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THE RELATIONSHIP BETWEEN TECHNICAL CHANGE
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THE RELATIONSHIP BETWEEN
TECHNICAL CHANGE AND REPORTED
PERFORMANCE

DISSERTATION
Presented in Partial Fulfillment of
the Requirements for the Degree
Doctor of Philosophy in the
Graduate School of The Ohio
State University

By
William Leroy Felix, Jr., B.S., M.S.

* * * * *
The Ohio State University
1970

Approved by:

[Signature]
Advisor
Department of Accounting
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W. L. F.
VITA

March 21, 1939  ............... Born - Kalispell, Montana

1961 ........................................ B.S., University of Montana, Missoula, Montana

1961-1962 ..................................... Part-time Instructor, Department of Accounting, University of Montana, Missoula, Montana


1964-1966 ..................................... Instructor and Assistant Professor, Department of Accounting, University of Montana, Missoula, Montana

1965 ........................................ M.S., University of Montana, Missoula, Montana

1966-1969 ..................................... Teaching and Research Associate, Department of Accounting, The Ohio State University, Columbus, Ohio

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CHAPTER I

THE RESEARCH PROBLEM

There has been considerable interest in the effects of technological change on all segments of our society in recent years. A likely reason for this interest is the increasing recognition that technology, growing at an increasing rate, influences our society in ways that are not easily understood and that do not fit well into existing models of behavior. Examples of this interest in the social science literature are numerous and include the work of a number of well known economists such as Solow, Massell, Griliches and Kendrick among many others.

1See Appendix A for definitions of some of the terms related to technology used in this paper.


This widespread interest by economists over the last ten to fifteen years is due in part to the inability of existing theories to explain adequately either the flow or the occurrence of technological changes. Many of the works to date have been attempts to develop or adapt tools of analysis that would explain either the incidence or the effect of technical change and, hopefully, to allow some first attempts at policy recommendations.

The work of Kendrick and others using the arithmetic index of output to inputs as a measure of productivity will be of particular interest in this study.\(^1\) The output per unit of input index and the common alternative, a production function explicitly including technological change as a variable\(^2\) are similar in that they are attempts to measure technological change by examining its effects rather than the changes themselves. Schmookler's study of inventions is an exception to this concentration on the effects.\(^3\) The effects of technological change are usually chosen for study because it is extremely difficult to conceive of ways to measure and aggregate the heterogeneous technological changes, particularly when the entity in question is the national economy.

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The business firm is a microeconomic entity that uses and is affected by technological changes. Almost all of the work done by economists has been on the industry or national economy level, but there is reason to hope that the techniques they have developed would be useful in improving our understanding of the influence of technological change on the business firm.

Since the arithmetic index (output per unit of inputs) measure of productivity has been used in studying the influence of technological or technical change on the national economy\(^1\) and the industry level\(^2\), it seems worthwhile to investigate its usefulness for studying the effects of technical change on the business firm. The purpose of this study is to accomplish a part of this investigation of particular interest to the field of accounting. Specifically, in this study the possibility of using the arithmetic index measure of productivity as a means of evaluating the influence of technical change on the reported performance of the firm, as indicated by operating earnings, will be investigated.

The specific plan of this investigation is first to develop the theoretical relationships between technological change and technical change, technical change and productivity, and productivity and performance drawing on economic literature in this area such as Salter's book, *Productivity and Technical Change*.\(^3\) This step will


provide justification for using a productivity measure as a surrogate for a measure of technical change and for expecting productivity to influence reported performance. Second, data are collected from three firms in one industry as an experiment to see if the expected theoretical relationship can be discerned empirically. Because of the possibilities for measurement errors and joint effects on the relevant variables, it is not certain, a priori, that this relationship can be discerned with currently available statistical methods. The regression model will be used in this experiment.

There are a number of comments in the literature emphasizing the importance of knowledge of technical change and productivity to those interested in the business firm. Kendrick and Creamer state "if we can assume proper adjustments to shifting market forces, probably the most important element in successful conduct of a business is the pace of its technological progress as reflected in the reduction of "real" costs (i.e., the physical volume of inputs) per unit of output." If this statement is accepted, then it is important that knowledge of this component of performance be expanded.

An explicit discussion of the importance of technical change to accounting is included in Edwards and Bell's The Theory and Measurement of Business Income. After pointing out the importance of knowledge of technical changes, they argue for excluding any

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specific provision for technical change from reported income on the
grounds that income based on current costs already reflect such
changes.\(^1\) They do not, however, state how the change in current cost
income can be attributed specifically to technical change rather than
some other factor. The problem management faces in determining the
cause of a change in income can be a difficult one. Knowledge of
the effects of technical change on income could be useful to them in
dealing with this problem. Edwards and Bell's position that a per­
formance report should be useful for evaluating different classes
of management decisions (e.g., the separation of income into oper­
ating and holding components) actually supports the attempt to iso­
late that part of reported income caused by technical changes.\(^2\)

\(^1\) Edwards and Bell use the term technological change rather
than technical change. Since their comments seem meant to include
both, no differentiation between the two terms is made here.

