conducted similar experiments, and the conclusions were the same as for $(1-\lambda^{EQP})$. Given this, in the estimation we keep the estimated values of $(1-\lambda^{EQP})$ and $(1-\lambda^{CAP})$ as they are. Table 1 presents the summary statistics for $(1-\lambda^{EQP})$ and $(1-\lambda^{CAP})$. The statistics indicate that, on average, upward adjustment costs are high. The estimates also show fair amount of cross-industry variation in these costs. Table 2 presents the correlations between CONC and FIRMS and the adjustment cost measures. These indicate that higher upward adjustment costs, represented by greater $(1-\lambda)$, are negatively correlated with CONC and positively correlated with FIRMS.

Table 2: Correlations

	$(1-\lambda^{EQP})$	$(1-\lambda^{CAP})$	Ω(W)	Ω(RENT)	Ω(USED)
FIRMS	0.227	0.219	-0.286	-0.279	-0.158
CONC	-0.096	-0.158	0.545	0.530	0.339
	Ω(DEPR)	Ω(EK)	R&D	ADVT	GROW
FIRMS	-0.295	-0.128	-0.156	-0.032	0.090
CONC	0.298	0.315	0.338	0.112	0.020

3.2 Sunk capital costs

The aim here is to get a measure of the downward adjustment costs, representing the magnitude of sunk capital costs. First, we discuss a conceptual issue. For the i^{th} industry, let K be the amount of new capital a firm is contemplating acquiring or the entry capital requirement, r the unit price of new capital, and ζ the resale/scrap price of this capital with $r > \zeta$. A firm contemplating entry into this industry, or expanding capital stock, must take into consideration the non-recoverable component of investment $\Omega=(r-\phi)K$, the sunk cost. To simplify, we ignore depreciation. Sunk costs will be relevant for the non-depreciated portion of capital. Given that characteristics of technology and capital vary considerably industries, *a priori* one expects wide cross-industry variation in Ω. Sunk capital costs act as a barrier to entry and mobility. This notion has been used to understand a firm's entry, exit and mobility decision; see, for example, Baumol *et al.* (1982), Caves and Porter (1977), Dixit (1980) and Spence (1977). In terms of implementation, obtaining data on ζ is extremely difficult implying that we are unable to measure Φ directly for the 267 industries. Instead, we pursue an alternative approach and adopt the methodology outlined in Kessides (1990) and Sutton (1991) to obtain proxies for sunk costs.

The extent of sunk capital outlays incurred will be determined by the durability, specificity and mobility of capital. While these characteristics are unobservable, one can construct proxies. Following Kessides, let RENT denote the fraction of total capital that a firm (entrant) can rent: RENT= rental payments on plant and equipment/capital stock. Let USED denote the fraction of total capital expenditures that were on used capital goods: USED=expenditures on used plant and equipment/total expenditures on new and used plant and equipment. Finally, let DEPR denote the share of depreciation payments: DEPR=depreciation payments/capital stock. These proxies are useful because if a potential entrant can buy used capital, or can lease capital, then sunk costs are correspondingly lower. Similarly, depreciation makes capital less sunk; in the limiting scenario if capital lives only for one period, then sunk costs, which arise from the non-depreciated component of capital, are negligible. We create the following three measures: Ω(RENT)=(1/RENT); Ω(US)=(1/USED); and Ω(DEPR)=(1/DEPR). High Ω(RENT) indicates a low-intensity rental market, implying higher sunk costs. High Ω(USED) signals a low-intensity used capital market, implying higher sunk costs. High Ω(DEPR) indicates that capital decays slowly, implying higher sunk costs, which arise from the undepreciated portion of capital. The final measure Ω(EK) is from Sutton (1991) for which the details are provided in the data appendix. This is a measure of median entry capital requirement based on the observed distribution of plant sizes. Sutton assumes that sunk costs are proportional to Ω(EK). We collected data to construct Ω(RENT), Ω(USED), Ω(DEPR) and Ω(EK) for the census years 1972, 1982 and 1992.[7]

In the estimates, we report results with these measures used separately. However, in the baseline specification, we use a 'weighted' index of sunk costs capturing elements of all the attributes described above: $\Omega(W)=[\theta_1\Omega(RENT)+\theta_2\Omega(USED)+\theta_3\Omega(DEPR)+\theta_4\Omega(EK)]$, where θ_i's are the weights. Owing to a lack of information which can be used to assign optimal weights θ, we assume each $\theta_i = 0.25$. For each variable, we use the mean value, computed over the years 1972, 1982 and 1992, in the estimated equations (8). Table 1 presents summary statistics for the sunk costs measures and Table 2 presents the cross-industry correlations between CONC and FIRMS and the various sunk costs measures. The correlations reveal that industries with higher sunk costs have higher CONC and lower FIRMS.

