HYSTERESIS OF PLANT CLOSURES AND REOPENINGS IN THE UK BRICK INDUSTRY: REAL OPTIONS AND/OR STRATEGY*

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Abstract

In this paper we analyse industry dynamics in the UK bricks industry. This is an industry characterised by conditions that predict real options type behaviour in entry and exit. In addition, strategic interactions are likely. The market structure is oligopolistic and the existence of spatial competition due to high transport costs may favour preemption.

We find evidence that uncertainty delays the decision to open and close plants, though this effect appears to be non-linear for the decision to open. We find (limited) evidence for pre-emption. There is also support for other predictions of strategic behaviour such as differential probability of entry and exit depending on market share and history of acquisition activity.

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1. Introduction

There has been increasing interest in industry dynamics - the process by which firms exit or enter an industry or region. No one theory has dominated this literature and it is characterised by a number of disparate approaches. One discourse focuses on evolutionary learning about productivity and selective exit or entry in explaining industry structure. There is also a literature on real options that addresses the timing of entry and exit as external shocks become less or more volatile. And finally there is a set of papers where the main focus is on the strategic interaction of differently placed rival firms in the entry and exit process. [1]

Our study is highly specific in that it concerns a single industry (bricks) characterised (due to high transport costs) by spatial competition. One implication of this is increased market power and likely strategic behaviour. In addition the technology is relatively mature and profitability is heavily influenced by external shocks to output price and the main input, energy. High sunk costs are a feature of the industry with much of the capital stock being industry and location specific. Given that simple framework, a natural question to explore is whether the observed patterns in opening and closing plants can be explained by I-O theories of real options and strategic behaviour. This paper addresses that question.

The highly cyclical nature of bricks stock data (see Figure 1) suggests that brick manufacturers have been slow to respond to variation in demand by varying production.[2]

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[1] The first set of theories is most relevant to technology using industries. The main hypothesis is the existence of a firm-specific learning process by which some firms are selected for exit on the basis of revealed competence (See Lambson and Jensen 1998 for a review and empirical testing). Learning in respect of entry conditions is also one explanation as to why the hazard rate of entry for a firm may be increasing in its rival's presence in a market (Toivanen and Waterson 1998); the dynamics may also depend on the size of the market (Asplund and Nocke 2000). In the second set of theories the shocks that cause entry and exit may be internal or common across firms (e.g. demand or relative price shocks); in either case the focus is on shocks characterised by stochastic processes where information is obtained by waiting. This implies that the effect on firms entry and exit is not immediate (Dixit 1989; Dixit and Pindyck 1994). The third body of literature analyses the strategic value of exiting to differently placed firms and posits a rich set of strategic determinants of entry (Ghemawat 1991, Geroski 1995; Lieberman 1987).

[2] This may be seen by analysing production and deliveries. Using standard procedures for a data sample 1970-2001 these two variables are found to be cointegrated with an AIC-selected lag of 1 year and a long-run cointegrating coefficient of almost exactly unity. The corresponding dynamic error correction equations show that the adjustment is of production to delivery as the error correction term is only significant for the dynamic production equation. However, the adjustment of production is slow with the coefficient on the error correction term being only -0.43. This means that less than half the desired adjustment is completed within a year.

As with many process industries, production and capacity are strongly correlated due to high energy costs making it uneconomic to operate much below capacity and due to the swift deterioration of unused capacity (kilns). Thus inventory and capacity remain the key controls and the cyclicality of stocks reveals delays in opening and shutting plants. Despite this cautious behaviour, there was a high level of plant closures, re-commissioning, and investment in new plants during the 16 year span that is the focus of this study.

[FIGURE 1: about here]

We first review in Sections 2 and 3 the main elements of each of the two theories that should contribute to explaining changes in plant status; we set out in each case the main hypotheses. Although hybrid models that combine strategic considerations and real options theory exist (See Boyer et al for a review), no robust or general conclusions have so far emerged. We therefore focus on elements of each theory that are relevant to our industry context. Section 4 introduces the data and estimation methods. The main results are presented in Section 5 with conclusions in Section 6

2. The real options approach to entry and exit

Real options theory provides one explanation for a delayed response under uncertainty to signals that would cause entry or exit in a frictionless world. The trigger values for irreversible investment or disinvestment are respectively above and below the corresponding Marshallian values (variable cost plus the servicing of sunk cost of entry or exit) in the presence of uncertainty, as long as information arrives stochastically over time.[3] Models of the relationship of adjustment speed to uncertainty for irreversible investment are developed in Brennan and Schwartz (1985), McDonald and Siegel (1986), and Dixit and Pindyk (1994). A similar approach, reconciling the theory with standard q-theory of investment, is developed in Abel and Eberly (1994) where it is shown that the extent of the zone of inaction with respect to the forcing variable depends on the level of uncertainty; furthermore, activity outside the zone of inaction is slowed by heightened uncertainty.

Empirically, real option models of hysteresis have been applied to firms' entry and exit into markets, in particular foreign markets (Dixit 1989) and to firms' closure and re-opening decisions, mainly, though not exclusively in the field of natural resources. (Slade 2000, Moel and Tufano 2002).[4] Our application to the bricks industry in the UK is one of

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[3] While most of the literature is concerned with the option to wait, and its effect on delaying investment, under some circumstances, increased uncertainty can accelerate project development, particularly where there is a time to build or where first mover advantages are significant (Bar-Ilan and Strange 1996; Folta and O'Brien 2004).

[4] A number of other attempts have been made to test real options theory. Chirinko and Schaller (2002) estimate a discount rate with a variable irreversibility premium for different sectors; Harchaoui and Lasserre (2001) test whether expected marginal profit is driven to zero by investment; Bell and Campa (1997) test the volatility of returns in the Chemicals industry. However, it has proved very difficult to test the theory of real options in a convincing way. Partly this is due to the theory itself being complex: option value depends on several factors such as the way information arrives over time; the duration of option rights; the importance of first mover advantages; and the rate of growth of the underlying project value. Indeed it is possible that the very complexity of the theory is responsible for the observation that firms frequently follow "rules of thumb" that apparently mimic real option optimisation within a limited range (McDonald 1998, Graham and Harvey 2001).

the few examples within manufacturing: see also Kovenoch and Phillips (1997). The bricks industry is of interest because three of the key assumptions of the real options model are prominent: capital investment is largely irreversible and not easily expandable ex-post; the demand for bricks is highly uncertain; and the existence of reserves and permissions correspond to an option to produce bricks.[5] Exacerbating the irreversibility of capital expenditures is the fact that high energy costs prevent operational plants from producing at much below full capacity. Investment in new plants is therefore undertaken in the knowledge that if demand conditions worsen the industry either has to accumulate stocks of unsold bricks in the hope of a recovery in demand or capacity will have to be closed or mothballed, decisions that are also costly to reverse. [6] These factors suggest some degree of hysteresis in the closing and re-opening decisions arising from the option value of waiting.

