INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.
Overview of the neoclassical production function and the market structure: An application to the Mexican cement industry from 1983 to 1983

García-Rojas Alarcón, Jorge Gabriel, M.A.

Rice University, 1991
RICE UNIVERSITY


by

Jorge Gabriel García Rojas Alarcón

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTERS OF ARTS

APPROVED, THESIS COMMITTEE

Robin C. Sickles, Professor of Economics and Statistics, Chair

Gordon W. Smith, Professor of Economics

Donald Huddell, Professor of Economics

Houston, Texas

January, 1991

by

Jorge Gabriel García Rojas Alarcón

Rice University

ABSTRACT

This study provides an overview of the Neoclassical theory of production as well as topics on market structure. It analyzes transportation costs, pricing, and economies of scale that determine production concentration and emphasizes the need of studies that would analyze possible effects if a North American Free Trade Area is implemented among the U.S., Canada and Mexico.

The Mexican cement industry is used as an example of a sector with diverse industrial organization schemes, where the production process results in a trade-off between energy-saving technologies and pollution wreckage. Labor, capital and materials inputs are considered in the case study where various policy simulations signal some distortions that controlled input markets have on output, efficiency, and productivity during the 1963-1983 period on the cement industry of Mexico.
ACKNOWLEDGEMENTS

I am greatly thankful to Robin Sickles for all his support, encouragement and good advice along the development of this thesis work.
I acknowledge the support of Ricardo, Regina, Mariana, Mafer, Eugenia and Juan Pablo for their interest in my feelings, failures and successes. I also acknowledge Juan Rosellón for the thousand laughs, and Carlos Manuel, Jane Dunham, John Caram and Juan Segura for their supportive friendship.
I am especially grateful to Rice University, and to Dante Delgado Rannauro for giving me financial support.
Finally, I am very thankful to all the Professors that contributed to my right thinking.
I dedicate this thesis with all my love:

To my beloved mother Eugenia, for teaching me Love and forgiveness since the very moment I can remember. For your immense unconditional support and all your counseling words. For being the best example to the loyalty and perseverance that you show to Life by never giving-up.
Dear mother, now that you have found within yourself the everlasting support that was missing, remember always that as a grown tree of your own Spirit, I will always be beside you to protect you from any cold wind that might ever try to reach you.
To Elvira, because your presence is still with me every time I remember the lesson you left behind, where you taught me that in our way to the most noble goals, there is no room for laments and complaints.
I hope, I certainly hope that one day I will fully understand this lesson that you, with your life, were able to demonstrate.
## CONTENTS

Preface

1. Basic Concepts
   1.1 Production unit, input, and output 1
   1.2 Scale, elasticity of scale and elasticity of substitution 3

2. Neoclassical Approach to the Production Function 4
   2.1 Johansen schema 4
   2.2 Efficiency distribution 9

3. Variables of production 12
   3.1 Output 12
   3.2 Capital input 14
   3.3 Labor input 21
   3.4 Other inputs 22

4. Productivity and Productivity Growth 23
   4.1 Scale 31
   4.2 Efficiency 33
      4.2.1 Economies of scale 40
      4.2.2 Technical change and efficiency 48

5. Concentration 50
   5.1 Transport costs 54
   5.2 Pricing structures 56
   5.3 Transport modes of Mexican cement 60
   5.4 Location, demand and scale of cement plants 62
   5.5 Cement plant pollution as an externality 64
   5.6 Rationale for mergers 65
6. Market Structure
   6.1 Perfect competition and Monopoly
   6.2 Oligopoly and Monopolistic competition

7. Industrial Organization
   7.1 Cournot-Nash and Stackelberg equilibria
   7.2 Bertrand and other equilibria

8. Model of Cement Production
   8.1 Cement production process
   8.2 Oligopoly pricing
   8.3 Price discrimination
   8.4 Profit maximization

9. The Production Function
   9.1 Characteristics of the Constant Elasticity of Substitution production function
   9.2 The Mexican cement production function
       9.2.1 Description of the data
       9.2.2 Empirical results

References
Appendix
Bibliography
PREFACE

This study provides a basic overview of the Neoclassical theory of production as well as topics in market structure. We will analyze certain elements such as transportation costs, pricing, and economies of scale that affect directly the evolution of production concentration. Our empirical focus will be on the cement industry in Mexico. We concentrate on the measurement of economies of scale and productivity of the factors of cement production, among other things. Conclusions of this research are instructive but limited in scope, since several important factors could not be considered because of data constraints. These include pollution wreckage due to cement production and the effects that it has over social welfare.

Cement is a binding material that is almost ubiquitous in the modern international construction industry, especially grey portland cement, which is the product considered in this thesis. Our study of the Mexican cement industry is from 1963 to 1983. During this period, the economy expanded at a rate of 6.3% per year, duplicating itself every 11.35 years (i). This growth rate implied a very fast urbanization rate with the corresponding expansion of the construction industry, which grew by a yearly average rate of 7.9% during the same period. Since the Mexican

(i)/ Meanwhile, the population doubled every 23 years.
construction industry is cement-intensive, demand for this material increased rapidly, at a rate that averaged 8 percent a year. In 1983 it accounted for 0.52 % of the total gross domestic product and as much as 1.31 % and 2.19 % of the industrial and manufacturing products, respectively. In the same year, the annual capacity of production was 30.7 million tons, up from 4.3 million in 1963. In 1983, such a capacity of production was about one third that of the U.S., almost as large as that of France, and twice larger than Britain's.

Even with such an impressive growth rate, the Mexican cement industry still remains undercapitalized, especially if we take into account the housing and urbanization deficit of the country which is by all counts large. If the Mexican economy recuperates from the slump of the 80's and if it follows a pattern of cement consumption similar to the one observed in Spain and Italy during the last 30 years (ii)/, then the industry could triple its capacity in the next twenty years or so. Moreover, the inclusion of new technologies that might cross the Mexican border after the signing of a free trade agreement with Canada and the U.S. may curb the domestic market. However, Mexico is likely to have an internal comparative advantage in cementitious

(ii)/ Which is likely to occur if we consider that Mexico has a large surplus of labor and that there is a cultural bias to considering that only the cement-intensive construction is permanent, and thus, worth to be considered "real".
materials relative to those where non-cement bricks, steel, and wood construction elements are abundant, as in the rest of North America.

More recent research on the cement industry in Mexico is required in order to analyze the possible effects on transportation costs, pricing, and scale, among others, if a North American Free Trade Area is implemented. Although we did not consider these issues formally in this research, our empirical results can form the basis for more extensive policy simulations.

Chapters one and two begin defining the basic concepts of the Neoclassical theory of production, where the Johansen schema has a relevant position in the classification of production through ex-ante and ex-post events. Chapter three presents brief descriptions of the variables in production.

Chapter four analyzes output and input productivities. It reviews the basic sources of economies and diseconomies of scale as well as technical change in their influence on efficiency.

In chapter five we review the impact of transportation costs and pricing policies (iii)/ on the evolution of production concentration using the cement industry as an example.

(iii)/ Where sometimes the government has an important role to play.
Chapters six and seven review the various market structures of production and the schemes of industrial organization under which any industry may evolve.

In chapter eight we apply the concepts of the previous two chapters to the particular case of the Mexican cement industry. We review the cement production process and discuss the empirical model of technology which is approximated by the Leontief functional form. The analyses of oligopoly pricing and the effects of price discrimination are included in this chapter. We also examine the individual cement firm profit maximization problem, considering the possibility of single-plant and multiple-plant firms together.

Finally, chapter nine analyzes the production function characterized by the Neoclassical CES function which nests both the Cobb-Douglas and the Leontief as special cases. The empirical study is presented, leading us to a number of conclusions about the cement industry in Mexico during the 1963-1983 period.

Along this study, the reader will find that the author uses "we" instead of "I" when referring to personal assertions and conclusions. However, all of these matters are of the exclusive responsibility of the author. Let it just be that if the assertion or conclusion is right, it was the result of all the Professors that contributed to my thinking in the last 27 years. To them, I owe a tribute of respect and admiration. If, however, such conclusion or
assertion is incorrect, I assume total responsibility. After all, whatsoever is good and righteous is eternal, while the incorrect interpretation of life is only a short-lived accident.
1. Basic Concepts

Among the major interests of the Science of Economics, the study of the production process has always had a privileged position. In the recent Neoclassical approach the production analyses can be divided into five areas:

i) The variation in unit costs of production with respect to changes in scale;

ii) the degree of substitutability among the factors of production;

iii) the rate of technological progress and its bias towards labor using or capital using innovations;

iv) the sources of technological progress; and

v) the spatial distribution of mobile economic resources.

Along this study on the Mexican cement industry we will revise some of these areas. However, special emphasis will be settled to the production function analysis, where we will analyze a specific kind of technology. First, there are various concepts that we ought to define.

1.1 Production unit, input, and output

There has been a long discussion as how should economists relate production processes to the diverse universe of economic agents. A production unit is usually viewed as a well defined activity over which production analyses are applied. This production unit takes the form of a household, a plant, a firm, an industry, and even a whole
economy or group of economies. This is: production units are defined according to a certain level of aggregation. In the specific case of this particular study, the activity defined is the cement production process, and the production unit will be that of the aggregate industry level which implicitly includes all the plants of different firms and all the firms in such industry.

The input variables are defined as the elements necessary to complete a process of production during the time such process takes place. To be more concrete, inputs are all the goods and services taken into production in order to produce a new different output (also a good or a service). Hence, output is a concept which resumes a complete production process. This process of production can be studied from cross-sectional or time-series viewpoints. The first one relates all inputs interacting through one or many economic units (plants, firms, etc.) during a determined time or period, while the second one relates the inputs interacting through the unit(s) of production along various periods or time period.

Examples of inputs are the factors of production: capital and labor (stocks or services), as well as intermediate inputs such as energy, fuel, raw materials, etc. Examples of outputs are: cement, motor vehicles, banking, airline transportation services, etc. As production gets to be more sophisticated, former outputs become other industries'
inputs as is the case of cement, which becomes an input for the construction industry.

1.2 Scale, elasticity of scale and elasticity of substitution

Scale is the economic equivalent of size, thus, it is usually defined in terms of the amount of output per production time period of an economic unit. Elasticity of scale is the measure of the concept of economies of scale. Economies of scale are defined as the increase of output corresponding to an increase of inputs. Both increases may or may not be equal. Economists are used to saying that economies of scale exist when for an equal expansion or increase of the inputs of production, there is a greater than proportional increase in output.

Elasticity of substitution is a measure of substitution among the inputs or factors of production. The quantitative value of the elasticity of substitution varies according to each production function for each specific study. Nevertheless, some general conclusions have been achieved. Bosworth (1976), in his study on the validity of the Neoclassical production function, points out that according to some results the elasticity of substitution between inputs centers around a value of one-half in most time-series studies, while in cross-sectional studies it is closer to unity.

While aggregation occurs, as happens in the case study covered here, there is an important observation that we
ought to make: factor substitution is really a microeconomic event, occurring at the plant or firm levels. In the particular case of the Mexican cement industry, the results of elasticities will come from the aggregate data of this industry, which are assumed to be aggregated in the correct form. We will later analyze some technological input fixities in the cement production process. For now, we can say that technology is defined as the functional form of production that allows for a range of input combinations in order to produce output. The technique of production is a specific set of input combination chosen to develop the production process.

2. Neoclassical Approach to the Production Function

In the varied Neoclassical Science of Economics, there are multiple ways of approaching production. In this chapter we will review major contributions of abstract representations of the production function.

2.1 Johansen schema

Johansen (1972), makes an extensive study of static production functions including the ex-ante and ex-post functions at the micro level as well as the short and long run production functions at the macro level. The technological choice of a production unit of the proportions of factors of production as well as the technique of production, occurs at the stage of investment in new production. Then, after operation has begun, the production
unit sets the capacity level at which it operates considering the chosen technique. The ex-ante function at the micro (plant or firm) level summarizes the available technological progress at that moment, and it shows the possibilities to choose when a new production unit is established. At this stage, input substitution especially that of capital and labor, is possible. As an example, let us assume a choice made to produce one output with three inputs. Such ex-ante micro production function will look like the following:

\[ x = \phi (v_1, v_2, k), \]  

[1]

where:  
- \( x \) = capacity (maximum output) of new production unit;  
- \( v_1 \) = input one (at full capacity of the unit);  
- \( v_2 \) = input two (at full capacity of the unit);  
- \( k \) = capital amount invested in the production unit.

Such production function describes a relative factor combination with an optimal scale or capacity level at which inputs per unit of output are less than at other levels. Now, inputs and output must have a dimension per unit of time. If capital is heterogeneous due to different vintages or because of different combinations, we may think that production units are price takers in the market of capital goods. The micro ex-ante function above is a somewhat vague concept, and

"It may be reasonably well defined for factor combinations that have been tried out in practice before, but for virgin parts of the domain of the function, there may be considerable uncertainty about it."
This means that the ex-ante function includes all the technological advancement available up until the last production process occurred, but it does not for experimental new technological applications which might have a large impact on the future production process.

The ex-post function at the micro level considers a unit of production when [1] has already been set. Hence, the former $x$, $v_1$, $v_2$, and $k$, are not variables anymore. If this is the case, the possibilities of production are assumed to be as the following:

$$0 \leq x \leq \bar{x} ;$$

$$v_1 = (\bar{v}_1/x)x, \text{ or } v_1 = \sigma_1 x, \text{ where } \sigma_1 = \bar{v}_1/x;$$

$$v_2 = (\bar{v}_2/x)x, \text{ or } v_2 = \sigma_2 x, \text{ where } \sigma_2 = \bar{v}_2/x.$$  \[2\]

Where $v$'s without bars represent current inputs and output, while $\sigma_1$ and $\sigma_2$ are the current input coefficients. This is: they are variables ex-ante, but fixed coefficients ex-post.

As this author proposes:

"It seems... that a better formulation is to specify the ex-post function only in terms of current inputs, the capital stock once installed playing the part of a fixed factor."  \[2\]

Taking this into account, a general formulation will look more like the following one:

$$x = \tau(v_1, v_2, t) \text{ for } (v_1, v_2) \in D_{tt},$$  \[3\]

representing an ex-post function in terms of actually consumed inputs, where the input combination has to belong to the domain $D_{tt}$ in the $v_1,v_2$-space. Now, if we specify the function in terms of available amounts of inputs, we would
not have to specify the domain $D_{tt}$. We could then let the ex-post function be defined over the whole non-negative quadrant of $v_1, v_2$.

The short-run production function at the macro level refers to any sector of production at any given moment in time comprising a certain number of production units. Each production unit has its own structure given by [2] above. Thus, for $i = 1, 2, \ldots, n$ production units and for aggregate $X, V_1$ and $V_2$, output and inputs respectively, we have:

$$X = \sum_{i=1}^{n} x_i, \quad [4]$$

$$V_1 \geq \sum_{i=1}^{n} \sigma_1 x_i, \quad [5]$$

$$V_2 \geq \sum_{i=1}^{n} \sigma_2 x_i, \quad [6]$$

$$0 \leq x_i \leq \bar{x}_i, \quad [7]$$

where $\sigma_1, \sigma_2$ are as before, but now defined for each $i$ production unit.

A sector (industry, etc.) is said to be efficient if for a given $V_1, V_2$, we maximize [4] subject to [5]-[7], and this is usually solved by linear programming.

It is precisely this short-run macro function which gets into dynamics, and, thus, explains the behavior of economic units in time. Thus, it will be the one chosen to explain the theoretical background of cement production.

Finally, the long-run macro production function is the steady state analysis of the aggregate production function
and has a more hypothetical construct. (i)/ In the chapter on elements of dynamics of production, Johansen (Ibid), studies the different factors contributing to changes in production through time. The main contributors are said to be the following:

First, creating movements along the surface of production function, the changes in current inputs \( V_1 \) and \( V_2 \) generate output changes. Second, investments in new equipment which affect the capacity distribution generate shifts in the short-run macro function. Finally, technological progress in its two forms: embodied and disembodied (ii)/; whose difference lies in that embodied technological progress shifts the ex-ante production function leaving the efficiency of established production units unaffected, while disembodied technological progress affects the modes of operation of existing production units in such a way as to improve their performance or efficiency, creating a shift in the short-run macro production function even in the absence of investment.

When we study a time-series production function, a parameter of time is introduced to the short-run macro function, which, by its way, leads to obtain an indicator or parameter of total capital stock. Such technological characterization will then look as follows: \( X = F (V_1, V_2; K) \). [8]

---

(i)/ For such construct, see Johansen (1972), pp. 20-5.
(ii)/ For further explanations of embodied and disembodied technological progress with their sub-classification, see Johansen (Ibid), pp. 145-70.
Along time, new capacity due to new investments, is assumed to be distributed in the same way as already existing capacity. If such were the case, then, total capital stock can be introduced as a parameter to take account of the shifts in the short-run macro function over time, and time-series data for \( X, V_1, V_2, \) and \( K \) can form the basis for the estimation of such function.

Now, speaking of the long-run aggregate production functions, Sato (1975), points out the following:

"There are two kinds of long-run aggregate production functions. The first is the full capacity production function which is the locus of full-capacity points. This function...is identical with the ex-ante function in form. The second is the long-run production function which is the envelope of the short-run aggregate production functions." ³

Economists and econometricians are interested in estimating the ex-ante production function from aggregate time-series data by employing the marginal equilibrium conditions. But the fact that the long-run function is the envelope of short-run functions implies that the same marginal conditions apply to both, short and long run functions at their tangent points. As Sato (Ibid), states,

"This indicates the nonidentifiability of the long run functions from short-run functions, especially under technical change. It explains why estimates of the macro elasticity of substitution are unstable and downward biased." ⁴

2.2 Efficiency distribution

When we study aggregate production functions, we must assume an efficiency distribution of the economic units (plants, firms) within each sector (industry, etc.). The so
called efficiency distribution of firms means that at any point in time, we can get a distribution of firms in terms of micro capital and labor efficiency coefficients. Nevertheless, if we intend to apply this model to the cement industry of Mexico, the best we can do is to assume that the efficiency distribution of firms or plants keeps being the same or constant during the 1963-83 period. This assumption is mainly due to the unavailability of non-aggregate data for this industry. We can only hope, then, that the general conclusions will not substantially differ if we take this limitation into consideration.

We can review the efficiency distribution approach to firms or plants. To do this, a capacity density function is defined for a given technology (Cobb-Douglas, C.E.S., etc.) or production function (iii)/ where, finally, the aggregate production function derived from this will look like the following:

\[ Q = F(J, B_L) = G(B_L/J)J, \quad [9] \text{ for } G' > 0 \text{ and } G'' < 0, \]

where:
- \( Q \) = aggregate output, defined as aggregate tonnage, etc., per period of production time;
- \( F \) = aggregate production function;
- \( J \) = maximum feasible output or total capacity of the industry;
- \( B \) = marginal productivity of labor input;
- \( L \) = aggregate employment, defined as aggregate man-hours per period of production time;
- \( G \) = aggregate production function derived from \( F \).

(iii)/ We will give a complete characterization of these production functions later.
Since the production function is assumed to be homogeneous of degree one in all capital and labor inputs, then the above transformation from $F$ into $G$ is possible. (iv) /

Now, when there are more inputs, like for example materials, the aggregate production function will look like the following:

$$Q = F(J, \beta_0L, \delta_0M), \quad [10]$$

where: $Q, F, J$, and $L$ are as defined above, and $M = \text{materials};$

$\beta_0 = \text{maximum of the micro labor efficiency coefficient};$

$\delta_0 = \text{maximum of the materials efficiency coefficient}.$

Hence, in an industry with multiple firms like the cement one, such firms operate short-run production functions characterized as the following: $q = f(\alpha k, \beta l), \quad [11]$ assumed to be homogeneous of degree one, and

where: $q = \text{micro (firm) output};$

$f = \text{micro production function};$

$k = \text{micro capital stock, specified as the maximum feasible output};$

$l = \text{micro employment (man-hours)};$

$\alpha = \text{micro capital-efficiency coefficient};$

$\beta = \text{micro labor-efficiency coefficient}.$

It should be distinguished that in the ex-ante analysis, the capital variable represents the service flows at normal

(iv)/ For further detail on how to make this transformation, see Sato (1975), pp.10-14.
rate of utilization, while in the ex-post analysis this variable represents the maximum capacity of production or the maximum feasible output (proxy of capital stock).

So far, we have implicitly assumed that there is some sort of technical substitution between all the production inputs. Nevertheless, as we will later observe for the cement industry this assumption is not true, though, especially when we take into account raw-materials.

3. Variables of Production

The variables of production are divided in two: dependent and independent variables, which are also called endogenous and exogenous variables, respectively. Thus, for the case of production units (plants, firms, etc.), output is the endogenous variable (to be explained), and inputs are the exogenous (taken as given) variables, unless otherwise established.

3.1 Output

It is not easy to define output, specially when it has close substitutes in both, use and characteristics. The definition of output is simpler when the product is very homogeneous. As for the horizon of our particular study, hydraulic grey portland cement has proven to be precisely a homogeneous product. The amount of output here will be measured in metric tons either of production or of capacity installed per year. Alternative most commonly used measures include the total value of cement production, and at the plant or firm levels, the value-added. Among the
characteristics of the plant value-added measure of output, we have the ability of separating two factors of production: capital and labor. One example of this is in the study of the U.S. manufacturing sector developed by Ullmann (1988), who uses constant dollar value-added by manufacture as measure of physical output. He gives the following definition for such output measure:

"Value-added by manufacture is the industry volume less cost of raw materials, fuel, and contract work. Thus it essentially [measures] the contributions of labor and capital into the firm and its profit." 5

Besides total value of production, total production in tons, and the value-added measures of output, there are other ways to measure output. A widely used alternative in Industrial Organization theories is, as we pointed out above, total capacity installed. Also, and as Morrison (1988), states,

"Capacity utilization measures have traditionally been constructed as indices of output for a firm an industry, or an economy, as compared to potential output." 6

This alternative measure of output results from the quotient of current output-to-total capacity. Nevertheless, and especially during recession periods, there may exist a large idle or excess capacity in the sector studied which generates costs and does not directly generate revenues.

It is important to get a measure of output, but probably as important as this is to get a measure for every homogeneous product. In the case of cement, there exist
various kinds and qualities of this product. Hence, it would seem not accurate to include all these kinds of cement into the grey portland cement output measure, since each particular cement kind has a particular grade and quality due to a different cement mix. An example of these diverse qualities is found in Abouchar (1971), in a study of the Soviet cement industry. He counts up to 17 different grades or kinds of hydraulic cement. However, this multiplicity of grades contrasts with that of the American practice, where all hydraulic grey portland cement must meet the same minimum grade except for certain special-purpose cements which have a higher minima. This approach has also characterized the cement industry in Mexico. Hence, for the cement industry in Mexico there is no doubt that the grade standardization of portland cement brings out some savings in both, transportation and production costs, as compared to that of several grades. We will also analyze transportation costs and their influence on location and concentration of production, later.

3.2 Capital input

If one variable of production has been especially polemic in the way it should be measured, this is the capital input or capital as a factor of production. We ought to distinguish between the capital service (flow), and capital stock measures. In a study of the Swedish manufacturing industry using cross-section analyses, Carlsson (1972), suggests four
alternative ways of measuring the capital factor of production. Which are: horsepower capacity of the machinery used in production; the consumption of electric power (v)/; the fire insurance value of buildings, machinery and equipment; and the fire insurance value excluding buildings. Now, the traditional difficulty of measuring the capital input comes from the existence of multiple diverse inputs that should be considered as capital. Even when the total money value (given by the blue-book) as well as interest rates (opportunity costs) may serve as close-to-the-best measures of capital stock and services, respectively, the problem of aggregation of different vintages or ages of capital adds to this matter an additional source of polemic. Especially in time-series studies, where technological change is present. On this matter, Jorgenson (1989), points out the difficulty of aggregation of capital input of different vintages. He states the following,

"The distinguishing feature of capital as a factor of production is that durable goods contribute services to production at different points in time. The capital services provided by a given durable good are proportional to the initial investment. We can refer to durable goods acquired at different points of time as different vintages of capital. The services provided by the different vintages at the same point of time are perfect substitutes." 7

For this author, the services of the flow of capital are the weighted sum of past investments, given by relative

---

(v)/ Usually measured in kilowatts-hour or in total value of the electricity bill, both per production time period.
efficiencies of capital goods of different ages. He builds a quantity index for capital input as follows:

\[ K_t = \sum_{\mu=0}^{\infty} d_{\mu} A_{t-\mu}, \quad [1] \]

where: \( A_{t-\mu} \) = quantity of capital good acquired at time \( t-\mu \); and \( d_{\mu} \) = relative efficiency. Defined as a non-negative number, such that \( \lim_{\mu \to \infty} d_{\mu} = 0 \), which means that the capital good is retired and its relative efficiency approaches zero as time goes to infinity.