3.3. Other control variables

Schmalensee (1989) provides a good survey of the determinants of industry structure variables, CONC and FIRMS. Following this literature, the main variables we consider are: (1) research and development intensity, R&D; (2) advertising intensity, ADVT; and (3) industry growth, GROW. Since these variables have been extensively discussed in the literature and this is not repeated here. The data on R&D and ADVT are from the detailed FTC line-of-business data (see data appendix). While the data are high quality, they are only available for a limited number of years. In the estimation we assume that the data on R&D and ADVT are representative for the full sample period. R&D is expected to be positively (negatively) related to CONC and (FIRMS). Greater ADVT may have both entry-retarding as well as entry-enhancing effects (Kessides, 1986). The former may reduce entry due to advertising related sunk cost barriers. The latter implies that a greater differentiated array of products may facilitate entry into 'niche' market segments. The net effect on CONC and FIRMS appears to be ambiguous. Finally, we include the industry's mean rate of growth over the sample period. Greater GROW may facilitate entry resulting in lower CONC and higher FIRMS, but these effects are likely to be conditioned on barriers-to-entry. GROW is the mean industry-specific rate of growth of real sales over the sample period. Tables 1 and 2 present the summary statistics and the correlations.

4. Estimation

The specification that we estimate is log-linear and is given by:

$$\text{CONC}_i \text{ or } \text{FIRMS}_i = a_0+b_1\ln(1\text{-}\varphi^{EQP})_i+b_2\ln\Omega(.)_i+b_3\ln\text{R\&D}_i+b_4\ln\text{ADVT}_i+b_5\ln\text{GROW}_i+e_i \qquad (13)$$

where ln denotes natural logarithms and 'i' indexes industry. Tables 3(a) and 3(b) present the results with CONC as the dependent variable and Tables 4(a) and 4(b) for FIRMS. As predicted in section 2, higher upward adjustment costs are associated with lower CONC and higher FIRMS. The results are not materially different whether we use equipment-capital or total-capital to measure adjustment costs i.e. the measures $(1\text{-}\lambda^{EQP})$ and $(1\text{-}\lambda^{CAP})$. Next, we examine the results for the sunk cost measures, i.e. the weighted sunk cost measure Ω(W) as well as the individual components Ω(RENT), Ω(USED), Ω(DEPR) and Ω(EK). While there are differences in the estimated quantitative effect across the alternative measures, higher sunk costs are associated with higher CONC and lower FIRMS. Overall, these findings are largely in tune with the discussion of the theory in section 2.

Table 3(a): Estimation Results: Dependent Variable: lnCONC[1]

Intercept	2.434 (0.001)	2.632 (0.001)	3.199 (0.001)	1.291 (0.004)	5.652 (0.001)
$(1\text{-}\lambda^{CAP})$	-0.391 (0.054)	-0.459 (0.028)	-0.284 (0.121)	-0.521 (0.023)	-0.217 (0.124)
Ω(W)	0.503 (0.001)				
Ω(RENT)		0.352 (0.001)			
Ω(USED)			0.337 (0.001)		
Ω(DEPR)				0.991 (0.001)	
Ω(EK)					0.358 (0.001)
R&D	0.062 (0.011)	0.064 (0.011)	0.103 (0.001)	0.127 (0.001)	0.016 (0.479)
ADVT	0.059 (0.001)	0.062 (0.001)	0.011 (0.570)	0.023 (0.244)	0.031 (0.056)
GROW	1.384 (0.237)	1.093 (0.362)	-1.791 (0.164)	3.358 (0.021)	2.744 (0.012)
Observations	267	267	267	267	267
Adj-R^2	0.3975	0.3642	0.2457	0.2305	0.4862

1. See Table 1 for variable definitions. p-values (two-tailed) from heteroscedasticity-consistent standard errors are in parentheses. All variables, except GROW, are measured in logarithms, since GROW can take negative values. Thus the coefficient estimates of GROW are not directly comparable with the others.

