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ESTIMATING A SHORT RUN COST FUNCTION FOR A HETEROGENOUS INDUSTRY

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Estimating a Short Run Cost Function for a Heterogeneous Industry*

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Abstract: Plant level heterogeneity and discrete production processes can produce problems for estimation With its simple production process, homogeneous output and considerable publicly available data, the U.S. Portland Cement industry provides an excellent opportunity to explicitly model and estimate some sources of plant level heterogeneity and their importance. This paper presents and estimates a structural model of discrete production decisions by heterogeneous price taking plants.

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1. Introduction

The use of recent increased availability of plant level data has forcefully highlighted two previously underappreciated features of manufacturing. First, that at any point in time, industries are composed of firms and plants that vary in productivity and size. Analysis of the data demonstrated this heterogeneity was economically significant as plants responded quite differently to aggregate shocks(Davis and Haltiwanger(1992)), and controlling for the heterogeneity led to improved estimation (Olley and Pakes(1994). The second feature is that economically significant changes are sometimes best described as non-convex and discrete rather than convex and continuous (Bresnahan and Ramey(1994)). Both of these features suggest potential problems in the estimation of cost parameters for at least some industries. And the estimation of, in particular, short run marginal cost parameters is of particular interest as they are needed to determine firm market power or the nature of their pricing, as is frequently done in the new empirical industrial organization(Bresnahan(1989)).

The cement industry provides an excellent opportunity to model and structurally estimate the short run cost functions of heterogeneous plants that make discrete production choices. First, cement is essentially homogeneous. Second, it is produced by a relatively simple fixed proportions production process. Third, at least some of the most important sources of plant level heterogeneity are observable and they can be systematically included in both the modelling of decision making by a cement plant, and in the estimation of the short run cost function. Finally, the discrete production choice arises naturally from the combination of the engineering attributes of the problem and the nature of competition in the industry.

In this paper, I adapt and extend earlier work on the cement industry to generate a structural model of a cement plant featuring discrete production choices. In this model, a set of sources of plant level heterogeneity is discussed and incorporated into a model of the production decision making. A new unusually detailed data set on the industry is then presented which features a mix of low level aggregate prices and quantities, and plant and equipment characteristics. The model to be estimated differs from earlier work in four respects. First, rather than primarily using output and inputs quantities to estimate the parameters of interest, as was done with earlier related work on the cement and steel industries, prices are used which potentially complicates the estimation. Second, the cost parameters are estimated using a generalized incompletely ordered probit, which directly captures the engineering aspects of the problem facing the plant - the first time this technique has been used in this fashion. Third, information on exit and plant survival are used to control for unobserved heterogeneity in the input requirements parameters of the cost function. Finally, this paper attempts a reduced form estimation of Ricardian rents to cement plants, the possibility of which has not been considered in earlier work. The estimates are compared with industry averages and, to a lesser extent, engineering estimates reported in trade journals.

However, even with the use of an unusually detailed dataset and an improved specification, the estimation itself is only partially successful. While some aspects of the results are consistent with expectations based on the characteristics of the technology, problems with either or all of capturing the underlying heterogeneity, Ricardian rents, or the distributional assumptions seem potential sources of the problems. The experience of specifying and estimating of this model suggests that, though it is a worthwhile task, that getting better estimates of short run cost parameters is going to require even greater use of industry knowledge and more detailed data sets than typically is the case in empirical industrial organization.

In the next section, after discussing the demand conditions and the technology of cement production, cost and profit functions are derived. In section three, some sources of plant level heterogeneity and previous experience with estimating cost function and pricing equations are discussed. Then in section four the competitive conditions and the kiln use equation are derived, followed by a discussion of the kiln and plant closure decision and the nature of Ricardian rents. The data is then introduced in section five. In section six, an estimation algorithm is presented, concluding with the general specification that will be taken to the data. Section seven presents the results and in section eight some conclusions are presented.

2. The Specification of the Plant Production, Cost and Profit Functions.

2.1 Demand

Cement is the powder that is mixed with sand, aggregates and water to produce concrete. Most cement is a standard grey Portland Cement which is effectively homogeneous across sellers, domestic and foreign. The primary use of concrete is in construction. The only stage at which significant substitution possibilities exist is in the choice of materials for a construction project e.g. asphalt is a substitute for road construction. Thus the demand for cement will vary directly with construction activity, the relative price of cement determining the share of construction using concrete.[1] Except for in the far south and southwest, construction is highly seasonal, being concentrated in the summer and fall.

2.2 The Production Function.[2]

The transformation of buried limestone into cement powder requires a short series of transformations with relatively few additional inputs. The quarried limestone, or a substitute, is ground into a raw mix. The raw mix is then baked in a large kiln, producing small pellets known as clinker. Cement is then produced by grinding the clinker and mixing it with gypsum. The raw (material) grinding mills, the finish (clinker) grinding mills, distribution facilities, and other components of the cement plant are usually scaled around the kiln, or bank of kilns. Kilns typically operate for decades, and are usually scrapped upon retirement. The buildings and grinding mills also feature long service lives. Once the modern kiln is installed, the quantities of inputs required to produce a short ton of cement are substantially fixed (Fφrsund and Hjalmarsson(1983), Das(1991a)).

The production function of the kiln, with its concatenated equipment, will now be developed in two steps. As in Bertin et al(1996), explicit use is made of the operating margins framework of Alchian(1959). First, an expression for the rate of

[1] Prentice(1995) developed a structural model of regional demand for cement.
[2] This section is based on Das(1992) and Peray(1986). Peray(1986) is a particularly useful resource as he presents recommended procedures for kiln operators to follow and discusses the problems that kiln operators may encounter.

production is specified. Then it is converted into an expression for the quantity of production by multiplying the production rate by the length of the production run. But because of the differences in the types of data that will subsequently be used, the treatment considerably differs from Bertin et al's.

First, the rate of production is specified as the product of the kiln's recommended daily capacity, a function of a Leontief production function and, to capture the role of inputs consumed in starting and shutting down the kiln, an indicator function:

$$Q_d = DC_k * \beta(\min(a * q_v)) * I(q_{fk}) \quad (2.2.1)$$

where Q_d is the quantity of cement produced per day, DC_k is the recommended daily capacity of the kiln, a and q_v are v by 1 vectors of input-output coefficients and input quantities and q_{fk} is a vector of inputs that must be consumed for the kiln to operate at all. In an appendix in Prentice(1997), it is argued that the firm operates at DC_k even when technically feasible to do otherwise (it is relatively straightforward to place conditions on the parameters to do this). The quantity of production, then, is equal to the rate of production multiplied by the length of the production run, ND_k. Because the kiln needs to be stopped for several days, MD_k, each year for maintenance and cleaning, the annual output of the kiln is given by:

$$Q = ND_k * DC_k * \beta(\min(a * q_v)) * I(q_{fk}) \text{ where } ND_k \leq (365 - MD_k) \quad (2.2.2)$$

In effect, output is determined by the firm's choice of ND_k and MD_k. Though MD_k is also decided by the firm, for simplicity, it will be taken as exogenous in this paper.[3]

2.3 The Cost and Profit Functions

The discussion in section 2.2 implies the cost function for the n^{th} kiln will be, substituting, for familiarity, q_n for $ND*DC_k$, the quantity of cement produced:

$$(2.3.1)\ C(w, q_n) = I_n(\bullet)\{w_v' \alpha * q_n + w_{fk} q_{fk}\} + FC_n = TVC_n + FC_n$$

[3] A structural model of the choice of MD_k is presented in Prentice(1994).

$I_n(*)$ is an indicator function that takes the value 1 if the n^{th} kiln is on and zero otherwise, w_v is a vector of input prices for the variable inputs, w_{fk} the input prices for the other inputs for the kiln, and FC, other fixed costs in operating the kiln.

Before specifying the profit function for the plant it is worth noting that while most cement plants usually do not engage in other activities, domestic producers in the United States became increasingly involved in importing clinker and cement during the nineteen seventies and nineteen eighties. This involvement was on a sufficient scale to justify including in the plants profit function, the costs and returns from importing.(see Prentice(1996a) for details). The profit function for a plant with N kilns is therefore specified as follows:

$$(2.3.2)\ \pi = \sum_{n=1}^{N}\left(Pq_n - TVC_n - FC_n\right)I_n(\bullet) + \left(\left(P - \alpha'_m w_m\right)q_m - FC_m\right)I_m(\bullet) - PFC$$

where P is the price of cement, q_m the quantity imported, w_m is a vector of the prices of the inputs for importing, α_m the inverse of the variable input coefficients for importing, FC_m the fixed costs of importing, I_m the indicator function that takes the value 1 if the plant imports and zero otherwise. PFC are any plant or kiln fixed costs including capital costs. The combination of the size of the kilns and changing technology means it is not unreasonable to treat much of the expenditure on the plant and equipment as sunk. The unsunk portion of capital is, then, considered a fixed cost and does not influence the decision whether to operate or idle the kiln.