He considers three patterns of decline in relative efficiency:

i) one-horse-shay pattern, where efficiency is constant over the lifetime of the capital good. The relative efficiency is (for \( T \) the lifetime of capital input),

\[ d_{\mu} = \begin{cases} 
1 & \text{if } \mu = 0,1,\ldots,T-1 \\
0 & \text{otherwise}; 
\end{cases} \]

ii) the straight-line pattern, where efficiency declines linearly over the lifetime of the capital good,

\[ d_{\mu} = \begin{cases} 
1-(\mu/T) & \text{if } \mu = 0,1,\ldots,T-1 \\
0 & \text{otherwise}; \quad \text{and} 
\end{cases} \]

iii) the declining balance pattern. Here efficiency declines geometrically,

\[ d_{\mu} = (1-\delta)^\mu, \quad \text{for } \mu = 0,1,\ldots,\infty \]

where \( \delta \) is a fixed determined depreciation rate.

What these patterns of efficiency decline represent is really the technological specifications of the capital input.
used in the durable goods (or total fixed-assets) model of production.

As we can realize, a complete system of investments and of capital stock is required for good estimation. Fortunately, and for the purpose of our empirical study, data on total yearly investments as well as on a measure of capital stock is available for the Mexican cement industry. This data shows replacement requirements in each period given by the depreciation amount, and also, the acquisition of investment goods. We will assume that the aggregate data on investment of the cement industry in Mexico has the same construct as that of Jorgenson (Ibid), where the capital stock at the end of each period is the weighted sum of past investments, written down as the following equation,

\[ K_t = \sum_{\mu=0}^{\infty} (1-\delta)^t A_{t-\mu}, \quad [2] \]

where: \( \delta \) = is the rate of decline in efficiency, which is assumed to be geometric.

Betancourt & Clague (1981), in the empirical implementation of their model and when speaking about capital utilization, state the following,

"The cost of owning a unit of capital stock for a year, \( r \), contains two terms not available [at least generally not available] in the data; that is, the annual rate of return \( i \), and the rate of depreciation \( d \)." 8

The procedure they follow in order to approximate the rate of return \( i \) is by adjusting the after-tax rates of return \( i' \) used thoroughly in Collins & Preston (1968), by the U.S.
corporate tax rate. Then, to this estimate, they added the annual depreciation \( d \), calculated from,

\[
\frac{1}{T} \sum_{s=1}^{T} (1+i')^{T-s} \tag{3}
\]

where: \( T \) = replacement time of capital stock (life-span); and \( s \) = current time period.

Other methods for estimating the depreciation rate have been developed. We can refer to the example that appears in Hulten & Wykoff (1981), who show that the geometric average rate of depreciation provides a good description of the decline in the price of acquisition of capital goods with vintage (or age). They developed cross-sectional analyses for the U.S. economy and inferred economic depreciation from vintage asset prices based on the Box-Cox power transformation (vi)/. This permits classical testing of the hypothesis that depreciation is either geometric, linear, or one-horse-shay. According to them,

"The use of the Box-Cox model to statistically discriminate between geometric, linear and one-horse-shay depreciation patterns (which are special cases of the Box-Cox form) is analogous to the use of the CES production function to discriminate between Cobb-Douglas and fixed proportion technologies (vii)/. We apply the Box-Cox model to a sample of used building prices and find that the appropriate depreciation pattern is approximately geometric." 9

\( (vi)/ \) For the Box-Cox power transformation see Kmenta (1986), pp. 517-21.

\( (vii)/ \) We will analyze these types of production functions in detail, later.
This last result suggests some kind of stable depreciation rates over time, which leads to the hypothesis of the constant depreciation rate as being a reasonable one for empirical work.

Finally, there are still other ways to measure capital input, an example of this is when it is linked to labor productivity. In such cases, a measure for this input will be obtained by the amount of spending for machinery and other capital equipment (capital spending) per employee, measured in constant dollars.

Now, because of inadequacies of measuring capital input as well as due to unavailable data, other authors prefer to use alternative methods for measuring it in their empirical studies. In this way, proxy variables are sometimes defined and used. Among such proxies and according to Bosworth (1976), there are the time trends and the fuel consumption measures. This last proxy, fuel-consumption, has some intuitive appeal as an alternative measure for the capital input as long as it is used in a somehow fixed proportion to capital. Also, a variable of energy is suggested to be used as a proxy measure for the capital input; but again, as long as it is used in fixed proportions too. Even in a study by Moody (1974), it is argued that fuel consumption, as proxy of capital input, is generally a more useful and accurate measure than that of the durable goods counterpart (also called perpetual inventory), which is often constructed in a
roundabout way and generally on the basis of either inadequate or hard-to-get information. An example is in the empirical chapter of the cross-section British engineering industry realized by Bosworth (1976), who uses fuel consumption as a proxy variable for capital input services. He did not assume that the capital input should be used in fixed proportions with the fuel variable, which as we said, has some intuitive appeal in order to broadly utilize such measure. Nevertheless, he makes the following observation relating such measure with capital flows,

"[while] the fuel-based proxy is unlikely to be useful in representing the stock of capital in its role as a measure of the store of wealth, it does appear to be a relevant proxy for the input of capital in the context of a production relationship. In particular, it allows two identical plants, worked at the same capacity, to have the same measure of the capital input even where their factor prices differ...fuel proxies reflect the consumption of capital services and not the stock of capital." 10

Now, it has been argued that it is very difficult, if not impossible, to aggregate capital input composed of various types of capital. This problem usually affects the relative efficiency of the productivity of the capital factor. But also, as we said before, in the aggregate industry level efficiency usually differs among firms (or plants) because they use different techniques of production, implying heterogeneous capital. Thus, and adding to the alternative methods of measuring the capital input, Sato (1975), proposes to use total productive capacity or
capacity installed (sometimes used as an output measure too) as the aggregate capital input.

Considering the availability of total capacity for the cement industry in Mexico during the 1963-83 time span, we could develop this last exercise among others presented before, as an alternative measure of the capital input. However, we will limit the empirical analysis to other more precise measures of this input.

3.3 Labor Input

Total labor as a factor of production is usually divided into production and non-production labor. This distinction has to do with the specific activities of employees: if they happen to participate directly in the production process, employees will be included in the production labor category, while if they do not participate directly in the production process, then employees are within the non-production labor category. Sometimes the difference is not clear.

Labor input is generally measured in man-hours per period, but also in the expenditure on salaries and wages on the total input. As an example, in Jorgenson, et.al., (1987), this input includes totals of employment units, hours worked, as well as labor compensation (total wages payed by the production unit). Other studies present alternative measures. Thus, the labor variable that Ullmann, op.cit., utilizes is defined by the measure of constant dollar value-added per employee, using total employees.
Now, as it is likely to occur with output, we can also aggregate labor over firms (or plants) if we assume it is homogeneous. In our case study of the cement industry, grey portland cement in Mexico has the characteristic of being a homogeneous product, due to the standardization we talked about above. Also, even when labor is diverse, it is assumed to be homogeneous across the plants and firms of the industry. This is: it usually has the same qualitative characteristics regardless the plant or firm location. Nevertheless, if we do not want to make this assumption, we will need to assume a certain efficiency distribution of the labor input along the industry in order to aggregate it, just as we did for the capital input.

3.4 Other Inputs

Other inputs are used when a non-value-added measure of output is utilized in the production function. Such intermediate inputs include among others the raw-materials, as well as fuel and energy (power). The energy input, as we pointed out before, when measured either in kilowatt-hours or in total money value expenditure has also been used as a proxy for capital input (capital flow of services). However, strictly speaking for the case of the cement industry, Norman (1979a), states that:

"the materials input per ton of cement is invariant with scale... more surprising is the indication that there are no scale economies of the energy input." 11

The first assertion above comes from the result of portland cement having rigorous quality or grade standards in its
chemical composition (technological fixities), and thus, fixing the proportion of raw-materials input with scale. As for the second assertion, it comes because once the output scale has been installed, the kilns used in the cement production process may require a fixed amount of energy in order to work, regardless if they are or are not used at their full capacity levels; bringing additional fixities to the form of the production function. We will later analyze the impact of technological fixities on the determination of the production function of cement.

4. Productivity and Productivity Growth

One of the major determinants of the relative share that the factors of production get from output has to do with the efficiency with which they "behave". Now,

"the concept of productivity is rooted in the notion of the production function. Simply stated, the production function merely expresses the fact that the physical volume of output depends on the physical volume of resource inputs used in the production process, and on the efficiency with which they are used, i.e., on their productivity." 12

The variable of productivity is usually obtained as the ratio of output-to-input. The broadest measure of productivity is the most aggregate one, which relates gross output to all the inputs associated in the production process, these are, to say: labor and capital inputs of all kinds (sometimes including land); and other inputs: materials, energy, intermediate purchases and supplies, etc.

It is as important to obtain a measure of productivity as it is to analyze the determinants of productivity growth
which usually occurs along a time-span. Probably the most important determinants of the growth of productivity are technological and organizational advances in knowledge. These, in turn, result in reducing costs in both, means and ways of production. The means of transmission of new technologies that tend to increase productivity over time occur through capacity expansion, embodied either by new entrants or by new production establishments of existent incumbents which use better techniques of production that increase input efficiency.

There are many examples that try to measure productivity and productivity growth. Jorgenson, et.al., op.cit., analyze economic growth for the different sectors of the U. S. economy during the time span going from 1948 to 1979. Their sectorial models give outputs as functions of labor, capital, and intermediate inputs, as well as of time. The distribution of the value of output is defined as the value shares given by the ratios of value of inputs to value of output, for each input. It is assumed that production functions have constant returns to scale. If this is so, then the productivity growth rate will equal the rate of output growth less a weighted average of the rates of growth of inputs; weights given by the corresponding value shares.

The authors introduce the concept of share elasticities defined as changes in value shares with respect to proportional changes in the quantities of intermediate,
capital, and labor inputs. They also introduce a basis for the analysis of biases of productivity growth, defined as changes in the value shares with respect to time.
In another part of their study, they assume Hicks neutrality, implying that input substitution is independent of time. They also use the value-added approach of the production function, assuming that sectorial productivity growth does not involve intermediate inputs.
Output growth has two sources: productivity growth, and growth in intermediate, capital and labor inputs. To construct productivity growth rates, a Translog index is derived (viii). Then, the contribution of each input to output growth is the product of that input's growth rate and its value-share in output. Thus, the growth rate of output is the sum of the productivity growth and the contributions of all inputs.

"The value of output includes the value of primary factor inputs, capital and labor, and the value of intermediate input... The value of output excludes trade and transportation margins associated with deliveries of output to consuming sectors. The value of input includes... all trade and transportation costs incurred in taking delivery of intermediate input." ¹³

Now, the accounting identity for an industry is in general, as follows: \[ qZ = pxX + pkK + pL \] [1]
where: \( Z, X, K \) and \( L \) are, output, intermediate input, and capital and labor factors of production; while \( q, px, pk, \) and \( pL \), are their respective prices.

(viii) For the definition of Translog (transcendental logarithm) production function from which this index is later constructed, see Kmenta (1986), pp. 517.
Now, to get the index of productivity, as suggested above, these authors use a Translog function of output with respect to all inputs. Hence, the index corresponding to such production function is also a Translog index of the rate of productivity growth, set as the following:

$$\Theta_T = \{[\ln Z(T) - \ln Z(T-1)] - \Theta_k[\ln X(T) - \ln X(T-1)]$$

$$- \Theta_k[\ln K(T) - \ln K(T-1)] - \Theta_1[\ln L(T) - \ln L(T-1)]\},$$

[2]

where the weights $\Theta$'s are the average shares of the corresponding inputs in the value of output.

Among some conclusions they found out that for most of the U. S. industries there is a weak association between output growth and productivity growth which is consistent with constant returns to scale (CRS). As they state,

"Economies of scale at the industry level could be constant, even if individual plants or firms within an industry are characterized by increasing returns, provided that expansion of the industry output occurs through expansion in the number of plants or firms, with no change in the average size of the plant or firm. Economies of scale at the industry level would result from increasing returns for plants and firms, and growth in the average size of the plants or firms."

Related to this, we can say that the average plant size that composed the cement industry in Mexico steadily increased during 1963-83. Therefore, we cannot affirm that this industry did not present scale economies. However, most studies on cement do certainly conclude that they exist.

As for the growth in productivity, most economists agree that productivity growth is less important a source for
explaining output growth than that of the growth of intermediate, capital and labor inputs.

In order to measure productivity growth at the sectorial level, Jorgenson, et.al., (Ibid), base their analysis on production function at the industrial level, giving output as a function of intermediate, capital and labor inputs. To analyze the changes in substitution possibilities over time, they create the rate of productivity growth. In the particular case of one sector or industry, they get a production function (ix) that can be assumed to have CRS (supporting the identity in [1]), and that looks like the following one:

\[ Z = F (X, K, L, T), \quad [3] \]

where: \( Z \) = output; \( X \) = intermediate input;

\( K \) = capital input; \( L \) = labor input;

\( T \) = time.

The shares of intermediate, capital and labor inputs are defined as the following:

\[ \pi_X = \frac{p_X X}{qZ}, \]
\[ \pi_K = \frac{p_K K}{qZ}, \quad [4] \]
\[ \pi_L = \frac{p_L L}{qZ}, \]

where: \( \{p\} \), \( \{q_X\} \), \( \{q_K\} \), and \( \{q_L\} \) represent output, intermediate, capital, and labor input prices, respectively.

On this respect, we ought to point out that the data sources for the analysis of the Mexican cement industry do not

(ix) Jorgenson, et.al., (Ibid), realize this analysis for every sector of the U.S. economy.
include explicit series of prices, but rather the total expenditure or value of each of these variables in the industry. However, there is data available on price indices and this will allow us to obtain the real value of output and expenditure on inputs for the industry as quantity indices.

The necessary conditions for producer equilibrium are that the inputs share of the value of output equal the output elasticities with respect to each input. This is:

\[ \pi_X = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln x} \]

\[ \pi_K = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln k} \] \[ \pi_L = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln l} \] \[ \pi_X = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln x} \]

\[ \pi_K = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln k} \] \[ \pi_L = \frac{\delta \ln Z (x,k,l,t)}{\delta \ln l} \]

Each of the inputs is an industry aggregate depending on quantities of individual non-aggregate intermediate, capital, and labor inputs:

\[ X = X(x_1, x_2, \ldots, x_n) \]
\[ K = K(k_1, k_2, \ldots, k_m) \] \[ L = L(l_1, l_2, \ldots, l_n) \]

The production function defined above in [3] is separable in h-intermediate, m-capital, and n-labor inputs. Also, if each aggregate variable is homogeneous of degree one in its
elements, the production function is homothetically separable. (x)/

An interesting characteristic is that the limiting assumption of CRS presupposes that the elasticities and value shares sum to unity for each of the input aggregates, and also that the values of aggregate inputs will equal the sum of the values of individual inputs. With this in mind the rate of productivity growth for a sector (industry) is defined as the rate of growth of output with respect to time, holding intermediate, capital, and labor inputs constant. This is: as stated above, the production function is homothetically separable in its inputs, which means that a separable production function \( Z = F(W(X,K,L),T), \) \[7\] can be represented as a function of aggregate inputs \( W(X,K,L) \) homogeneous of degree one and independent of technology \( T. \) Adding the assumption of CRS, the productivity growth is Hicks neutral and the production function can be rewritten as: \( Z = A(T)\cdot W(X,K,L), \) \[8\] hence,

\[
\pi_T = \frac{\delta \ln A(T)}{\delta T}, \quad [9]
\]

meaning that the productivity growth is independent of intermediate, capital, and labor inputs. (xi)/

In the case of cement production, some technological fixities do not allow for input substitution. In particular

(x)/ This is something that Shephard (1953), developed and proved.
(xi)/ For the analysis of the dual to this model, refer to Jorgenson, et.al., (1987), pp. 36-7.
that of the raw-materials. Hence, this will bring out a production function of the Leontief type, where the rate of productivity growth of this industry cannot be independent of the raw-materials input. We will later analyze the characteristics of this type of technology.

An alternative way to measuring productivity growth uses the value-added approach. It is based on output as a function of intermediate inputs and value-added, where value-added is a function of capital input, labor input, and time. Thus, time, labor and capital must be separable from the intermediate inputs. In this approach, intermediate inputs are not symmetrical to capital and labor inputs. The value-added scheme requires the same data as before - quantities and prices of output, intermediate, capital, and labor inputs - but has more restrictive assumptions. The production function will come from the total output $Z$ defined as:

$$ Z = F(X,V), \quad [10] $$

where $X$ is intermediate input and $V$ is a value-added function of the form: $V = G(K,L,T), \quad [11]$ where: $K$, $L$, and $T$ are capital, labor and time variables. Hence, $Z = F[X,G(K,L,T)]. \quad [10']$

If the value-added function is homogeneous of degree one in capital input and in labor input, and if the production function is neutral with respect to the intermediate input, then the production function is said to be homothetically neutral with respect to intermediate input. This value-added
function is, then, characterized by CRS. The necessary conditions, as well as the value-share conditions, and the Translog value-added indices, can be expressed in the same way as in the representation of the total-output production function above.

4.1 Scale

The concept of scale was shortly developed above. We ought to go further and talk more about some limitations that plant scale imposes to the particular case of the cement study, and perhaps, to some other cases as well. The concept of scale of production is generally related to the rate of output per production unit per period of time; but in a long-run perspective it may also be defined as the total quantity produced over the life of the production unit (plant, firm, etc.).

Now, as repeatedly stated before, due to the lack of individual plant or firm data available from the cement industry in Mexico, we find ourselves unable to get a measure of the minimum efficient scale of such economic units. Nevertheless, we can suggest that the minimum efficient scale of the cement plants has increased, as evidence for other countries confirm (xii), mainly due to larger market areas and better information, giving way to the existence of considerable economies of scale.

(xii) For these evidences, see Pratten and Dean (1965), and Bianchi (1981).
As we said before, the average plant size of the Mexican cement industry has steadily increased from an annual capacity of 202,786 tons in 1963, to 1,058,138 tons in 1983.

Related to the optimal plant size, empirical evidence has been consistent in proving the hypothesis that there is a broad range of optimal plant sizes in most industries, especially when there is the possibility of price discrimination. On this matter, the cement industry in Mexico presents a large range of plant scales, interacting in multiple regional markets, each one presenting its own demand. This situation has been present for a long time, promoted mainly by market distortions as well as by an uneven distribution of infrastructure along the country, leading to face regional markets conformed by monopolic or oligopolic structures.

Just to give an example, excessive government-regulated transportation freight policies and routes have set transport costs very high, bringing important externalities to the development of most sectors of production, including the cement industry. (xiii)/

A very important conclusion relating scale and economies of scale, is the one we find in Norman, op.cit., in his analyses of the U.S. and West German economies. He affirms (xiii)/Although the former and current government Administrations have been able to deregulate some of these sources of externalities, further deregulation is needed, especially the one concerning to railroads.
that economies of scale in cement production plants decrease as the scale increases, rejecting any assumption of concave cost functions. This last conclusion deals with the idea that there certainly exists an optimal plant scale, and that economies of scale decrease perhaps because of the appearance of diseconomies of scale in some parts of the cement production process, limiting the overall economies of scale due to larger plant size or scale. (xiv)

4.2 Efficiency

In current macroeconomic production theory there are parametric as well as non-parametric characterizations of efficiency. The parametric approach is the traditional one, using specified production functions (xv). The non-parametric approach as Sengupta (1989), points out,

"can be specified... through a flexible form of the production function which satisfies the efficiency hypothesis. In [this] case, the production frontier can be of any general shape satisfying some very weak conditions like quasi-concavity or monotonicity." 15

The most used approach to characterize efficiency is the parametric approach, mainly because it is theoretically rich, but also because it simplifies empirical evidence. Among the advantages of the parametric approach there is that it is statistical, making accommodation for noise, measurement error, and exogenous shocks beyond the control of the production unit. The major disadvantage of the

(xiv)/ We will refer to economies and diseconomies of scale later.
(xv)/ As the production function to be estimated in the empirical chapter of this analysis.
parametric approach is that it is parametric, sometimes imposing an unwarranted structure on the production function and on the distribution of efficiency.

Färe, et.al., (1985), state that the structure of efficiency at the industry level,

"is a reflection of the dispersion in overall private efficiency among the constituent firms in an industry. It measures the extent to which an industry keeps up with the performance of its own most efficient firms" 16

Nevertheless, this assertion assumes perfect information and perfect competition at the industry level. However, when the aggregate industry market is discontinuous and we allow for the existence of local monopolies, this may not be evident, as occurs in the Mexican cement industry.

Carlsson, op.cit., tries to measure efficiency in the micro production function, and approaches both: price, and technical efficiency. Price efficiency refers to the selection of the optimum combination of inputs, given the relative factor prices, while technical efficiency refers to producing the maximum obtainable output with the available inputs or factors of production. Hence, resource or input allocation has to do with price efficiency, while the form of the production function has to do with technical efficiency.

Now in an ideal world of perfect competition among profit maximizing firms (of an industry) with costless and perfect information and with costless and instantaneous technological change, there could not be any inefficiency
neither in the short nor in the long runs. When reality differs from this ideal situation, and it generally does, it is clear that sources of inefficiency derive from breaking any of the assumptions of this ideal world. (xvi)/

In econometric analysis, the study of efficiency in the production function presents various ways of measurement. In this area, Lovell & Schmidt (1988), make a thorough review of the different ways of approaching the measurement of productive efficiency at the production unit (plant, firm, etc.) level. As the authors state,

"These approaches differ in the way they specify the relevant frontier of production (i.e., non-parametric or parametric) in the way the frontier is constructed (i.e., by programming or statistical techniques), and in the way deviations from the constructed frontier are interpreted (i.e., as inefficiency or as a mixture of inefficiency and noise). Although each approach has strengths and weaknesses, only the stochastic frontier approach has the ability to distinguish efficiency from statistical noise, and we think this property is of great importance." 17

Färe (1975), develops the theory for measuring efficiency for a large class of technologies (parametric approach) by using an input-efficiency function. Later, in a recent paper, Färe, et.al., op.cit., measure efficiency using the non-parametric approach. (xvii)/

Now, in order to measure the relative efficiency of the factors of production, there are various ways to doing so.

---
(xvi)/ As a realistic Professor would add, "this ideal world free of Communism" is still to be seen.
(xvii)/ For these theoretical backgrounds, see the corresponding references.
We can use the example presented in Ullmann, op.cit., who when speaking of the labor input, states that

"labor productivity is essentially the quantity of a product turned out for each unit of labor expended." 18

Hence, in order to measure the productivity of labor in an industry there is the common interpretation that has to do with estimating how much labor will an industry (or any other economic unit) require or utilize in order to fulfill a production function.

Also, at the aggregate level and when value-added approach to output is used, various are the factors contributing to the growth of long-run output per worker or to the growth of labor productivity. Among these forces there are: a larger endowment of capital per worker; increasing returns to scale; increasing elasticity of substitution between the two factors of production (when capital stock is increasing more rapidly than the labor force); and technical progress, embodied in an increasing factor efficiency through time, or also in disembodied organizational technical progress that does not require new investment in order to take place.

As for the capital input, its measure of productivity is symmetrical to the definition of the labor input. But it can take different forms. Among them, we can recall the following ones: constant dollars spent per unit of output in capital input; amount of energy cost per unit of output; the ratio of total capacity of production to actual output.
or production; and various others, depending on the definition of capital input.

In general, results will differ according to the specification of the relevant model and its variables. Some econometric models have been developed in order to measure factor productivity growth. We ought to comment on that of Sickles (1985), who using panel data sets studies a non-linear model of technology and specific growth of factor productivity for the U. S. airline industry over 35 periods (quarters). He constructs a Translog cost function and specifies the model by using a multivariate error components technique of estimation.

In the empirical chapter of this study we will specify the technology for the Mexican cement industry that will allow us to test, among others, hypotheses concerning input elasticity of substitution, input productivity, and input relative shares of output. Now, considering this last point, and for almost any kind of industrial organization scheme, it is interesting to observe the major sources of change in the relative shares of output or income that the labor and capital factors of production get during any production process. On this respect, along time-series analyses, the relative share that the labor input receives will increase if either one or several of the following conditions occur: i) The nominal capital-to-labor ratio increases and technological progress is non-existent, neutral or labor-using (biased to labor).
ii) Technological progress is capital using (biased to capital), but the rate of growth of the nominal capital to labor ratio exceeds the positive rate of differential factor augmentation.

iii) The nominal capital to labor ratio decreases, but at a rate smaller than the negative rate of differential factor augmentation.