Of the remaining effects we consider, R&D appears to have a relatively consistent positive impact on CONC and negative on FIRMS. This is largely in keeping with previous findings in the literature. The level of statistical significance for the ADVT effect is relatively mixed; no clear inference emerges. This may be due to the forces indicated in Kessides (1986) where ADVT has both entry-enhancing as well as entry-retarding effects with an ambiguous impact on industry structure. GROW does not appear to have a consistent effect on CONC, but typically leads to greater FIRMS. Since these are not the main focus of the study, we do not comment on these effects further.

Table 3(b): Estimation Results. Dependent Variable: lnCONC.[1]

Intercept	2.452 (0.001)	2.656 (0.001)	3.196 (0.001)	1.392 (0.002)	5.628 (0.001)
$(1-\lambda^{CAP})$	-0.432 (0.054)	-0.498 (0.031)	-0.445 (0.077)	-0.587 (0.020)	-0.310 (0.105)
Ω(W)	0.495 (0.001)				
Ω(RENT)		0.345 (0.001)			
Ω(USED)			0.331 (0.001)		
Ω(DEPR)				0.953 (0.001)	
Ω(EK)					0.356 (0.001)
R&D	0.064 (0.009)	0.066 (0.009)	0.103 (0.001)	0.128 (0.001)	0.017 (0.456)
ADVT	0.058 (0.002)	0.059 (0.002)	0.010 (0.614)	0.021 (0.289)	0.030 (0.064)
GROW	1.343 (0.251)	1.043 (0.384)	-1.776 (0.167)	3.179 (0.028)	2.716 (0.013)
Observations	267	267	267	267	267
Adj-R^2	0.3975	0.3638	0.2502	0.2313	0.4879

1. See Tables 1 and 3(a) for details.

To get a better feel for the key relationships, Figures 1 and 2 plot the estimated relationship between CONC and $(1-\lambda^{EQP})$ and Ω(W), at the sample-mean values of the other explanatory variables. Even though the estimated specification (13) allows for non-linearity in the relationships, the estimated coefficients reveal near-linear relationships between CONC and $(1-\lambda^{EQP})$, and CONC and Ω(W). Over the range of sample values of $(1-\lambda^{EQP})$ and Ω(W), the quantitative effects on CONC are considerable. Similarly, figures 3 and 4 plot the estimated relationship for FIRMS. As for CONC, the estimated relationship

Table 4(a): Estimation Results. Dependent Variable: lnFIRMS.[1]

Intercept	8.465 (0.001)	7.928 (0.001)	6.869 (0.001)	9.744 (0.001)	1.098 (0.001)
$(1-\lambda^{EQP})$	1.090 (0.011)	1.233 (0.006)	0.851 (0.077)	1.335 (0.008)	0.648 (0.059)
Ω(W)	-1.084 (0.001)				
Ω(RENT)		-0.736 (0.001)			
Ω(USED)			-0.745 (0.001)		
Ω(DEPR)				-1.737 (0.001)	
Ω(EK)					-0.881 (0.001)
R&D	-0.098 (0.058)	-0.107 (0.047)	-0.184 (0.001)	-0.245 (0.001)	0.038 (0.367)
ADVT	-0.016 (0.674)	-0.016 (0.688)	0.088 (0.035)	0.070 (0.110)	0.036 (0.224)
GROW	6.185 (0.012)	6.967 (0.007)	13.067 (0.001)	3.757 (0.237)	2.072 (0.301)
Observations	267	267	267	267	267
Adj-R^2	0.4289	0.3787	0.2869	0.2140	0.6359

Table 4(b): Estimation Results. Dependent Variable: lnFIRMS.

Intercept	8.411 (0.001)	7.864 (0.001)	6.870 (0.001)	9.486 (0.001)	1.140 (0.001)
$(1-\lambda^{CAP})$	1.163 (0.014)	1.318 (0.008)	1.173 (0.088)	1.545 (0.005)	0.778 (0.040)
Ω(W)	-1.065 (0.001)				
Ω(RENT)		-0.718 (0.001)			
Ω(USED)			-0.731 (0.001)		
Ω(DEPR)				-1.638 (0.001)	
Ω(EK)					-0.876 (0.001)
R&D	-0.102 (0.049)	-0.112 (0.038)	-0.186 (0.001)	-0.247 (0.001)	0.036 (0.394)
ADVT	-0.011 (0.765)	-0.010 (0.798)	0.091 (0.028)	0.076 (0.085)	0.038 (0.197)
GROW	6.299 (0.011)	7.100 (0.006)	13.038 (0.001)	4.221 (0.183)	2.137 (0.285)
Observations	267	267	267	267	267
Adj-R^2	0.4279	0.3775	0.2916	0.2162	0.6368

1. See tables 1 and 3(a) for details.

between FIRMS and (1-λ^{EQP}) is almost linear. However, the relationship between FIRMS and O(W) is highly non-linear with initial small increases in Ω(W) producing large decreases in FIRMS and the subsequent increases generating a relatively smaller decrease in FIRMS. The overall conclusions are: (1) greater upward adjustment costs lead to lower industry concentration and a greater number of firms; and (2) greater downward adjustment costs, or sunk costs, lead to greater industry concentration and a lower number of firms. In both cases, the effects are highly significant statistically and economically meaningful.