\(^2\) Edwards and Bell, Op. Cit.
CHAPTER II
THE ENVIRONMENT OF THE STUDY

Technology, Technological Change, and Technical Change

In Appendix A technology is defined as the social pool of knowledge of the industrial arts. This definition is quite broad. Technology, using this definition, would include all knowledge available for use in physically combining factors to produce output. Examples of technology would include chemical and physical processes, material handling techniques, labor training methods and management techniques. Technological change is defined as the new technology produced in any period. Thus, technological change represents new knowledge available to society for production purposes and includes such diverse events as inventions, development of new educational techniques, and development of new management methods.

Mansfield distinguishes between technological change and scientific advance. He states, "Pure science is directed toward understanding, whereas technology is directed toward use." While this distinction is not of importance here, it is interesting to note the attempt to partition knowledge between that which is useful for understanding and that which is directly useful for industrial activities. It seems clear that this definition is not exclusive,

i.e., there are likely to be components of knowledge that fall in both categories. The main point of this definition may be to identify that subset of useful knowledge that is useful in the industrial arts.

Technical change is defined as the production of a good or service or use of a method or input that is new to the business firm. Technical change occurs when the firm uses some part of the available technology or production knowledge that it has not used previously. If it is assumed that the decision to use a technique is made within the framework of an economic decision model, the chosen technique is expected to be an improvement in the firm's production abilities or a change in output. This improvement could be an improvement in output quality, a new output, a reduction in the inputs needed per unit of output, or some shift in the combination of inputs to take advantage of shifts in input prices. Examples of technical changes in a business firm would include the use of new machinery such as a faster, larger airplane, the use of a new employee training technique such as the use of televised lectures on the operation of a new machine, and new management techniques such as the use of an inventory control model.

While the primary purpose of this paper is to study the effects of technical change on the firm, the relationship between technological change and technical change is important. Technological changes are a major determinant of the environment in which the firm operates and will directly influence the range of alternatives from which the firm's management chooses technical changes.
The following is a summary of an analysis developed by Salter to remedy the lack of a framework for interpreting the empirical results of productivity studies.\(^1\) His analysis develops a framework for viewing the relationship between technological change and technical change. Salter views technical change and productivity as the same phenomenon in his analysis by excluding the other factors influencing productivity. These other factors are the quality of inputs, economies of scale, and degree of utilization according to Stigler.\(^2\)

These factors will be considered in a later section of this chapter.

Salter develops a framework to analyze the flow of technological changes into the technical changes chosen by the firm in two steps. These two steps are (1) the development of "best-practice techniques" and (2) the adjustment of the firm to the changes in best-practice techniques. Best-practice techniques are defined as the techniques at each date which employ the most recent technical advances and are economically appropriate to current factor prices.\(^3\)

The definition of best-practice techniques implies that there are two variables determining best-practice techniques, changing technical knowledge and changing factor prices. The consideration of factor prices as a variable indicates that these prices influence the range of techniques available to the firm. This influence ap-

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\(^1\)Salter, Op. Cit.


pears reasonable since engineers are likely to consider the economic as well as the technical possibilities of a technique before deciding to develop it to the point that it can be used in the business firm.

Salter reclassifies the two variables, changes in technical knowledge and relative factor prices into four variables for his analysis. They are (1) the rate of technical advance, (2) biases toward uneven factor saving, (3) opportunities for factor substitution, and (4) changes in relative factor prices. Using these variables he develops a means of explaining the movement over time of best-practice input requirements (assuming the requirements are affected only by technical change) in terms of three measurements which summarize the influence of the four variables. The three measurements are the general effect of the rate of technical advance, the bias effect arising out of technical advances which tend to save more of one factor than another, and the substitution effect reflecting changes in relative factor prices, including those arising out of technical progress in the manufacture of capital goods.

The functional forms of Salter's relationships with all quantities expressed as proportionate rates of change (denoted by the subscript \( r \)) are as follows:\(^1\)

\[
\begin{align*}
L_r &= T_r - \pi D_r + \sigma \pi (g/w)_r \\
C_r &= T_r + (1-\pi)D_r + \sigma (1-\pi)(w/g)_r 
\end{align*}
\]

where \( L_r \) and \( C_r \) are the proportional rates of change of unit labor

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and capital requirements, $T_r$ is the proportional rate of neutral technical advance, $D_r$ is the proportional bias in the technical advance, $\pi$ is the share of capital costs in total cost, $\sigma$ is the elasticity of substitution, and $(g/w)_r$ is the proportional rate of change in relative factor prices. These relationships explain the movements of best practice labor requirements and capital requirements per unit of output - each in terms of neutral technical advances, the bias of the technical advances toward labor or capital, and the relative changes in factor prices.