On the other hand, the relative (to capital) share of labor will decrease, if:

i) The observed rate of capital accumulation (due to new investment) falls short of the observed rate of growth of employment, and technological progress is non-existent, neutral, or relatively labor augmenting (or capital using).

ii) The observed capital-to-labor ratio is stable and the technological progress is capital using (or biased to capital).

iii) The observed capital-to-labor ratio increases, but at a slower rate than the positive rate of differential factor augmentation.

As for the relative share of capital, the analysis is symmetric. Conclusions about capital and labor share of the value of output in the Mexican cement industry will be obtained in the empirical results of this study.

Now, when we speak of production efficiency in the particular case of the cement industry, there are several premises that contribute to such efficiency, among them there are: scale, raw-materials advantage, operating
conditions (such as externalities and other distortions), cement pricing structure, and proximity to the market demand or location.

Speaking of input efficiency, there is some empirical evidence in prior research that has measured total factor efficiency in the Mexican cement industry. An example is in Alducín, et.al., (1981), who conclude that plants producing more than a million tons per year use approximately 50% less inputs (per ton) than those producing less than 500,000 tons.

At this stage of our analysis, we ought to point out that in developing countries there usually exists a surplus of labor alongside high capital costs and capital-intensive techniques of production, especially in the modern industrial sector. This is due to the limited range of technologies available for adoption; since most technologies are imported from developed capital-intensive countries. In the particular case of the cement industry in Mexico, only the latest technologies available were acquired for new capacity expansion during the period covered here: 1963-83. It is being said, that cement production is capital and raw-materials intensive, which might definitely be true; but there is no labor-intensive technology which is also efficient for the production of cement. Therefore, we can affirm that this availability bias is somehow inevitable as long as a middle income country like Mexico requires to produce cement.
4.2.1 Economies of scale

As we defined above, economies of scale occur when a proportional increase in inputs result in a more than proportional increase in output. In its dual form, economies of scale are said to be present when for unitary (or proportional) increases of all input costs in the total cost function, there is a less than unitary (or proportional) increase in this cost function. At any given moment in time, returns to scale are usually defined in a similar way as economies of scale are. Hence this concept is present in three different forms, according as to how the input scale parameters affect the production function or the output scale. Thus, constant, increasing or decreasing returns to scale can be defined as having proportional, more than proportional, or less than proportional effect on output scale as input scale changes, respectively. (xviii)/

We should be able to ask if there is any difference between economies of scale and returns to scale. On this respect, Nadiri & Schankerman (1981), point out the following,

"... economies of scale must be evaluated along the expansion path, whereas returns to scale are conventionally defined along an arbitrary input-mix ray." 19

Now, following this same order of ideas a very general concept of the sources of economies of scale which by the way affect the economic growth rate as well as its

(xviii)/ For the formal methodology of returns to scale, see Varian (1984a), pp. 18-20.
variability is given by Kendrick & Grossman (1980), who point out that

"[economies of scale] come with the growth of local, national, and international markets, permitting greater specialization of personnel, equipment, plants, and firms, and the spreading of overhead costs over increasing quantities of output." 20

In a more concrete way, Pratten (1971), suggests that the sources of economies of scale can basically be reduced to the following:

i) Indivisibilities, which materialize in costs that are wholly or partially indivisible with respect to output. Some examples are: initial development and design costs, invention of new techniques of production, some types of capital equipment, etc.

ii) Economies of increased dimensions, that appear when initial costs as well as operating costs increase less rapidly than what capacity of production does. This occurs quite frequently with capital equipment costs.

iii) The economies of specialization. This source of scale economies comes when larger output brings greater opportunities and advantages of labor force and capital equipment specialization.

iv) The economies of massed resources, coming from indivisibilities of the factors of production as well as of decision making. As an example, the ability of a large firm to spread risk may enable it to take greater risks.

v) Superior techniques or organization of production, where increased scale allows the use of increasingly
efficient techniques or methods of production organization that promote either input productivity shifts, or faster production rates, or both.

vi) economies through control of markets. This type of source of economies of scale reduces the uncertainty of producers due to the lack of competition with other producers.

On this respect, we can a priori say that most, if not all, of these sources of scale economies were present in the Mexican cement industry. However, the last source, i.e. economies through control of markets, might be the most important one. We will later analyze the market structure and industrial organization of this industry.

There are also various possible sources of diseconomies of scale, which are represented as a more than proportional increase in unit costs corresponding to a proportional increase of the scale of production. Among them, there are:

i) Technical forces. This source of diseconomies occur when by increasing the capacity of output, the unit of production (plant or firm) incurs in larger costs. An example applied to cement plants is related to pollution, usually increased when capacity expansion occurs, and this may enforce (considering an enforcement authority exists) to invest in anti-pollutant equipment with the corresponding costs.
ii) Management. This source of diseconomies of scale argues that management costs increase more than proportionately with scale, this is, "that the effectiveness of management may decline as scale is increased... If such management effectiveness falls as scale is increased, the costs of production are increased, but not necessarily the cost of management itself." 21

Increased management costs when scale increases means that costs of coordination and organization of production increase more than proportionately. The fall in management effectiveness when scale increases is due mainly to delays in decision-making brought about by the increased length of the management chain.

iii) Labor relations. When scale of production increases it is usually more difficult to monitor individual labor productivity, hence, promoting people working less or less well (xix)/.

iv) Selling and distribution costs. This kind of Diseconomies of scale are usually present when the scale of a plant is increased; then, the geographic spread of a market is increased, and the average length of haul is also increased in order to be able to sell all production. This will have a direct effect in increased average unit costs of transport. As we will later see, this source or scale

(xix)/ This outcome will have a larger impact on sectors characterized by labor-intensive technologies and techniques of production. On this respect, plants or firms should set a production structure where such adverse selection occurrences are minimized. A suggested model is the Principal-Agent, see Varian (1984a).
diseconomies is important in determining the industrial organization of the cement industry.

Now, there are alternative definitions and ways of measuring economies of scale. Norman, op. cit., suggests a static definition of economies of scale, where a given state of technical knowledge and managerial skill allows for cross-section analyses. He defines two main types of elasticity of scale: physical and cost scale elasticities. The first one, the physical scale elasticity, defines an optimum input mix for each relative factor price regime, identified as the following,

\[
P \frac{d \log \left[ P(x^*) \right]}{d \log (x^*)} = E_x \quad [12]
\]

where: \( P(*) \) = production function;
and \( x^* \) = optimum input mix for a particular factor price regime.

The second type, the cost scale elasticity (the dual of the production scale elasticity), where for each particular relative factor price regime he determines the minimizing expenditure on each input required to produce a given output, is identified as follows (for \( i = 1, 2, \ldots, n \) inputs):

\[
\frac{C_i^*}{E_q} = \frac{d \log [C_i(q)]}{d \log (q)} \quad [13]
\]

where: \( C_i(q) \) = cost minimizing expenditure under a determined factor price regime;
and \( q \) = output.

The total cost function is then defined as,
\[ \text{TC}(q) = \sum_i \text{C}_i(q), \quad [14] \]

such that the total cost elasticity looks like the following:

\[ \frac{\text{TC}}{(E_q)} = \frac{d \log [\text{TC}(q)]}{d \log (q)}. \quad [15] \]

Thus, considering this identification, and given a choice of production unit (plant or firm) in cross-section studies, this author states that,

"[economies of scale] are said to exist with respect to a particular input, or to all inputs, when the appropriate elasticity of the cost (production) function evaluated at constant relative factor prices and incorporating a given technology, is less (greater) than unity over some or all of the range of attainable scales." 22

This author got empirical evidence for the cement industries of the United States and Western Germany in the 1970-71 period. Among the major conclusions of his study are the following: the existence of substantial economies of scale to capital and labor inputs; the condition that the capacity installed, at the firm or plant levels, is related to volume of capital equipment; and that the estimates of production costs elasticity to scale ought to be taken with caution, since evidence shows that such elasticity may vary with scale.

This last conclusion might be very powerful to explain different levels of economies of scale at different scales of production for the particular case of the Mexican cement firms or plants at any time.
Now, diverse studies show how to measure economies of scale derived from a production function. Griliches & Ringstad (1971), make a cross-section study of the Norwegian manufacturing sector and measured the economies of scale of various types of production functions (or technologies). In the particular case of cement industry, their estimate of the scale elasticity gives evidence that there are economies of scale in this industry. Also, the estimates of the elasticity of substitution between capital and labor are found to be above unity, giving evidence that this industry is capital-intensive.

Owen (1983), explores the economies of internal trade manufactures within the four major European Community members: West Germany, France, Italy, and the United Kingdom, and the role that economies of scale have played in determining competition among the manufacturing sector of these countries. This study follows the common idea that large markets foster the development of large-scale production technologies which in turn increase the levels of productivity.

In the view of a possible free trade agreement (FTA) between the U.S. and Mexico, with a long-term de facto conformation of a North American Free Trade Area that will include Canada as well, research of this kind will be necessary to study the effects of freer trade on costs and scale. Undoubtedly
that the Mexican cement industry will adapt to the changing role of international trade. (xx)/

Generally speaking we can assume that economies of scale are both, cause and effect. It is not always easy to distinguish when it is acting just as an active force for increasing productivity, and when it is the result of a certain market structure. It seems that it is both things at the same time. There are some examples about this. Among them, and using the dual (to production) cost function approach to economies of scale, Cowing & Stevenson (1981), point out the characteristics of this issue in regulated industries. Economies of scale in such cases will come in the same way as before. This is, when with constant prices of inputs there is an increase in costs which is less than proportional to the increase in output. An important point relating scale economies and productivity is that,

"the possible existence of economies of scale is also important for the accurate measurement of productivity growth since the results of scale effects and technical change are generally confounded in observed output-input changes over time. Thus, failure to account correctly for scale effects will lead to biased productivity measure in those industries that are not characterized by constant returns to scale." 23

(xx)/ During the realization of this thesis, the USITC (United States International Trade Commission) established a duty on Mexican cement imports of approximately 55%, allegedly due to dumping by cement exporters. We ought to point out that in 1989 the penetration of Mexican cement imports in the United States had reached such level that it supplied as much as 25.9% of the Florida market, as well as 11.9 per cent of the Texas, New Mexico, and Arizona markets together.
Also, Tinbergen (1985), relates competitiveness to returns to scale. He states that,

"In a situation of macroeconomic increasing returns [to scale], permanent losses accompany free competition between private production units (plants or firms). This is an unstable situation, bound to result in cartelization, public ownership, or both." 24

Now, the existence of internal economies of scale (over plant and firms) is incompatible with long-run competitive industrial organization. Hence, when lower unit costs are achieved by increasing plant size, a systematic increase in the concentration of output is to be expected at fewer plant or firms than before. On this respect, the structure of the Mexican cement industry is far from being a competitive one, thus promoting production concentration in fewer firms during the period studied. However, at the plant level production concentration has not occurred, but rather a generalized capacity expansion, leaving individual plant capacity-to-total industry capacity ratio at a similar level (see Table 1 in Appendix). In some regions, there even seems to be an increasing competition among firms, but then, fewer firms competed, anyway.(xxi)/

4.2.2 Technical change and efficiency

Another characteristic of economic efficiency, besides economies of scale, is technical change. It results when the maximum efficient output that can be produced from any given bundle of inputs increases over time due to such

(xxii)/ For the study of cartelization attempts within some European cement industries, particularly the U.K. and West Germany, see Bianchi (1982).
things as experience, increased knowledge (know-how), new innovations, and, in general, better techniques of production.

Technology is implicit in the production function. So, in sectors using fixed proportions of raw-materials, like cement, such technology is not very likely to change; not even in the long-run. However, the possibility of changing the technique of production concerning the capital and labor inputs appears to be almost a necessity. This event tends to be intensified when there is more competition in the market structure. Thus, profit-maximizing firms not only persistently search for better technologies (when feasible), but also switch to better techniques that will allow them to increase input efficiency.

To clarify the difference between technological change and technical change, in general when technological change occurs the direction of input intensity may or may not change. We say that technological change is Hicks neutral if the elasticity of substitution between inputs does not change when new technologies are adopted, as we noted before. Nevertheless, in the real world, technological change tends to be biased to the utilization of one or various inputs. The way in which these inputs are combined to produce one unit of output has to do with the concept of technical change. The degree to which the output of a production unit approaches its maximum is called the technical
efficiency of production. Thus, a sufficient condition for technical efficiency is that the economic unit (firm or industry) must operate on its production function, while a necessary condition for a technically efficient unit is that it may operate beneath its production function (production possibilities frontier).

In the case of cement, this sector has a well defined technology where input substitution resulting from technical change can only occur in the capital-labor relation, but not in the raw-materials input. We will later define this fixed-input technology.

5. Concentration

It has been argued that concentration of production in few firms tends to reduce efficiency. This supports the somehow vague idea that efficiency in production can be expected to vary inversely with market power. However, as we pointed out before, production concentration can also be a large source of scale economies. In particular, we may ask what trend does the Mexican cement industry followed in the period studied concerning output concentration by firm? An answer to this question can lead us to important conclusions about economies of scale.

According to Katz (1969),

"a static measure of business concentration has shown to have a major incidence on productive efficiency through the agency of technological progress and returns to scale which tends to be higher in sectors with a high degree of business concentration."
In this way, using a measure of concentration such as the percentage of total output supplied by a given number of firms, is required. In the Mexican cement industry, as we have said before, while there has been a trend to the concentration of production in fewer firms, production concentration in fewer plants is not evident. If, however the demand is concentrated in a specific region, and when distribution costs are high, we might expect that supply is usually concentrated near-by. Nevertheless, for price discriminating monopolies this does not occur. We might also expect that the scale of production will be larger when demand is larger, resulting perhaps in larger economies of scale, and thus, in an increased concentration of production. But then, larger market areas are usually supplied by more firms than smaller market areas are. Therefore, it is not evident that market concentration promotes production concentration in fewer plants or firms.

Now, while strong competitive pressures impose productive efficiency on firms as a survival condition, under a monopoly sheltered from such pressures the pursuit of productive efficiency is an option rather than a necessity. Nevertheless, we ought to point out that this outcome will break down as long as there is free entry and threats of entry are credible, thus possible. In such a situation the incumbent monopoly will behave more competitively in its pursuit of efficiency.
Concentration is measured by using diverse methodologies. A common one is to get a concentration ratio that results from dividing the output of a plant or firm by the total or aggregate output of the industry.

Carlsson, op.cit., affirms that the concentration ratio is commonly used as a measure of the competitive structure of an industry. He assumes that the higher the degree of concentration ratio is, the stronger the market power of the largest firm is. However, this is not taking into consideration some other elements such as foreign competition (for the case of open economies), as well as the existence of close substitutes. Hence, the concentration ratio may not be a very good measure of competition. An important result that links concentration and efficiency is,

"it is not certain that the concentration ratio should be negatively correlated with the level of efficiency, especially in the presence of economies of scale... In fact, the more important are economies of scale, the greater is the probability that the concentration ratio is positively correlated with efficiency." 26

Among empirical results on concentration, Bianchi, et.al., (1981), study the post-war European cement industry. The analyses and conclusions are very similar to those Bianchi (1982), presented later. Among the major conclusions are the following:

1) Speaking on the concentration of production in France and Western Germany it has been increasing; but with no dominant firm. In Italy concentration has been stable, as
it has also been in the United Kingdom, but in Italy there is no dominant firm, while in the U.K. there is one.

ii) Technological improvements have been adopted, and except for the U.K., the largest producers have taken full advantage of larger plants and less energy-intensive technologies.

Now, in the particular case of the Mexican cement industry, Alducin, et.al., op.cit., show that there is a trend to concentration of aggregate output in fewer firms. They also show that the relative profitability of cement firms as compared to other sectors of the Mexican economy (which is universally oligopolistic), is more or less the same during the period they studied 1974-78 (xxii)/. Finally, they conclude that production concentration led to increasing returns to scale by setting production at optimum efficient scale levels.

We can say that an apparent outcome will result in lower prices, and thus, increased market shares in even fewer firms. However, if we depart from the plant level, we might observe that each plant presents a natural regional market where monopoly power is unchallenged. If this is so, then this outcome of lower prices is not obvious.

We notice that prices have a lot to do in how the cement industry is organized and concentrated. But then, since this product has weight and bulk which are high relative to its value and also because it will harden on prolonged exposure (xxii)/ As data of the Mexican Stock Exchange show.
to the air (forcing it to be stored and transported either
in special tanks or sealed bags), transport costs tend to
have an important influence in the determination of cement
final price to consumers. Simply stated: transport costs are
high relative to the production costs of cement.

5.1 Transport costs

Even when transport costs usually have little to do
with costs of production at the cement plant level, they
become important at the distribution process. Thus,
transport costs are important in determining production
concentration in regions where larger markets exist. Total
transport costs will depend on the haul over which cement
has to be carried. As Bianchi (1982), points out, there may
exist some sources of scale economies depending on the
chosen mode,

"Some economies of scale exist in relation to the
minimum optimum load of different modes of transport.
For example, with full loads, unit transport costs are
less for transport by ship or rail than for transport
by road. But, of course, the minimum load by ship or
rail is very much larger so that transport by [this
modes] is only convenient for very large
consignments." 27

Thus, we can also suggest that truck or road transport mode
has a marginal cost advantage over the rail and ship modes
on hauls of less than a predetermined number of miles or
loads.

There are three main methods used in adding transport
costs to costs of production in order to determine the price
customers pay. They are the following:
i) **Free on board (FOB)**, also called actual delivery cost, is the one used for cement distribution in Mexico. Here, the production unit (plant or firm) publishes a factory price (where government approval is still usually required), and the distributing agents take that price as the base and add the corresponding cost of transportation from the factory to the final market place. A variation of this pricing method is the **Costs-Insurance-and-Fleet (CIF)** method where the distributing agent charges additional costs associated to the FOB process.

ii) **Fixed and uniform transport surcharge** to the factory (or ex-works) price, also called Uniform Delivery Price or Zonal Price System. Here, a fixed amount or surcharge is added to the factory price; so, the final price will be the same along a whole region. Under this system, customers located near to the production unit will be subsidizing those who are further away from it. Since different zones or regions are delineated around each production unit and interregional trade is not allowed, the production units may probably have monopoly power within their established market area. Also as a result, this system offers customers or distributors located at the **margin** (between to pre-established differentiated regions) little incentive to buy from a plant that is closer in order to save in transportation costs, since their supplier is a fixed one. For this pricing system to work, an explicit, and more likely, **forced agreement** among producers or distributors is
required; because some will find it profitable to sell outside the boundary line. This pricing method is very costly in terms of efficiency in location. Nevertheless, as Abouchar, op.cit., points out in his study of the Soviet cement industry, in planned economies there is no cheating, and

"this [pricing system] would give incentives for the industry and the distributing agents to strive for the most efficient pattern of cement distribution." 28

However, in free market economies the uniform transport surcharge is very costly to be enforced, thus proving to be an inefficient way of setting prices.

iii) A third system of price determination including transport cost is the so called Basing Point System (BPS). In this system the final price customers pay is the published ex-works price plus a delivery surcharge that varies according to the distance to be transported. This delivery surcharge is calculated from a determined point or base point, usually a production unit, but not necessarily. This system was extensively used in the past. However, numerous studies have given evidence that this pricing structure results in capacity underutilization.

5.2 Pricing structures

Another important subject that explains production concentration are the various pricing methods of a market or group of markets in an industry. Bianchi (1982), in a study that includes European and non-European cement industries, gets interesting conclusions of the post-war evolution of
this particular industry. His major interest is to analyze how the establishment of a well defined pricing policy helped to effectively promote the development of this sector in various countries, while in others it was a major source of inefficiency. The best behaved European cement industry of the post-war is the Italian, followed by the German and the French. The British, though, behaved poorly and it can be said that the pricing policy there established helped to distort this market. As a matter of fact, a cartel was created and almost no regulation was established by the government. Thus,

"in 1961, the Restrictive Practices Court accepted that the private regulation of the market was not against public interest. That private control had been based on a centralized system for price fixing for every works (based on the average costs of the existing works at the present capacity utilization) and a unified transport system (the Basing Point System)." 29

The performance of the policy previously described was the freezing of the British market structure, where after years of price wars, the aim of survival firms had been to freeze the relations among producers avoiding any disagreement. In particular, the largest firm realized how expensive (xxiii)/it is to try to monopolize, and thus provided a "shock-absorbing system" to manage the agreement, accepting to increase excess capacity without any attempt to increase its sales during economic downturns or recessions.

(xxiii)/ As larger firms have larger capital investment, they usually have larger fixed costs, and therefore when price competition was used as a mechanism to gain market shares, diseconomies of scale arose higher than in smaller firms.
Unfortunately, the performance of such market has been very poor in terms of technological progress, as is its ability to react against input cost increases.

In Italy, by contrast, there is a public system of price regulation which started in 1936. This system has enforced cement prices to be low, relative to that of close substitutes like bricks, thus, promoting cement consumption and also enhancing competition among regional and national producers. This policy also resulted in production increase and technological progress to be established as capacity expanded and firms took advantage of economies of scale, making the Italian cement industry one of the largest and most efficient in Europe. As the author states,

"[In Italy] the control of prices provided a secure background to investment planning and the avoidance of price-cutting pressure, as long as the market structure remained relatively undisturbed. Nevertheless, there has been considerable technological improvement and growth in output." 30

In France, price control provided the framework which permitted the reorganization of the industry. The French market was divided into twelve zones and the prices were set by the government. These prices determined the market sizes on which different firms had to face their competitors. In this case,

"continuous innovation and enlargement of capacity by the largest firms had been the way to communicate to the small firms the reality of the fact they faced continuously increasing risks by staying in the market." 31
Later, during the 70's, cement price control became useless as an instrument of policy for structure in both, France and Italy, since a stable structure had already been reached. Price control then became a counter-inflationary policy, at least until the so called 1973-74 oil-shock had been absorbed by the economies.

The German case is the closest of the four larger European cement industries to present a competitive framework. It is also the most complex structure, since competition resulted in price wars and varied behavioral responses of the incumbent firms. In this industry,

"the market shows the effect of two major groups of influences: first, the concentration inducing stimulus, deriving from economies of scale and innovation in fuel saving technology, and second, the drive for greater concentration as means of controlling the competitive forces intensified by any recession... Small one-plant firms did not have the burden of fixed costs faced by the firms with the latest modern plants, so they were able to cut prices. During recession it was impossible to limit price-cutting to particular areas or products because of the way the cement industry purchasers is organized [very homogeneously]...Expansion has provided the investments opportunities for the industry to take full advantage of rapidly evolving technology." 32

During recessions, the main goal of smaller German cement firms had become to survive and this is why they refused reduction of production as well as the cartelization that larger firms proposed; but rather they (the smaller firms) preferred price reduction. Thus, during these recessions there was an asymmetrical conduct between the producers of different sizes.
As we can observe, the four pricing examples of these European nations give different results for either private or public price controls. Hence, we can conclude that,

"price control seems to be too general a term to designate such a many-faceted instrument of economic and industrial policy to favor structural changes or to preserve the existing structure and a guideline for industrial development." 

5.3 Transport modes of Mexican cement

Besides considering the different methods for final pricing of cement after transport costs have been added, we ought to point out the different transport modes available to doing so. As we affirmed before, ship transportation is usually cheaper for large amounts of cement, but then, this mode is restricted, as any other, to its availability. In the case of cement industry in Mexico, this mode is not only almost inexistente, but it is also inoperable, since most cement plants are not situated along the coastline. The same occurs with the pluvial fresh water system, which is totally inexistente. Hence, the only two available transport modes are road or highway-freight and railroad-freight. We can say a-priori that the Mexican railroad system is far from being an efficient one due to structural externalities. It has been government owned for a long time. Thus, the lack of investment to modernize it has created a ceiling to economic development that affects not only the cement industry but the whole economy. This has resulted in poor maintenance, undercapacity and overpricing (xxiv). Actually, the

(xxiv) According to USITC Pub. 2212 of 2-10 Aug. 1989,
panorama of the railroad transportation could hardly be worse. Immediate action is required to promote productive investment in this important transport mode. However, in spite of its considerable inefficiencies, railroads has proven to be an importantly used mode for cement transportation in Mexico. Although not as important as the highway-truck mode.  

Besides railroads, the only alternative competing transport mode is the highway freight mode. But for long hauls this system increases the cost of transportation not only because of the low value-to-weight ratio of cement, but also because during the 1963-83 period, there existed a government regulated route system which gave oligopoly power to some "appointed" freight companies increasing even more the freight costs. Hence, as we can see, diseconomies of scale coming from transportation costs have been structurally settled for the Mexican cement industry and the aggregate economy. On this respect, Manne (1967), makes an important observation linking it to plant scale,

"If a cement plant is constantly employed to serve a predetermined market area, it has been argued that an optimal plant size can be chosen without regard to the costs of transport. Transport costs are unaffected by the choice of plant size." 34

... for a similar haul of 70 miles, during May 1989, the freight cost per metric ton in the U.S. was $2.50, while in Mexico it was $2.85.  