Figure 1. Concentration

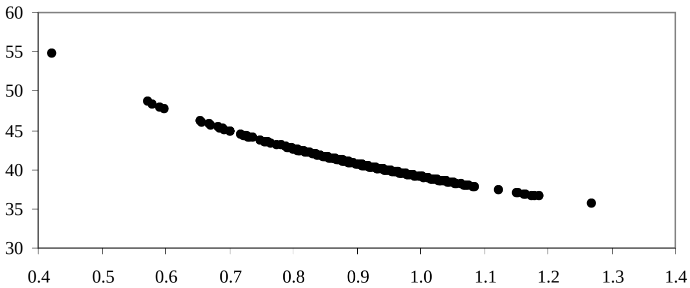


Figure 2. Concentration

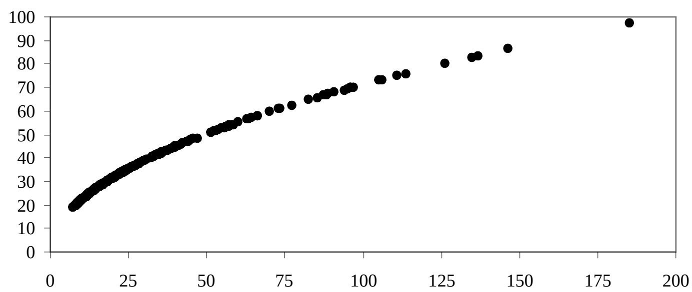


Figure 3. Number of Firms

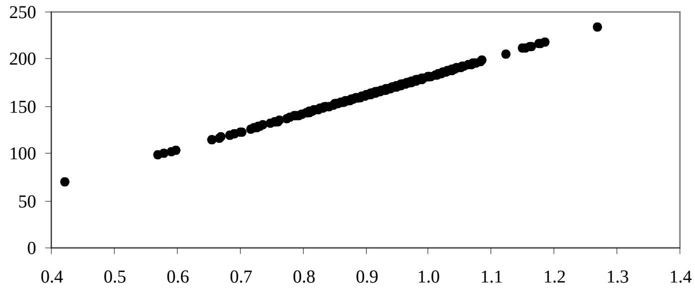
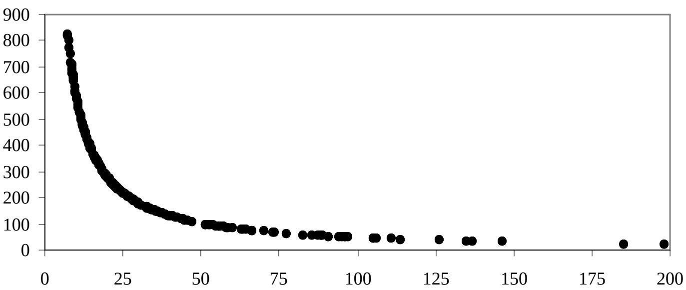


Figure 4. Number of Firms



5. Final remarks and implications

Our objective was to develop an alternative method of testing models of pre-emptive, or strategic, investment behaviour. We modified Dixit's (1980) model to incorporate convex adjustment costs of capital. From this we were able to gain insights into the underlying parameters that are likely to influence firms' incentives for acquiring capacity. In particular, we were able to focus on issues related to upward versus downward adjustment costs of capital. While there are several limitations of the approach, this exploration appears to supportive of the predictions from theory.