A useful insight is given by Figure 2 below adapted from Brennan and Schwartz (1985).[7] This shows that there are critical prices at which the closure of previously open plants and the opening of previously closed ones become just optimal, given the cost of re-opening or closing the plant. The trigger prices are the solutions of the pair of Bellman equations that define the dynamic equilibrium for the plant in open and shut states, specifically:

$$0.5\sigma^2 P^2 V_i^{''}(P) + (r-\delta)PV_i^{'}(P) - rV_i(P) + \Psi(P-C) = 0 \qquad \ldots(1)$$

where the i subscript represents the open or shut state and where Ψ is an indicator variable that equals zero if the plant is shut and 1 if it is open.
The solution of these equations is derived in Dixit (1989) and some comparative statics are presented in Dixit and Pindyck (1994) for the classic case of GBM, infinitely lived options and complete irreversibility. The results here are intuitively obvious. For example the entry price trigger rises with exit cost as well as entry costs and the exit price trigger falls with entry cost as well as exit cost. Higher operating costs raise both the entry trigger and the exit trigger. These trigger prices also depend on other standard determinants of option value such as the current price, the volatility of the stochastic variable, assumed here to be price, the discount rate and the convenience yield.[8]

[FIGURE 2: about here]

2.1 Specific Real Options Hypotheses
The theories above have suggested that the speed of implementation of a decision to close or re-open a plant may depend on a number of influences. While we do not have direct data on the speed of adjustment of firms we are able to set up a model for the hazard rate for reopening and closure. Specifically, the theory gives predictors of the probability of

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[5] Uncertainty in respect of demand is compounded by the high transport cost element that makes it uneconomic to export outside of a small catchment area. The bulk of the output from a typical brick plant is supplied within a radius of 50-100 miles.
[6] As we are talking here about industry level uncertainty where firms cannot dispose of assets in a general downturn due to industry specificity of these assets, the effect of uncertainty is to slow down adjustment irrespective of the market structure.
[7] Dixit and Pindyck (1994) show that the difference between the value open and value shut between the two threshold prices is an s-shaped function in price.
[8] The latter is taken by Brennan and Schwartz to be a constant of the output price on the assumption that the yield derives from the ability to profit from temporary local shortages through ownership (p. 139).

the current state of each plant i.e. whether the plant is open or closed, conditional on its state in the previous period. We present a summary of the predictions in Table 1, columns 2 and 3 which is adapted from Moel and Tufano (2002).

Table 1 shows that the probability of triggering a change in status for the plant is determined by variables that determine the current value of the plant (price, quality, demand and operating cost); a set of volatility variables; the discount rate; and the costs of closure, reopening and maintaining a closed plant. The volatility measures are entered along with a quadratic term because of the putative non-linear effects in recent literature.[9]

[TABLE 1 ABOUT HERE]

3. The strategic approach to entry and exit

Strategic considerations may also influence the timing of plant openings and closures. One prediction on plant status depends on firm size. Firms with a large existing share in a region should be less likely to stay open or reopen given that any extra revenue would be offset by a negative effect of increased capacity on existing revenue – more so than for small share firms.

The timing of entry and exit may also be seen in strategic terms. As this industry faces derived demand for a homogenous low-tech product, neither advertising nor product differentiation will feature strongly as a deterrent. Conditions are more favourable to a preemption strategy: the industry is geographically dispersed; capacity increments are large relative to the regional market size; investments are irreversible so the commissioning of a new plant represents a credible commitment to expanding output (Lieberman 1987).[10]

The preemptive decision to keep plants open or to reopen plants previously closed can be addressed in our context by theories that predict the number and location of firms that are competing in spatially defined markets. The simplest such model predicts that plants will be equally spaced.[11] The *density* of the spacing depends on the balance between static

[9] Real options theory predicts a higher threshold for action but the argument that this produces delay is subject to a simultaneity critique in that increased uncertainty while increasing the threshold or trigger value for entry or exit also increases the probability of hitting the threshold. It is shown in Sarkar (2000) under highly specific assumptions that the probability of delay is related non-linearly to uncertainty with the assumed delaying effect evident only at higher degrees of uncertainty. This gives rise to an inverted U-shape relationship between investment and uncertainty. Other explanations for this based on risk attitude are explained in Bo and Lensink (2004). A separate argument for a non-linear uncertainty effect – this time U-shaped – is given in Folta and O'Brien (2004) where the combination of deferment and growth options is shown to create possible non-linearities, due to the unbounded nature of the latter.

[10] Plant proliferation strategies are compared with limit pricing in a model of the ready-mixed concrete industry in Scherer and Ross (1990). The conclusion is that although proliferation may yield a lower expected profit conditional on the credibility of each policy, nevertheless proliferation may be chosen because of its superior credibility (p.402) and that this is more likely the higher the proportion of transport costs to the ex-works price.

[11] The assumptions are that firms can locate anywhere on a linear space; plants are sequentially built; plants are immobile once built; customers pay their own transport cost and /or there is no price discrimination. If in addition we make the assumptions of equal marginal costs of production and transport and also a

profits (favouring wide spacing) and the entry-deterrence effect (favouring dense spacing). A variety of approaches yield different values to entry deterrence depending on the exact assumptions. For example if we ignore any change in price on entry, the location of a plant (B) less than twice the minimum market size on either side of an existing plant (A) should forestall future entry between A and B; if the price should fall on entry this distance could be larger.