(XXV) In a study by CANACEM (National Chamber of Cement), railroads provided for 24.4% of all the transportation of cement during 1983, while highway truck-load accounted for 71.3% and ship transportation for 4.3%.
Related to this, if we analyze the pattern of plant size and location of cement plants in Mexico during the 1963-83 period, we will find such location does not always respond to the proximity of the market or region it serves. As a matter of fact, there are some huge modern plants located far away from the large markets, making evidence of price discriminating monopolies. We will later analyze this type of market structure.

5.4 Location, demand and scale of cement plants

In the particular case of cement production, the relative ubiquity of cement-making raw-materials, except perhaps for energy and fuel inputs, makes possible for the location of different plants to be demand-oriented. This, would suggest that production tends to follow demand in location and that there should be production units located in many regions. However, as we have stated above, this pattern was not always present in Mexico, especially when multiple-plant firms serving various regional markets distributed their output as to maximize profits, which in the presence of price discrimination, yield different conclusions. Nevertheless, when we refer to production inputs, cement plants are constrained to locate near the sources of raw-materials, because many of these materials are heavy, bulky and of low specific value, so they cannot be economically transported for long distances.

Norman, op.cit., relates location with efficiency and scale, and explains why it should be efficient to build
plants of different scale which apparently do not fully exploit the potential economies of scale. As he states,

"the point here is that production conditions are not independent of location, or time. Consider for example a monopolist considering region R. If R contains the basic minerals required for cement production and is sufficiently remote from other feasible production sites, it may well be efficient to operate a small-scale plant in R. Alternatively, if demand in some market S is growing slowly (relative to the minimum efficient plant scale), an efficient production strategy in S may well involve the sacrifice of production cost economies in order to avoid the costs of carrying spare capacity or incurring additional transport or storage costs." 35

Commenting on this note, even when detailed information on Mexican cement individual plants and firms was not available during this study, we can make an "educated guess" that both of the above situations occurred along the 1963-83 period. (xxvi)/

In another study, Norman (1979b), emphasizes the importance of spatial distribution of production and demand. Several theories are analyzed, among them, are the least-cost theory, introduced by Alfred Weber, and the central-place and inter-dependence theories (xxvii)/. The context for such theories is that of a static approach, which means

(xxvi)/ In his doctoral dissertation, G. Norman indicates that cement plant capacities of less than 200,000 tons per year may be perfectly efficient choices in a multi-period event. If we compare this measure with that for Mexican cement plants there were many small scale plants under this situation. The rationale for their persistent existence was that they were able to behave as local monopolies either by non-competition or by collusive behavior with other firms in their market area.

(xxvii)/ For a thorough explanation of these location theories, refer to this reference.
that the analysis is developed at a determined point in time.
The study of these theories on location rationality were left out from this research. Nevertheless, further research pertaining to this subject is highly encouraged.

5.5 Cement plant pollution as an externality

Externalities are distortions generated during most production processes, which may also affect other production processes. In the case of production of cement a major externality generated by this industry is environmental pollution.

While it might be true that some capital-intensive and most energy-intensive processes of production are major sources of pollution, this is totally applicable to the case of cement manufacture. As Ullman, op.cit., points out about the U.S. cement industry,

"[The cement industry] has problems in both, air pollution and energy use... A badly designed and operated cement mill can wreak extensive environmental damage. By 1980, this industry expenditure for environmental protection was rising at a rate of 33 per cent a year, as opposed to 8 percent for all manufacturing." 36

Since large investments are required to prevent environmental damage, it is likely to happen that such investments will induce diseconomies of scale and will affect productivity. (xxviii)/

(xxviii)/ Actually, one of the major complaints of the American cement producers when the hearings of the USITC held in Washington alleged dumping policies of Mexican cement exporters to the U.S., was that while American firms face
We will later issue how is it that cement plants pollute, which will depend on the type of production process chosen.

5.6 Rationale for mergers

One way in which the concentration of production in fewer firms also materializes, besides production expansion of incumbent economic units (plants or firms), is by mergers. During the period covered by this research and certainly in even more recent times, there has been a trend for mergers in the Mexican cement industry.

Ravenscraft & Scherer (1987), study the rationale for mergers. As a basic approach, mergers occur when both, buyers and sellers, consider themselves to be better-off from such transaction than without it. But then, we should ask: why do the parties involved consider themselves better-off? Generally speaking, we can say that sellers sell when buyers make offers too good to refuse. The rationale of the buyer to merge itself with a seller,

"might include introducing superior management into the acquired entity, the realization of complementarities in production or marketing, the exploitation of scale economies and the elimination of duplicative functions, risk-spreading and its favorable consequences for the cost of acquiring new capital, a reduction of tax obligations through the pooling of losses and the internationalization of capital transfers, and the enhancement of monopoly power by consolidation of competing interests." 37

...tough requirements related to pollution control, the Mexican side did not face so tough measures, enabling them to reduce costs and, thus, offer the final product at a better price.
Most, if not all of the diverse reasons suggested above for mergers to occur might well have been present in the Mexican cement industry during 1963-83. As a direct result, firm concentration has increased and the industry under this perspective became less competitive than before. Nevertheless, under the plant level perspective, capacity expansion has occurred in most plants, and as we pointed out before, the trend for production concentration is not so evident. As a matter of fact, if we build a Gini concentration coefficient at the plant level, regardless the parent firm, we get that in 1964 it was 0.3296, while in 1983 it was 0.3984, actually improving the distribution of production among incumbent plants.

Of course that the aggregate market structure has to be analyzed in order to get deeper conclusions about this, since multiple-plant firms as well as single-plant firms might take advantage of the possibility of price discrimination in their pursuit for profit maximization. We will briefly analyze the market structure and the industrial organization determining the cement industry before we develop the model of the production function.

6. Market Structure

The power that individual plants or firms have over a market is directly related to the market structure of that sector or industry. This structure will not only determine the form of the profit or objective function, but the form of the production function as well. Thus, we can view the
market structure as the battle-field of any industrial organization scheme where the contenders are either incumbent or entrant firms and over which a final outcome will determine the relative share of output and profits of each participant.

6.1 Perfect Competition and Monopoly

We can say that the two opposite cases of the market structure are Perfect Competition, on one side, and Pure Monopoly, on the other. The real world is generally between these two extremes.

A competitive market has multiple buyers and sellers, none of whom looms large enough to have noticeable effect on the market demand and supply functions. Information is assumed to be perfect concerning output and prices and the product is assumed to be identical or homogeneous. As a result, the impact that each individual consumer and firm have on the market is nil. This means that they cannot change the output and price levels of the market at all. Thus, firms and consumers are price-takers.

Concentrating our attention on the production function, and as in any other market structure, each firm profits are defined to be: $\text{Max } qz - c(z)$, [1]

where: $q = \text{output price; }$

$z = \text{output quantity; }$

$c(z) = \text{cost function.}$
The first order condition will set the marginal revenue (MR) equal to marginal cost (MC): \( q = c'(z^*) \), for \( z^* > 0 \). [2]

We can see that in the competitive structure, the marginal revenue is equal to the output price.

The second order condition of profit maximization establishes that marginal costs are an increasing function of output: \( c''[z(q)] > 0 \), [3] which sets a limit to the capacity expansion of every competitive firm.

In general, the total cost function (TC) of every individual firm has two basic elements, fixed and variable costs. Fixed costs are those in which the firm incurs once a capacity of production is chosen. They usually include the cost of some capital inputs such as interest rates, rents and other flows of capital services; or the cost of capital equipment and other durable goods which can be considered as capital stock. These fixed costs are always present whenever \( z > 0 \), regardless of the capacity level of production at any time. Hence, fixed costs are inevitable and are represented by a fixed parameter or number.

Variable costs depend on the production or output level. This means that they usually increase or decrease following output. These costs often include the labor inputs and some raw-materials, depending on each production process.

Thus, the Total costs of each firm are represented as follows:
\[ c(z) = c_f + c_V(z), \quad [4] \]

where: \( c_f = \) fixed costs parameter;
\( c_V(z) = \) variable costs.

The supply curve of each competitive plant or firm comes from:
\[ q = c'(z) \text{ if } qz - c_f - c_V(z) \geq -c_f, \quad [5] \]
and \( z = 0 \text{ if } qz - c_f - c_V(z) < -c_f. \)

We notice that if \( q \geq c_V(z) \implies z > 0 \), \[6\]
which is the nonnegative profit condition. However, in the short-run, if the revenues of the firm cover the variable costs, the firm will produce even in the presence of negative profits. Figure 1 shows the three possible profit outcomes.

**Figure 1**

![](image)

Negative profits  Zero profits  Positive profits

In general, in the long-run it has been said that all the inputs of a production process are variable. This is mainly due to technical and technological changes, which modify the relative efficiency of inputs. And also because capacity expansion is possible. These, in turn, open the possibility
of factor substitution when feasible, and thus, the cost structure of firms can actually change.

Now, while in the short-run the market performance of competitive firms may vary, allowing for different profits among firms, in the long-run, however, such market structure will tend to equalize the profit levels of all the incumbent firms. Now, if we relax the assumption of perfect competition allowing for some sort of imperfect information, the long-run structure of average costs may be diverse, happening to be either constant, increasing, or decreasing. This cost structure, plus the possibility of free or restricted entry into the industry, will determine whether there are positive or zero profits as well as the relative market share that each firm gets of the aggregate market. Thus, there will be a large range of outcomes for the non-perfectly competitive framework. (xxix) /

On the opposite end of the market structure is the Pure Monopoly, who is the sole supplier of a good or service. Its demand function is, at most, affected negligibly by the actions of any other single firm. Since the monopoly usually presents long-run positive profits, there is an incentive for other firms to enter and the number of incumbent firms in such industry may increase; but this will depend on the possibility of entry. However, a long-run monopolistic market structure is always assumed to have few incumbents,

(xxix)/ For a complete outcome scheme on this, refer to Varian (1984a), pp. 88-9.
in which case we call it Oligopoly, or only one which as stated above is called a Pure Monopoly. As it occurs in the competitive framework, technical, technological changes, and entry will also affect the development of monopolies in the long-run.

In the short-run, a monopolist, as in any other market structure, will also set its production point whenever marginal costs equal marginal revenues; and its shutdown decision will depend on the level of the short-run-average-variable-cost (SRAVC). This is, if $q_m < SRAVC$, where $q_m$ is the monopoly price, the monopolist will drop-out of this market. In the long-run, the shutdown decision depends on the long-run-average-cost (LRAC). Thus, if $q_m < LRAC$, the monopoly will drop-out.

A pure monopoly as the sole producer of a good or service will face the whole industry demand, and under the inexistence of any regulating agent, it will be free to set the market price. From this: $MR = q_m \left( 1 + 1/\varepsilon_d \right)$, [7] where: $\varepsilon_d =$ price elasticity of market demand. Hence, the monopolist will always produce at output levels where the market demand is elastic, this is: $\varepsilon_d < -1$. See Figure 2.

![Figure 2](image-url)
Now, as it occurs in the cement market, aggregate markets usually are either differentiated or discontinuous, or both, presenting multiple disaggregated markets to be covered. This gives room for the existence of two kinds of monopolies which might serve part (local or regional monopolies) or the whole aggregate market of a good. So, there are single-plant monopolies serving one or various markets, each with its own demand structure, and multiple-plant monopolies, where each plant serves a determined number of markets. In either case, price discrimination will be likely to exist. A monopolist will be willing to engage in price discrimination as long as buyers fall into classes or markets with differences in the price elasticity of demand for the product, and these markets can be identified and segregated effectively. But for price discrimination to work, it is important that no other economic agent (besides the monopolist) is able to transfer the commodity from the low-price markets to the high-price markets; since this will make it difficult to maintain the price differentials between them. Price differentiation is made possible primarily to differences between consumers income levels, tastes, location, and the availability of close substitutes.

A single-plant price-discriminating monopoly will serve in various markets (or classes of consumers) at points where \( MC = MR_m \) , for \( m = 1, \ldots, M \), markets.
In the case of a multiple-plant monopoly, if at any point in time each plant faces different marginal costs, a profit-maximizing monopoly will transfer output from plants with higher marginal costs to those with lower marginal costs, until \( MC_h = MC_j \), for \( i, h \in H \), such that \( H = 1, \ldots, H \), plants, and \( i \neq h \); and as long as \( MC = MR \) is satisfied in every market \( m \).

We will later present the framework of price discrimination. As for now, we will analyze the intermediate market structures between perfect competition and pure monopoly.

6.2 Oligopoly and Monopolistic Competition

An oligopoly is a market characterized by a small number of firms producing a homogeneous product and having a great deal of interdependence among firms. As the monopoly, it usually arises from economies of scale or from barriers to entry of various kinds. It lies between pure monopoly and perfect competition, but analytically it is quite different from these two opposite market structures. Because under an oligopoly, each firm is aware that its actions will likely change the policies of its competitors. In this way, the major analytical constructs that nest most oligopoly theories deal with the idea of dominant and follower firms. All these characteristics will have an impact on the price levels and quantities as well as on the decisions to choose output capacities, among others. We will later analyze some of the most common industrial organization schemes likely
to occur in oligopolic market structures like the Mexican cement one.

An important observation about oligopolies is that it is precisely under this structure that cartels are formed. Cartels result from the agreement among various incumbent firms in an industry to set prices and output at the level that a pure monopoly would. If such is the case, a perfect cartel will behave as a monopolist, and thus, will determine the marginal cost curve for the cartel as a whole. Hence, it produces output when $MC = MR$, charging the corresponding monopoly price ($q_m$). However, there is an incentive to cheat by some incumbent firms of the cartel whenever their individual marginal cost curves are lower than that of the cartel. So, they can increase their individual profits by increasing output until $MR = MC_i$ for each firm. Since this outcome is likely to occur, it is often costly to enforce a cartel.

In general, under oligopoly, price and profits are lower than at monopoly, but larger than at perfect competition. Output is likely to be more than under monopoly, but less than under perfect competition.

Monopolistic Competition is a market structure characterized by few or many producers each of whom makes a distinctly different variant of the product of their industry. So, unlike the other market structures, it is characterized by differentiated products. This structure
usually emerges when positive economic profits of an industry or sector give incentives to the constituent firms, incumbents and entrants (when possibility of entry exists), to produce very close substitutes to the relevant good. In this way, part of the market demand is attracted to each participant firm. We ought to point out that monopolistic competition helps us to get a better idea of the difficulty to define output, and reaffirms the good old idea that consumers usually seek for equal or similar characteristics from a range of products (goods or services), rather than a specific product. As a direct result, an outcome very likely to occur is to have many brands of similar products, each one slightly differentiated. Thus, demands will tend to be more elastic too.

Each firm $i$ will choose its output level in order to maximize profits (for $i \neq j$):

$$q_i(z_i; z_j)z_i - c_i(z_i), \quad [8]$$

The demand that each firm faces will depend on what other firms do. So, the typical representative firm in a monopolistic competitive market structure will make an optimal choice considering some kind of actual or assumed behavior of the other firms producing closely differentiated substitutes. This leads us to industrial organization schemes where games formed of various stages are developed. As examples of typical games of this kind there are the ones that allow for quality differentiation among similar
goods, as well as those whose differentiation is in their location. (xxx)

On this structure we have that,

"in order for the market to be in equilibrium, each firm's forecast about the behavior of the other firms must be compatible with what the other firms actually do." 38

This suggests some sort of rational expectations implicitly imbedded in this structure. Thus, a monopolistic competition equilibrium \((z_1, z_2, \ldots, z_n)\), must satisfy:

\[
\frac{\delta q_i(z_i; z_{-i})}{\delta z_i} q_i(z_i; z_{-i}) + \ldots z_i - c_i'(z_i) = 0, \quad [9]
\]

where: z's are the optimal choices or strategies of the i=1,2,...,n incumbents in a market.

In the short-run there is the possibility that some firms have positive economic profits. But as more and more firms enter to produce close substitutes, profits will eventually approach zero and a long-run equilibrium will have been achieved. This occurs when output price equals average cost for each firm i. This is:

\[
q_i = \frac{c_i(z_i)}{z_i}, \quad [10]
\]

Also, under the long-run monopolistic competition equilibrium, each firm must operate at the maximal profit point of its demand curve. Hence, the relevant demand curve

that each firm faces must be tangent to its average cost curve. This is clearly seen in Figure 3.

![Figure 3](image_url)

A very important conclusion that emerges from this, is that

"as long as the demand curve facing each firm still has some negative slope [hence, there is a limited number of substitutes], each firm will produce at a point where average costs are greater than the minimum average costs. The monopolistic competition equilibrium exhibits excess capacity." 39

Now, once we have described some characteristics of various market structures, the next step is to review the framework under which monopolies and oligopolies interact, usually as a result of imperfect information.

7. Industrial Organization

Industrial Organization (I.O.) is probably one of the most dynamic microeconomic areas in the world of Economics today. Roughly speaking, it is the study of how the markets work under static and changing states of the arts.
Modern I.O. treats firms as single-decision makers that will continuously adapt to the market structure in order to maximize profits and achieve new levels of market equilibria. We will very briefly go through the most basic relevant models of this important field.

7.1 Cournot-Nash and Stackelberg equilibria

Augustin Cournot, postulated that each firm chooses to produce the quantity of output that maximizes its own profits and assumes the quantities produced by rival firms to be fixed. Hence, for any industry there is a determinate and stable equilibrium, where the equilibrium price will depend on the number of producers, just as we have seen in the previous chapter.

Later, the concept of reaction functions or curves introduced new dynamism to this theory. Here, the decision of the firm depends on a function which incorporates the behavior of the rivals, with certainty, that will define a market equilibrium. This is called the Cournot-Nash equilibrium, characterized by a set of players (the firms), a set of strategies, and a set of payoff functions (profits).

In the Stackelberg model, a variant of the Cournot model, a reaction function is also defined for every incumbent firm in the market. But in comparison, Stackelberg assumes the existence of leader and follower firms. Under this model, if we reduce our analysis to that of only two firms, one firm will take the lead in production and the other firm will
follow. Hence, each firm will take the reaction function of the other firm as fixed. Such reaction functions will have the general form: \( Z_i(z_j) \); setting the output level of firm \( i \) given that it expects firm \( j \) to produce \( z_j \). So, firm \( j \) leads the output decision and firm \( i \) follows this decision and chooses an output level that will maximize its profits.

7.2 Bertrand and Other Equilibria

So far, we have dealt only with the decision of the firms on their output levels. However, in oligopoly and monopoly structures, most firms are interested in affecting the price levels in order to maximize their profits. A simple approach to this other element of the market equilibrium was developed by Bertrand. In his model, the incumbent firms compete in prices in order to get a larger share of the market. These firms are assumed to produce simultaneously and independently (no collusion is possible), and their respective demand shares will be directly related to the prices they charge. Thus, at any point in time demand will be allocated to the lowest price producers who will produce up to the demand they have access to. Any unsatisfied demand will go to the second lowest price producers, and so on.

As most of the models of I.O. that we have briefly described before, Bertrand assumes a perfectly homogeneous product, thus, all the relevant goods in the industry are perfect substitutes. A small variant allows for firms to produce not up to all the demand they encounter or have access to, but
to produce up to their capacity limit, at a given moment in time. Price competition takes place as usual, until an equilibrium price is finally obtained, where each incumbent firm maximizes its profits. Of course, that such price competition will depend on the number of firms engaged in the industry. The relevant maximization for the simple case of 2 incumbent firms will be:

\[
\text{Max } q_i z_i(q_i, \bar{q}_j) - c_i[z_i(q_i, \bar{q}_j)], \tag{7}
\]

for \(i, j = 1, 2\), and \(i \neq j\),

where:

\(q_i = \text{output price charged by firm } i\);

\(\bar{q}_j = \text{output price charged by firm } j\), taken as given by firm \(i\);

\(c_i = \text{cost function of firm } i\);

\(z_i = \text{output supplied by firm } i\).

However, in general, if there are more than two incumbent firms and some kind of product differentiation is allowed (monopolistic competition), the profit maximization of a representative firm \(i\) will be:

\[
\text{Max } q_i D_i(q_1, \ldots, q_i, \ldots, q_n) - c_i[D_i(q_1, \ldots, q_i, \ldots, q_n)], \tag{8}
\]

for \(i = 1, 2, \ldots, I\), firms, and where \(D_i\) is the demand that firm \(i\) faces. If we derive the first order condition for \(q_i\), we will get the following:

\[
\frac{\delta c_i}{\delta q_i} - \frac{\delta D_i}{\delta q_i} \frac{\delta q_i}{\delta q_i} + \ldots + \frac{\delta D_i}{\delta q_i} + \ldots + \frac{\delta D_i}{\delta q_i} = c_i[q_1, \ldots, q_i, \ldots, q_n], \tag{9}
\]

\[
\frac{\delta D_i}{\delta q_i} = 0,
\]

where: \(\frac{\delta c_i}{\delta q_i} = \text{firm's } i \text{ conjecture about how the other } j \text{ firms will change their prices.}\)
There exist more models of I.O. Especially interesting are those that consider capacity expansion and barriers to entry or deterrence and under which various types of equilibria are reached.

There are also some models that allow for a broader definition of output where the possibility of non-perfect substitutes but close enough to challenge the behavior of incumbent firms, exists. We have already presented this possibility in the price-competitive structure. Nevertheless, models that will allow for decisions on output quantities and of firms producing multiple products can also be developed under product differentiation schemes.

Because of the multiplicity and particular specifications of these kind of models, we leave them out of the analyses on the cement production process. However, their theoretical flavor has proven to be of much help to models that consider both, growth of production and product differentiation, together.

In the next chapter we will go through a model we believe to be of much relevance for the industrial organization of cement production in Mexico.

8. Model of Cement Production

Some economists tend to separate economic theory from the empirical evidence that should support it. While it is true that economic theories and models do not intend to exactly replicate the economic reality that surrounds them, we can say that they are abstract representations of the
empirical world and should be pictured only as economic maps of such real world. After all, that is what maps are for, to simplify and guide us; since if it were possible to experiment with the real world, no models would be required at all. Hence, economic models seem to be necessary and sometimes essential in order to either explain or avoid theoretically-founded mistakes, which would prove individually and socially costly. Especially when we are trying to model the behavior of economic agents. However, it is true though, that theory by itself is useless if we do not know where we are heading to and how to approach the objective (usually represented by an objective function). After all, this is why economic models become fundamental to us. Thus, the more predictive power a model has, the more it can effectively cope with reality, and this will let us know that we are on the right path.

In the following pages we will describe the way in which cement production takes place in the empirical world. We will later try to model this behavior under a varied industrial organization scheme with a specific type of aggregate production function. Finally, we will estimate this production function using econometric techniques of estimation.

8.1 Cement production process

Cement is a material composed of minerals which, when in fine powder form, reacts with water forming a mass with the physical characteristics of low solubility and small
quantities of heat emission. These characteristics have led to the use of cement as a binder material in the construction industry. In earlier times natural cements made out of limestone or of volcanic origins were widely used. As an example, the Romans used a natural type of cement called puzzolan cement, whose volcanic origin is named after Pozzuli, a town in Italy a few miles from Naples and Mount Vesuvius.

In 1824 Joseph Aspdin, living in Leeds, England, was granted a patent for a new type of cementitious material. The color of the product after hydration reminded him of a limestone of the island of Portland. Because of this, he named the product portland cement.

"Portland, therefore, is the name of a product made by a given process... manufactured by individual companies." 40

Since then, portland cement has not changed its chemical composition in a significant way. It has the characteristic of hardening under the water, hence, it has also received the name of hydraulic grey portland cement.

The chemical composition of cement varies slightly from firm to firm, according to the availability of its major raw-materials components. However, the final mix of raw-materials must be more or less the same since it must satisfy certain requirements on elasticity, mass, and other characteristics. In general, portland cement's percentage composition is the following (where the parentheses percentages refer to an alternative composition):
22.56 (21.29) of silica SiO₂, 2.85 (2.72) of ferric oxide FeO₃, 7.44 (7.64) Alumina Al₂O₃, 62.73 (63.48) of calcium oxide CaO, 1.99 (1.53) Manganese MgO, 1.46 (1.77) sulfur trioxide SO₃. Some gypsum is added at the end of the manufacturing process before packing or storage. Recently, some carbonate additions have been introduced to portland cement, but only in limited quantities, and this apparently does not significantly change the grade or quality of this type of cement.

We can divide the production process in four major engineering stages. In the first stage of the manufacture of cement, two basic minerals are ground and blended together. One is chalk or limestone (which contains calcium oxide), and the other is clay or shale (containing silica). Then, the other materials are added. The second stage consists of pouring the resulting mixture, called raw-mix, into a kiln and heat it to melting point, causing a chemical reaction to take place. The new material that emerges from this reaction is cement clinker. The third stage consists of finely grinding cement clinker and mixing the cement with gypsum, used as a retardant. Since portland cement hardens very easily if it is exposed openly to the air, packing is usually the fourth and final stage before it is distributed. Nevertheless, storage in closed dehumidified areas is also possible if cement is to be distributed as a bulk product.