It is best to treat the results as suggestive and the approach as an alternative way of examining pre-emptive investment behaviour. The study has several data and conceptual limitations, which could be addressed providing richer datasets, are available. First, we have a direct relationship between adjustment and sunk costs and firms' market shares via the strategic investment channel. Since we use industry-level data, we were unable to study this. Firm-level data, combined with industry information, would better enable us to examine this link. Second, the Census dataset does not provide annual observations on the number of firms in an industry. Where these are available, one can, within a dynamic model of investment, such as the one presented in Hay and Liu (1998), examine the patterns of incumbent firms' investments when confronted with new entry and link these patterns to the underlying adjustment and sunk cost parameters. This may shed richer light into what (dominant) incumbents do regarding their capital stock decisions when threatened with entry. Third, we were unable to sort competing theories that may generate similar predictions. That is, the results may mask observational equivalence. For example, sunk costs per se are expected to raise entry barriers leading to more concentrated industry structures. And this effect is independent of strategic investment behaviour. With richer datasets, one may be able to break this observational equivalence. Fourth, as Appelbaum and Lim (1985) and Spencer and Brander (1992) show, the presence of demand uncertainty may lower the optimal pre-commitment to capacity due to greater uncertainty about the success of the entry-deterring strategy. This aspect could be addressed where more disaggregated market level data are available to measure demand (and cost) uncertainty. Fifth, we do not control for alternative strategic instruments that can be used by firms related to patenting, pricing actions, purchasing policies, among others; Singh *et al.* (1998) highlight these strategies.

While the SIC four-digit data are relatively aggregated to offer direct implications for antitrust/competition policy analysis, we nevertheless offer some comments. The US v. ALCOA (1947) landmark decision dwelled on ALCOA's apparent strategic investment behaviour, which the judge ruled was excluding competitors and resulting in ALCOA's stranglehold on the aluminum market. The judge ruled that ALCOA's market share remained high as a result of this behaviour and the number of firms (competitors) in the industry were low. Since this landmark decision, there has been much debate on the rationality and effectiveness of strategic investment behaviour. Smiley's (1988) study indicates that firms appear to use this strategy relatively frequently. Setting aside issues of rationality and likelihood, antitrust analysis could benefit from closer examination of the key underlying parameters that are likely to influence the strategic investment behaviour of incumbent firms. The analysis identifies upward adjustment costs of capital as one key parameter influencing the desirability of such behaviour. Where this is high, it is less likely that incumbents will install additional capital to gain market share or deter entry. In this case, sharing the market may be the more optimal response. The downward adjustment cost, or sunk cost, component has already been identified as a key variable influencing the credibility of such behaviour. Where sunk costs are low, strategic investments are less credible. The analysis contributed to this by demonstrating that the quantitative effect of sunk costs on industry concentration and the number of firms is rather large and even small amounts of sunk costs can generate significant decreases in the number of firms. In short, in markets under scrutiny for the likelihood of strategic investment behaviour, antitrust/competition policy authorities may benefit from estimating the key underlying parameters related to upward and downward adjustment costs of capital.

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Data Appendix

1. The US SIC 4-Digit Manufacturing Industry Database.

Variable	*Source*	*Years available*
Industry time-series data: sales, investment, capital stock, etc.	Bartlesman and Gray (1998): Annual Survey and Census of Manufacturing.	1958-94
Four-firm concentration ratio and the number of firms.	Census of Manufacturing	1963, 67, 72, 77, 82, 87, 92
Used capital expenditures.	Census of Manufacturing	1972, 82, 92
Rental payments.	Census of Manufacturing	1972, 82, 92
Depreciation payments.	Census of Manufacturing	1972, 82, 92
R&D Intensity.	FTC Line-of-Business Data	1975-1978
Advertizing Intensity.	FTC Line-of-Business Data	1975-1978
Aggregate variables:federal funds rate, energy prices.	Economic Report of the President.	1958-1994

The following industries were excluded from the sample: (1) 'Not elsewhere classified' since they do not correspond to well-defined product markets; (2) Industries that could not be matched properly over time due to SIC definitional changes. There were important definition changes in 1972 and 1987. For these industries, the industry time-series and other structural characteristics data are not comparable over the sample period; and (3) Industries that had missing data on the industry structure, sunk cost, R&D or advertising variables. The final sample contains 267 SIC 4-digit manufacturing industries. Given the above exclusions, the final sample contains industries that are mature and well-defined over the sample period and have data consistency.

We use the FTC line-of-business data for R&D and advertizing. The data are high quality and have been used in many studies. Unfortunately they are available only for a few years and were discontinued. In addition, some of the data are at the SIC 3-digit level. Where data are available only at the 3-digit level, all the underlying 4-digit industries are assumed to have the same values. I am not aware of the availability of SIC 4-digit data for R&D and advertising for all the industries over the 30 year period.