The outcome of the above model is that there is no interpenetration of each plants' markets and this may be thought unrealistic. Although firms may be spread over a region in a way that would make it difficult to serve each other's customers there are many examples of rival plants in close proximity. We thus define a locality as an area where two or more plants exist within a 10-mile radius. The literature suggests some insights in respect of plants within localities or without localities. Extending the product differentiation theory of Shaked and Sutton (1990) to location choice, the location pattern should depend on a combination of two concerns: the incentive of all firms to expand demand by opening new plants and the incentive of incumbent firms to maintain spatial. A monopoly result is predicted as a sub-game perfect equilibrium at some high degree of post-entry competition. At lower levels of competition there is scope for duopoly to emerge as demand is expanded. Assuming homogeneous quality but spatial differentiation we may distinguish between location decisions *within* a locality and without it. In the latter case the expansion incentive may be high because the localities are more like "islands" with low cross-price elasticity; the corollary is also that there is less competition between localities. In the within locality case on the other hand the output of different firms plants are not differentiated so the incentive to expand is low. If firms do not collude, the competition effect will also favour the monopoly outcome. Indeed if the monopoly outcome is not found it implies collusion. These points may be summarised in the following matrix:

Within localities		Between localities
Competition	Collusion	
Expected result: Each locality served by a separate firms plants	Expected result: inter-penetration of local markets by different firm plants	Inter-penetration of non-local markets i.e. plants from different firms characterise distinct local markets

uniform density of demand sufficient to cover fixed costs, we obtain the result that plants should be equally spaced. The proof is contained in Hay (1976) and used in Scherer (1986). Demand is related linearly to the sum of the price and transport cost: q=a-P(+tZ) where Z is the customer distance from the plant and t is the transport cost. For a plant supplying over a distance M in either direction, sales are given by:

$Q(P,z) = 2\int_0^M [a - b(P + tZ)]dZ$ =2aM-2bPM-btM^2 resulting in profit contribution: (P-c)Q.

Profit maximisation results in equal M between plants with a price that rises linearly with M. Other models of spatial location give conflicting results depending on the form of the demand or transport functions or the type of competition (Anderson and Neven 1991;Chamorro-Rivas 2000).

3.1 Specific Strategic Hypotheses

Our first hypothesis relates to the relative size within the region of the firm that owns a plant. The larger the existing revenue (as proxied by regional market share) the more the incentive for the firm to exit and the lower the incentive for the firm to reopen plants (Gilbert and Harris 1984; Ghemawat and Nalebuff 1985, 1990; Lieberman 1990).

Given our view on the importance of preemptive behaviour we also include the *total* number of plants in the region whether own or rival. This represents the extent to which the available spatial niches have been filled up by plants and a high score on this should deter reopening and maybe encourage exit.

Bearing in mind the discussion of Shaked and Sutton above, we further hypothesise that the existence of a local *rival* plant (i.e. within 10 miles) will also encourage exit and deter reopening (though a local own plant would not be expected to have this effect) as long as post-entry competition is strong, which we regard as a maintained hypothesis.

An important consideration in strategic behaviour is whether a firm or its regional rival is financially constrained. Although we do not have data on liquidity, we do know which firms concluded recent acquisitions that are likely to have led to increased gearing. This will make these firms more cautious but their rivals may simultaneously become less timid. These hypotheses are tested using two dummy variables, one indicating that the plant is owned by a firm that has recently acquired; the other indicating that the plant has a regional rival that has recently acquired. Both of these dummies are then interacted with dummies for the plant's initial status (open or closed).

The predicted influence of the strategic variables under the hypotheses outlined above in shown in Table 1, columns 4 and 5.

4. Estimation methods and data sources

The data set covers all brick firms that at some point during the period 1985-2000 possessed brick plants with a total capacity of at least 50 million brick per year (between 1% and 1.7% of total national capacity) and includes histories for all plants that have been owned by these firms. The sample period covers a number of economic cycles with three distinct sub-periods. The first runs from 1985-89 during which time a number of new factories were commissioned to meet the rapidly increasing demand for bricks that was being fuelled by the 1980s housing boom. The end of the boom was followed by a sharp contraction in demand during the early 1990s that resulted in both an increase in stocks and a substantial number of plant closures. Then a brief recovery in 1994 has been followed by an unprecedented period of stability.

A full list of firms included in the panel is provided in Appendix 2. The omitted firms are small, investment inactive single plant firms who are primarily operating from small scale sites that produce special bricks for niche markets.[12] A list of plants operating during 1981 was obtained from Ridgway (1982), the capacities of these plants and the

[12] Some small single plant firms are included in the panel because they are acquired by larger firms during the sample period (for example, Collier, Rudgwick and Yorkshire Brick).

subsequent plant histories (including expansions, closures and reopenings) were obtained from a variety of sources including company reports, media news articles, the trade association and from the firms themselves. The resulting unbalanced panel consists of annual data for a total of 122 plants.

Using probit analysis we estimate the probability of a plant being open at time t conditional on it being open at time t-1.

$$y_{i,t} = y_{i,t-1}\alpha + x_{i,t}\beta + z_t\delta + f_j + \varepsilon_{i,t} \qquad \ldots(2)$$

where $y_{i,t}$ takes the value one if plant i is open at the end of period t or zero if it begins the period closed,[13] $x_{i,t}$ is a vector of plant specific variables, z_t is a vector of demand variables, including price uncertainty, and f_j are firm based fixed effects.

Due to the high weight to price ratio the majority of the output from a given plant is sold within 100 miles of the plant. When calculating some of the demand variables and the strategic variables it is necessary to assign each plant to a region. The assignment rule should reflect the road infrastructure adjacent to the plant in question. So while use is made of the eleven standard regions of mainland Britain, when a plant is located adjacent to an efficient road network that makes for easy access to major metropolises of neighbouring regions that plant is classified as being a supplier to each of those regions.[14] We also define a *local* plant as one within 10 miles of the plant in question.

5. Results

Table 2 reports results for the panel regressions with firm fixed effects as the likelihood ratio tests indicate the fixed effects are important. Many of the strategic variables are interacted with a dummy signifying whether the plant begins the period open or closed. Accordingly coefficients situated on the left of the column are estimated for open plants, those on the right are for plants that begin the period closed, while those in the centre of the columns are estimated without distinguishing between the plants' initial status. We also allow for potential differences between the decision to reopen previously closed (mothballed) plants and the decision to open greenfield or brownfield plants by first defining the 'closed' interaction term to include only mothballed plants, i.e. those plants that begin the period closed but had at some point in the past been open (columns 3 and 4), and then defining it more broadly so that it includes all plants that begin the period

[13] Once closed, unless the plant has been demolished by the owning firm with the land being turned over to alternative use it remains in the panel for a further five years during which time it is regarded as a live option which the firm could exercise by re-opening. Five years is chosen as the cut off point as by this time the mothballed plant will have seriously deteriorated and if the firm wishes to re-commission the site it will be required to request planning permission. Firms with major capacity expansions on the same site are classed as reopenings.

[14] For example, a number of plants are situated in and around the West Midlands town of Stoke-on-Trent which is adjacent to the M6 that provides easy access to the major markets of Birmingham in the West Midlands and Manchester and Liverpool in the North West. For this reason these plants are considered to be competing with other firms that supply both the West Midlands markets and the markets of the North West.

closed, whether they had been open in the past or whether they were new greenfield or brownfield plants (columns 5 and 6). In each case two results are reported, one including the majority of the variables listed in table 1, the other reports a parsimonious version.