The operation of the kiln is a very important feature of the cement manufacturing process. Originally, chamber kilns
and vertical kilns were used. Their inconvenience was that they necessitated batch production. But with the introduction of horizontal rotary kilns, continuous production became possible.

"A modern kiln consists of a steel cylinder lined with refractory bricks, mounted at a slightly inclined angle on rollers and turned slowly by electric motors. The kiln is heated at the lower end, either by coal, oil or gas. The size of the kiln depends on the planned throughput," 41

Even though we have generally described the production process of cement, we ought to point out that there are two quite different variations in this manufacturing process along with several other intermediate variations, too. The most basic distinction is between the wet process and the dry process. With the wet process the raw-materials are blended together forming slurry by the addition of water, and before it is being introduced to the kiln. In contrast to this, the dry process involves mixing the raw materials together at their dry state. A semi-dry process has been developed, in which some water is added only after the raw-materials that form the raw-mix have been blended. More recently, a semi-wet process has also been utilized in which the slurry, prepared as in the wet process, has much of the water removed by filterpressing before it enters into the kiln.

There is a large controversy as to what production process is better. We can say that they all have advantages and disadvantages. The dry process, because there is no water to
remove when the raw mix gets into the kiln, uses much less energy than the wet process does. Nevertheless, the dry process tends to pollute more the environment due to the dry grinding of the raw materials, even with modern dust collectors. However, while dust pollution is almost inexistent in the wet process, water pollution is a fact here. In the middle, the semi-dry and semi-wet processes, use less energy than the wet, and usually pollute less than both, the dry and the wet processes.

As a result of these facts, besides the availability of the fuel that heats the kilns and the electric energy used for grinding, government regulations seem to have a large determination on the type of production process chosen. When anti-pollutant laws are passed, stricter methods are established and cement firms might be required to control air and water pollution conscientiously. Further research is highly encouraged in order to try to measure these externalities provoked by cement firms in Mexico and set stricter regulations to prevent it.

We can realize that whatever technique is chosen to manufacture portland cement, the raw-mix remains unchanged. This means that regardless if the technique is energy-saving or is subject to anti-pollutant laws, or both, in order to produce cement it must contain a certain fixed percentage of raw-materials. This is so, because it must satisfy a certain minimum standard. Hence, a certain functional form structure of the production function is imposed, suggesting that the
firms of the industry will choose first the capital and labor technique of production, given the fixed-coefficient technology, and then, after this capital-labor ratio has been chosen, the production process begins by using a fixed raw-materials input for a given decision of output or capacity installed. Therefore, the raw-materials input is assumed to be fixed and has no substitutes with the other factors of production. This is, the production function is of the Leontief form, which is a special case of the CES (Constant Elasticity of Substitution) production function. In this case, it looks like the following:

\[ Z = \text{Min} \{ (K,L), X \}, \quad [1] \]

where: \( Z \) = output of cement;  
\( K \) = capital input;  
\( L \) = labor input;  
and \( X \) = raw-materials input.

This functional form suggests a two-stage economic production process that we will analyze later.

Once we have briefly exposed how cement is actually manufactured, we will now review some specific characteristics of Industrial Organization that are present in the cement sector of Mexico.

8.2 Oligopoly Pricing

As we pointed out before, portland cement in Mexico is manufactured by both, single-plant and multiple-plant firms.

Along the whole Nation, as of 1983 (1963), there were
29 (21) plants having an annual capacity of production of 30.7 million (4.3 million) tons setting the per-capita capacity installed of cement at 409 (105) kilograms or 901 (231) pounds per year. (xxxi)/

Some firms are local monopolies and some others participate in larger markets, but the whole structure is oligopolistic and the product is a standard one. These characteristics remind us the model of Chamberlin, where the oligopolies must recognize their interdependence. Therefore, they will tend to interact together at the monopoly level. However,

"no formal collusion or agreement is necessary. Each firm can make its own price and output decisions without consulting the others. For the monopoly price to emerge, it is essential only that the firms recognize their mutual interdependence [in action or tacit agreement] and their mutual interest in a high price." 42

So, if there is no formal collusion, we rule out the possibility of a cartel, especially in spatially differentiated market areas that are fomented by high transport costs and where each local market presents its own demand structure.

Chamberlin's idea assumed incumbent firms presenting zero costs. So, when long-run costs are not only non-zero but

(xxni)/ Making a comparison in order to demonstrate the importance of this industry in Mexico, other countries' per-capita capacity in 1983 was the following (in kilograms):
Spain 1,023, U.K. 357, France 554, Italy 962, West Germany 753, Soviet Union 568, U.S. 357, Canada 321, Japan 1,017, R. of Korea 623, India 49, P.R. of China 121, and Brazil 300.
different among the firms, difficulties arise; mainly in the way firms want their prices to be set. However, in equilibrium, all the incumbent firms of each oligopolistic (monopolistic) regional market will end up charging the same price for their products. This is very likely to occur in markets where the products are perfect substitutes, as portland cements are.

Up until now in the analysis we have made of I.O. we have implicitly assumed that every firm supplies an equal market share. However, a more realistic approach assumes the possibility of unequal long and short runs installed capacities of incumbents, and thus, different marginal costs and market shares. These facts will bring out various possible outcomes. Also, when collusive behavior is inexisten and there is a homogeneous product, price competition is likely to appear, which, by the way, implies the sacrifice of the so desired pricing independence.

The final market outcome will depend on the relevant organization of each market as well as on the assumptions made on it. (xxxii)/

In the particular case of the Mexican cement industry, the industrial organization shows that most price-differentiated regional or local markets are conformed by one or various plants of multiple sizes belonging to different firms and this has been the basic organization

(3xxii)/ For further details on every outcome, see Scherer (1980), pp. 159-69.
during the 1963-83 period. We also realize that capacity expansion has occurred incessantly at most plants, regardless their size or their market share. This particular outcome suggests very interesting assumptions about how this was reached without price wars and without significant changes in the market shares of the plants along this period. This is: plants or firms with small market shares and/or small capacity installed can hardly take as much advantage of scale economies as larger plants or firms with larger market shares and/or small capacity generally do. However, small-scale and small-share plants were able to survive along this period. Also, in time-series models like ours, technological or technical innovations are likely to occur first in the large-scale producers than in the small-scale producers. This is mainly because in general cement technology and capital equipment is imported from countries where a major goal in technological innovation is to take advantage of economies of scale, reducing unit costs and increasing profits. In this sense, technological change is kind of economies-of-scale-oriented or biased. Thus, the more unevenly these changes are diffused, the more likely it will be that smaller plants or firms will not only present higher marginal costs, but also higher average costs, for a given output level, at any moment in time. This suggests sort of an inverse correlation between plant scale and costs. And it might also be the case that this inverse correlation is
present between market share and costs. Let us observe, that during this period, very few cement plants shutdown, giving us a signal that, in general, \( MR > LRAC \), where: \( MR = \) long-run marginal revenue; and \( LRAC = \) long-run average costs.

We do not have information of which cement plants or firms supplied which market(s). As a result, we do not know the relative importance or market share that these plants or firms had in each market. But, just as an example, it could well have been the situation of a small plant or firm supplying a large share (if not all) of its market demand(s), and that of a large plant or firm that supplied a small share of its market(s). \textit{E.g.} Cementos Acapulco, S.A. plant selling cement in the city of Acapulco, and Cementos Anahuac, S.A. plant supplying Mexico City. (xxxiii)/

When local demands are strong, as generally were along 1963-83, plants or firms will be able to produce at their capacity levels and sell their product at the price likely to be set by the leader (large-share) incumbent(s). Nevertheless, during recessions small-share plants or firms may well operate below desired \( MR = MC \) levels, if they adhere to the high prices that large-share leaders attempt to maintain. In such situations, small-share follower plant(s) will bid for additional orders at reduced prices. The reaction of the large-share leader(s) will depend on how small a share the followers have. If the market share is

\( (xxxiii)/ \) See Appendix for information about percentage of the aggregate market production of individual plants, (Table 1).
small, the leaders will consent the followers' rebellious decision. However, if the share is no negligible and long-run market share transfers are imminent, larger firms will set defensive price reductions. This price-cutting procedure will depend on the following: i) the expected duration of the recession or downward demand shift; ii) the degree to which the cost constraints (remember that, MR > SRAC) exhibit price competition; and iii) the reaction of the smaller-share follower plant(s) or firm(s) to the larger-share leader plant(s) or firms(s) price reduction.

"In general, oligopoly structure breakdowns are more likely the higher the proportion of industry capacity in the hands of competitive fringe producers and the more industry leaders find themselves departing form desired operating levels at posted prices." 43

Whatever market shares and prices were achieved, capacity expansion has been able to follow demand in most regional cement markets. Therefore we can only assume that these different prices were certainly above the perfectly competitive levels, allowing for positive long-run profits for most incumbent plants or firms in each market.

8.3 Price Discrimination

Even though we have somehow presented how price discrimination works, further analysis is required. In general, a producer is said to price-discriminate when he sells two or more units of the same good at different prices. But price differentiation is not always so clear, especially when there are vertically integrated firms or
industries. A clear example of this event occurs precisely for cement producers. As Tirole J. (1989), states,

"Consider the case of a cement producer serving a geographic area. To the producer's costs must be added the freight costs. Suppose that the cement producer is vertically integrated and thus provides his own transportation. In such a case, a uniform delivered price is discriminatory, whereas delivered prices that respond fully to transportation-cost differential among consumers located at different distances from the factory are not. Hence, we will say that there is no price discrimination if differences in prices between consumers exactly reflect differences in the costs of serving these consumers (this amounts to considering the net cost of serving a consumer)."

However, there is no precise way to know if the price differential is due to transport cost differential or because the monopolist is price-discriminating the market it serves. Hence, firms can take advantage of this source of uncertainty and society assumes the burden by paying higher prices. It has also been said that homogeneous goods delivered at different dates and at different locations are distinct economic goods and thus, the scope of price discrimination is limited. However, in partial equilibrium differentiation is likely to occur when we have homogeneous goods in different locations at any given time.

There are three main classes of price discrimination:

i) First degree or perfect discrimination is a very hypothetical case. Here, each production unit is sold at its reservation price, where utility maximizing consumers are in equilibrium. This is: the reservation price is an

"index of the value of an extra unit of consumption from the consumer's viewpoint and hence,... from the viewpoint of society."
In other words, perfect price discrimination leaves no consumer's surplus, but appropriates it all as producers' surplus. For this first degree price discrimination to exist it is assumed that the producers have perfect information about each consumer's preferences. As this is unlikely, this class of discrimination is hardly existent.

ii) Second degree price discrimination appears when there is imperfect information about every consumer preferences, but the producer is still able to extract consumers' surplus by dividing their demand in blocks. This division is possible due to the so called self-selection devices of consumers, where they reveal their preferences when exposed to product signals. So, there is some sort of possible product differentiation as for example, different qualities of goods.

iii) Third degree price discrimination occurs when the producer can divide customers in two or more independent groups each of which has its own demand function reflecting quantities sold to that group at alternative prices. Hence, if these demand functions have different elasticities at common prices, it will certainly pay to discriminate. However, a price-discriminating equilibrium will be reached when the discriminator maximizes profits by charging the highest price in the market whose demand elasticity at the monopoly price is lowest, and the lowest price in the market with the highest elasticity at the monopoly price. This is clearly seen in Figure 1.
Figure 1
Third Degree Price Discrimination

(a) Market 1  (b) Market 2  (c) Markets 1 and 2, [image of graphs]
(low demand (high demand combined.
elasticity) elasticity)

As Figure 1 shows, the last unit sold in Market 1 adds the same amount of total revenue as the last unit sold in Market 2, so that the monopolist sets the marginal revenues of both markets at the same level: $MR_1 = MR_2$. The marginal revenues of the two markets are summed horizontally, giving the combined marginal revenue CMR function in (c). So, CMR is equated to the monopoly marginal cost MC and this indicates the optimal combined output, $Z$. To equalize marginal revenue in the separate markets 1 & 2 at the profit-maximizing value, a horizontal line is drawn from the point where CMR = MC. The output in each market ($z_1$ and $z_2$) is found as usual, this is, by setting the price on each demand function at which the profit maximizing quantity is demanded ($q_1$ and $q_2$).

This analysis can also be visualized in Figure 2.
Again, the monopolist determines its total output \( Z \) by summing horizontally over the two marginal revenue curves, \( MR_1 \) and \( MR_2 \), represented by \( RR' \). It shows, for each level of marginal revenue, the total output needed if the marginal revenue in each class or market is to be maintained at this level. The optimal output point is when the marginal cost curve, \( MM' \), equals the marginal revenue curve \( RR' \), at \( Z \), since the marginal cost must be equal to the common value of the marginal revenue in each market. Thus, this plant or firm produces \( z_1 \) units of output for market one, and \( z_2 \) for market two. Charging the respective \( q_1 \) and \( q_2 \) prices.

Without any other assumption, the case of a monopolist interacting in two price-differentiated markets can be extended to that of multiple markets, where the total output level will be established when the combined marginal revenues equal the combined marginal costs, \( CMR = CMC \).
It is precisely this third degree price discrimination the one we observe along cement markets in Mexico. Here, multiple-plant firms, as well as single-plant firms serving one or more markets will take advantage of this and will maximize their profits at points where their single or combined marginal revenues equal their single or combined marginal costs. This class of discrimination seems to be systematic or repeated, strengthening the market power of the existing firms and facilitating adherence to either a collusive price structure, or a leader-follower price equilibrium behavior, where each incumbent gets a market share. Whether this promotes entry deterrence or not, should be treated in each market separately and is out of the scope of this research.

8.4 Profit Maximization

Individual firms in an industry, just as individual consumers in a society, are assumed to have an objective function that they maximize. The objective function of firms usually is the profit function. Sometimes these maximizations include subjective characteristics such as fame and prestige, but these characteristics have a quantitative representation too. In this way, firms may be willing to sacrifice short-run profits in order to gain market share and increase their long-run profits. However, while this might appear suggestive for firms that try to differentiate their products, it is not so likely to occur
with firms producing a very homogeneous or standard product, like cement.
Most firms are at any given time making both, short-run and long-run decisions: determining the level of output, on the one hand, buying new equipment or hiring new labor units, on the other; and incurring corresponding costs. The difference is that short-run relates to output decisions with given capacity and to costs varying with such decisions, while the long-run relates to investment decisions defined as the acquisition of fixed factors of production giving rise to other costs. Thus, the difference is between fixed and variable costs. In a dynamic world, all costs are variable if investment and/or capacity expansion occurs. The larger the incremental unit of capacity level, the more costs become variable. But if a long-run equilibrium is to be reached, the long-run profit function must also include fixed and variable costs, since the idea of equilibrium brings us the concept of a static world at any point in time, also called steady state.

In order to explain the functional form of profit maximization, we present the following market structure and industrial organization scheme of the Mexican cement industry during the 1963-83 time-period. Assume the following:

1) Local monopoly and oligopoly structures are present throughout the cement markets, where single-plant as well as multiple-plant firms conform each and every local market.
Two basic extreme types of firms are present here; on one hand, a single-plant firm acting in one (a pure monopoly) or various regional markets, and, a multiple-plant firm interacting in one or various regional markets, on the other.

2) All firms produce a unique homogeneous product, namely, hydraulic grey portland cement; which, as we have pointed out before, has a chemical composition that defines a technological fixity in the raw-materials component of this activity.

3) Third degree price discrimination is present, allowing for the firms to sell their product in different markets. This price discrimination does not emerge from product differentiation in its own right, but rather from differentiation in location. Thus, each regional market presents its own demand structure, and the elasticities of demand are different. Let there be $m = 1, 2, \ldots, M$, markets.

4) Each market manages to set the price of cement in such a way as to maximize profits, allowing for long-run capacity expansion by most incumbent firms in every regional market. On this assumption, we ought to comment that at first sight such price-setting behavior might appear to contrast with the real evidence, where every change to the various regional market prices had to be previously authorized by the Secretaria de Comercio. However, even when price changes were subject to approval, most, if not all of the proposed price revisions were timely conceded. Hence,
the cement industry did certainly had the degrees of freedom
to set prices as if no regulatory agent existed.

5) Every cement firm is assumed to be a profit-maximizer
at any point in time. Let there be \( i = 1,2,\ldots,I \), firms; and
let \( h \in H \) be the number of plants in any firm, such that
\( H = \{1,\ldots,H\} \).

6) Firms are price-takers in the input markets and unable
to influence these markets. Let there be \( m = 1,2,\ldots,M \),
input markets available to each \( i \) firm. As we realize, there
is the same number of input and output markets. This does
not mean that if, for example, an input was acquired at
certain market, the output resulting from its relevant
production process will be sold at the same market. This
assumption is just dividing the aggregate markets of cement
and inputs in \( M \) differentiated regions or markets.

7) As we said before, the way in which regional output
market prices are established will directly depend on the
industrial organization present in every region. However,
either by the leader-follower model, a tendency to collusive
behavior, or by making assumptions on the cost structure of
each incumbent firm in a market, an optimal solution will
always be reached.

We are going to develop a model of profit maximization
for a representative firm \( i \). Following Brendt, R. and M.
Fuss (1989), we can define a measure of output when firms
* are at long-run equilibrium. Let \( z_i \) be the full-capacity
of output of firm $i$ at any point in time. Also, let $z_i$ be the current or actual output level of the firm. We can define the capacity utilization rate as: $CU_i = \frac{z_i}{z_i}$.

In order to maximize profits each firm will allocate output from its $h \in H$ plants in such a way as to equalize their respective marginal costs, obtaining combined marginal costs (CMC). Profits will then be maximized at a level where this combined marginal costs equals the combined marginal revenues (CMR) of all the regional markets where the firm sells its product. This is: $CMR = CMC$.

To set this problem let $T$ be an $[M \times (h \in H) \times (h \in H)]$ technology set such that $(Z_i, K_i, X_i) \in T$, where:

$Z_i =$ total output supplied by firm $i$, such that $Z_i = \sum_{m=1}^{M} z_m$, where, $z_m =$ output supplied to market $m$ by firm $i$;

$K_i =$ total variable-input vector available to $i$, such that $K_i = \sum_{m=1}^{M} \sum_{h \in H} K_{h,m}$, where $K_{h,m} =$ variable-input vector available at market $m$ to $h \in H$ plant(s) of firm $i$;

$X_i =$ total fixed-input vector available to firm $i$, such that $X_i = \sum_{m=1}^{M} \sum_{h \in H} X_{h,m}$, where $X_{h,m} =$ fixed-input vector available at market $m$ to $h \in H$ plant(s) of $i$ firm.

Also, let $P$ represent an $(M \times M \times M)$ price set such that

$(q_i, P_i, s_i) \in P$, where:

$q_i =$ weighted average output price of firm $i$, such that

$q_i = \sum_{m=1}^{M} \mu_m \cdot q_m$, where, $q_m =$ output price of firm $i$ at market $m$, 


output of firm \( i \) sold at market \( m \) and \( \mu_m = \frac{\sum_i q_{im}}{\sum_i q_m} \),

since \( \sum_{m=1}^M \mu_m = 1 \), hence,

\[
q_i = \sum_{m=1}^M \mu_m q_m ;
\]

\( p_i \) = weighted average of variable-input price vector of \( i \), such that,

\[
p_i = \sum_{m=1}^M \sum_{h \in H} \sigma_{h,m} \cdot p_{h,m} , \text{ where, } \sigma_{h,m} = \text{variable-input expenditure on variable input of } h \in H \text{ plant(s) of firm } i, \text{ in market } m \]

where

\[
\sigma_{h,m} = \frac{\sum_i \tau_{h,m}}{\sum_i \tau_{h,m} / \text{total variable-input expenditure of firm } i};
\]

since \( \sum_{m=1}^M \sum_{h \in H} \tau_{h,m} = 1 \),

then, \( p_i = \sum_{m=1}^M \sum_{h \in H} \sigma_{h,m} p_{h,m} ; \)

and \( s_i \) = weighted average of fixed-input price vector of \( i \) firm, such that,

\[
s_i = \sum_{m=1}^M \sum_{h \in H} \sigma_{h,m} \cdot s_{h,m} , \text{ where, } \sigma_{h,m} = \text{fixed-input expenditure on fixed-input of } h \in H \text{ plant(s) of firm } i \text{ at market } m ;
\]

where

\[
\sigma_{h,m} = \frac{\sum_i \theta_{h,m}}{\sum_i \theta_{h,m} / \text{total fixed-input expenditure of firm } i};
\]
since \( \sum_{m=1}^{M} \sum_{h \in H}^{i} \theta_{h,m} = 1 \),

then \( s_{i} = \sum_{m=1}^{M} \sum_{h \in H}^{i} s_{h,m} \).

We can define an ex-ante short-run profit maximization problem of the firm. This will determine the capacity installed of every firm and is based on the expected output and input prices. The functional form of the profit function will be:

\[
\pi_{i}^{*}(e_{i}, e_{i}, e_{i}) = \pi_{i} [q_{i}, p_{i}, X_{i}(q_{i}, p_{i}, s_{i})].
\]

From Hotelling's Lemma, the full capacity equilibrium output *\( Z_{i}^{*} \) can be obtained as follows:

\[
Z_{i}^{*} = \frac{\delta \pi_{i}^{*}}{\delta q_{i}}.
\]

Now, the firm's short-run ex-post maximization problem takes into account an already chosen technology, hence, the firm is already active at a given capacity installed. Here, the relevant output measure is not the total or full capacity, but the actual or current level of output, \( Z_{i} \), produced. This maximization problem is also made over the variable-input vector, because the fixed-input vector is determined.

So once the fixed-input vector *\( X_{i} \) is chosen on the basis of expected prices, the maximization problem of a representative firm \( i \) from this industry has the following functional form:

\[
\pi_{i} = \pi_{i} [q_{i}, p_{i}, X_{i}(q_{i}, p_{i}, s_{i})].
\]
Using again Hotelling's Lemma, we will obtain the current output level as follows:

\[ Z_i = \frac{\delta \pi_i}{\delta q_i}. \]

Let us define the output-specific capacity utilization ratio of firm \( i \), as:

\[ CU_i = (Z_i/Z_i) = \left[ \frac{\delta \pi_i}{\delta q_i} / \frac{\delta \pi_i}{\delta q_i} \right]. \]

Note that when: \( CU_i < 1 \), the output capacity of the firm is underutilized;

and \( CU_i = 1 \), expectations are realized and firm \( i \) is producing at short-run full capacity level.

We can assume that since firms are profit maximizers and excess capacity is not costless in the absence of free disposability, firms will try to minimize their costs. We will not analyze this dual here, but we assume the results will not change. We also assume that every period, firms will try to produce output at their capacity level, such that \( CU_i = 1 \). However, if along any given period of time \( CU_i < 1 \), the representative firm can be assumed to change the composition of its inputs in order to reach the desired unitary capacity utilization ratio. Taking this into account we can define a long-run profit maximization problem. While it is true that time-series long-run models allow for all the inputs to vary, in order to obtain a new long-run equilibrium, these inputs will also be classified as fixed and variable. However, it can be the case that the composition of short-run inputs will not be the same than those of the long-run.
In the case of cement production we can assume that the labor input is variable in both, the short and long runs and will adjust to the level of production freely (xxxiv)/. As for the capital input along a time-span, there has been investment in durable-goods in order to both, replace old capital vintages and/or to expand capacity. So, while in the short-run it was part of the fixed-input, in the long-run it might have changed, but reaching a new level of equilibrium which will be, again, fixed.

If capacity expanded, the raw-materials input for cement must also have expanded. So, again, while it was fixed in order to produce a given capacity in the short-run, it may also have varied when expansion occurred. However, in the new long-run equilibrium it must be fixed, too.

Resuming, the long-run profit maximization function of the representative firm i, will be:

\[ \pi_i = \pi_i \left[ q_i, p_i, X_i(q_i, p_i, s) \right], \]

where expectations will always be realized, setting the price levels at an optimum at: MR_i = MC_i.

The following step in our analysis is to develop the production function that we will estimate. Since we have got only aggregate data of the cement industry in Mexico, we

( xxxiv )/ Nevertheless, when there is a recession, if there are labor contracts, it might not be so easy at all to adjust the labor input instantaneously. When this occurs, labor can be considered part of a fixed cost. However, generally speaking, at a longer run, and when output is increasing, labor is a variable cost.
will estimate a production function for the aggregate industry.