3. The Sources and Effects of Plant Level Heterogeneity

With the characteristics of the kiln being substantially fixed when installed, the kiln potentially operating for decades, technological change and input prices and demand varying over regional markets and over time, with regional markets there is the potential for plants at a point in time to be operating a variety of types and vintages of kilns. Researchers using cement industry data have been able to account for this, to a greater extent, it appears, than in other industries, as the industry association publishes directories of the plants including kiln capacities, types and vintages, as well as other useful data (PCA, various). In the next two subsections, the effect of the characteristics reported in the PCA directories on cost parameters will be discussed. Then the use of this data in earlier empirical work will be discussed. The final two subsections discuss two additional sources of heterogeneity that have not been previously considered: changes in labor relations, and the cost and quality of the raw materials.

3.1 Type of Production Process

The energy consumed per ton of cement will depend, in part, on the type of kiln. There are three main types of kilns in the U.S Cement Industry: Wet Process, the Dry Process and the Preheater/Precalciner Processes. Their characteristics are summarized over the page in Table 3.1.1:

Table 3.1.1 Types and Characteristics of Kilns

Type	Fuel Rqt. mBTU per short ton	Power Rqt. kwh per st	Typical Vintage
Wet	5.64	128.69	1920-70s
Dry	5.575	146.35	Pre20s & 1950-70s
Suspension Preheater	Included Below	included in Dry	1950s & 1970-80s
Preheater & Precalciner	4.09	included in Dry	Mid 1970s - 1990s

Sources: (1)Fuel Requirements: National Average for 1977-1988 from B.O.M(1977-88)
(2) Power Requirements: National Average for 1977-1990 from B.O.M(1977-1990)
(3) Typical Vintage - PCA(1974-1992), Trade Journals, B.O.M Yearbooks

The wet and dry processes differ in the quantity of water added to the raw mix of ground limestone before it is fed into the kiln. For wet process kilns, water is added to the raw mix to form a slurry. The water must then be boiled away during processing. For dry process kilns, the raw mix is fed in as is. Preheater and precalciner Kilns are dry process kilns which feature even lower fuel requirements due to various preliminary processing stages before the raw mix enters the kiln.

By the late nineteen seventies, the average differences in fuel consumption between wet and dry process kilns are relatively small. Indeed, after 1983, they are effectively identical. This is surprising given the emphasis placed on the distinction in the trade literature and in engineering descriptions. During the period of the survey the average fuel consumption of the preheater and precalciner kilns is consistently around 20-30% lower than the wet and dry process kilns. The fuel consumption advantage of the dry process kilns is partially offset by the higher electricity consumption required for the additional grinding of the raw materials that must be done.

3.2 Vintage or Capacity

The second characteristic considered in earlier work has been the vintage of the kilns. Older kilns may be less fuel efficient for two reasons. First, Das(1992) argued that depreciation for a kiln takes the form of increased input consumption rather than lower production. Rosenbaum(1994) provides additional information on this, stating this is due to the wearing of the refractory bricks, despite periodic relining. The engineering literature makes no specific reference to this though. Peray((1986) p19) refers to "linings in the upper, cooler regions of the kiln...(with)...lives of 5-20 years" but the maximum of the average lives for refractory bricks in the three zones of a kiln reported in a survey of Macey(1986) was 20 months. Estimates of kiln consumption in the trade journals over time are relatively rare but scattered evidence of increasing input consumption over time was found.

A second reason for vintage effects is embodied technological change. The trade literature emphasizes embodied technological progress in the form of instrumentation, automation and fuel saving devices in newer kilns leading to lower fuel consumption. In addition, the size of kilns has gradually increased over the century, especially since 1959, and there is engineering evidence that larger kilns are more fuel efficient (Schroth(1973) on Suspension Preheaters).

3.3 Successes of and Problems with Earlier Work

Earlier work using cement industry data can be broadly categorized into three groups. The first group used plant level data, and made use of plant characteristics data (McBride(1981) and Das(1991 a&b and 1992). The second group of papers performed reduced form estimation with low level aggregate data, making use of plant or regional characteristics (Rosenbaum and co-authors, in a series of papers, the most recent being in 1994, and Prentice(1996a)). The third group, which will not be considered here, used plant level data (Abbot(1994)) or aggregate data, but, in some cases inexplicably, chose not to use regional or plant level characteristics data. Estimation will be judged as successful if, for the structural papers, the estimated coefficients are similar to industry averages, calculated from Bureau of Mines statistics(BOM various) and for the reduced form papers if the coefficient signs and values are all broadly plausible.

The papers using plant level data and controlling for vintage and process have generally been successful. The main problem encountered by McBride(1981) and Das(1991a&b) has been sample selection. McBride has a sample of plant data from 27 North American plants from between 1963-1965. Das(1991a&b) works with a sample of plant data from 95 U.S plants from between 1972-1980. As McBride notes, he obtains too implausibly small estimates for the fuel coefficient for dry process plants. Das(1991b)'s fixed effects estimates for the fuel consumption of a new kiln for the wet and dry processes are quite plausible, with the average fuel consumption of new kilns reported in the trade journals (12 wet, 5 dry, 10 preheater), of a comparable size, fall well within a standard confidence interval around her estimates, though the estimate for preheater kiln just scrapes in for a 99% confidence interval. The use of fixed effects in the estimation of the fuel coefficients is troubling as these have no obvious engineering interpretation, suggesting her specification is missing a significant source of plant level heterogeneity. The similarity in fuel consumption coefficients across the processes suggests the fixed effects may be picking up more than non-process related plant idiosyncrasies too. Both McBride and Das also control for vintage. McBride's estimates are problematic but Das's estimates are reasonable.[4] With respect to electricity, the industry averages are well above the upper bound of even a 99% confidence interval around her estimates for the different processes. Das(1991a)'s estimates of the labor input and other costs are of particular interest. Das obtains estimates using a logit and a semi-parametric estimator. The semi-parametric estimator does well, the industry average falling within a regular confidence interval of her

[4] It is not clear how McBride does this, as if ages in years are used the implied fuel coefficients explode except for very new kilns, which suggests either some transformation of the age variable or a recording error.

preferred estimate. But the logit estimates are very small - for the first estimate, for which a standard error is reported, the industry average is above even the upper bound of a 99% confidence interval around her estimate. The second estimate is negative. A common constant term is specified to capture other variable inputs, including raw materials. Her estimates are significantly higher than an aggregate average reported in the paper.

The reduced form papers, using aggregate data run into more problems. Rosenbaum(1994) works with a sample of 25 regional markets for 1974-1989. Prentice(1996a) works with an unbalanced panel of small aggregates of plants for 1977-1992. Both estimate reduced form pricing equations, with both different explanatory variables, and the same explanatory variables constructed in different ways. Neither are completely successful. Rosenbaum obtains plausible effects for fuel, the percentage of capacity in the region that is dry process, the average regional kiln capacity and a set of variables to capture the competitiveness of the market. However, the price of electricity is insignificantly different from zero, and the coefficients on the wage rate and the average age of the kilns in the region are significantly negative and significantly negative at 90% (two tailed test). The constant term in Rosenbaum is unexpectedly large. Prentice, in comparison, has correct signs on all variables, though electricity, again, is not significantly different from zero. To capture the effects of different shares of different vintages and dry and wet processes(in different regressions[5]) the shares of the different types of capacity (three groups of vintages, Pre1960, 1960-1973, Post 1973) were interacted with the regional fuel price. All featured positive signs. With the dry and wet process shares, contrary to expectations, the coefficient on the share of dry process capacity was larger than the share on wet process capacity, though the difference is not great. With the coefficients for the three vintage groups, while coefficient on the pre-1960 group is much larger than the two later groups, the coefficient for the 1960-1973 group is below that of the most recent group though, again, the difference is not great. The explanatory power of the pricing

[5] The regression including the process variables is not included in Prentice(1996a)

equations of both Rosenbaum(1994) and Prentice(1996a) is relatively low. One possible explanation for the unexpected results is that the problematic explanatory variables are correlated with an unobserved variable(s).