[TABLE 2 ABOUT HERE]

Column 3 shows that many of the hypotheses of the real option model are supported. Variables representing the value of the plant such as price and size of plant (plant capacity as a proxy for cost) are significant and plants that produce bricks of high aesthetic quality are significantly more likely to be open. The high coefficient for the Fletton dummy variable confirms the long term downward trend in the demand for Fletton bricks. The fuel cost variable was never significant and is not reported. Recent capital investment, intended as a proxy for operating cost is correctly signed but not significant; neither is the interest rate.

Uncertainty plays an important role in influencing the decision to open or close a plant. Plants that begin the period closed are likely to remain closed at high levels of uncertainty but as uncertainty decreases, the probability of being opened also increases. The relationship between uncertainty and the probability of an open plant remaining opened is non-linear, with the probability of inaction being very high for average levels of uncertainty but decreasing as uncertainty increases or decreases (figure 3). The non-linearity is statistically significant but modest. The lowest level of uncertainty that was measured during the sample period was 0.20 at which point the probability of remaining open was 0.933. The probability rose to a peak of 0.994 before falling to 0.967 at the highest level of observed uncertainty (1.94).

(FIGURE 3 ABOUT HERE)

The character of the observed non-linearity suggests that over most of the sampled range of price uncertainty hysteresis increases in uncertainty for both the closing and the reopening decision. There is some suggestion that at very high levels of uncertainty the probability of remaining open is reduced. Our preferred explanation for this is the behavioural effect of risk attitude that may differ according to the level of uncertainty (Bo and Lensink 2004). Specifically at very high levels of uncertainty firms appear to act in a risk-averse manner.

Turning now to the strategic variables, our first specific hypothesis from section 3.1 was that own capacity share in a region should negatively affect the likelihood of re-opening or remaining open. This prediction is strongly confirmed for the reopening decision in Table 2, column 4. Thus, larger firms are less likely to open plants in regions where they already have a large presence. This is consistent with the Gilbert and Harris (1984) argument that larger firms will adopt a more conservative capacity stance because their incremental revenue is less than smaller firms.[15] The number of the firm's plants in a region (which might indicate the spatial spread) does not add any extra explanatory power to the regional share variable. However, the total number of plants (own plus rival) does deter reopening in line with the view that preemptive activity operates to fill all available spatial niches.

[15] A size effect (for single establishment firms) is found in Disney et al 2003.

Another hypothesis set out in section 3.1 is that the existence of a local rival plant will deter reopening and encourage exit. We find strong support *against* this in column 4 of Table 2. Of the plants that reopen approximately 60% have a local rival and it is these plants that are more likely to re-open. This is a similar result to that found in Toivanen and Waterson (2003) and is explained there in terms of learning in respect of demand conditions. An alternative explanation could be the possibility of poaching skilled labour from the rival plant if the efficiency of the newly opened plant accommodated higher wage rates. Given the homogeneous nature of bricks, the failure to find a negative significance for local rivals (irrespective of the prior status of plants) could also suggest that the maintained hypothesis of strong ex-post competition may be incorrect and that some degree of collusion exists that supports an outcome of two rival local plants

There is some indirect support for the influence of financing constraints in influencing firms' decisions. Although previous acquisition does not significantly influence the probability of the acquiring firms' plants remaining open, it does influence the probability that regional rival firms' plants remain open. This supports our hypothesis that acquiring firms are regarded as vulnerable because they are highly geared, giving regional rival firms an incentive to keep their plants open for longer in the expectation that the highly indebted acquirer will have to retrench should demand conditions require it. [16]

5.2 The Extent and Causes of Hysteresis

Plots of the probability of a plant being open at the end of the period based on the model reported in column 4 of table 2 are reported in figure 4.[17] Figure 4a shows a large gap between the two probability curves, indicating that across a range of prices the most likely outcome is inaction, with open plants remaining open and closed plants staying closed.

The sources of this hysteresis effect are explored in figures 4b and 4c. The plot for the 'full model' corresponds to that in figure 4a, while the plots for the 'option model' exclude the impact from the variables that have been identified as strategic and the 'strategic model' excludes the uncertainty variables. Finally, the 'no model' plot excludes both the strategic and uncertainty variables and is therefore based solely on the impact of the demand and plant specific variables, and of course the dummy signifier of whether the plant began the period open, as reported in column 4 of table 2.

[FIGURE 4: about here]

Using the 'no model' plot as a benchmark, both the strategic variables and the uncertainty variables can be seen to result in a higher price being required to trigger the opening of a previously closed plant, with the hysteresis effect being stronger for the strategic variables than for the uncertainty variables (Figure 4b). This can be contrasted with the impact of the same variables on the probability of an open plant remaining open where it

[16] While the insignificant coefficient for the acquiring firm dummy would seem to suggest that this expectation is not actually realised, there is evidence to show that on two occasions (following Redland's acquisition of Steetley in 1992 and Ibstock's acquisition of Redland in 1996) the acquiring firm did indeed follow these acquisitions with substantial rationalisations (Wood 2003).

[17] Probabilities are calculated for the average firm, with averages of independent variables calculated over the whole sample period for both open and closed plants.

can be seen that while the uncertainty variables reduce the price at which a plant is likely to be closed, this hysteresis effect is not contributed to by the strategic variables which have virtually no net effect; hence the curve for the strategic model is coincident with that of the 'no model' benchmark (Figure 4c).

The results here constitute something of a puzzle. If the industry is regarded as one where pre-emption is important, then first mover advantages should destroy option effects for the case of plant openings (Weeds 2002). Put differently, if an available niche becomes available for pre-emption, the option to wait to preempt is not valuable. Option value still characterises open plants so that hysteresis effects are understandable for the decision to close. The pattern that would be expected therefore would be for strategic effects to dominate for the opening decision and options effects to dominate for closure. However, we find no such pattern in these results.

6. Conclusions

This paper has examined the influences of decisions to open or close brick plants, with particular interest in identifying hysteresis effects that may explain the delay in the brick manufacturers in responding to swings in demand. The real options approach to investment behaviour suggests that hysteresis results from high uncertainty that increases the value of waiting. Our results show that higher levels of uncertainty do indeed result in inactivity, be it in opening or closing brick plants. There is, however, evidence of this effect diminishing at high levels of uncertainty for the decision to open a brick plant. This is consistent with recent theoretical work that suggests that the relationship between uncertainty and investment behaviour may be non-linear, possibly due to risk attitude.