9 The Production Function

A production function (or correspondence) is the abstract representation of the production process of an economic unit. There are two major approaches to the study of production functions: parametric and non-parametric. The first one, as its name allows us to imagine, is structured under certain parameter range. Specifically to those related to elasticities of scale, substitution and share. An example of parametric production functions is the C.E.S (Constant Elasticity of Substitution) function. The second major approach to production functions, the non-parametric one, has to do with a general specification where there is no limited range. This approach is sometimes said to give measurements without theory, or should we better say: measurements without theoretical restrictions. But then, there is no apparent world without restrictions. Our analysis will concentrate on the parametric approach where the cement industry will have a well defined production structure.

Aigner & Chu (1968), analyze production functions at the industry level, they suggest that production functions at lower levels of aggregation of the individual firms that conform the industry may conceptually be obtained from the industry function in terms of the ability of such firms to implement the optimal value of the relevant aggregate
parameters. The firm production function is defined according to a given state of the arts and it should express the maximum obtainable product given the factors of production combination during the time of production. Following this, there exist several reasons to explain why the output of many firms lies below the production possibilities frontier. We can summarize these reasons as the following ones:

i) Random shocks in production, as for example: damaged or defective final product.

ii) Differences in economic efficiency, where given a production function facing market imperfections, a firm should produce a certain level of output so as to maximize its profits. As we have repeatedly pointed out, this maximization determines the output and input levels. Hence, in an industrial environment in continuous change, plants and firms adjust their input-output relations according to these changes either by scaling them or by changing the input composition, when possible. However, the ability to make such adjustments cannot be expected to be the same for all firms or plants.

iii) Differences in technical efficiency, such as varied holdings of capital input in both, vintage and quantity. Larger firms tend to have better and larger credit terms, thus, they generally are in a better position to replace old equipment and acquire new equipment which usually is technically improved. Following this idea, as the
composition of capital equipment differs between larger and smaller firms, larger firms might be closer to efficiency, too. Related to this and after long conversations with experts in the field, in the Mexican cement industry we face a situation where larger firms tend to have better techniques of production (more efficient capital and labor usage, as well as lower energy use per unit of output), giving them advantage over smaller less technically efficient plants or firms. Nevertheless, smaller firms will be able to survive as long as they get their insured share of the market they face, as we already pointed out before.

A somehow unclear representation of an aggregate production function comes from the conceptual construct of the average production function. Some economists refer to it as the function for a firm of average size, which in the case of the cement industry this is quite unrealistic. Others refer to the average function as having average technology, which is reasonalbe for the cement case. However, we cannot assume an average technique of production too, because such coincidence with respect to capital and labor intensity is unfeasible. Especially in time-series studies. Another approach is suggested in Aigner & Chu (Ibid), who state that,

"from a more practical standpoint, if, for example, we wish to estimate how much output on the average, could be obtained for a firm in the industry with a certain set of inputs, then, the average concept would obviously be the correct one to employ... We can [then] approximate an average firm production function when we have data on industry aggregates."
Hence, under this point of view, the micro-macro connection of the production function is used indifferently in production theory. On this subject, Sato (1975), points out the somehow weak link between such micro-macro connection. According to his order of ideas,

"unlike the micro production functions, the macro production function is after all a fictitious entity. There is no single macroeconomic decision-maker who allocates resources optimally or attempts to maximize profits collectively on the basis of this function. On the contrary, the macro function is built-up from micro functions after micro units behave rationally. It is therefore improper to infer macroeconomic behavior by analogy purely from corresponding microeconomic behavior... The macroeconomic production function ought to be a quantitative representation of this (behavioral rules of microeconomic units)." 47

In a sectorial industry such as the Mexican cement one, our analysis of a macro production function should depart from the idea that heterogeneous behavior given by multiple firms, using different techniques of production, in diverse locations, facing different cost functions, and different market demands and patterns of industrial organization, conform the industry at a determined point in time. Nevertheless, even knowing the immense limitations of such a diverse production structure, we will be able to obtain conclusions arising from an aggregate production function. Under this light, the industry production function to be developed in the empirical chapter of this research will only try to be an effective quantitative representation of production. This means that the production function to be obtained will be useful only as an indicator of how cement
is really produced, and the conclusions arising from this will be necessarily limited and somehow inaccurate. Related to this, Sato (Ibid), states that,

"in any realistic circumstances there coexist firms that differ widely in efficiency... we can envisage and efficiency distribution of firms. It should be obvious that the industry aggregate production function crucially depends on this efficiency distribution of firms which is the strategic link between micro and macroeconomic behaviors." 48

So, as we did for capital and labor inputs we ought to assume that the efficiency distribution of cement firms during 1963-83 remained unchanged.

Let us begin observing a general form of the Neoclassical production function that appears in Bosworth (1976), as follows:

\[ Y_{it} = Y_t(K_{it}, L_{it}, H_{it}) \]  \hspace{1cm} [1]

where:

\[ Y = \text{value-added}; \]

\[ K = \text{input of capital services}; \]

\[ L = \text{number of employees}; \]

\[ H = \text{hours worked by employees}; \]

\[ i = \text{firm, such that } i=1,2,\ldots,I; \]

and \[ t = \text{time}. \]

Now, there is an unlimited number of examples of various kinds of aggregate production functions. Just to give one of a parametric production function, we refer to Forsund & Hjalmarsson (1979), who study a time-series production function and the technical progress of general milk processing in Swedish dairy plants. They allow for non-neutral technical change, which means that along time technical change is biased either to capital input, to labor
input, or to any other input required for the production process. They also allow for changes in optimal scale at the plant or firm level, by using homothetic production functions (xxxv)/.

In the empirical analysis of these authors, the measure of output of milk is in tons. The labor input variable is defined by total hours worked per labor unit, including technical staff. The capital input vector consists of various elements, such as data on buildings and machinery including current replacement cost depreciation, cost of maintenance, and interest payments.

Now, in order to set the form of the aggregate production function of cement to be estimated, we first refer to the Johansen schema we analyzed in Chapter 2. This analysis allows us to connect various theories of production, such as the fixed-coefficient and the Neoclassical ones by distinguishing alternative aggregation levels.

We have already defined the form of the two short-run profit functions at the micro or firm level, as well as that for the long-run. However, since our model is aggregate and considers all the incumbent firms in an industry, we ought to define the relevant production function that the industry will present, considering, a-priori, that all the firms are short and long run profit maximizers.

(***v)**/ According to Varian (1984b), "a function f(x) is homothetic if it is a monotonic transform of a homogeneous function. That is, f(x) = g[ h(x) ], where h(x) is homogeneous of degree one and g(h) is a monotonic function." p.586
As we stated before, the cement production function has the following technological representation:

\[ Z = \min \{ (K,L), X \} \tag{2} \]

where \(Z\), \(K\), \(L\), and \(X\), are output, capital, labor, and raw-materials, respectively.

From this fixed-coefficient or Leontief type of technology we distinguish two economic levels or stages of the production process. Concentrating on the firm level, the first stage of production will determine the output or capacity level, given an industrial organization and market structure. Thus, the firm will choose an input combination that allows for an efficient allocation (i.e. no larger output level can be supported with those inputs), given a certain technology and input price ratio, at any time.

It is assumed that along the capital and labor markets there is perfect information, ruling-out the possibility of random shocks emerging from market imperfections. So, when the firm has decided an output level, as we stated before, the ex-post rationalization of input prices must be realized as expected.

Once the cement firm has chosen a capital-labor \((K,L)\) combination, it must involve into production considering the technological fixities of the raw-materials input in order to produce the chosen output level. Here is where the second stage or level of production emerges from. This fixed input-output coefficient behavior is represented in the Leontief technology above (see equation \([2]\)). It denies the
possibility of substitution between (K,L) and the raw-materials input (X).

Using Johansen's schema, this type of technology will define an ex-post micro production function where the firm actually begins its production activity. When it comes to aggregation, the Leontief technology will be defined for the whole cement industry and a short-run macro function is now established. However, since our study is based on time-series data at the industry level, we will really be estimating a long-run aggregate production function allowing for changes in the (K,L) ratio as well as in the output capacity and the raw-materials input along time.

The jump from short-run to long-run comes inevitably from the nature of our data. But we think it is possible if we assume that the decision on output is either to produce at capacity level, or to assume free disposability, when spare capacity is present. This assumption might appear unreasonable in the empirical world where labor contracts are inflexible and fixed-costs are large, but when output is close to capacity, as in the cement industry of Mexico, this simplification might be coherent (xxxvi)/.

The way in which we set our production function from technological information is often referred to as the engineering approach. This is: it comes from the analytical deductions of the basic physical, chemical and technological (xxxvi)/ As a matter of fact, the output-to-capacity ratio of the industry had an average of 89.23% during the 1963-83 period.
principles explained in section 8.1 of last chapter. In this approach, the production function describes the input-output relationship according to known possible ways of organization in production.

Speaking of the micro-macro connection of the engineering approach, Johansen, op. cit., states that,

"it gives information of the ex-ante function at the micro level. Since the long-run function at the macro level can be derived from the ex-ante function at the micro level, the engineering studies are of course also relevant for this type of production function." 49

On the first stage, the substitution possibilities of capital and labor occur at the ex-ante production level. But the mode of operation is clearly ex-post, and it is embodied in the equipment and machinery of the plants constructed in the industry. Hence, it is important to assume that our model of cement production reveals ex-post substitution possibilities between capital and labor at the macro level.

On the second stage of production, the input-output fixed coefficients between (K,L) and X are constant, and a short-run macro function will be well defined. In the long-run, the substitution possibilities exist only within the first-stage capital and labor coefficients, but not on the second-stage (K,L)-to-X coefficients, since it is assumed to be zero. Hence, the long-run macro function at the second-stage will keep the same characteristics than the macro-short-run function, except for capacity levels.

Another way to view this is by distinguishing between essential and non-essential factors of production. We can
say that production will become zero if an essential factor is not used (i.e. its input is zero). On the opposite side, when production is positive if one or more factors are not used, then these factors are non-essential. Following this order of ideas, our ex-post short-run micro and long-run macro production functions of the Leontief technology present essential inputs; since cement cannot be produced neither without raw-materials nor without capital and labor (K,L). In the first-stage, however, capital and labor individual units are non-essential, since there can be substitution between them.

Having distinguished the first-stage of production from the second-stage, we now have to determine the relevant characteristics of the production functions conforming this two-stage process.

The parametric approach to the first-stage of cement production, i.e., when capital and labor are chosen, will be assumed to present a production function of the CES type. This kind of production function nests two extreme cases: Cobb-Douglas and Leontief technologies. The CES function is constructed in such a way as to preserve or maintain an elasticity of substitution ($\sigma$) that is not only constant but that can take any value.

Also at this first-stage, we will alternatively estimate a Cobb-Douglas production function, where the elasticity of substitution is fixed at $\sigma=1$. 
The technique of estimation for the CES is non-linear, while that of the Cobb-Douglas, when log-linearized, is linear. We will later describe the relevant characteristics of each estimation method.

On the second-stage, the other extreme case of the CES function is a-priori established, i.e. the Leontief type, where the elasticity of substitution is zero. Here, the relevant inputs will be composed of the capital-labor obtained in the first-stage, and the raw-materials input, introduced in this second stage. However, we will test the validity of this hypothesis by estimating second-stage Cobb-Douglas and CES functions.

9.1 Characteristics of the Constant Elasticity of Substitution production function and examples

The CES function is nested in the linearly homogeneous class of production functions. In general, the functional form of this function (considering capital and labor inputs), is:

\[ Z = \tau [ \delta L + (1-\delta)K ]^{-\theta/\mu}, \]  \hspace{1cm} [3]

with \( \sigma = 1/(1+\theta) \), \hspace{1cm} [4]

where: \( Z = \) output;
\( K, L = \) capital and labor inputs, respectively;
\( \tau = \) efficiency parameter;
\( \delta = \) input intensity (share), such that \( 0 < \delta < 1 \);
\( \theta = \) substitution parameter, such that \( \infty > \theta \geq -1 \);
\( \mu = \) returns to scale parameter;
and \( \sigma = \) elasticity of substitution.
Among the major properties of this function, are:

i) Strong separability.

ii) Its marginal products,

\[
\frac{dZ}{dL} = \delta \tau ^{1+\theta} \frac{Z}{L} \geq 0 ,
\]

and

\[
\frac{dZ}{dK} = (1-\delta) \tau ^{1+\theta} \frac{Z}{K} \geq 0 ,
\]

which are decreasing monotonically for non-zero value of inputs.

iii) The marginal rate of technical substitution (MRS) of K and L, is

\[
MRS = (\delta/1-\delta) \cdot (K/L)^{1/\sigma}.
\]

iv) \(\sigma = 1/(1+\theta)\), the elasticity of substitution is constant and can take any value. There are three cases.

If:

a) \(\theta = 0\), then \(\sigma = 1\), and the CES reduces to the Cobb-Douglas;

b) \(\theta = \infty\), then \(\sigma = 0\), and the CES reduces to the fixed-coefficient Leontief function;

c) \(\theta = -1\), then \(\sigma\) is indeterminate, and the CES becomes the Linear technology.

The isoquants of the three cases are drawn in Figure 1, for the K and L factors of production.

**Figure 1**

![Figure 1](image-url)
The Cobb-Douglas function as a special case of the CES linearly homogeneous function is represented by the following functional form:

\[ Z = A L^\alpha K^\beta \]  \[ \text{with } \Gamma = \alpha + \beta, \]

where: \( Z, L, K \), are as before, output and inputs; and \( A \) = scale parameter.

The Cobb-Douglas can be log-linearized, which will look like the following: \( \ln Z = a + \alpha \ln L + \beta \ln K. \) \[ 6' \]

The Leontief production function nested in the general CES function is obtained from:

\[ Z = \tau[ -\theta \delta x_1 + (1-\delta)x_2 ] \]

\[ \text{where } x_1 \text{ and } x_2 \text{ are inputs.} \]

To prove that the Leontief technology has fixed-coefficients, let \( x_1 = \text{Min} [ x_1, x_2 ] \),

\[ \text{then, } x_1 = \lim_{\theta \to -\infty} \tau[ -\theta \delta x_1 + (1-\delta)x_2 ] \]

For simplicity, assume \( \tau = 1 = \mu \), and \( \delta = 1-\delta \implies \delta = 1/2 \),

then, \( x_1 = \lim_{\theta \to -\infty} [ x_1 + x_2 ] \). From here, \( x_1 + x_2 \geq x_1 \),

\[ x_1 \geq \left( \frac{1}{\theta} \right) \left( x_1 + x_2 \right) \]

Since \( \theta < 0 \), and \( x_1 = \text{Min} [ x_1, x_2 ] \),

\[ \theta \theta \theta \theta \theta \theta \]

then, \( 2x_1 = x_1 + x_1 \geq x_1 + x_2 \), so that \( 2 \cdot x_1 \geq \left( \frac{1}{\theta} \right) \left( x_1 + x_2 \right) \).

Hence, if \( \theta \to -\infty \), \( 1 = 1 \), and the proof is completed.

As Shepherd, R.W. (1974), affirms,

"what is implied here is that there is only one input mix to obtain efficiently a particular output and all scalar variations of it. This is the encumbrance of the Leontief input-output model, in that it does not allow for alternative technologically efficient input vectors to yield a given output." \[ 50 \]
There are various other forms of production functions which we will not include in our analysis. Just to name one of them, there is the Variable Elasticity of Substitution (VES), where $\sigma$ is assumed to be the same along time but may vary along an isoquant, i.e., along different techniques of production. This VES type of function nests the Liu-Hildebrand as well as the Transcendental functions, among others. (xxxvii)/

Before we present the results of the empirical study on the cement industry in Mexico, we will describe some empirical examples of Cobb-Douglas and CES production functions.

Reviewing the literature about the Cobb-Douglas production function, there are three main approaches to this type of function. The first one has to do with how economists regard the Cobb-Douglas function empirically. The second approach establishes that even though the underlying technology of production may not be Cobb-Douglas, observations from the empirical analyses behave as if they were so. Finally, a criticism to such production function suggests that it arises from features of the data that have little or nothing to do with the underlying technology of production. Nevertheless, even with many limitations, the Cobb-Douglas production function has proved effective to

(xxxvii)/ For a brief analyses on these and other VES functions, refer to Nadiri (1987), pp. 460-62.
model many abstractions of the real world and has been widely used.

In the case of the cement industry, the Cobb-Douglas production function certainly seems to be one appropriate characterization of the production process. Especially once the capacity of production has been established. Hence, we will estimate this type of function in our empirical study at both stages of production.

Regarding the relation between micro and macro or aggregate production functions and according to Bosworth, op.cit., the existence of micro Cobb-Douglas functions exhibiting CRS and with capital measured in common or money value units is sufficient to ensure that the aggregate functions have the same form. As the author states,

"This [the money value] gives some explanation of the aggregate relationship that economists often estimate... [since] the stocks of physical inputs that constitute the aggregate variables may differ from firm to firm and every firm can be considered as an amalgamation of different types and ages of capital and labor." 51

Another example that relates micro and macro production functions is in Aigner & Chu (op. cit.), who approximate an average-plant function with available data on industry aggregates. They estimate a Cobb-Douglas one-output, two-input production function with random shocks. Any difference in technical efficiency are subsumed within the disturbance term. Measurement errors in variables are assumed negligible. Their model looks like the following:
\[ x_0 = A x_1 x_2 u, \quad [5'] \]

where: \( x_0 \) = output;
\( x_1, x_2 \) = inputs;
\( u \) = random shock;
\( A, \alpha, \beta \) = parameters.

Now, usually when a Cobb-Douglas function is defined, the value-added approach to output measure is used. This is done when capital and labor inputs are assumed to be the only relevant inputs in production. Nevertheless, when other inputs are included, the value-added measure will prove inaccurate.

An example of a Cobb-Douglas approach to production function using value-added output measure is studied in Katz (1969), who estimates time-series aggregate functions for the manufacturing sector in post-war Argentina (1946-61). He assumes CRS and disembodied technical progress. The general production function is set to be as the following:

\[ Y = A(t) K^\alpha L^{1-\alpha} \quad [6] \]

where: \( A(t) \) is a time-index of total factor productivity;
\( \alpha \), and \( (1-\alpha) \) are the output elasticities with respect to capital and labor;
\( Y \) = output at constant prices, in value terms;
\( K \) = capital input, in physical units;
and \( L \) = labor input, in physical units.
Since technical progress is specified to be neutral, then output changes given from input changes leave the marginal rate of substitution of inputs unchanged. Now, since $a$ is constant due to the assumption of neutral technical change, to obtain the output growth rate, \([15]\) is differentiated with respect to time. It will look like:

\[
\frac{Y}{Y} = \frac{A}{A} + (1-a)\frac{L}{L} + a\frac{K}{K} .
\]  

[7]

Later, in this same analysis, the author estimates an unrestricted version of the Cobb-Douglas production function. He drops the assumption of CRS, and allow the output elasticities with respect to capital and labor to be unconstrained (take any value). Perfect competition is not assumed, and technical change is assumed to be disembodied and neutral. The corresponding specified production function looks like the following:

\[
Y = A L^\alpha K^\beta e^\tau ,
\]  

[8]

where: $\alpha$ and $\beta$ are the unconstrained output elasticities with respect to labor and capital;

$\tau = \text{annual rate estimate of neutral technical progress}$;

$t = \text{time}$; and $A$, $K$, and $L$ are as before.

Among limitations of the data that this author faces, we can mention the one related to the capital input. As he states,

"Apart from the aggregate estimate of fixed capital stock... no further data is available [in Argentina] concerning the capital stock of individual industries." 52
We ought to comment that for the case of the Mexican cement industry, we have information of the value of net fixed assets (capital stock), as well as that of gross and net investment per year. However, since data on individual firms is unavailable, we can only assume that the distribution of such a measure of capital stock and gross investment was uniform along the incumbent firms during the 1963-83 period.

Reviewing literature related to previous analyses on the Mexican cement industry production function, in 1980 the Office of Presidential Advisors prepared a document on this subject. As the economic growth rate of the country was around 8 per cent a year in those days, demand for cement derived form the demand for construction was growing at even faster rates. A study contemplating cross-section analysis was developed on a yearly base from 1974 to 1978, and the production function was assumed to have the Cobb-Douglas technology,

\[ Y = AK^\alpha L^\beta, \]  \[9\]

where:

- \( Y \) = value-added
- \( K \) = value of total assets
- \( L \) = total payments to labor

- \( A \) = cement price
- \( \alpha \) = price of capital
- \( \beta \) = price of labor

and \( A, \alpha, \) and \( \beta \) are the usual parameters.
They were able to realize a survey containing information at the plant level, and finally got estimates of the elasticity of scale, which proved to be increasing, except for 1977, when a mild recession occurred.

Now, among empirical examples of the CES type of production function, we find the analyses of 27 manufacturing sectors presented in Griliches & Ringstad (1971) for Norway during 1963. They develop a cross-section CES function, that looks like the following:

\[ V = B \left[ \delta K + (1-\delta) L \right]^{-\mu/\delta}, \quad [10] \]

where:  
\( V \) = value-added;  
\( K \) = capital input;  
\( L \) = labor input;  
\( B \) = scale parameter;  
\( \delta \) = output share elasticity;  
\( \phi \) = parameter of substitution of the elasticity of substitution \( \sigma \), such that:  
\[ \sigma = 1/(1+\phi); \]
and  
\( \mu \) = elasticity of scale.

The capital input they used is an unweighted sum of its elements, which include: full fire insurance value of buildings, machinery and other equipment, as well as the value of inventories, and transportation vehicles (cars, trucks and buses).

Among some conclusions are the following ones:

"In general, it appears that both: the scale elasticity and the output with respect to labor input elasticity, decline with scale... The estimated capital elasticities are seriously biased downward, and the labor elasticities are biased upward... Value-added does seem to be a better measure than any alternative." 53
An example of a time-series CES production function at the firm level is in Katz, op.cit., again for the Argentine manufacturing sector. His specification of the CES production function does not contemplate capital stock data, but rather the flow of services in money terms at constant prices. This might be interpreted as the money value of rental rates over the capital stock.

Net profits are defined as value-added less the sum of capital and labor costs:

$$\pi = pY - wL - rK$$  \[11\]

where: \(pY\) = value-added; \(wL\) = labor costs; \(rK\) = capital costs.

The profit maximizing condition, is:

$$\delta\pi/\delta L = p(\delta Y/\delta L) + Y(\delta p/\delta Y) (\delta Y/\delta L) - w - (\delta w/\delta L)L = 0$$ \[12\]

which rearranging:

$$(\delta Y/\delta L) [p + Y(\delta p/\delta Y)] = w (\delta w/\delta L)L$$ \[13\]

Solving for \((\delta Y/\delta L)\),

$$\frac{\delta Y}{\delta L} = \frac{1}{p} \frac{1}{\delta p/\delta Y} \frac{Y}{p} \left( 1 + \frac{\delta w/\delta L}{\delta w/\delta L} \right) \frac{L}{w}$$

$$\begin{align*}
\delta Y & \quad \delta w/\delta L \quad L \quad w \quad 1+(\delta w/\delta L)L \quad L/w \\
\delta L & \quad p \quad \delta p/\delta Y \quad Y \quad p \quad 1+(\delta p/\delta Y)Y \quad Y/p
\end{align*}$$

$$\Rightarrow \frac{\delta Y}{\delta L} = \frac{1}{p} \frac{1}{E_{PWY}} \left( 1 + \frac{E_{PWY}}{E_{PY}} \right)$$ \[14\]

where: \(w\) = money wages and salaries;

\(p\) = output price;

\(E_{PWY}\) = elasticity of wages with respect to the quantity of labor employed;

\(E_{PY}\) = elasticity of price of output with respect to output (quantity).
An important conclusion is related to periods of recession. Thus, when there is a recession during the time-span, labor and capital inputs will not be utilized in their full capacity and the producers will be under the pressure to cut personnel and reduce fixed costs too. As a result,

"this would impart a downwards bias to the estimate of the elasticity of substitution. Which is basically attributed to changes in the quality of labor services, especially during periods of expansion and contraction... In recession years an increase in unemployment is normally accompanied by an increase in the quality of labor services because the more efficient workers (at each wage rate) are the ones retained. The value-added per man tends to increase in recession, and the opposite tends to be true in periods of expansion." 54

This may also occur to the capital input variable.

The next step in our analysis is to define the exact structure of the cement production process using the two-stage approach proposed before.

9.2 The Mexican cement production function

Both, the CES and Cobb-Douglas technology characterizations will be used to describe the production function of cement in Mexico. The first step consists in describing the data.

9.2.1 Description of the data

If we follow the two-stage cement production process, we notice that various types of capital goods as well as labor and intermediate inputs (materials) enter into the technological framework. Therefore, we require a certain
degree of aggregation in order to make such production function manageable. (xxxviii)/

The best results could come not only from a two-stage, but also from a two-level of aggregation production structure, where the multiple inputs within their category are aggregated into a single index, composing either capital, labor, or any other good. Unfortunately the limited number of periods (21) and thus degrees of freedom with which we count cannot give a basis for estimating a two-level of aggregation production function. However, we ought to point out that the assumptions of this structure do certainly hold for our analysis of the cement industry, where data is sometimes obtained considering such scheme.