3.4 Labor Relations

The first additional source of heterogeneity results from changing labor relations in the cement industry. In particular, up until 1984, labor in the cement industry was almost completely unionized under a strong union that engaged in pattern bargaining. After 1984, the union effectively collapsed(Northrup(1987)). Though an earlier study of the impact of union activity in the cement industry (Clark(1980)) suggested unionized plants tended to be more productive, the adoption of labor saving technology before the collapse of the union, and the changes in conditions and benefits after the collapse are inconsistent with Clark's results.[6] If non-wage labor costs fall and work practices improve after the change, the parameter on wages will fall. This will probably take place over time.

A second potential effect of the change in labor relations could be to also increase the variation in wages, work practices and productivity across plants.

3.5 Raw Materials

Besides McBride(1981) who had plant level consumption of raw materials, and Capone and Elzinga(1987) who had a national price index (source unclear, though probably from BOM(various))) of which little is made, raw materials have generally not been considered in earlier work. There are several ways this omission could be problematic.

Of the inputs, raw materials are probably the most plant specific or, as cement plants are not infrequently clustered, region specific. The quarry is potentially the component of the plant's assets with the longest life, and hence will influence decisions on kiln investment, including replacement. Some plants have used remote quarries, with the cost of transportation on top of any regular costs of quarrying. Most of these plants appear to have closed by the end of the seventies though (which is at least

[6] The industry response to Clark's findings was not supportive(Northrup(1987)

consistent with the additional costs not being trivial). The delay in the diffusion of the lower fuel consuming preheater kilns has been attributed, in part to problems arising from the interaction of the quality of raw materials in the U.S with the earlier versions of the technology(Schroth(1973)). The nature of the raw materials can also affect fuel consumption. For dry process kilns (including suspension preheater and precalciner kilns), the fuel required for processing will increase with the moisture of the raw materials, as the raw materials must be dried before being fed into the kiln(Norbom(1974)). In addition, plants that were previously wet process because of moist raw materials, but switched to dry process to reduce fuel consumption will still have higher fuel costs than long-term dry plants because of the moisture of the raw materials. Hence, all things being equal, the fuel requirements across plants will differ with the moisture of the raw materials. Differences in transportation or extraction costs, or in fuel consumption will be plant specific rather than kiln specific, and will persist over time.

Hence, differences in raw materials may result in different parameters on raw materials and on fuel consumption. Furthermore, differences in raw materials may also affect the choice of the process of a new kiln and even the decision whether to build a new kiln or retire the plant. To the extent differences in raw materials are included in an error term, they will introduce a plant, rather than a kiln, specific component there.

4. Competition and the Specification of the Production and Exit Decisions

As the first order conditions from which the pricing or production equation will be derived, depend on the competitiveness of the industry, this will be discussed below in section 4.1. Then, in section two, the profit function of section two will be combined with the information on plant heterogeneity in section three to yield a kiln use equation for estimation. In section 4.3, to motivate the use of plant exit and survival information as assisting in controlling for plant level heterogeneity, a kiln retirement rule is presented.

4.1 Competition in the Cement Industry.

The traditional view of the cement industry is that the combination of economies of scale with high transportation costs has created, within the U.S, a set of regional oligopolies(recent papers in this tradition include McBride(1983), Koller and Weiss(1989) and Rosenbaum(1994)). This view can be criticized on two grounds though. First, the importance of both domestic and international transportation costs may have decreased significantly from the nineteen sixties on. Second, while there appear to be substantial economies of scale, and, more to the point, substantial sunk costs, in the production of cement, each market in which cement is sold may be, in a sense, a contestable market which limits the price-setting power of the plant. While a formal encompassing model of the equilibrium in such a market is beyond the scope of this paper, some arguments will be presented to support the assumption of price taking behavior.

There is a strand of literature that has argued that transportation costs for cement have been falling since the nineteen sixties. Peck and McGowan(1967) noted the falling internal transportation costs, in the nineteen sixties, with the increased use of truck and water transportation, effectively expanding the size of the markets and increasing their competitiveness. This was reflected by the rapid expansion of the use by firms of distribution terminals, particularly for the large plants that were built on the Mississippi River. More recently, there has been a substantial fall in the delivered price of imported cement(Prentice(1996a)). This fall may have resulted from a combination of three changes. First, ocean transport costs apparently fell during this period. Second, the US dollar appreciated. Third, there may have been an expansion of low cost capacity overseas and in the neighbors of the U.S (especially Mexico). The combination of falling domestic transportation costs, and changes in the competitiveness of imported cement may have increased the competitiveness of the market for cement.

Second, it is possible that the role of economies of scale in creating the regional oligopolies may have been overstated. As argued earlier, entry into cement production involves considerable sunk costs. The distribution of cement, though, appears to require much less. Cement is transported from the plant mainly in specialized trucks (Owen(1994)) as well as train carriages and barges, and as an intermediate product, is shipped mainly to Ready Mix Concrete producers or Concrete Products Producers. Both of these consumers will have specialized facilities for the unloading of cement. Hence, entry, in terms of distribution, into a market does not appear to require sunk costs (as the transportation cost is not considered sunk) for the cement producer. Changes in distribution arrangements, in particular the increased usage of terminals, from the nineteen sixties (which do not appear to have been substantially reversed since then) seem directed more towards reducing transportation costs or other disadvantages of long distance supply (Federal Trade Commission(1966) p63-67, though they still concluded the industry was oligopolistic, Jondrow, Chase and Gamble(1982)). Hence, the market for cement may be more competitive than is suggested by the examination of entry conditions into the production of cement.

In the absence of transportation costs, the substantial number of plants in the industry (over a hundred at the end of the sample period) and zero sunk costs would result in an equivalent of a price taking equilibrium. While domestic and international transportation costs appear to have been falling, further evidence would be needed to be able to firmly state the market for cement is competitive. In a price taking equilibrium, each plant would believe that variations in its output would not affect the prices charged in the markets it could distribute to. This would occur if there were a sufficient number of plants that would, at the price in each market, would offset actions by the firm considering its output decision. Is this a reasonable characterization for the cement industry? This will depend on how many plants are needed to make an industry competitive, an issue not yet resolved.

At first there seems a tension between assuming price taking behavior and extensive heterogeneity as described in the earlier section as competition would be expected to drive out the more costly equipment and plants. This tension was resolved by Salter(1966). With the expenditure on capital equipment at least partially sunk, if demand exceeds capacity and price rises above average cost, Ricardian rents will be earned. The size of the rent earned by each kiln will depend on the characteristics of the kiln, the locational advantage of the plant, and demand (see also Lindenberg and Ross(1981), Alchian(1987)). Unless entrants expect that the rents subsequently earned by the kiln (or plant) will exceed the sunk capital costs (the cement plant as a producer is a natural monopoly or may be part of a natural oligopoly), entry will not occur and there will be a price taking equilibrium.

4.2 The Production Decision

With the assumption of price-taking, it is easily shown that the decision to operate a kiln simplifies to a simple rule, as represented below (Das(1991a)):

Kiln Use Equation for the Price Taking Firm (4.2.1)

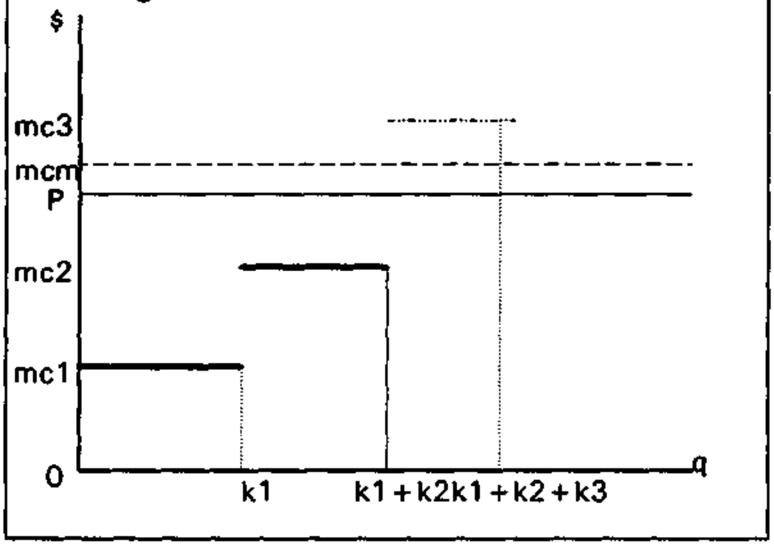
$$\text{Produce}\begin{cases} k_n \text{ if} \left(P - w'\alpha_{v,p}\right) - \dfrac{FC_n}{k_n} > 0 \\ 0 \text{ otherwise} \end{cases}$$

At the start of the year, the kiln is fired if the price is expected to exceed average cost. Otherwise the kiln is idled.