Complementary explanations rest on strategic considerations and also on a variety of direct and indirect costs incurred when opening or closing factories. After taking account of demand and cost influences we do not find strong evidence of strategic influences in the decision as to whether to close or keep open an existing plant.

There is stronger support for a strategic influence in the decision to reopen existing closed plants. Here we find evidence of a size effect whereby smaller firms are more likely to enter given that the effect on existing own sales is less than for larger firms. The higher the total number of plants in a region, given its demand profile, the less the likelihood of reopening this result is consistent with spatial preemption. Firms that reopen are more likely to do so where there is a local rival. This rather surprising result echoes that of Toivanen and Waterson for the fast food industry and may be due to learning in respect of demand conditions or the availability of skilled labour.

The high number of acquisitions that have taken place during the sample period appear to have influenced the timing of plant closures. Although we cannot establish that plants of acquiring firms are significantly more likely to close (or not re-open) we find that regional rivals react strongly when a firm acquires. Specifically the firm is perceived to have high debt and this increases the chance of rival being open.

Overall, the results suggest that in addition to standard cost and demand considerations, real options influences are of great importance in understanding the closure and the reopening decisions. Strategic considerations seem important for the decision to reopen but negligible for the decision to close. The latter finding is consistent with the multiple and complex set of reasons for closure that have been found in case studies of exit behaviour. However, the finding here undermines the simple theoretical prediction that options effects should be more important for the decision to close than to open if the latter decision involves pre-emption.

Appendix 1. Data sources and description

Plant begins period open	Dummy takes the value of 1 if the plant is open at the begin of the period, otherwise zero
Demand variables	
Brick price	The brick price index is obtained from official sources and is deflated by the GDP deflator
Stocks	Stocks vary with both changes in demand and in production, and since production is approximately equal to capacity, the regional level of stocks is included as a proxy for excess capacity
Change in housing starts	the change in regional housing starts (more than half of brick production is used in the construction of housing)
Real interest rate	the real spot rate on 10 year government bonds obtained from the Bank of England
Plant variables	
Aesthetic quality	With advice from one of the country's leading brick consultants plant output was graded according to its aesthetic quality. The main determinant of the aesthetic quality of a brick is the clay, though additives and the technique for forming the brick are also important. While this may be regarded as a highly subjective venture, there are certain aesthetic qualities relating to the colour and texture of a brick that can be recognised as more or less desirable, and therefore being reflected in the price. The output of each plant was given a grade ranging from A for bricks which possess an inherent beauty in terms of both colour and texture, B for bricks which can be described as less handsome but nevertheless capable of being used for the construction of an attractive house, to C for the more utilitarian bricks which may be used for mass housing but require mixing with some bricks of different colours to avoid a barrack-block effect. The final classifications were shown to Production Directors for corroboration
Fletton brick	Fletton clay is used by London Brick Company. The product is generally inferior to non-fletton bricks in terms of both aesthetic quality and durability. With the long term decline in demand for inferior bricks LBC has substantially rationalised its capacity and invested heavily in the remaining plants in an attempt to improve the quality of its output.
Log Plant capacity	Plant capacity is measured at the beginning of each year. Information on plant capacity is obtained from media sources and from interviews with firm managers.
Received substantial investment in past 5years	Investment histories for individual plants are obtained from trade journals. Details of investment in new capacity and in modernising existing plants are often well publicised in advance.
Strategic variables	
Firm has recently acquired	Dummy variables indicating whether the owning firm has made a large acquisition (in excess of £50m) during the preceding two years (including the year of acquisition)
Firm's neighbour has recently acquired	A dummy variable for whether a rival firm operating within it's locality has made a large acquisition during the preceding two years

Regional capacity share	Each plant is situated within a region that is defined according to the available road infrastructure. The owning firm's total capacity of plants supplying that region is then divided by the capacity of all plants supplying that region.
Total number of regional plants	The total number of operating plants that supply the region.
Own local plant	A dummy variable indicating whether the owning firm owns another open plant within a 10 mile radius. This relatively short distance is chosen because the variable is intended to capture the impact a friendly neighbour has on recruitment and redundancies. 10 miles is considered appropriate given the rural settings and localised employment of many brick plants
Rival local plant	A dummy variable indicating whether a rival plant is operational within a 10 mile radius.
Uncertainty	
Uncertainty	In keeping with much of the literature we model uncertainty by the volatility of prices. A standard ADF test suggests that both the log of brick price and the fuel price are non-stationary. Accordingly we difference the series before testing for ARCH effects in a parsimonious autoregressive equation obtained from testing down from a model with 12 lags. As we did not discover any ARCH effects we calculated price volatility as the standard deviation of the twelve previous monthly residuals from the AR model. The resulting measure is standardized so that the average is 1
Uncertainty squared	Following Sarkar (2000) and Folta and O'Brien (2004) we allow for the possibility of a non-linear uncertainty effect.

Correlation table for variables used

	dependent variable	plant begins open	brick price	stocks	housing starts	interest rate	low aesthetic quality	high aesthetic quality	fletton	capacity	substantial investment	firm has recently acquired	regional rival has acquired	share	number of plants	local own plant	local rival plant	uncertainty	uncertainty squared
dependent variable	1.000																		
plant begins open	0.803	1.000																	
brick price	0.236	0.192	1.000																
stocks	-0.101	-0.058	-0.285	1.000															
housing starts	-0.036	-0.058	-0.072	-0.283	1.000														
interest rate	-0.048	-0.077	0.121	-0.223	0.271	1.000													
low aesthetic quality	-0.097	-0.090	0.025	-0.153	0.053	0.010	1.000												
high aesthetic quality	0.027	0.025	-0.018	0.161	-0.056	-0.006	-0.480	1.000											
fletton	-0.098	-0.088	0.024	0.344	0.000	0.004	0.203	-0.130	1.000										
capacity	0.198	0.170	-0.036	0.129	0.014	-0.051	0.310	-0.403	0.450	1.000									
substantial investment	0.106	0.031	0.130	-0.017	-0.014	-0.010	0.096	-0.037	-0.036	0.150	1.000								
firm has recently acquired	-0.130	-0.090	-0.301	0.037	0.069	-0.009	-0.092	0.096	-0.079	-0.035	-0.006	1.000							
regional rival has acquired	-0.064	-0.095	-0.184	0.063	-0.100	0.030	-0.025	0.021	-0.005	0.022	-0.019	-0.013	1.000						
share	0.037	0.064	-0.121	-0.266	0.037	-0.056	0.141	-0.173	0.033	0.299	-0.050	0.227	-0.016	1.000					
number of plants	0.019	0.034	0.239	0.655	-0.113	-0.005	-0.062	0.145	0.554	0.192	0.080	-0.111	-0.037	-0.355	1.000				
local own plant	0.013	0.014	0.015	0.131	-0.011	-0.019	0.042	-0.132	0.182	0.240	0.035	0.071	-0.018	0.248	0.192	1.000			
local rival plant	0.139	0.129	0.050	-0.022	-0.047	-0.021	-0.154	0.094	-0.298	-0.078	0.125	0.061	-0.036	-0.053	-0.024	0.068	1.000		
uncertainty	0.033	-0.004	-0.018	-0.158	0.116	0.077	-0.002	0.005	0.002	0.003	-0.016	0.081	0.247	0.034	-0.023	-0.004	-0.025	1.000	
uncertainty squared	0.034	0.015	-0.018	-0.102	0.071	0.054	0.002	0.002	0.003	-0.001	0.003	0.089	0.230	0.019	0.008	0.000	-0.012	0.975	1.000