The first assumption deals with the condition of separability. In the case of the cement industry we assume that output \( Z \) is produced by three inputs, \( K, L \) and \( X \), such that: \( Z = F(K, L, X) \). [1].

Let partition each input category into bundles with various elements such that \( k_i \in K, l_j \in L, \) and \( x_n \in X \), where: \( i \in I = \{1, \ldots, I\} \), \( j \in J = \{1, \ldots, J\} \), and \( n \in N = \{1, \ldots, N\} \). Hence, \( F \) is weakly separable if it can be rewritten as:

\[
Z = F[\tau_1(K), \tau_2(L), \tau_3(X)]. \quad [2]
\]

Also, let [2] be strongly separable, such that:

\[
Z = F[f_1(\tau_1(K)) + f_2(\tau_2(L)) + f_3(\tau_3(X))]. \quad [3]
\]

(dddiiii) In the specification of this model the analyses are based on the study made by Sato (1967), as well as on those of Uzawa (1962), and Mc Fadden (1963).
Now, [3] consists of two levels, the lower level determining each input mix: K, L, and X, and the upper level dealing with the production function itself.

Also, as we said before, along the production process we distinguish two stages. At the first-stage the capital-labor ratio, now formed of various elements each is chosen, entering into the production process with the materials input in a fixed-coefficient manner at the second-stage. Since the two stages involve certain technology and taking into account that the CES production function nests the various cases at the first-stage alternative technologies, namely the generalized CES and the Cobb-Douglas as well as the hypothetical Leontief fixed-coefficient technology at the second stage, we will estimate both, the CES and the Cobb-Douglas production functions, which are special cases of the strongly separable function in [3].

We now proceed to define the various aggregate inputs in cement production using the available yearly data for the 1963-83 period. At this state, we ought to point out that the data were extracted from multiple series of publications of I.N.E.G.I. (National Institute of Computer Science, Geography and Statistics), Banco de Mexico (Central Bank), and CANACEM (National Chamber of Cement).

There are various ways of getting a measure of the labor input, we will utilize one, namely L₁, such that:

\[ L₁ = \text{real expenditure on salaries and other benefits.} \]
Alternative measures that could also be used are the total labor units in the industry comprising production and non-production labor as well as the total hours worked by the labor units of the industry.

From here, we note that total labor is a measure of the stock, while $L_1$ and total hours represent measures of flows of services. We assume that labor availability is uniformly distributed, which is consistent with the assumption of labor markets perfect information. The labor input $L_1$ was deflated by using an index of the average wage deflator, having 1963 as its base year.

The capital input used in the empirical analyses will be either $K_1$, $K_2$, $K_3$, or $K_4$, where:

$K_1 = \text{Real expenditure on capital flows of services (xxxix)/,}$

such that:

$$K_1 = \begin{cases} \frac{1}{k_i}, \frac{1}{k_r}, \frac{1}{k_o} \end{cases}, \text{ where: }$$

$$k_i = \text{interest payments;}$$

$$k_r = \text{rents and leases;}$$

$$k_o = \text{other capital input services.}$$

$K_2 = \text{Real fixed net assets of the industry, obtained by the perpetual inventory method of capital stock:}$

$$K_t = I_t + (1-d) K_{t-1}, \text{ (xl)/}$$

where: $I_t = \text{net investments in period } t$;

and $d = \text{depreciation rate.}$

\text{(xxxix)/ For measures of output not including materials or any intermediate input. This is generally used in the case considering Cobb-Douglas technologies, but not necessarily. (xl)/ See Christiansen and Jorgenson (1970), p. 294.}
\[ K_3 = \text{Real energy input expenditure, such that } K_3 = \{k_f, k_e\}, \]
\[ \text{where: } k_f = \text{expenditure in fuel and lubricants;} \]
\[ \text{and } k_e = \text{expenditure in electricity.} \]

\[ K_4 = \text{Flow of services of the capital stock, such that } K_4 = K_2 \ast \text{SEPK, where } K_2 \text{ is as defined above, and } \]

\[ \text{SEPK = service price of capital constructed yearly} \]
\[ \text{by the formula: } \text{SEPK} = \frac{q}{(1-t) \ast (r+d)}, \]
\[ \text{where: } q = \text{investment goods deflator;} \]
\[ t = \text{corporate income tax rate;} \]
\[ r = \text{after tax rate of return;} \]
\[ d = \text{depreciation rate. (xli)} \]

Hence, \( K_2 \) represents a measure of capital stock (durable goods approach), \( K_1 \) is a measure of the capital input flows, \( K_4 \) is a precise measure of the capital service flows, and \( K_3 \) is a proxy for measuring the capital service flows utilizing the expenditure in energy which, as we stated before, must be assumed to be used in fixed-proportion to a hypothetical capital stock. Hence, \( K_3 \) is really an element of the materials input used along production. However, we also let it be defined as a kind of proxy of the capital input used only at the first-stage. The real money value of \( K_1 \) and \( K_2 \) is obtained by deflating them by the investment goods deflator index, while \( K_3 \) is deflated by the index price of fuel and energy, the three of them with 1963 as the base year.

Let the materials input \( K_1 \) conformed by various elements be defined as:

\[ (xli)/ \text{This index was based on the studies by Nadiri & Schankerman (1981), and Jones A. (1988).} \]
$X_1$ = materials input when non-energy capital measure is utilized in the production process (xlili), such that,

$$X_1 = \{ x_m, x_p, x_f, x_e, x_o \},$$

where: $x_m$ = real raw-materials expenditure;

$\frac{1}{1}$ $x_p$ = real expenditure in packing cement;

$\frac{1}{1}$ $x_f$ = real expenditure in fuel and lubricants;

$\frac{1}{1}$ $x_e$ = real expenditure in electricity;

$\frac{1}{1}$ $x_o$ = real expenditure in other intermediate inputs assumed to be used in fixed-proportions to output.

This measure of the materials input can be interpreted as a stock, represented at its value and entering in the production process only at the second-stage, i.e., once the capital-labor ratio has been chosen. $X_1$ is deflated by the index price of materials in 1963 pesos.

Now, from the definitions of the variables above, we clearly notice that $K_1$, $K_3$, and $X_1$, can be obtained regarding a quantum index of their respective elements. This means that if we use the CES approach to determine such indices their structures are:

i) $K_1 = k \left( k_i, k_r, k_o \right)$, this is,

$$K_1 = [ \delta_{k,i} \left( k_i \right) + \delta_{k,r} \left( k_r \right) + \delta_{k,o} \left( k_o \right) ]^{1/\gamma_k} \cdot$$

where: $\delta_{k,i}, \delta_{k,r}, \delta_{k,o} > 0$,

and $\gamma_k = (1 - \sigma_k)/\sigma_k$, such that $\sigma_k = 1/(1+\gamma_k)$.

(xlili) I.e., when either $K_1$, $K_2$, or $K_4$ but not $K_3$ are used in the second-stage of the production process.
ii) \[ K_3 = k \left( k_f, k_e \right) = \left[ \delta_{k,f} k_f^{3} - \Theta_k k_e^{3} + \delta_{k,e} k_e^{3} \right] \]
where: \[ \delta_{k,f}, \delta_{k,e} > 0 \]

and \[ \Theta_k = \left(1 - \frac{3}{\sigma_k}\right) / \sigma_k, \] such that \[ \sigma_k = 1 / \left(1 + \Theta_k\right). \]

iii) \[ X_1 = x^{1} \left( x_m, x_p, x_f, x_e, x_o \right), \] this is,

\[ X_1 = \left[ \delta_{x,m} \left( x_m \right) + \delta_{x,p} \left( x_p \right) + \delta_{x,f} \left( x_f \right) + \delta_{x,e} \left( x_e \right) + \delta_{x,o} \left( x_o \right) \right] \]

where: \[ \delta_{x,m}, \delta_{x,p}, \delta_{x,f}, \delta_{x,e}, \delta_{x,o} > 0 \]

and \[ \Theta_x = \left(1 - \frac{1}{\sigma_x}\right) / \sigma_x, \] such that \[ \sigma_x = 1 / \left(1 + \Theta_x\right). \]

However, our sample is too small to allow estimation of these input-aggregation structure, leaving this out of our analysis.

Now, before we continue to develop the production process into the first and second stages, we ought to define the various measures of output that we will utilize.

Let output \( Z \) be either \( Z_1 \), or \( Z_3 \), such that:

\[ Z_1 = \text{real value of cement production}; \]

and \( Z_3 = \text{real value-added}. \)

Therefore, \( Z_3 \) can only be used at the first-stage when considering \( K \) and \( L \) inputs with either the general CES or restricting it to be Cobb-Douglas, i.e., when \( \sigma = 1 \), while \( Z_1 \) is used either at the first stage or at the second-stage.
Both were deflated by the index price of cement in Mexico in pesos of 1963. Hence, on the first stage of production we settle a generalized CES function that nests the Cobb-Douglas. At this stage the composite indices of K and L determine the technique of production. Therefore, we define:

\[ Z_j = z( K_i, L_1 ) = \tau[ \alpha (K_i)^{-\theta} + (1-\alpha) (L_1)^{-\theta} ]^{\mu/\theta} + \epsilon, \quad [7] \]

for \( j=1,3 \), and \( i=1,2,3,4 \), where \( \alpha > 0 \), and \( \theta = (1-\sigma)/\sigma \), such that: \( \sigma = 1/(1+\theta) \).

Hence, if \( \sigma = 1 \) then the analysis reduces to the Cobb-Douglas case.

On the second stage, the materials input is introduced into the analysis with the output measure now \( Z_1 \). The a-priori assumption of Leontief type of technology does not allow for extensive empirical estimation of this second stage since \( \sigma = 0 \). This is, \( Z_1 = z [(K_1,L_1), X_1] \) In particular, \( Z = \text{Min} [(K,L), X] \). However, in the long-run we can assume there is some sort of substitution and thus the corresponding hypothetical CES function defined at the second stage of the production process is:

\[ Z_1 = \tau \left[ \frac{1}{(1-\alpha) (L_1)^{\theta}} \right] + \varepsilon, \quad [8] \]

where: \( \Gamma > 0 \), and \( \theta = (1-\sigma)/\sigma \), such that \( \sigma = 1/(1+\theta) \).

If \( \theta = -\infty \implies \sigma = 0 \), we will have precisely the Leontief function that we refer above with the fixed-coefficients required of \((K,L)\) and \(X\) (see proof of this after equation...
[4'] of section 9.1). Nevertheless, the estimation of equation [8] gives an idea of the long-run substitution among these inputs.

The next step is to obtain the parameter estimates for the structures described above. Finally, we will present the conclusions pertaining to the empirical results as well as some other results obtained combining the data and the parameter estimates considering changes in input prices and their rationale on factor substitution and intensities as well as of the bias of technology.

9.2.2 Empirical results

The methods of estimation used in this study include both, linear and non-linear least squares techniques. (xliii)/

The linear least-squares technique is used for estimating the first-stage log-linearized Cobb-Douglas function in which case the error term ε will appear in a multiplicative manner. In such a case the Cobb-Douglas equations here estimated will have the following specification:

\[ Z_3 = \alpha \beta \epsilon_i \text{ for } i = 1, 2, 3. \]  \[7'\]

This is intrinsically assuming that ε is normally distributed with zero mean and variance σ². Hence, the logarithmic transformation results in a relationship that is linear in the unknown parameters of the regression equations. As Kmenta (1986), comments on this,

(xliii)/ For the definition and characteristics of the Least Squares estimates see Kmenta (1986), as well as Klein (1974).
"the particular way in which the disturbance is introduced into the equation implies that the distribution of outputs for any given set of inputs is log-normal, i.e., skewed." 55

The non-linear least squares technique is used for estimating the specified generalized CES at the first and second stages, in which case ε enters additively. As Jorgenson (1986), affirms,

"The assumption that the input prices and the level of technology are exogenous variables implies that the [CES] model becomes a nonlinear multivariate regression model with additive errors, so that nonlinear techniques can be employed." 56

The CES model specified in equations [7] for the first stage, and [8] for the second stage, are known as intrinsically non-linear with respect to variables and parameters. Using this technique we first take logarithms of both sides of [8]. K and L are non-stochastic, and using the non-linear least squares method we do not need to make assumptions on the structure of the disturbance term ε, as that of normal distribution when using the maximum likelihood (ML) method. However, when the ML function is obtained by the minimization of the sum of squared deviations of output Z fitted values,

"estimates obtained by the nonlinear least squares method are exactly the same as the maximum likelihood estimates... the assumption of normality of the stochastic disturbance is not... crucial." 57

The computer package utilized for estimation in this study uses the Gauss-Newton iteration algorithm where the sum of squared residuals (SSR) declines on every iteration
until it is minimized, thus the SSR stops declining and a given convergence criterion is met.

Various regressions were estimated each one using different combination of either capital input and output as well as different structures, which were either Cobb-Douglas, or CES for the first and second stages. I.e., we allow for a long-run path of the Leontief structure where the intermediate inputs were included. This means that we will test the hypothesis of long-run fixed-coefficients technology where the short-run input-output relations describe long-run substitutability among K, L, and X. This is represented in Figure 2.

**Figure 2**

<table>
<thead>
<tr>
<th>K,L</th>
<th>Long run Leontief envelope</th>
</tr>
</thead>
<tbody>
<tr>
<td>short run</td>
<td></td>
</tr>
<tr>
<td>long run</td>
<td>X</td>
</tr>
</tbody>
</table>

Tables 1, 2, and 3 present the results of the empirical study where the parameter estimates represent the variables behavior over the 1963-83 period, with the variables and parameters defined as follow:

\[ C-D_i = \text{First-stage Cobb-Douglas using } K_i \text{ measures of capital input such that } i=1,2,3,4 \text{ and } Z_3 \text{ measure of output}; \]

\[ CES_{j,k} = \text{First-stage Constant Elasticity of Substitution using } K_j \text{ measures of capital input, such that } j=1,2, \text{ and } Z_k \text{ measures of output, such that } k=1,3; \]
C-D_x = Second-stage Cobb-Douglas using K_1, L_1, X_1, and Z_1 measures of capital, labor, materials, and output, respectively.

CES_x = Second-stage Constant Elasticity of Substitution using K_1, L_1, X_1, and Z_1 variables.

c = coefficient; s.e. = standard error; t-s. = t - Student statistic;

\( \tau = \) efficiency (output scale) parameter;

\( \alpha, \beta = \) output elasticities with respect to capital and labor inputs, respectively;

\( \Phi = \) output elasticity w.r.t. materials input;

\( \mu = \) scale elasticity parameter; \( \Theta = \) substitution parameter;

\( \sigma = \) elasticity of substitution parameter.

### Table 1 First Stage Cobb-Douglas

<table>
<thead>
<tr>
<th></th>
<th>( \hat{\tau} )</th>
<th>( \hat{\alpha} )</th>
<th>( \hat{\beta} )</th>
<th>( \hat{\Theta} )</th>
<th>( \hat{\sigma} )</th>
<th>R^2</th>
<th>D-W</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-D_1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>-0.177</td>
<td>0.966</td>
<td>0.094</td>
<td>0.952</td>
<td>1.542</td>
<td>20.446</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>1.015</td>
<td>0.149</td>
<td>0.215</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-0.174</td>
<td>6.497</td>
<td>0.438</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(B)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-D_2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>-5.838</td>
<td>0.587</td>
<td>0.946</td>
<td>0.933</td>
<td>1.936</td>
<td>24.446</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>1.193</td>
<td>0.117</td>
<td>0.1272</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-14895</td>
<td>5.007</td>
<td>7.436</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(C)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD_3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>-6.804</td>
<td>1.114</td>
<td>0.552</td>
<td>0.953</td>
<td>2.099</td>
<td>20.540</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>1.054</td>
<td>0.170</td>
<td>0.150</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-6.457</td>
<td>6.559</td>
<td>3.688</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(D)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CD_4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>5.484</td>
<td>0.247</td>
<td>0.472</td>
<td>0.946</td>
<td>2.240</td>
<td>22.0872</td>
<td></td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>1.758</td>
<td>0.042</td>
<td>0.177</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>3.119</td>
<td>5.896</td>
<td>2.661</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table 2 First Stage CES

<table>
<thead>
<tr>
<th></th>
<th>( \hat{\tau} )</th>
<th>( \hat{\alpha} )</th>
<th>( \hat{\mu} )</th>
<th>( \hat{\theta} )</th>
<th>( \hat{\sigma} )</th>
<th>( R^2 )</th>
<th>D-W</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>CES_{1.3}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>0.191</td>
<td>0.454</td>
<td>1.205</td>
<td>0.520</td>
<td>0.658</td>
<td>0.999</td>
<td>1.19</td>
<td>5.69</td>
</tr>
<tr>
<td>s.e.</td>
<td>0.472</td>
<td>0.377</td>
<td>0.033</td>
<td>1.838</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-3.505</td>
<td>1.205</td>
<td>36.568</td>
<td>0.282</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CES_{2.1}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>0.706</td>
<td>0.241</td>
<td>1.165</td>
<td>1.163</td>
<td>0.462</td>
<td>0.981</td>
<td>1.41</td>
<td>6.99</td>
</tr>
<tr>
<td>s.e.</td>
<td>1.312</td>
<td>2.050</td>
<td>0.039</td>
<td>0.042</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-0.266</td>
<td>0.117</td>
<td>29.687</td>
<td>0.144</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3 Second Stage C-D and CES

<table>
<thead>
<tr>
<th></th>
<th>( \hat{\tau} )</th>
<th>( \hat{\alpha} )</th>
<th>( \hat{\beta} )</th>
<th>( \hat{\phi} )</th>
<th>( \hat{\theta} )</th>
<th>( \hat{\sigma} )</th>
<th>( R^2 )</th>
<th>D-W</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>(G)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-D_{X}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>-2.277</td>
<td>0.276</td>
<td>-0.203</td>
<td>1.142</td>
<td>0.010</td>
<td>0.986</td>
<td>2.19</td>
<td>5.95</td>
<td></td>
</tr>
<tr>
<td>s.e.</td>
<td>0.619</td>
<td>0.085</td>
<td>0.113</td>
<td>0.110</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-3.676</td>
<td>-3.250</td>
<td>-1.803</td>
<td>10.377</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(H)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CES_{X}</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>0.27</td>
<td>0.61</td>
<td>-1.62</td>
<td>1.09</td>
<td>-1.14</td>
<td>-6.99</td>
<td>0.966</td>
<td>1.09</td>
<td>8.82</td>
</tr>
<tr>
<td>s.e.</td>
<td>5.36</td>
<td>5.24</td>
<td>21.26</td>
<td>0.07</td>
<td>3.44</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>t-s.</td>
<td>-0.24</td>
<td>0.12</td>
<td>-0.08</td>
<td>14.85</td>
<td>-0.33</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The results in Tables 1 and 2 are for the first-stage of the production process, i.e., when the capital-labor ratio
is chosen at the short and long runs. The second-stage long-run path is the result of short-run $Z = \text{Min}[(K, L), X]$ functions with the parameter estimates in Table 3, where $Z = [K, L, X]$ allowing for long-run substitution among variables.

Most parameter estimates are significatively different from zero at a level of 0.05, except for: $\tau$ in regressions (A), (F), and (H); $\alpha$ in (E), (F), and (H); $\beta$ in (A) and (H); and $\theta$ in (E), (F), and (H). A possible source of this lack of significance in these parameter estimates is that their respective variance might be overstated because of collinearity. This suggestion is due to the existence of goodness of fit in all regressions as the F statistic shows. Thus, when parameter estimates are not significant in the existence of large F's, there is evidence of collinearity. Also, relatively small sample size can be a major reason to explain why those parameter estimates proved to be not significatively different from zero.

However, important conclusions can arise. We can observe that probably the best results were obtained from equations (B), (C), (D) and (G) where the Cobb-Douglas production functions not only give good fit, but present no autocorrelation and collinearity.

In the First-stage Cobb-Douglas models, we capture evidence of economies of scale, especially in regressions (B) and (C). This means that when the capital stock $K_2$ and the labor input $L_1$ are increased in one unit each, output
(measured in real value-added) is increased in 1.5327 units. But here, the labor input has a larger effect since its output elasticity is 0.9460, while that of $K_2$ is 0.5867.

Also, when the capital input is measured by the energy proxy $K_3$, there are scale economies of this input over output with an elasticity of 1.1139 while that of $L_1$ now becomes of 0.5524, for a total of 1.6663 units of output increase per one unit of increase of these two inputs simultaneously.

The CES models (E) and (F), capture the elasticity of substitution of the capital and labor inputs at the first-stage. The parameters of elasticity of substitution reflect that there is evidence of some degree of substitutability between capital and labor inputs. However, $(K_1,L_1)$ are less substitutes than $(K_2,L_1)$. This is: the capital flow of services ($K_1$) and the labor flow of services ($L_1$) complement each other and are able to generate scale economies together, while the relation between the capital stock ($K_2$) and the service flow of labor ($L_1$) tend to be more substitutes in a long-run perspective and also generate scale economies.

At the Second-stage, when the materials input is introduced in order to observe a long-run path of the Leontief function, only the analysis of regression (G) shows good results since that of (H) shows that none of the parameter coefficients is significatively different from zero, except for the scale elasticity parameter estimate $\mu$. Hence, in the Second-stage the regression analyses yield
that there are scale economies of the three combined input
categories by increasing output in 21.5% more that of their
increase.
As for the conclusions about second-stage long-run
substitutability, equation (H) shows that we cannot obtain a
reasonable outcome for this, since most parameter estimates
are not significative and there is no evidence of the
inexistence of autocorrelation. Therefore, the only
suggestion we can make is to increase the sample size and
see what happens with the estimates. However, this will not
be realized in this particular study.

Now, from the data we can directly obtain measures of the
relative factor productivity. These ratios are obtained from
the quotient resulting when the real expenditure of either
capital, labor or materials inputs is divided by the output
measure, now taking the form of total production of cement
in tons. With these ratios, an index is formed where 1963
takes the base value of 1.00. Making this exercise, \( K_1 \) has
decreased its productivity from 1.00 in 1963 to 0.38 in
1983. This is mainly due to the increased financial burden
of cement companies, an element of this capital input
measure. \( K_2 \) decreased it to 0.71 in 1983, while \( K_3 \) came up
108\%, showing that the cement industry is more energy
productive and is able to generate the same output with less
electricity and fuel. Similarly, \( L_1 \) shows that this input
productivity has increased 77% from 1963 to 1983. The
materials input $X_1$ was also able to increase it up 43% in the same period.

These results are consistent with those of the regressions showing that cement technology tended to increase labor productivity through the investment in capital goods, increasing the share that labor gets from output.

Also, the cement technology has been biased to save energy. This is probably the result of having a cement industry which tries to save energy by implementing this kind of technology. If we review the characteristics of the production process we realize that the dry and semi-dry processes save more energy than the wet and semi-wet ones. Therefore, there is evidence that the Mexican cement industry has been increasingly using the dry process for cement production, which by the way is more air pollutant than the other processes. This result presents a dilemma between saving energy and polluting less. Further research is encouraged in order to measure these two effects.

The real expenditure on the materials input has steadily decreased, and this input presents substantial scale economies, i.e., has increased its productivity. The intuitive appeal of this result is due probably to a universal decrease of the relative prices of raw-materials worldwide, except perhaps of that of fuel (at least during 1963-83). Thus, the Mexican cement industry did respond to these trends effectively.
Finally, it is interesting to analyze the effects of relative-price changes over output and over factor productivity. On this respect we can introduce possible policies in order to promote a better allocation of resources. To do this we construct indices of relative factor productivity and see what would have happened had their prices changed.

Among some results of the observed factor productivities we have that the energy input increased its participation in output share less rapidly than that of labor and capital inputs. By its way, the raw-materials input has been reducing such participation. This denotes the closed character of the Mexican economy during 1963-83. If the government had liberalized the energy input prices at international levels, then the cement industry would have been even more energy saving.

Since the capital input per worker steadily increased, had the Mexican labor market been set free, the cement labor input would have increased its productivity further. Also, the capital input prices could have decreased if the economy had opened its capital markets during this period. By setting the capital input prices artificially high and with the impossibility of reducing the labor share of output and of reducing even further the materials input share, the only event plausible was to increase either the cement prices in such a fashion as to increase or maintain the rate of return of the industry, or by promoting price
discrimination. This two outcomes were reinforced due to the lack of regional competition in each cement market.