If the plant, as is not uncommon, has multiple kilns, unlike in the imperfect competition case (covered in Prentice(1996b), the production decisions for each kiln and on importing are made independently of each other. The kiln use equation is applied to each kiln (and a similar rule applies to importing). However, there is a relationship between the kiln decisions that can be used to structure estimation of the kiln use equation.

While plants tend to operate kilns of one process, they, not infrequently, operate kilns of varying vintage. In 1977 nearly 50% of plants featured a maximum difference between the vintages of two kilns (when ranked by age) of 4 years or more. And in 1992 just over 35% still featured a maximum difference of 4 years or more. As suggested by Das(1991a), the multi-kiln plant can be characterized as featuring a set of kilns of different efficiencies. The kilns will effectively be ranked by their efficiency, and operated in that order. This will be referred to as the Kiln Use Rule and is illustrated below in Figure 4.2.1.

Figure 4.2.1 The Cement Plant's Problem



This plant has three kilns, with capacities, k1,k2 and k3, and matching marginal costs, mc1,mc2,mc3. The plant faces an import price of mcm, and an output price of P. Kilns with marginal costs below P (k1 and k2) are operated, the firm producing k1+k2. Kiln k2 is referred to as the marginal kiln. The third kiln is idled and the firm does not import. If P exceeds mcm, the firm would import cement, rather than switching on the third kiln.[7]

4.3 Kiln Retirement and Average Cost

While this paper will neither specify nor estimate the parameters for the investment, or retirement, decisions, it is worth spending some time on the influences on these decisions as such decisions, under certain conditions may convey information about the values of the parameters for the static operating decisions. Griliches and Regev(1995), working with a panel of Israeli manufacturers, noted that plants that closed during the sample period had significantly lower labor productivity than the other plants. Olley and Pakes(1996) include a simple model of investment and exit, as dependent on an unobserved scaled productivity term, which is used in their estimation of a production function for the telecommunications equipment industry.

As mentioned earlier, the kiln is potentially durable, with lives, in the sample, reaching up to eighty-two years. The kiln will be retired if the scrap value that can be obtained now is greater than the expected discounted future rents, as described below:

[7] In this model the quantity of imported cement is not determined. The overseas producers would operate under capacity constraints with the world price of cement being effectively determined in a global market, and the potential exporters making their decisions based on this. Formally modelling this is beyond the scope of the paper.

Kiln Retirement Rule (4.3.1)

$$\text{Retire if } E_t\left(\sum_{j=t}^{T^*}\beta^{j-t}\left(P_j - AC_j\right)\right) - SV_t < 0$$

where β is the discount factor, T^* the (endogenous) retirement date, if the kiln is not retired this period, and SV_t the scrap value at time t. The retirement decision can then be modelled as depending on current and future input and output prices, the parameters of the cost function, and the current scrap value.

In the absence of plant specific variation in output and inputs prices, the pattern of retirements in a regional market depends on the vintages and processes of the kilns. Then, in response to common shocks, the vintage and process of the kilns should provide an ordering for the retirements that are observed. And while older, wet process kilns did appear to be closed during this period, there are striking examples of relatively new kilns being closed, and of plants continuing to operate kilns that were more than fifty years old. This suggests other plant specific factors may be important. As described above, the costs associated with differences in the extraction and use of the raw materials may result in the plant having, on average, higher marginal costs or higher kiln fixed costs, than would be typical for a plant with kilns of the relevant process, vintage and facing otherwise identical input prices. A second apparent source of cross plant differences in costs is the maintenance of the kilns. In general, though, this decision would be dependent on expected life of the kiln and plant, which would then depend on the factors such as the vintage of the kiln and the quality of the raw materials. With the data that is available, available only for, in terms of the life of the kiln, a short time the distinction between the two for plants that close is not important.

5. Data

In this section, the sources of the data that will be used in this paper will be briefly described, though the specific variables used in estimation will be described in section six. A complete list of sources is included in a data appendix. The method used to extract operating decisions of the plant will then be outlined. Finally, the characteristics of the sample of operating decisions will be presented.

5.1 The Nature of the Data

In estimating this model, annual data from 1977-1992 are available. All prices are deflated using the GDP deflator (1987=100). Except for the construction data used to construct the demand variables, which is purchasable from a construction statistics company, all data is from public sources. Where relevant, missing observations were replaced using data from adjacent or similar plants, similar variables, or interpolated.

The first source that was used, for the price and quantity of cement and clinker, the average number of maintenance days, prices and quantities of imports and the price of limestone, was the Bureau of Mines Minerals Yearbooks. For all of the aforementioned variables, excluding imports and the price of limestone, the data is published for aggregates of small groups of plants, usually adjacent to one another. The modal plant number is 4 with 85% of the region years featuring 6 plants or less. The modal number of kilns per group is 7 with 82% of the region years featuring 13 kilns or less. The price of limestone was published at the state or substate level and the price and quantities of imports of cement were published at the Customs district level (33 of them). A customs district is a collection of adjacent ports or other entry points.

The second main source, for input prices was various U.S government reports. Again, for all states except Pennsylvania, Texas and, to a lesser extent, California, these are aggregates over relatively small numbers of plants.

The third group of sources is from the PCA Plant Information Directories. These directories include kiln capacities, vintages, primary and supplementary types of fuels used and ownership. The PCA directory entries were cross checked against BOM plant and kiln counts, trade journal reports and company annual reports. Construction data was obtained from FW Dodge and is at the state level (though FW Dodge aggregate state construction data is also available from the Statistical Abstract of the United States).

The next step in assembling the data was to assign input and output prices, import prices, to plants. This data was then converted into a plant level data series by matching the state and BOM region prices to the plants located within the relevant areas. The PCA fuel usages were used unless contradicted by a more reliable source for assigning fuel prices to plants.

At this point it is worth comparing the advantages and disadvantages of the available data set compared with those used by earlier authors. Unlike Das(1991a&b), this paper uses low level aggregated data rather than plant level data. Unlike Bertin et al(1996) and Das(1991a&b), rather than using quantities of inputs and outputs to estimate input-output coefficients, input and output prices are used. This data set is, then, more like those used for the reduced form papers of Prentice(1996a) and Rosenbaum(1994). Estimating input requirements parameters from input and output prices features an extra layer of potential difficulties over using input and output quantities. Prices are influenced by factors besides the technological characteristics of the firm. Output prices are particularly vulnerable to problems in this respect. And the fixed proportions, discrete choice production doesn't make things any easier.

The data set constructed for this paper is an improvement over earlier data sets in two respects - the wage rate and limestone price series. No paper has calculated a state limestone price series before and only one paper(Capone and Elzinga(1987) has used national limestone prices. While a plant level series would be ideal, the low level of aggregation for the series makes the series used here the next best thing. For wages, earlier work has used national wage series, or even state average non-supervisory wages for manufacturing. This data set, though, has used a variety of sources to construct a state level cement manufacturing wage series, which, given the changes in labor relations in the industry, seems particularly useful. All data used in the paper is publicly available (or at least can be purchased) so the results and methods can be used by others, and the results replicated, unlike some of the earlier work.

5.2 Calculating Plant Output Decisions

Unlike in Bertin et al(1996) the scale of operations of each cement plant i.e the number of kilns, is not directly observable. Das(1991a) used the Kiln Use Rule, presented in section 4.2, to infer which kilns were operating at each plant - basically by allocating the output across the kilns in the order suggested by their efficiency until all output was allocated. This method is not feasible for low level aggregate data for two reasons. First, the kilns are not large enough for aggregate data to unambiguously reveal the ordering. Second, even if the Kiln Use Rule is followed by each plant, this does not guarantee that it is effectively followed across plants, as the efficiency of plants on average may differ. Hence the ordering across plants may differ from that suggested by a simple application of the Kiln Use Rule. To deal with this problem, I constructed to algorithm to get some incomplete information on which kilns were operating at all plants during the sample period, which is outlined below. Furthermore, I have improved on Das's algorithm by making a correction to the estimates of the capacity used, which could lead to overestimating the number of kilns operating in boom periods, and underestimating the number of kilns operating in slower periods. An examination of some maintenance data and operations data suggested that plants tended to perform more major maintenance task during the relatively slow period. I use low level aggregate data to adjust the capacity figures used by Das to allow for counter-cyclical maintenance. More details are contained in the data appendix of Prentice(1997). The algorithm is as follows:

1. Determine if only one kiln per plant or all kilns at all plants could produce the observed output. If so, then this outcome was selected. If not, then
2. Assume each plant followed the kiln use rule and compare different combinations of kiln capacities across plants with the actual output of clinker.