Appendix 2

	1985	1989	2000
Ambion*			5
Armitage	2	Acquired by Marshalls (1988: £70m)	
Baggeridge	3	5	6
Blockleys	1	3	2
Butterley	18	17	11
Caradale**			2
Chelwood***			6
Blue Circle	1	2	Acquired by Chelwood (1997: £14.4m)
Cranleigh****			1
Collier	1	Acquired by Salvesen (1988: £3.7m)	
Errol*****			1
GISCOL	7	7	MBO Caradale (1997)
Ibstock	11	11	26
Innes Lee	2	Acquired by Tarmac (1988: £10.6m)	
LBC	9	9	3
Lumley	1	Acquired by Steetley (1987: £1.6m)	
Marley	1	4	Acquired by Tarmac (1993: Asset swap)
Marshalls		3	4
McAlpine	1	Acquired by Marley (1988: £3.6m)	
Nottingham	2	Acquired by Marley (1987: £40.2m)	
Ockley	1	Acquired by Blue Circle (1987: £73m)	
Phoenix******			1
Raeburn	1	2	1
Redland	18	18	Acquired by Ibstock (1996: £155m)
Rudgwick	1	1	Acquired by Chelwood (1998)
Salvesen	2	4	MBO Chelwood (1995: £63.5m)
SBC	2	2	Acquired by Ibstock (1994: £14.8m)
Sevalco	1	Acquired by Tarmac (1987: £13m)	
Yorkshire Brick	1	1	Acquired by Marhsalls (1994:)
Steetley	9	12	Acquired by Redland Brick (1992: £625m[18])
Tarmac	6	9	Acquired by Ibstock (1995: £65m)
Wemyss	1	1	1

* MBO of Ibstock plants following DTI ruling on Ibstock's acquisition of Redland, £53m.
** MBO of GISCOL bricks in 1997.
*** MBO of Salvesen brick, 1995.
**** MBO of this Redland plant following an OFT ruling relating to Redland's acquisition of Steetley, 1992.
***** Mothballed by Marley and sold by Tarmac to Errol Brick, 1994.
****** Mothballed by Tarmac, re-opened following MBO, 1993.

[18] Includes acquisition of Steetley tiles.

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Figure 1

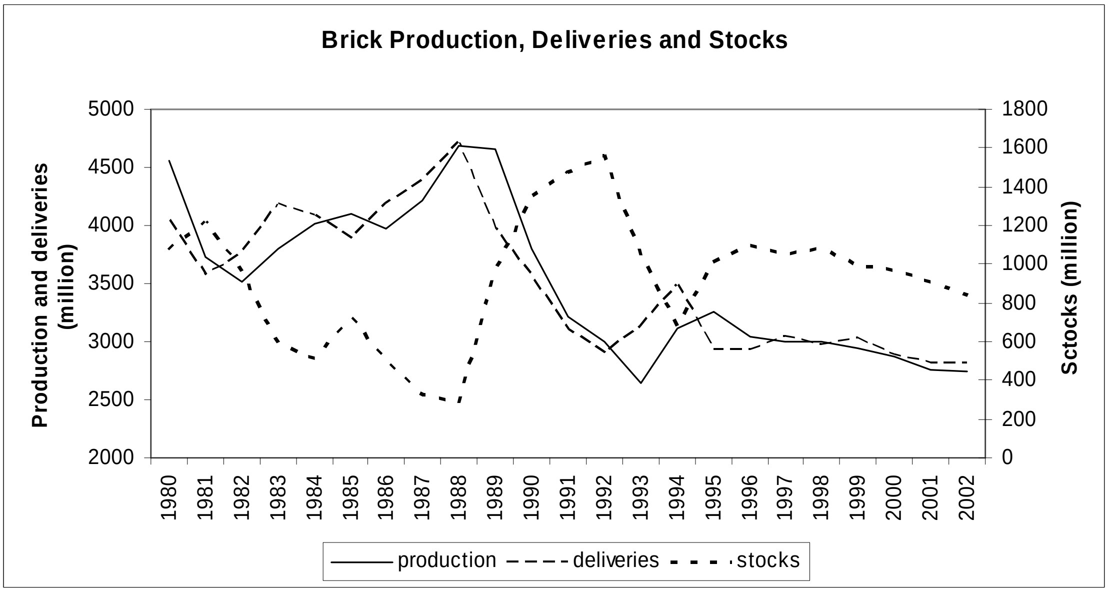
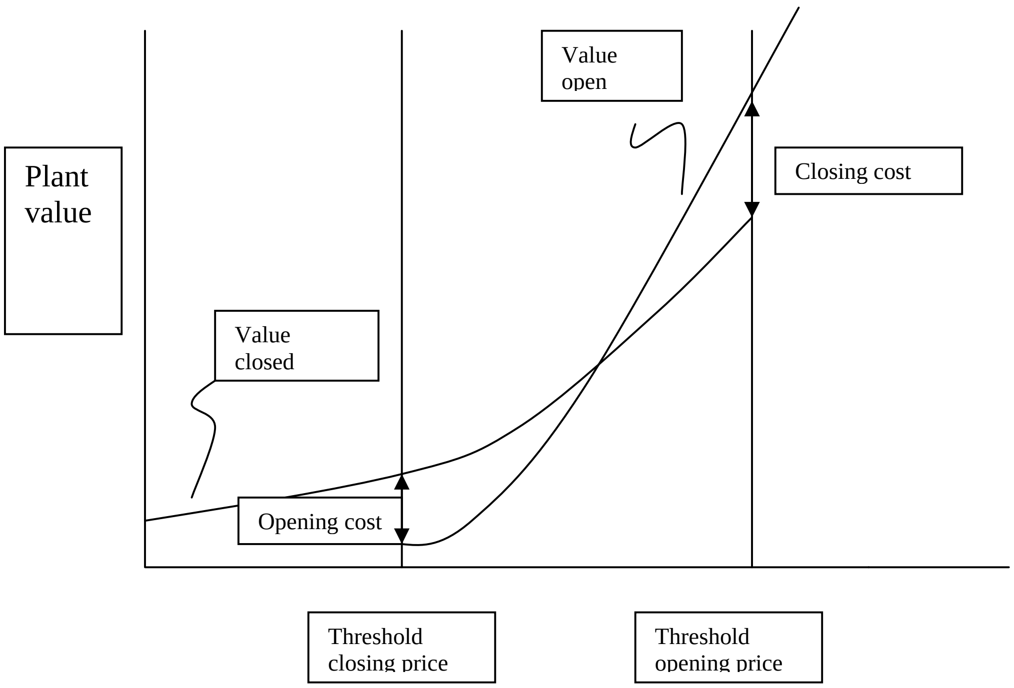