2. Sunk cost

The construction here follows Sutton (1991, Ch.2). Let ξ (>0) be defined as the setup cost or the minimal level of sunk cost that an entrant must incur, and *S* denote total industry sales (market size). Thus, in theory, ξ/S is the sunk cost relative to market size. In quantifying setup/sunk costs (Sutton 1991, Ch.4), he proposes a proxy that measures the 'relative' level of setup costs across industries. Sunk costs are assumed to be proportional to the cost of constructing a single plant of minimum efficient scale (MES). Let ψ be a measure of MES, where ψ is the output of the median plant relative to industry output. Assume that the capital-sales ratio of the median firm is the same as the industry as a whole and denote industry capital-sales ratio by K/S. Then $(\xi/S)=\psi(K/S)$. If we can obtain a proxy for ψ, and have data for industry *K* and *S*, we can approximate ξ/S. ψ is constructed using the distribution of plants within each SIC four-digit industry according to employment size. Let 'm' be the number of group sizes within the industry, and 'n_j' and 'S_j' denote number of plants and total sales of the j^{th} size group (j=1,...,m.). Let $Ms_j=(S_j/n_j)$; $S_e=(1/m)\Sigma_j(Ms_j)$; and $S_o=\Sigma_j S_j$. Then $\psi=(S_e/S_o)$. Using ψ and industry K/S, we obtain a proxy for ξ/S. We label the term $\psi(K/S)$ as Ω(EK) (sunk costs - entry capital). As noted by Sutton (p.98), the cross-industry variation in Ω(EK) provides a rough proxy for the cross-industry variation in sunk costs. Sutton notes several limitations of this proxy. For example, (1) he assumes that the capital-output ratio of the median plant is representative of the entire industry; (2) the book value of capital assets is used to compute the capital-sales ratio; and (3) the computation assumes that the age structure of capital does not vary across industries. We obtained data to calculate Ω(EK) for the Census years 1972, 1982 and 1992. These are the same years as for the computations for the measures Ω(RE), Ω(US) and Ω(DE).

ENDNOTES

1. School of Economics, Georgia Institute of Technology, Atlanta, GA 30332 USA; CESifo (Munich); and Deutsches Institut für Wirtschaftsforschung (DIW, Berlin). E-mail vivek.ghosal@econ.gatech.edu The paper was completed during summer 2003 when I was a research visitor at CESifo and Wissenschaftzentrun Berlin für Sozialforschung, and I thank them for their hospitality. This paper emerged from teaching Industrial Organization classes for undergraduate seniors and first-year MA economics students using the Dixit (1980) model, which is widely used and useful for demonstrating two-period strategies and equilibrium concepts.

2. There is a conceptual problem with trying to relate observed excess capacity (or unutilized capacity) to entry. In Dixit's Nash equilibrium outcomes, the incumbent firm will not hold any unutilized capacity. However, the incumbent firm can still restrict or deter entry. If we consider Spence's Stackelberg equilibrium outcomes, then it is possible that the incumbent firm may build capacity, which it may not utilize. In this case there will be a relationship between excess capacity and entry. However, if there is no observed significant relationship between excess capacity and entry it does not necessarily imply that pre-emptive investment behavior is absent.

3. In the simultaneous-move case the equilibrium capacities are $k = (1+2\varphi)\{4(1+\varphi)^2-1\}^{-1}$. When$\varphi$=0 we get $k_1=k_2=1/3$ (as in equation 3). As φ increases from 0 to 1, the absolute capacities of both firms 1 and 2 decline, and their market shares always remain at 50 percent.

4. In different contexts, Gilbert and Vives (1986), Kirman and Masson (1986), and Waldman (1987) show that pre-emptive investments to deter entry can occur even in industries with many incumbents. One of the key issues in the many-incumbents case is the free-rider problem with respect to capacity investment.

5. The literature also shows that, while it may be optimal for the incumbent/first-mover to pre-commit to capacity investment, the presence of demand uncertainty lowers the optimal pre-commitment owing to greater uncertainty about the success of the entry-deterring strategy (Appelbaum and Lim, 1985; Spencer and Brander, 1992). In the analysis we do not address the issue of market uncertainty.

6. It is useful to note that Reynolds (1987) shows that even mid-range of sunk costs may be sufficient for installed capacity to represent a credible commitment. Thus one does not necessarily need all installed capacity to be sunk.

7. Collecting these for some of the additional (particularly, earlier) years presented problems owing to changing industry definitions and many missing data points. The data revealed fairly high correlation (between 0.6-0.9) for the sunk cost proxies across the different years, indicating a fair degree of stability in these measures.

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