3. If only one combination matches the output (came within .8 or 1.05 of the actual output (my choice)), the combination is selected. Otherwise:
4. The kilns that either operated in all feasible combinations were recorded as operating and the kilns that did not operate in all of the feasible combinations were recorded as not operating.
5. Plants that were known to be mothballed (or else had closed the year before, without any evidence of being scrapped) were also included as operating zero kilns.

Hence, for each plant, an estimate of which kilns were operating is obtained.

5.3 Characteristics of the Sample

The original sample began with 2154 observations (each one per plant per year). All plants which had kilns both operating and not operating, the differences in their vintages being less than or equal to 2 years were deleted. Also one plant which had an unusual combination of processes, vintages and capacities was also deleted. This left 1999 observations. The outcomes of the algorithm to infer the operations of the plants, for the remaining observations, are stated below:

Table 5.3.1 Outcomes of inferring operations - by plant years

Outcome	Number of Plant Years (1999)
Not all kilns operated (known)	139
All kilns operated at each plant	1428
Total number of kilns operated unknown	357
No kilns operated though available for use	75

It was noted that some earlier work had experienced difficulties when plants and kilns of different types were not adequately represented in the sample. Table 5.3.2 demonstrates that the representation of the different types in the sample is quite adequate.

Table 5.3.2 Kilns in Sample by Vintage and by Process

	Pre 1948	1948-1959	1960-1972	1972-
Dry	75	172	209	52
Wet	145	294	424	86
Preheater	6	29	20	487

Finally, to aid in the interpretation of the results, some statistics of some of the key explanatory variables, calculated from the sample are presented below in Table 5.3.3. The price of cement and vintages are averages, the statistics on the plants and kilns are numbers recorded in the sample for that year.

Table 5.3.2 Annual Averages and Numbers of Some Variables			
Variable	1979	1985	1992
Price of Cement	70.11	54.86	41.02
Vintage	37.58	27.40	25.23
Plants	148	124	105
Kilns-Dry	41	28	26
Kilns-Wet	85	55	38
Kilns-Preheater	22	41	41

This shows a substantial drop in the average real price of cement. The changes in the vintage, number of plants and types of kilns represented in the sample reflect the shakeout that took place in the industry, primarily in the late seventies and first half of the eighties. Older kilns were retired, wet process plants were closed, and wet and dry process kilns replaced with preheater kilns.

6. The Econometric Specification for Estimation

In this section, a structural interpretation of the error term will be presented and it will be suggested that a generalized incomplete ordered probit is the appropriate technique for the estimation of the kiln use equation. However, the discussion earlier suggests unobserved heterogeneity and Ricardian rents are potential problems for using an ordered probit. In the second subsection, then, an account of how to control for these problems will be presented. Then in the final subsection the details of the likelihood function for estimation will be presented.

6.1 Unobservable Costs and the Distribution of the Error Term

While prices for most of the variable inputs are observable, and the functional form is based on the engineering characteristics of the problem, prices of some variable inputs, such as transportation and other raw materials, and some fixed inputs, such as maintenance are not. Hence, they will be components of the error term, with, potentially, three implications for its nature. First, as maintenance and transportation use labour as inputs, there may be omitted variable bias. This will be discussed in more detail with the results in section seven. Secondly, the error term is likely to be heteroscedastic as the quantities, and therefore the total costs, of all three unobservable inputs are likely to vary directly with production. Thirdly, all three are more likely to vary across plants than kilns. Other raw materials are either quarried locally or purchased externally and, hence the quantities required are unlikely to vary with the characteristics of the kiln. The extent of maintenance will vary with the expected life of the plant which, as argued earlier, is determined by the quality of the raw materials and expected demand. And selling and distribution costs will vary with the type and location of the customer.

At the very least, this last feature suggests estimates of the kiln use equation using data on the operating status of each kiln, without considering correlation in the errors across kilns at the same plant, will be inefficient. Any further implications will depend on, and require assumptions on, the strength and other characteristics of the error term. Assuming the error term features a kiln specific component creates an additional complication in that the kiln use rule can no longer be assumed to hold as certain combinations of plantwide and kiln specific errors lead to alternative orderings of kilns. Hence, in this paper, it will be assumed that the error term, ρ_{int}, is wholly plantwide but varies normally across plants(i), over time and is a linear function of the capacity of the relevant kiln,k:

$$\rho_{int} \sim N(\mu, \sigma^2 k^2)$$

The return to operating each kiln is thus a latent variable. Each kiln will be operated if the return to is positive. Hence, in a plant with n* kilns, the n^{th} kiln, n<n*, will be the marginal kiln, where $\rho_{it} = \rho_{int}/k$, if the following conditions are satisfied:

(i) $(P - AVC_n) \geq \rho_{it}$
(ii) $(P - AVC_{n+1}) < \rho_{it}$

where AVC_n is the estimated average variable cost for kiln n, and kiln n+1 is the kiln ranked just below kiln n. With ρ_{it} being normally distributed, the parameters of the short run cost function can be estimated using an ordered probit. For a plant with n* kilns, the probabilities of observing no kilns operating, between one and (n*-1) kilns operating and n* kilns operating are summarized below in table 6.1.1:

Table 6.1.1 Probabilities of Observing Particular Outcomes	
Number of kilns operating	Probability
0	$\Phi((P - AVC_1) < \rho_{it})$
0< n < n*	$\Phi((P - AVC_n) \geq \rho_{it}) - \Phi((P - AVC_{n+1}) \geq \rho_{it})$
n*	$\Phi((P - AVC_{n^*}) \geq \rho_{it})$

With all other things being equal, for this plant, if it, in effect, draws a relatively high value of ρ_{it}, then it will only be profitable to operate the lowest cost (first) kiln or, if ρ_{it} is high enough, not operate at all. But if a low value of ρ_{it} is drawn, then it will be profitable to operate less efficient kilns or even, if ρ_{it} is low enough, operate all kilns. Similarly, when the price of cement is high, or input prices low enough, for a given ρ_{it}, less efficient kilns will be observed operating.

The characterization of the ordered probit in table 6.1.1 does not explicitly feature the estimated thresholds, usually constant terms, that are frequently part of textbook presentations of the technique. The conditions stated there can be re-expressed in terms of thresholds as follows. First, note the AVC for a particular kiln can be separated into a component that is common across kilns, AVC_i, and a component that alters with the characteristics of the kiln, such as vintage and process, AVC_{in}. The Kiln Use Rule results from the ranking of the kilns according to AVC_{in}, which can be interpreted as thresholds, with a shift of the whole distribution by (P-AVC_i). Rather than estimating common thresholds across plants and across time which, with the heterogeneity across plants and changes in conditions across locations and over time, would be a very restrictive specification, the thresholds can vary with the characteristics of the plants and the input prices each plant faces in each period.

The ordered probit has been used to infer distributions of fixed costs from entry decisions(Bresnahan and Reiss(1990)). Bertin et al(1996) also uses the ordered probit to estimate expected production rates. But, this is the first time it has been used to estimate short run parameters of a cost function.

This paper also features a minor extension of the technique so to enable information on plants, when the marginal kiln is unknown, to be used. Table 6.1.2 presents the probabilities of observing two sets of outcomes when there is incomplete information.

Table 6.1.2 Probabilities of Observing Outcomes when the marginal kiln is unknown	
Outcome	Probability
Kiln n, n<n*, observed operating but marginal kiln unknown	$\Phi((P - AVC_n) \geq \rho_{it})$
Kiln n observed operating, kiln n+j observed idle, j>1, marginal kiln unknown	$\Phi((P - AVC_n) \geq \rho_{it}) - \Phi((P - AVC_{n+j}) \geq \rho_{it})$

For the first case, if the operating status of at least one kiln is known, but the operating status of lower ranked kilns is unknown, ρ_{it} can be any value below that which would be needed to observe kiln n operating. Similarly, for the second case, ρ_{it} can take any value between that for which kiln n would be observed operating, and that for which kiln n+j would be idled. All else proceeds as in the standard ordered probit outlined above.