Brick Production, Deliveries and Stocks
Production and deliveries (million)
Sctocks (million)
5000
4500
4000
3500
3000
2500
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
production
deliveries
stocks

Figure 2



Plant value
Value open
Closing cost
Value closed
Opening cost
Threshold closing price
Threshold opening price

Figure 3: Probability of plant being open at end of period

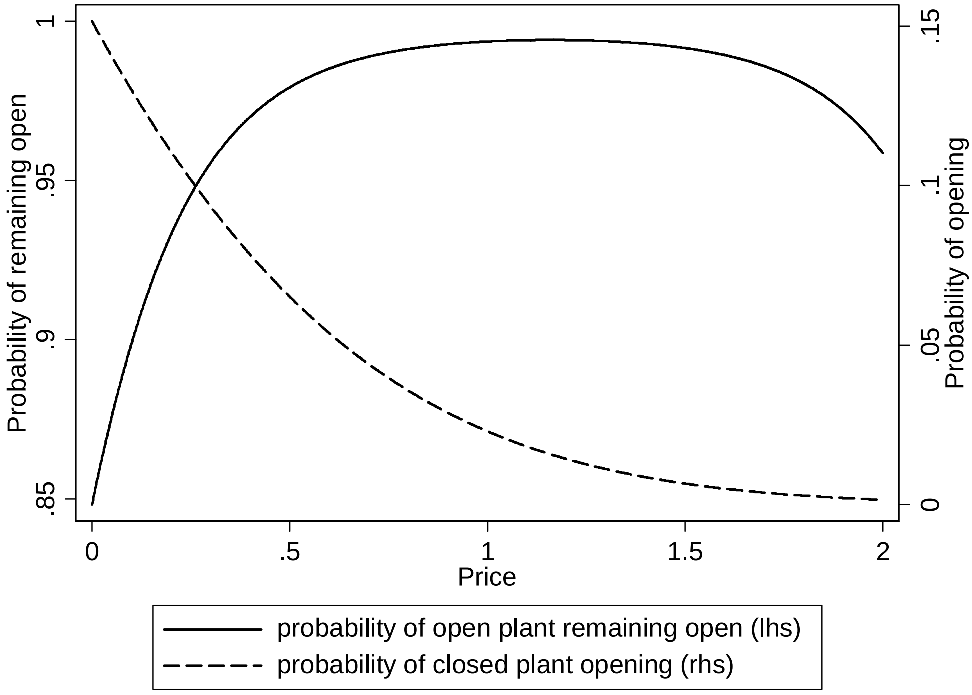


Figure 4a: Probability of plant being open at end of period

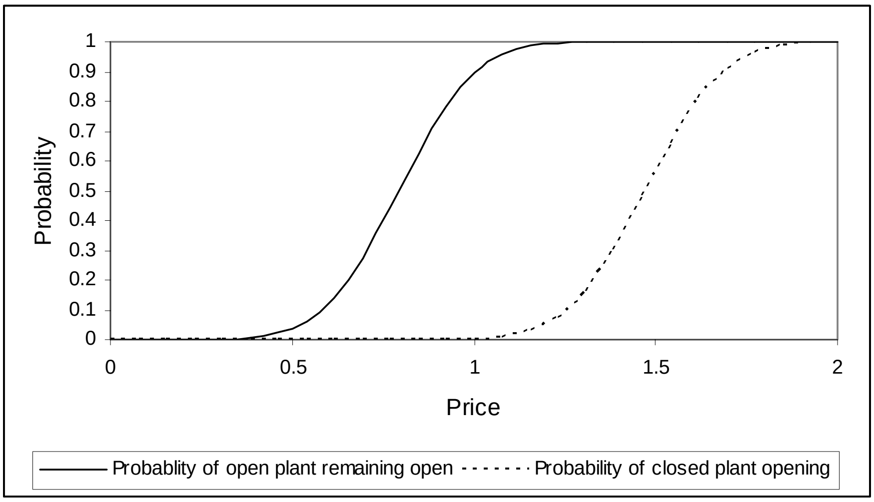


Figure 4b: Probability of closed plant being opened

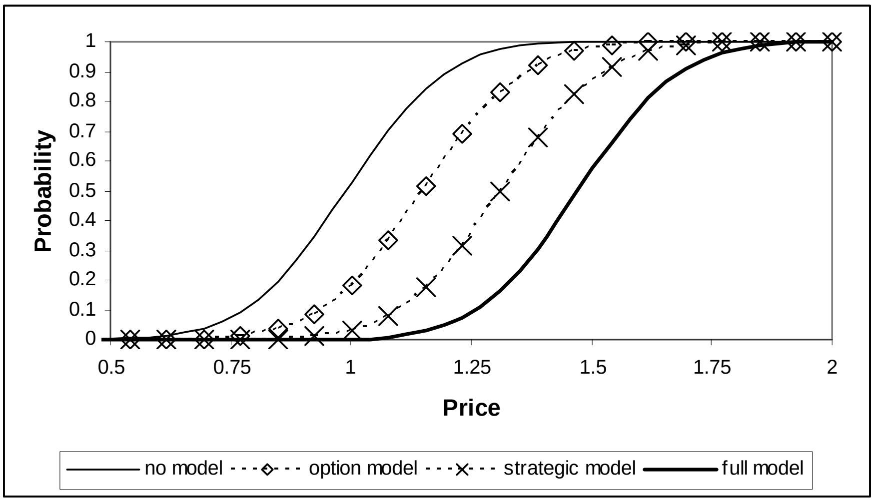


Figure 4c: Probability of open plant remaining open

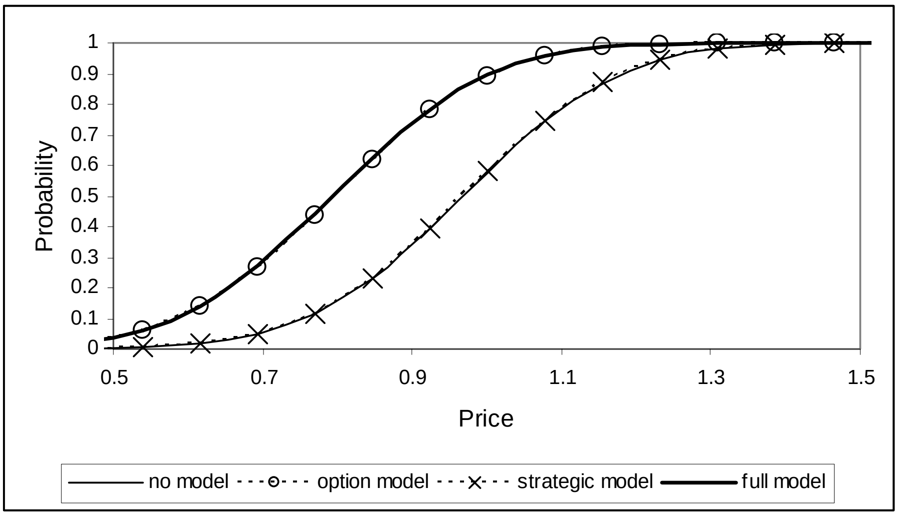


Table 1: Hypotheses

Hysteresis explained by	**Real Options**	**Real Options**	**Strategic behaviour**	**Strategic behaviour**
	Previously open	Previously shut	Previously open	Previously shut
Prior state	+	-	+	-
Brick price	+	+	+	-
Brick quality (1=high)	+	+	+	+
Proxy for inverse regional demand: Stocks	-	-	-	-
Proxy for regional demand: housing starts	+	+	+	+
Discount rate (real long rate)	+	+	-	-
Operating cost proxy 1: fuel cost index	-	-	-	-
Operating cost proxy 2: size of plant	-	-	-	-
Operating cost proxy 3: recent investment in the plant	-	-	-	-
Price volatility	+ [non-linear]	-[non-linear]	NA	NA
Fuel cost volatility	+ [non-linear]	-[non-linear]	NA	NA
Cost of shut-down and reopening: function of size	+	-	+	NA
Regional size of company	NA	NA	-	-
Number of plants owned by company	NA	NA	-	+
Total number of plants operating in the region	NA	NA	-	-
Existence of own local plant	NA	NA	?	?
Existence of rival local plant	NA	NA	-	-
Plant owned by recently acquired or acquiring firm (proxy for gearing)	NA	NA	-	-
Local company plant owned by recently acquired or acquiring firm (proxy for gearing)	NA	NA	+	+

Table 2: Probit analysis of probability of plant being open at end of period

	average	Open	Mothball	Open	Mothball	Open	Close	Open	Close
Plant begins period open	0.855	0.0821		0.0163		0.2563		0.2854	
		(0.291)		(0.713)		(0.053)		(0.000)	
Demand variables									
Brick price	1.141	0.7900		0.7498		0.6860		0.7559	
		(0.000)		(0.000)		(0.000)		(0.000)	
Stocks	158.564	0.001				0.0000			