Multiple other conclusions can arise from the analyses of the cement industry. However, space and time are certainly limited. If this study helps to explain the evolution of the Mexican cement industry with its sources of efficiencies and inefficiencies, and if it is a benchmark for further research on this and other topics, it would have fulfilled its main objectives.
REFERENCES

1 Johansen, L. (1972), p.9
2 Ibid., p.11
4 Ibid., XXV
5 Ullman, J. (1988), p.15
10 Bosworth, D. (1976), p.100
11 Norman, G. (1979a), p.324
14 Ibid., p.196
17 Lovell, C. and P. Schmidt (1988), p.21
18 Ullman, op.cit., p. 13
20 Kendrick and Grossman, op.cit., p.20
21 Pratten, C. (1971), p.15
22 Norman, op.cit., p.321
24 Tinbergen, J. (1985), p.6
26 Carlsson, B. (1972), p.479
29 Bianchi, op.cit., p. 106
30 Ibid., p.114
31 Ibid., p.108
32 Ibid., p.109
33 Ibid., p.115
35 Norman, op.cit., p.324
36 Ullman, op.cit., p.103
39 Ibid., p.95
41 Bianchi, op.cit., p.1
42 Scherer, F. (1980), p.155
43 Ibid., p.200
45 Scherer, op.cit., p.17
46 Aigner, D. and S. Chu (1968), p.830
47 Sato, op.cit., XX
48 Ibid., XXII
49 Johansen, op.cit., p.140
51 Bosworth, op.cit., p. 140
52 Katz, op.cit., p.35
54 Katz, op.cit., p.54
57 Kmenta, op.cit., p.517
APPENDIX
<table>
<thead>
<tr>
<th>Subsidiary Plant</th>
<th>Mother Firm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cemento Portland Blanco de Mexico, S.A.</td>
<td>MEXICANOS</td>
</tr>
<tr>
<td>2 Cemento Portland Nacional, S. A. de C. V.</td>
<td>PORTLAND N.</td>
</tr>
<tr>
<td>3 Cementos Anahuac S. A.</td>
<td>ANAHUAC</td>
</tr>
<tr>
<td>4 Cementos Anahuac del Golfo, S. A.</td>
<td>ANAHUAC G.</td>
</tr>
<tr>
<td>5 Cementos Apasco, S. A. de C. V. (central)</td>
<td>APASCO</td>
</tr>
<tr>
<td>6 Cementos Apasco, S. A. de C. V. (Tabasco)</td>
<td>APASCO</td>
</tr>
<tr>
<td>7 Cementos Atoyac, S. A. de C. V.</td>
<td>ATOYAC</td>
</tr>
<tr>
<td>8 Cementos de Acapulco, S. A.</td>
<td>ACAPULCO</td>
</tr>
<tr>
<td>9 Cementos de Chihuahua, S. A. de C. V.</td>
<td>CHIHUAHUA</td>
</tr>
<tr>
<td>10 Cementos de Chihuahua, S. A. de C. V. (Juarez)</td>
<td>CHIHUAHUA</td>
</tr>
<tr>
<td>11 Cementos del Norte, S. A. de C. V.</td>
<td>DEL NORTE</td>
</tr>
<tr>
<td>12 Cementos del Pacifico, S. A. de C. V.</td>
<td>DEL PACIFICO</td>
</tr>
<tr>
<td>13 Cementos Guadalajara, S. A. (Guadalajara)</td>
<td>GUADALAJARA</td>
</tr>
<tr>
<td>14 Cementos Guadalajara, S. A. (B. California)</td>
<td>GUADALAJARA</td>
</tr>
<tr>
<td>15 Cementos Hidalgo, S. C. L.</td>
<td>HIDALGO</td>
</tr>
<tr>
<td>16 Cementos Maya, S. A. (Bajio)</td>
<td>MAYA</td>
</tr>
<tr>
<td>17 Cementos Maya, S. A. (Merida)</td>
<td>MAYA</td>
</tr>
<tr>
<td>18 Cementos Mexicanos, S. A. de C. V. (Monterrey)</td>
<td>MEXICANOS</td>
</tr>
<tr>
<td>19 Cementos Mexicanos, S. A. de C. V. (Torreon)</td>
<td>MEXICANOS</td>
</tr>
<tr>
<td>20 Cementos Mexicanos, S. A. de C. V. (Valles)</td>
<td>MEXICANOS</td>
</tr>
<tr>
<td>21 Cementos Portland Moctezuma, S. A. de C. V.</td>
<td>MOCTEZUMA</td>
</tr>
<tr>
<td>22 Cementos Sinaloa, S. A. de C. V.</td>
<td>SINALOA</td>
</tr>
<tr>
<td>23 Cementos Tolteca, S. A. de C. V. (Atotonilco)</td>
<td>TOLTECA</td>
</tr>
<tr>
<td>24 Cementos Tolteca, S. A. de C. V. (Mixcoac)</td>
<td>TOLTECA</td>
</tr>
<tr>
<td>25 Cementos Tolteca, S. A. de C. V. (Tula)</td>
<td>TOLTECA</td>
</tr>
<tr>
<td>26 Cementos Tolteca, S. A. de C. V. (Zapotiltic)</td>
<td>TOLTECA</td>
</tr>
<tr>
<td>27 Cementos Veracruz, S. A. de C. V.</td>
<td>VERACRUZ</td>
</tr>
<tr>
<td>28 Cementos Cruz Azul, S. C. L. (Jasso)</td>
<td>CRUZ AZUL</td>
</tr>
<tr>
<td>29 Cementos Cruz Azul, S. C. L. (Lagunas)</td>
<td>CRUZ AZUL</td>
</tr>
<tr>
<td>----</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>0.81%</td>
</tr>
<tr>
<td>2</td>
<td>2.75%</td>
</tr>
<tr>
<td>3</td>
<td>11.80%</td>
</tr>
<tr>
<td>4</td>
<td>0.00%</td>
</tr>
<tr>
<td>5</td>
<td>4.96%</td>
</tr>
<tr>
<td>6</td>
<td>0.00%</td>
</tr>
<tr>
<td>7</td>
<td>3.07%</td>
</tr>
<tr>
<td>8</td>
<td>1.06%</td>
</tr>
<tr>
<td>9</td>
<td>3.48%</td>
</tr>
<tr>
<td>10</td>
<td>0.00%</td>
</tr>
<tr>
<td>11</td>
<td>1.59%</td>
</tr>
<tr>
<td>12</td>
<td>2.37%</td>
</tr>
<tr>
<td>13</td>
<td>7.35%</td>
</tr>
<tr>
<td>14</td>
<td>2.07%</td>
</tr>
<tr>
<td>15</td>
<td>3.43%</td>
</tr>
<tr>
<td>16</td>
<td>5.00%</td>
</tr>
<tr>
<td>17</td>
<td>0.60%</td>
</tr>
<tr>
<td>18</td>
<td>8.50%</td>
</tr>
<tr>
<td>19</td>
<td>0.00%</td>
</tr>
<tr>
<td>20</td>
<td>0.00%</td>
</tr>
<tr>
<td>21</td>
<td>1.94%</td>
</tr>
<tr>
<td>22</td>
<td>0.00%</td>
</tr>
<tr>
<td>23</td>
<td>6.68%</td>
</tr>
<tr>
<td>24</td>
<td>3.92%</td>
</tr>
<tr>
<td>25</td>
<td>12.91%</td>
</tr>
<tr>
<td>26</td>
<td>0.00%</td>
</tr>
<tr>
<td>27</td>
<td>5.69%</td>
</tr>
<tr>
<td>28</td>
<td>6.71%</td>
</tr>
<tr>
<td>29</td>
<td>3.27%</td>
</tr>
<tr>
<td>------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>0.10%</td>
</tr>
<tr>
<td>2</td>
<td>1.43%</td>
</tr>
<tr>
<td>3</td>
<td>8.62%</td>
</tr>
<tr>
<td>4</td>
<td>5.31%</td>
</tr>
<tr>
<td>5</td>
<td>7.97%</td>
</tr>
<tr>
<td>6</td>
<td>0.00%</td>
</tr>
<tr>
<td>7</td>
<td>1.74%</td>
</tr>
<tr>
<td>8</td>
<td>1.34%</td>
</tr>
<tr>
<td>9</td>
<td>2.69%</td>
</tr>
<tr>
<td>10</td>
<td>0.00%</td>
</tr>
<tr>
<td>11</td>
<td>0.74%</td>
</tr>
<tr>
<td>12</td>
<td>1.49%</td>
</tr>
<tr>
<td>13</td>
<td>5.10%</td>
</tr>
<tr>
<td>14</td>
<td>2.67%</td>
</tr>
<tr>
<td>15</td>
<td>3.80%</td>
</tr>
<tr>
<td>16</td>
<td>3.82%</td>
</tr>
<tr>
<td>17</td>
<td>0.61%</td>
</tr>
<tr>
<td>18</td>
<td>6.11%</td>
</tr>
<tr>
<td>19</td>
<td>2.74%</td>
</tr>
<tr>
<td>20</td>
<td>2.49%</td>
</tr>
<tr>
<td>21</td>
<td>1.81%</td>
</tr>
<tr>
<td>22</td>
<td>1.91%</td>
</tr>
<tr>
<td>23</td>
<td>8.01%</td>
</tr>
<tr>
<td>24</td>
<td>3.01%</td>
</tr>
<tr>
<td>25</td>
<td>7.90%</td>
</tr>
<tr>
<td>26</td>
<td>4.36%</td>
</tr>
<tr>
<td>27</td>
<td>3.13%</td>
</tr>
<tr>
<td>28</td>
<td>8.90%</td>
</tr>
<tr>
<td>29</td>
<td>2.20%</td>
</tr>
<tr>
<td>------</td>
<td>-------</td>
</tr>
<tr>
<td>1</td>
<td>0.00%</td>
</tr>
<tr>
<td>2</td>
<td>0.77%</td>
</tr>
<tr>
<td>3</td>
<td>11.48%</td>
</tr>
<tr>
<td>4</td>
<td>8.86%</td>
</tr>
<tr>
<td>5</td>
<td>8.79%</td>
</tr>
<tr>
<td>6</td>
<td>0.00%</td>
</tr>
<tr>
<td>7</td>
<td>1.29%</td>
</tr>
<tr>
<td>8</td>
<td>1.45%</td>
</tr>
<tr>
<td>9</td>
<td>1.99%</td>
</tr>
<tr>
<td>10</td>
<td>0.88%</td>
</tr>
<tr>
<td>11</td>
<td>1.11%</td>
</tr>
<tr>
<td>12</td>
<td>1.26%</td>
</tr>
<tr>
<td>13</td>
<td>4.17%</td>
</tr>
<tr>
<td>14</td>
<td>2.75%</td>
</tr>
<tr>
<td>15</td>
<td>2.09%</td>
</tr>
<tr>
<td>16</td>
<td>3.92%</td>
</tr>
<tr>
<td>17</td>
<td>1.62%</td>
</tr>
<tr>
<td>18</td>
<td>7.52%</td>
</tr>
<tr>
<td>19</td>
<td>2.81%</td>
</tr>
<tr>
<td>20</td>
<td>1.31%</td>
</tr>
<tr>
<td>21</td>
<td>1.30%</td>
</tr>
<tr>
<td>22</td>
<td>3.00%</td>
</tr>
<tr>
<td>23</td>
<td>7.58%</td>
</tr>
<tr>
<td>24</td>
<td>1.60%</td>
</tr>
<tr>
<td>25</td>
<td>3.34%</td>
</tr>
<tr>
<td>26</td>
<td>3.96%</td>
</tr>
<tr>
<td>27</td>
<td>3.85%</td>
</tr>
<tr>
<td>28</td>
<td>7.66%</td>
</tr>
<tr>
<td>29</td>
<td>3.64%</td>
</tr>
<tr>
<td></td>
<td>1982</td>
</tr>
<tr>
<td>---</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>0.00%</td>
</tr>
<tr>
<td>2</td>
<td>2.33%</td>
</tr>
<tr>
<td>3</td>
<td>9.16%</td>
</tr>
<tr>
<td>4</td>
<td>7.60%</td>
</tr>
<tr>
<td>5</td>
<td>6.85%</td>
</tr>
<tr>
<td>6</td>
<td>1.90%</td>
</tr>
<tr>
<td>7</td>
<td>0.78%</td>
</tr>
<tr>
<td>8</td>
<td>1.38%</td>
</tr>
<tr>
<td>9</td>
<td>2.11%</td>
</tr>
<tr>
<td>10</td>
<td>0.77%</td>
</tr>
<tr>
<td>11</td>
<td>0.86%</td>
</tr>
<tr>
<td>12</td>
<td>0.56%</td>
</tr>
<tr>
<td>13</td>
<td>3.64%</td>
</tr>
<tr>
<td>14</td>
<td>3.23%</td>
</tr>
<tr>
<td>15</td>
<td>2.25%</td>
</tr>
<tr>
<td>16</td>
<td>3.63%</td>
</tr>
<tr>
<td>17</td>
<td>2.81%</td>
</tr>
<tr>
<td>18</td>
<td>8.40%</td>
</tr>
<tr>
<td>19</td>
<td>4.06%</td>
</tr>
<tr>
<td>20</td>
<td>3.99%</td>
</tr>
<tr>
<td>21</td>
<td>0.79%</td>
</tr>
<tr>
<td>22</td>
<td>1.45%</td>
</tr>
<tr>
<td>23</td>
<td>7.61%</td>
</tr>
<tr>
<td>24</td>
<td>0.96%</td>
</tr>
<tr>
<td>25</td>
<td>3.29%</td>
</tr>
<tr>
<td>26</td>
<td>3.14%</td>
</tr>
<tr>
<td>27</td>
<td>5.86%</td>
</tr>
<tr>
<td>28</td>
<td>7.92%</td>
</tr>
<tr>
<td>29</td>
<td>2.68%</td>
</tr>
</tbody>
</table>
Abouchar, A. (1971)
EFFICIENCY, THE PREWAR CEMENT INDUSTRY
Bloomington, IN: Indiana University Press.

PRODUCTION DUALITY AND THE VON NEUMANN
THEORY OF GROWTH AND INTEREST
W. Germany: Verlag Anton Hain - Meisenheim Am Glan.

Aigner, D. and S. Chu (1968)
On Estimating the Industry Production Function

LA INDUSTRIA DEL CEMENTO EN MEXICO
Oficina de Asesores del C. Presidente
Mimeo.

Bartlett, G. and J. Lesley (1972)
HISTORY OF THE PORTLAND CEMENT
INDUSTRY IN THE UNITED STATES

CAPITAL UTILIZATION
Cambridge, MA: Cambridge University Press.

MASS PRODUCT INDUSTRY: THE CEMENT INDUSTRY CASES

------, et.al., (1981)
The Cement Industry: Studies in Public
and Private Control
In H.W. de Jong, editor,
THE STRUCTURE OF EUROPEAN INDUSTRY

Bosworth, D. (1976)
PRODUCTION FUNCTIONS: A THEORETICAL
AND EMPIRICAL STUDY
Economic Capacity Utilization and Productivity
Measurement of Multiproduct Firms with Multiple
Quasi-fixed Inputs
WORKING PAPER # 3001-89-EF&A,
Cambridge, MA: M.I.T.

Carlsson, B. (1972)
The Measurement of Efficiency in Production:
An Application to Swedish Manufacturing
Industries 1968

Christensen, L.R. and D. W. Jorgenson (1970)
The Measurement of the U.S. Real Capital
Input 1929-1967
REVIEW OF INCOME AND WEALTH

Collins, N. and L. Preston (1968)
CONCENTRATION AND PRICE-COST MARGINS
IN MANUFACTURING INDUSTRIES

Cowing, T. and R. Stevenson (1981)
Introduction
In T. Cowing and R. Stevenson, editors
PRODUCTIVITY MEASUREMENT IN REGULATED INDUSTRIES

Linear Programming Tests of Regularity
Conditions for Production Functions
In W. Eichhorn, R. Henn, K. Neumann, R. Shephard +, 
editors
QUANTITATIVE STUDIES ON PRODUCTION AND PRICES

Färe, R. (1975)
Efficiency and the Production Function

-------- and C.K. Lovell (1978)
Measuring the Technical Efficiency of Production
--------, et.al., (1985)
THE MEASUREMENT OF EFFICIENCY OF PRODUCTION

Ferguson, C. (1965)
Time Series Production Function and the Rate
of Technical Efficiency of Production
JOURNAL OF POLITICAL ECONOMY (August):

Friedman, J. (1983)
OLIGOPOLY THEORY
Cambridge, MA: Cambridge University Press.

-------- (1987)
Oligopoly Theory
In K.J. Arrow and M.D. Intriligator, editors
HANDBOOK OF MATHEMATICAL ECONOMICS, Vol. II,
Third printing

Førsund, F. and L. Hjalmarsson (1979)
Frontier Production Functions and Technical
Progress, a study of General Milk Processing in
Swedish Dairy Plants

In Pursuit of Monopoly Power: Recent
Quantitative Work in Industrial Economics

Raw Materials, Geological Characteristics,
Nomenclature, Origin, Occurrences and Exploration
In S. N. Ghosh, editor
ADVANCES IN CEMENT TECHNOLOGY

Gorman, W. M. (1965)
Production Functions in Which the
Elasticities of Substitution Stand
in Fixed Proportion to Each Other
Griliches, Z. and V. Ringstad (1971)
ECONOMIES OF SCALE AND THE FORM OF THE PRODUCTION FUNCTION: AND ECONOMETRIC STUDY OF NORWEGIAN MANUFACTURING ESTABLISHMENT DATA

Effects of Carbonate Additions on Heat of Hydration and Sulfate Resistance of Portland Cements
In D. Hooton and K. Klieger, editors
CARBONATE ADDITIONS TO CEMENT

Hulten, C. and F. Wykoff (1981)
The Estimation of Economic Depreciation Using Vintage Asset Prices an Application of the Box-Cox Power Transformation

Intriligator, M. D. (1978)
ECONOMETRIC MODELS, TECHNIQUES, AND APPLICATIONS

Johansen, L. (1972)
PRODUCTION FUNCTIONS

Jones, Alberto S. (1988)
ANALISIS DE LAS TASAS DE RENDIMIENTO DEL CAPITAL: EL COSTO ECONOMICO DEL MONOPOLIO Y LAS DISTORSIONES FISCALES SOBRE EL INGRESO DEL CAPITAL. EL CASO DE MEXICO 1950-1980
B.A. Thesis, I.T.A.M.
Mexico City.

Econometric Methods for Modeling Producer Behavior
In Z. Griliches and M. D. Intriligator, editors
HANDBOOK OF ECONOMETRICS, Vol. III
-------- (1989)
Capital as a Factor of Production
In D.W. Jorgenson and R. Landau, editors
TECHNOLOGY AND CAPITAL FORMATION

--------, et.al., (1987)
PRODUCTIVITY AND U.S. ECONOMIC GROWTH
Cambridge, MA: Harvard University Press.

Judge, G., et.al.,(1985)
THE THEORY AND PRACTICE OF
ECONOMETRICS, Second Edition
New York: Macmillan.

THE ECONOMICS OF REGULATION,
Principles and Institutions
Cambridge, MA: The M.I.T. Press.

PRODUCTION FUNCTIONS, FOREIGN INVESTMENT AND GROWTH,

Klein, L. R. (1974)
A TEXTBOOK OF ECONOMETRICS, Second edition

Kmenta, J. (1986)
ELEMENTS OF ECONOMETRICS, Second Edition
New York: Macmillan

PRODUCTIVITY IN THE UNITED STATES,
TRENDS AND CYCLES
Baltimore: The Johns Hopkins University Press.

Price Levels and Seller Concentration:
The Case of Portland Cement
In L.W. Weiss, editor
CONCENTRATION AND PRICE
The Aggregate Production Function
and The Representative Firm
In F. G. Adams and B. G. Hickman, editors
GLOBAL ECONOMETRICS,
Essays in Honor of Lawrence R. Klein

Lovell, C. and P. Schmidt (1988)
A Comarison of Alternative Approaches
to the Measurement of Productive Efficiency
In A. Dogramaci and R. Färe, editors
APPLICATIONS OF MODERN PRODUCTION
THEORY, EFFICIENCY AND PRODUCTIVITY

Manne, A. (1967)
The Cement Industry
In A.S. Manne, editor
INVESTMENTS FOR CAPACITY ESPANSION
SIZE, LOCATION, AND TIME-PHASING

Mc Fadden, D. (1963)
Further Results on C.E.S. Production Functions
THE REVIEW OF ECONOMIC STUDIES XXX (2): 73-83.

Mansfield, E. (1979)
MICROECONOMIC THEORY AND APPLICATIONS

The Measurement of Capital Services
by Electrical Energy
BULLETIN OF ECONOMIC RESEARCH, 1974.

Capacity Utilization and Productivity Measurement:
An Application to the U.S. Automobile Industry
In A. Dogramaci and R. Färe, editors
APPLICATIONS OF MODERN PRODUCTION
THEORY, EFFICIENCY AND PRODUCTIVITY
Kluwer Academic (Boston-Dodrecht-Lancaster):163-93
Producers Theory
In K. J. Arrow and M. D. Intriligator, editors
HANDBOOK OF MATHEMATICAL ECONOMICS, Vol. II,
Third printing
Amsterdam-New York: North-Holland, 432-90.

---------- and M. Schankerman (1981)
The Structure of Production, Technological
Change, and the Rate of Growth of Total Factor
Productivity in the U.S. Bell System
In T.G. Cowing and R.E. Stevenson, editors
PRODUCTIVITY MEASUREMENT
IN REGULATED INDUSTRIES

Needy, C. (1975)
REGULATION-INDEXED DISTORTIONS

Norman, G. (1979a)
Economies of Scale in the Cement Industry
THE JOURNAL OF INDUSTRIAL ECONOMICS 27.4: 317-37.

---------- (1979b)
ECONOMIES OF SCALE, TRANSPORT COSTS, AND LOCATION

Owen, N. (1983)
ECONOMIES OF SCALE, COMPETITIVENESS AND TRADE
PATTERNS WITHIN THE EUROPEAN COMMUNITY

Pratten C. (1971)
ECONOMIES OF SCALE IN MANUFACTURING INDUSTRY

----------, and R. Dean (1965)
THE ECONOMIES OF LARGE-SCALE PRODUCTION IN
BRITISH INDUSTRY, AN INTRODUCTORY STUDY

Ravenscraft, D. and F. Scherer (1987)
MERGERS, SELL-OFFS, AND ECONOMIC EFFICIENCY
Sato, K. (1975)
PRODUCTION FUNCTIONS AND AGGREGATION
Amsterdam, Holland: North-Holland Publishing Company.

----- (1967)
A Two-Level Constant-Elasticity-Of-Substitution
Production Function

Sherer, F. M. (1980)
INDUSTRIAL MARKET STRUCTURE
AND ECONOMIC PERFORMANCE, Second edition

EFFICIENCY ANALYSIS BY PRODUCTION
FRONTIERS, THE NONPARAMETRIC APPROACH
Boston-Dodrecht-London: Kluwer Academic
Publishers.

Relaxing Price Competition
Through Product Differentiation
REVIEW OF ECONOMIC STUDIES XLIX: 3-13.

Shephard, R. (1953)
COST AND PRODUCTION FUNCTIONS

-------- (1970)
THEORY OF COST AND PRODUCTION FUNCTIONS

-------- (1974)
INDIRECT PRODUCTION FUNCTIONS
W. Germany: Verlag Anton Hain - Meisenheim Am Glan.

Sickles, R. (1985)
A Nonlinear Multivariate Error Components Analysis
of Technology and Specific Factor Productivity
Growth with an Application to the U.S. Airlines
JOURNAL OF ECONOMICS 27: 61-78.
Tinbergen, J. (1979)
Changing Factor Shares and the Translog Production Function
In H.I. Greenfield and others, editors
THEORY FOR ECONOMIC EFFICIENCY

--------- (1985)
PRODUCTION, INCOME AND WELFARE: THE SEARCH FOR AN OPTIMAL SOCIAL ORDER
Lincoln, Nebraska: University of Nebraska Press.

Tirole, J. (1989)
THE THEORY OF INDUSTRIAL ORGANIZATION,
Third Printing
Cambridge, MA: The M.I.T. Press.

Ullman, J. (1988)
THE ANATOMY OF INDUSTRIAL DECLINE, PRODUCTIVITY, INVESTMENT, AND LOCATION IN U.S. MANUFACTURING

In COMMODITY PRODUCTION STATISTICS

Uzawa, H. (1962)
Production Functions with Constant Elasticities of Substitution

Varian, H. (1984a)
MICROECONOMIC ANALYSIS, Second edition
New York: W. W. Norton & Company.

----- (1984b)
The Nonparametric Approach to Production Analysis
ECONOMETRICA 52 (MAY): 579-97.

Von Neumann, J. (1945)
A Model of General Economic Equilibrium
Witt, J. C. (1966)
PORTLAND CEMENT TECHNOLOGY, Second edition
New York: Chemical Publishing Co.