Before commencing estimation, two, related, issues will need to be discussed: the set of variables with which AVC will be estimated, and the specification of the mean of the distribution of ρ_{int}, μ. If conditions were such that estimation of the kiln use equation could commence (in the next subsection, it will be argued that two corrections potentially need to be made), the variables that would be used are presented below in Table 6.1.3. This set of variables will be referred to as the base-case set of variables:

Table 6.1.3 "Base-Case" Set of Variables

Variable	Definition
Cement Price	$ per short ton of cement
Limestone Price	$ per short ton of raw materials
Electricity Price-Dry	$ per million BTU of Electricity for Non-Wet Process Kilns
Electricity Price-Wet	$ per million BTU of Electricity for Wet Process Kilns
Fuel Price-Dry	$ per million BTU of Fuel for Dry and non Suspension Preheater Kilns
Fuel Price-Wet	$ per million BTU of Fuel for Wet Process Kilns
Fuel Price- Preheater	$ per million BTU of Fuel for Suspension Preheater and Precalciner Kilns
Fuel Price multiplied by Vintage*	Fuel Price and 1993- Year Kiln Opened
Wage Rate	$ per hour of production labor
Wage Rate multiplied by Post Collapse of Union Power Variable*	Wage Rate and a variable defined as follows: Pre 1985 = 0 1985 = 1, 1986 =2 and so on
* To capture non-linearities in the relationship, squared terms were also included.	

In effect, a variable coefficient model will be estimated. The parameters for fuel consumption, for each process, and labor requirements are modelled as functions of the vintage and vintage squared and a variable capturing the change in labor relations.

6.2 Adjusting for Rents and Heterogeneity

While the model as specified as such could be estimated, with a common μ across plants over time. This is a strong assumption. Before proceeding, some industry average data compiled from the Bureau of Mines Minerals Yearbook chapters on the Cement industry was used, as a first go, to see if this assumption is likely to hold. Information was available on electricity consumption by process, average labor and limestone requirements and fuel requirements for dry, wet and suspension preheater kilns (1988 values for fuel requirements were used for 1989-1992). These annual averages were used as parameters for the kiln use equation, and the sample to be used to estimate the data was then used to calculate average returns (the gap between price and estimated marginal cost), average marginal cost, and some other statistics as reported below in Table 6.2.1:

Table 6.2.1 Average Estimated Returns							
Period	Mean Return	Std Dvn	Mean MC	Mean Margin	Mean #Plants	Mean Max	Mean Min

1977-1981	31.03	10.52	36.06	0.46	143.2	53.25	0.17
1984-1988	25.57	7.48	26.43	0.49	120.6	54.76	7.12
1989-1992	21.69	6.45	21.03	0.51	105.5	49.96	7.29

Without data on fixed costs, with plants exiting, a little entry, and changing average vintages, interpretation of these statistics is not straightforward. The downward trend suggests, though, at least something is going on, that the mean is not constant across plants or over time. There are two potential sources of differences across plants and over time - differences in rents being earned by plants, and differences in the costs. And the size of these gaps suggests something needs to be done to control for them.

6.2.1 Heterogeneity in Costs

The immediate improvement that can be made over the averages in Table 6.2.1 is to include the observable data on vintages, as is done in the base case. The second set of improvements to be made is to include, as discussed in section 4.3, information on kiln closures, and from the relative vintage of the kilns that remain open. This will be done by extending the variable coefficient framework introduced in the previous subsection to include a variable to include this information. Two types of plants will be selected. Plants which closed earlier, than would be expected by the vintage of their kiln, will be referred to as "Exiters". Plants that remained open, even with relatively old capital will be referred to "Survivors". To determine whether a plant was an exiter or a survivor or neither, the following process was used. The average vintage was calculated for plants that were near to the plant of interest. If there five or more plants within two hundred miles of the plant, the five nearest were used. If there were between one and four plants within two hundred miles of the plant, an average was taken across the first kilns of these plants. Finally, if there were no plants within two hundred miles, no observation was calculated. A plant was then termed an exiter, if during anytime during the sample period, the ratio of the vintage of its first kiln to this average was less than one. A plant was termed a survivor, if during the whole sample period, its vintage was always greater than the average. The variable included in all coefficients then equalled the product of a dummy variable (survivor or not, and exiter or not) and the average ratio (for the exiters) or the minimum ratio (for the survivors). A potential problem here is if the decision to close the plant or kiln is a function of the unobserved differences in kiln fixed costs. Indeed, equation 4.2.1 states that this is the case. But, I argue that this effect is unlikely to be econometrically important. The argument is based on the potentially long lives of two central assets of the cement plant - the kiln and the source of raw materials. As noted earlier, kilns tend to last for decades. Limestone reserves appear to last for longer (there are references for a few plants to centuries) Combined with the fairly complete coverage of inputs and prices in the cost function, it is unlikely that current unobserved fixed costs would be significantly correlated with the decision to close the plant.

6.2.2 Ricardian Rents

As discussed earlier, even with the firms being price takers, it is possible that Ricardian Rents will be earned by the plants. Several changes occurred in the industry during the sample period which would suggest a decline in the rents earned by domestic plants. For most of the sample period, total demand was relatively strong. However, increased potential or actual competition resulting from the fall of ocean and land transportation costs may have led to a fall in the rents earned by firms.

Neither the engineering literature nor economic theory provides a convenient structural form to estimate rents that vary over time and location. The rents will be a function of the kiln characteristics variables and demand variables. So, a reduced form approximation will be used:

$$R_{k,t} = \beta_1 Demand + \beta_2 * I_{water} * P_{imports} + \beta_3 DFC + \beta_4 * DFCD + \beta_5 Vintage + \beta_6 Vintage^2$$

The first term, Demand, captures higher market demand. It is equal to the ratio of actual plant construction demand for the year to the average construction demand for the period for the plant. For details on construction of this variable (see Prentice(1997)). I_{water} is a dummy variable that takes the value 1 if the plant is within 200 miles of a customs district or river port and zero otherwise. $P_{imports}$ is the average price of imported cement at the nearest customs district or river port. The average is calculated across that and a group of neighboring customs districts (see Prentice(1997) for details). DFC is the average distance to near plants (as defined in the previous section). DFCD is the distance to the nearest customs district or river port. Both of these variables are capped above at 400 miles. Vintage is as defined earlier.

While it is theoretically possible that rental effects could be present for observations where kilns are operating and not operating (the average rent would be bounded above by the difference in marginal costs between the operating and idled kilns) it is likely that this will not be detected in estimation, and it proved difficult to finding starting values consistent with such a specification. Hence, these terms are included only for the observations where the plant is at full capacity or the marginal kiln is unknown. They are not relevant for the plants that are closed.

6.3 Likelihood Function

A final point before presenting the likelihood function is to note that the estimate of the standard error of the distribution will, at best, provide an upper bound on the standard errors of the underlying errors ρ. As long as the deviations from the reduced form estimate of the rents are normally distributed and uncorrelated with the ρ the estimated standard error will be an estimate of the sum of the square root of the sum of the variances for the two normal distributions.

The different classes of observations in the likelihood function are thus summarized below in Table 6.3.1

Table 6.3.1 Likelihood function and its components	
Class of observation	Component of the likelihood function
Known that kiln n operates and kiln n+j does not, $j \geq 1$	$\Phi(RET_n) - \Phi(RET_{n+1})$
Known the last kiln, n, operates.	$\Phi(RET_n)$
Known kiln n operates, but not known whether kiln n+1 operates	$\Phi(RET_n)$
Kiln 1 does not operate	$-\Phi(RET_1)$
where RET_n is the estimated return to operating Kiln n and Φ(RET) a normal distribution with mean AFC	

The likelihood function for the population is then as below:

Likelihood function based on and for estimating the Kiln Use Equation (6.3.1):

$$L = \prod_{j=1}^{N_1}\left(\Phi\left(RET_{j,n}\right) - \Phi\left(RET_{n+j}\right)\right) * \prod_{j=1}^{N_2}\Phi\left(RET_{j,n}\right) * \prod_{j=1}^{N_3}\Phi\left(RET_{j,n}\right) * \prod_{j=1}^{N_2}\left(1 - \Phi\left(RET_{j,1}\right)\right)$$

Three sets of equations will be estimated. First, the base case will be estimated, with kiln fixed costs modelled as a constant and as a quadratic function of the kiln vintage. The second set of specifications will include the adjustment factors for exiters and survivors (eight in total). These are also done with constant and quadratic in vintage kiln fixed cost expressions. The third set of specifications includes the reduced form expression for Ricardian rents and, in one case, the adjustment factors used in the second set. These are done only for the constant form of kiln fixed costs.