		(0.512)				(0.749)			
Change in housing starts	-0.082	0.0007				0.0003			
		(0.369)				(0.641)			
Real interest rate	4.000	0.0034				0.0006			
		(0.585)				(0.899)			
Plant variables									
Low aesthetic quality	0.089	-0.0524		-0.0523		-0.0490		-0.0511	
		(0.004)		(0.007)		(0.002)		(0.002)	
High aesthetic quality	0.436	0.0504		0.0526		0.0407		0.0435	
		(0.015)		(0.021)		(0.014)		(0.011)	
Fletton brick	0.086	-0.2302		-0.3209		-0.1906		-0.1937	
		(0.002)		(0.000)		(0.007)		(0.004)	
Log Plant capacity	1.400	0.1778		0.1996		0.1576		0.1629	
		(0.000)		(0.000)		(0.000)		(0.000)	
Substantial investment in past 5years	0.104	0.0354				0.0421		0.0469	
		(0.226)				(0.070)		(0.054)	
Uncertainty									
Uncertainty	0.992	0.2712	-0.0984	0.3200	-0.1200	0.2224	-0.0900	0.2504	-0.0570
		(0.000)	(0.383)	(0.000)	(0.001)	(0.000)	(0.324)	(0.000)	(0.007)
Uncertainty squared	1.345	-0.1172	0.0026	-0.1381		-0.0967	0.0251	-0.1080	
		(0.001)	(0.966)	(0.000)		(0.001)	(0.563)	(0.000)	
Strategic variables									
Regional capacity share	0.272	0.0421	-0.6156		-0.6124	0.0190	-0.3600		-0.3835
		(0.449)	(0.002)		(0.001)	(0.694)	(0.001)		(0.004)
Total number of open plants in region		-0.0022	-0.0089		-0.0090	-0.0015	-0.0014	-0.0020	
	16.94	(0.208)	(0.004)		(0.007)	(0.367)	(0.457)	(0.053)	
Local own plant		-0.0228	0.0101	-0.0252		-0.0173	0.0017		
	0.499	(0.216)	(0.782)	(0.149)		(0.275)	(0.946)		
Local rival plant		-0.0037	0.0551		0.0634	-0.0055	0.0455		0.0513
	0.485	(0.853)	(0.041)		(0.017)	(0.748)	(0.002)		(0.001)
Firm has recently acquired	0.107	-0.0536	0.0400			-0.0359	-0.0250		
		(0.166)	(0.355)			(0.262)	(0.671)		
Firm's regional rival has recently acquired	0.156	0.0607	0.0453	0.0616		0.0520	0.0098	0.0442	
		(0.007)	(0.191)	(0.003)		(0.006)	(0.768)	(0.002)	
Sample		1714		1714		1714		1714	
McFadden R^2		0.7014		0.6957		0.6876		0.6840	
Log likelihood		-230.30		-234.66		-240.92		-243.67	

Reported coefficients are marginal effects calculated at the variables' mean values, with the exception of coefficients for dummy variables that measure the effect of a change of the dummy variable from 0 to 1 (calculated at the mean values for all other variables).
p-values calculated from robust standard errors are reported in parentheses.