7. Results

Several specifications of the kiln use equation, (6.3.1), estimated by Maximum Likelihood, are presented below in Table 7.1.1. Each cell of the table below contains the coefficient value, the standard error (in parentheses) and the t-statistic. Columns (1)- (2) contain the base case, (3)-(4), include the adjustment factors, and (5)-(6) the reduced form expressions for the rents.

Table 7.1.1 Results						
Variables	Regressions					
	Simple (1)	Simple (2)	& Char. (3)	& Char. (4)	& Rent (5)	& Rent & Char. (6)
Limestone	3.786732 (1.3791) 2.745782	3.459149 (0.5686) 6.08414	2.690749 (0.5367) 5.013983	2.364553 (0.5323) 4.442275	3.268395 (0.9604) 3.403104	2.762080 (0.9621) 2.870798
Electricity-D	0.30365 (0.4829) 0.628801	0.240845 (0.3432) 0.701825	0.820178 (0.3353) 2.446115	0.816378 (0.3278) 2.490671	3.887471 (0.5487) 7.084390	4.484307 (0.5350) 8.382592
Electricity-W	0.496017 (0.3495) 1.419063	0.423602 (0.4922) 0.860587	1.278115 (0.4632) 2.759054	1.271100 (0.4581) 2.774797	2.034018 (0.8595) 2.366573	3.127197 (0.8619) 3.628373
Fuel-D	-27.6310 (5.4493) -5.07060	-10.6402 (1.1918) -8.92748	-26.7695 (1.1191) -23.9200	-12.9105 (1.1156) -11.5726	-48.0936 (1.8835) -25.5340	-55.8486 (1.8631) -29.9766
Fuel-W	-30.6516 (5.7163) -5.36215	-13.5592 (1.3613) -9.96038	-31.6646 (1.3144) -24.0899	-17.8932 (1.3004) -13.7603	-41.9879 (2.4211) -17.3424	-56.8193 (2.4157) -23.5214
Fuel-PH	-34.1869 (5.8660) -5.82796	-16.7864 (1.7053) -9.84380	-31.5781 (1.6295) -19.3791	-17.6404 (1.6053) -10.9887	-65.1732 (2.9488) -22.1015	-69.5704 (2.9217) -23.8118
Fuel-Vintage	1.128473 (0.1767) 6.386230	0.658438 (0.1461) 4.506888	1.115953 (0.1454) 7.675504	0.880982 (0.1464) 6.016278	0.742701 (0.3873) 1.917822	1.046700 (0.4000) 2.616561
Fuel- Vintage Squared	-0.00842 (0.0014) -5.84022	-0.00656 (0.0307) -0.2141	-0.00829 (0.0302) -0.27401	-0.00998 (0.0305) -0.32743	0.017371 (0.1062) 0.163568	0.015748 (0.1107) 0.142204
Labor	0.445114 (0.6078) 0.732396	0.252825 (0.6254) 0.404284	0.823208 (0.5879) 1.400342	0.582241 (0.5839) 0.997099	-4.59279 (1.0636) -4.31822	-5.14548 (1.0729) -4.79601
Union-D	-0.0886 (0.1229) -0.72079	-0.06245 (0.2012) -0.31039	-0.03475 (0.1911) -0.18184	-0.00293 (0.1897) -0.01544	0.163114 (0.3551) 0.459373	0.161184 (0.3571) 0.451326
Union-D2	-0.03347 (0.0183) -1.82305	-0.03442 (0.1342) -0.25659	-0.03235 (0.1264) -0.25586	-0.0326 (0.1257) -0.25937	-0.03701 (0.2317) -0.15974	-0.03549 (0.234) -0.15169
FC-Const	8.072327 (11.297) 0.714576	-19.636 (4.6613) -4.21256	2.371138 (3.1580) 0.750834	-17.3147 (4.4410) -3.8988	88.53164 (5.8139) 15.22767	88.74639 (6.0917) 14.56835
FC-Vin		0.834918 (0.4192) 1.991816		0.252931 (0.4092) 0.618060		

FC-VinSqd		-0.00202 (0.078) -0.02524		0.006810 (0.0788) 0.086454		
Limst (Exiter)			10.39015 (1.1761) 8.834244	11.21741 (1.1649) 9.629760		-43.1733 (2.6011) -16.5981
Elect (Exiter)			-1.93604 (0.8688) -2.22841	-2.14962 (0.861) -2.49672		8.862220 (2.2409) 3.954742
Fuel (Exiter)			6.458465 (2.7895) 2.315266	6.291610 (2.7305) 2.304225		-60.2931 (7.0658) -8.53315
Labor (Exiter)			-0.49735 (1.3716) -0.3626	-0.55656 (1.3537) -0.41113		21.47226 (3.4773) 6.175059
Limst (Survivor)			5.335994 (0.906) 5.889951	5.003887 (0.8881) 5.634287		0.849143 (1.7353) 0.489334
Elect (Survivor)			-0.78840 (0.8549) -0.92224	-1.21545 (0.8462) -1.43632		-5.2771 (1.6205) -3.25644
Fuel (Survivor)			-3.83104 (2.2672) -1.6898	-0.61690 (2.2181) -0.27813		12.35908 (9.9628) 1.240521
Labor (Survivor)			-1.26922 (1.0868) -1.16787	-1.22806 (1.0648) -1.15337		2.734751 (1.9142) 1.428694
Import Price					0.880332 (11.465) 0.076784	-3.9383 (20.101) -0.19593
Demand					-625.126 (186.39) -3.35392	-868.344 (77.781) -11.1640
Average Distance from Competitors					0.569900 (8.0146) 0.071107	0.562433 (15.835) 0.035518
Average Distance from CD					0.075604 9.569262 0.007901	0.822665 (17.814) 0.046182
Vintage (for Rents)					6.481937 (34.712) 0.186734	-.900266 (33.230) -.027092
Vintage Sqd (for Rents)					-0.13555 (7.7440) -0.0175	0.000246 (7.4185) 0.000033
Std. Error	25.91012	25.57847	22.22645	21.83297	36.51331	35.91074
Log Likelihood	-712.158	-707.566	-670.866	-663.084	-218.098	-203.900

For the coefficients on the input prices, the industry averages referred to earlier provide a useful benchmark with which to evaluate these results. The estimated coefficients may exceed the engineering estimates if there are significant components of the unobserved costs that include labor, limestone, electricity and fuel, which cannot be ruled out. While there is less information for guidance, with the reduced form expressions for the rents, much can still be said about the sign, size and significance of each coefficient.

Beginning with the basic kiln use equation in columns (1) and (2), the coefficients on the price of limestone are higher than expected. The coefficients on electricity prices are not significantly different from the industry averages, but also not significantly different from zero. Furthermore, with appropriate caveats for the significance, the estimate for wet process plants is higher than that for the dry process, which is also contrary to expectations.

The coefficients on fuel prices at first glance look a mess. For the simplest specification, in column (1), the results for new kilns, are unreasonable (significantly below zero). But though the coefficients on the vintage variables suggest an, implausibly, rapid increase in fuel consumption with the vintage, this makes the predicted fuel consumption for the older kilns more reasonable. For example, the maximum fuel consumptions for the dry, wet and preheater processes are 10.18, 7.16 and 3.62 million BTUs per short ton (for kilns built in 1926). The dry process maximum is quite plausible. The maximums for the other two processes are too low, though.

The coefficients on labor, before the change in bargaining are similar to those on electricity, in that they are not significantly different from the industry averages or from zero. The implied increase in productivity resulting from the change in bargaining arrangements is too large and occurs too quickly. From three years after the change in bargaining conditions on, the coefficient on the wage rate as a whole is negative.

The standard error of the regression is relatively high. With annual average real prices of cement varying between $70.11 and $41.02, a standard error of nearly $26 seems too large, suggesting considerable variation is not being picked up by the model.

The vintage and squared vintage terms in fixed costs make a significant improvement in the equation. The value of most of the coefficients falls, and their standard errors also fall. The change in the fuel coefficients is the most striking. However, the fall in the coefficients on the vintage terms leads to a substantial fall in the maximums (now for kilns built in 1943) to 5.88, 2.96 and -0.26 million BTUs per short ton, which are not plausible. The coefficients for the fixed cost terms suggest negative fixed costs for kilns built after 1967. This is consistent with a pattern that will be discussed further below.

Likelihood ratio tests show introducing the variables to capture productivity differences significantly improves on equations (1) and (2). The standard error on the regression has dropped, though it remains high. Encouragingly, the coefficients on the set of variables in the simple equation are also broadly similar with a few exceptions. The coefficients on electricity prices are now significantly different from zero, and though high, still not significantly different from the industry averages. The coefficients on limestone prices, also high, are also not significantly different from industry averages. For the other coefficients, there are some small changes, but the results are broadly similar to those achieved in estimated equations (1) and (2).

Next, the adjustment coefficients for the exiters will be considered. These appear to be only partially successful in capturing higher costs. The value on the fuel coefficients is broadly plausible, suggesting plants that exited consumed, up to an extra 6 million BTUs per short ton of cement. The accounts in the trade journals suggest would make the fuel consumption of a relatively new plant comparable to that of an old plant. The value of the limestone coefficient is also positive but seems way too high (about seven times the industry average), on top of a coefficient value that is high to begin with. The coefficient on electricity is negative. At first this seems implausible, but recalling that wet process plants on average consume less electricity than dry process kilns, and that it was the wet process plants that closed, the negative sign is reasonable. Though the estimated values are too high relative to the estimated values for the base kiln, the standard errors on these coefficients are substantial and would be consistent with a less unreasonable true value for the parameter. The negative sign on the labor coefficient is puzzling, but it does not appear to be estimated particularly precisely.

Next the coefficients on the adjustment factors for the survivors will be considered. The significant positive value on the limestone price is contrary to expectations, suggesting this variable may be picking up something else. This will be discussed further below. The coefficients on the other variables are high but estimated relatively imprecisely so, for reasons similar to those for electricity in the previous section, it is difficult to draw too strong conclusions from them.

Likelihood ratio tests(between (1) and (5) and (3) and (6)) show introducing variables to capture location rents significantly improves the equations. The standard error on the regressions though jumps considerably up to around $30 a short ton, which seems very high and contrary to what would have been expected if the size of the standard error in the earlier specification was due to failing to capture variations in rents.

The effect of introducing the rent variables on the coefficients on the input prices varies. While the coefficients on the price of limestone do not change greatly from those recorded in columns (3) and (4), the coefficients on electricity prices rise substantially, though, now, the coefficient on dry process kilns is substantially greater than that on the wet process kilns. Likewise, in column (5) the ordering of the fuel consumption is now more consistent with expectations, though the fall in the coefficients, even with the steeper effect of vintage, yields predicted values that are too low. The coefficients on hourly wages now seem completely wrong, with a negative constant, and changes in the bargaining arrangements leading to declining productivity. The value of the constant term is now unreasonably high.

The coefficients on the rental variables are a mess. All except those on demand are insignificant by any usual standard. Though the coefficient on demand is significant, it is negative and the value is enormous. The improvement in the equations performance suggests something is being picked up but it does not appear to be rents.

Introducing the coefficients on the exiters and survivors significantly improves on equation (5). There are no substantial changes of interest in the base case kiln coefficients and the coefficients on the rent variables. The coefficient values for the exiters have changed sign and are now implausibly large. The coefficients on the survivors are relatively moderate, but the signs are not always interpretable. Unlike equations (1) to (4), where the deviations from expectations were moderate and explainable, introducing the rental variables has lead to, in the main, inexplicable changes.

In general, these estimates suggest that the model as specified is failing to capture, in varying degrees, the short run cost function, the heterogeneity across plants and the Ricardian rents (if they exist) being earned by plants. The nature of the problems are suggested by the problems with equations (1) to (4) and highlighted by the severe problems demonstrated in equations (5) and (6). Before discussing how the equations may be failing, it is worthwhile briefly noting the nature of the changes suggested in the data section. During this period, about a third of the plants close such that at the end of the period the capacity has gone from the majority featuring wet process kilns to the majority featuring dry process kilns. Within the dry process kilns, the older shorter and long dry kilns, and the first wave of preheater kilns have been replaced by the larger preheater and preheater/precalciner kilns. Over the sample period, both input prices and output prices have fallen.

The equations, then, may be failing in three respects. First, they fail to control for the heterogeneity across plants. Second, the rent variables fail to pick up movements in the Ricardian Rents. Thirdly, the assumption of the errors being normally distributed with a constant standard error may not be appropriate. The negative fuel coefficient, with the steep vintage effects for newer kilns, the negative coefficient on labor late in the sample period, and the negative fixed costs for newer kilns in equations (2) and (4) suggest the expected model is failing to capture the changes in the market in the second part of the sample period. In effect, the estimated returns are too low in the second period, and the ML estimates adjust for it by switching the coefficients on variables trending downwards to being negative. Though insignificant in equation (1), the higher coefficient on the wet process electricity coefficient, and the too low estimates for preheater kilns, is also consistent with this, as the wet process dominated early in the sample. If there are Ricardian rents, or if the heterogeneity is not being picked up the equations, then serial correlation should appear in the errors. The prices for electricity and limestone do trend downwards but are relatively less variable than the other prices in the model. The higher than expected coefficients for these (and the high values picked up when attempting to model the plants that exit or remain unexpectedly) are consistent with these coefficients picking up this correlation.

There are echoes of these findings in earlier work. Rosenbaum(1994) reported negative coefficients on a measure of Vintage (which would trend downwards in his sample) and on Wage rates (it would be interesting to see if Rosenbaum's measure of wages was also trending downwards). The use of the earlier part of the sample period may have avoided this problem with fuel prices. Prentice(1996a), for the same sample period, had reversed coefficient sizes on variables capturing the interaction of fuel prices with process types. Das(1991a) had a constant term that was too high. Also, her results, using the prices data, improved when she shifted from using a logit to a semi-parametric estimation technique. The work of Rosenbaum and Das, to a certain extent, through their different sample periods, may have been insulated from the problems with either specification or unobserved variables that seem to be a feature of this paper.

8. Conclusion

This paper has presented and estimated a model of a short run cost function for an industry with heterogeneous capital that makes discrete production choices. The model is based heavily on the engineering characteristics of the technology of cement plants, removing one potential source of misspecification. An unusually detailed data set, which, while publicly available, also includes detailed plant characteristics data, is presented, which is used in an attempt to capture underlying heterogeneity in plants. In addition, further aspects of the underlying heterogeneity are controlled for using information on plant exit and survival patterns, and using variables to capture Ricardian Rents being earned by price taking cement plants. The results, though suggest the extra efforts were only partially successful in doing so, with distributional assumptions also possibly being a problem.

Data Appendix

The sources of the data are as listed below. For more details see Prentice(1997).

Sources of the Data	
Price of Cement	Bureau of Mines Minerals Yearbook Cement Chapter
Clinker Production	as above
Average Kiln Maintenance Days	as above
Import Prices	as above, see Prentice(1996a) for more details, also Prentice(1997)
Price of Limestone	Bureau of Mines Minerals Yearbook, Crushed Stone Chapter, Cement Chapter, State Chapters
Price of Electricity	Department of Energy(DOE -see Below)
Wage Rate	(BLS, CBP) See Prentice(1997) for details
Fuel Price	DOE
Plant Construction Demand	Based on Total Construction by State, from FW Dodge. See Prentice(1997) for details
Kiln Annual Capacity, Vintage, Process	PCA(see below), crosschecked(see text)
Distance Variables - based on Coordinates from National Atlas of the United States and U.S Gazetter(http://www.census.gov/cgi-bin/gazetteer)	

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BOM (1976-1992) Bureau of Mines "Minerals Yearbook" chapters on Cement and Crushed Stone. U.S Department of the Interior G.P.O Washington DC

CBP(1977-1992) "County Business Patterns", Bureau of the Census, U.S. Department of Commerce G.P.O Washington DC

DOE(various years) "State Energy Price and Expenditure Report" U.S Department of Energy G.P.O Washington DC

PCA (1974-1992) "U.S. and Canadian Portland Cement Industry: Plant Information Summary" Portland Cement Association Skokie IL

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