More specifically:

$$L_r = \frac{dL}{dt} \cdot \frac{1}{L} \quad \text{and} \quad C_r = \frac{dC}{dt} \cdot \frac{1}{C}$$

$$T_r = \frac{dL}{dt} \cdot \frac{w + dC}{Lw + Cg} \quad \text{and} \quad D_r = \frac{d(C/L)}{dt} \cdot \frac{L}{C}$$

$$\pi = \frac{Cg}{Lw + Cg}$$

$$\sigma = \frac{d(C/L)}{C/L} \left[ \frac{g/w}{d(g/w)} \right]$$

$$(g/w)_r = \frac{d(g/w)}{dt} \cdot \frac{w}{g}$$

$$(w/g)_r = \frac{d(w/g)}{dt} \cdot \frac{g}{w}$$

where $L$ is labor, $w$ is the labor price, $C$ is capital, $g$ is the capital price, and $t$ is time. The result of a neutral technical advance would be negative values for both $dL/dt$ and $dC/dt$. As the above formulation indicate, $T_r$ would be negative resulting a decline in both
L_r and C_r as expected. If there is a labor-saving bias in the technical advance, d(C/L)/dt will be positive making D_r positive. A positive D_r results in an increase in C_r and a decrease in L_r, as expected. The effect would be reversed if there were a capital-saving bias in the technical advance. If a price shift reducing the price of labor relative to that of capital occurs, d(g/w)/dt will be positive which results in (g/w)_r > 0. This result indicates an increase in L_r the proportional rate of change of unit labor requirements, as expected. In this situation d(w/g)/dt > 0 so that (w/g)_r > 0 indicating that C_r will fall, as expected. The same analysis of a relative reduction in the capital price would result in the reverse effects on L_r and C_r. It is important to remember that the above analysis is in terms of constant output and that the conceptual input requirement variables C_r and L_r are the reciprocals of the two partial productivities. The neutral and biased advance classifications are comparable to the Hicksian classification. His labor-saving technical advance would reduce L_r, and his capital-saving advance would reduce C_r.

While Salter's analysis does not extend to the consideration of total factor requirements, the extension of his relationships might be some function:

\[ Q_r = f [T_r, D_r, (g/w)_r] \]

where Q_r is the proportional rate of change in unit requirements of all factors weighted in some way for aggregation of the inputs. Direct addition of Salter's two functions would not be equivalent to the reciprocal of the total factor productivity index used in this
study (and defined in a later chapter).

The analysis of the flow of best-practice techniques, outlined above, is essentially concerned with how an economic system determines the spectrum of techniques that will become available to the firm. The next part of the analysis considers how the firm (or industry) would adjust to a flow of improving techniques. In this part of his analysis Salter assumes a highly simplified model of an industry made up of a number of plants. Each plant is an indivisible complex of capital equipment which embodies the best-practice technique of its construction date and cannot be adapted to other techniques. He also assumes perfect competition; that all plants work at "normal" capacity and have no scrap value; and that labor and managerial efficiency are equal in all plants. After developing his model using these assumptions, Salter does consider the effect of relaxing some of the more important assumptions such as competition and adaptation of existing equipment.

The industry being modeled is a collection of plants which include techniques ranging from current best-practice techniques in the newest plant to the outmoded techniques of the oldest plant. The range of techniques in existence is defined by the condition that plants are not scrapped until their operating costs per unit of output exceed price. As new best-practice techniques appear,

\[ L_r = \frac{AL}{L} \quad \text{and} \quad C_r = \frac{AC}{C} \]

Their sum would be \[ \frac{AC + AL}{C} \] rather than \[ \frac{C_0 + Lw}{C} \]; \( \theta \) is output.

\[ 1 \]The discrete formulations would be \[ L = A_k \frac{k^2}{k} \] and \[ C = A_k \frac{k^2}{k} \].
industry output will expand until price falls to equality with the
total costs per unit including amortization and interest on plants
employing the new technique. Older plants will be scrapped until
the operating costs per unit of the oldest plant just equals the
new price... A flow of best-practice techniques will lead to a series
of equilibria and chart the time path of technical changes in the
industry.

Salter's analysis concentrates on the study of capital em-
bodied technical change in an industry, but it provides a reasonable
indication of the effect of all types of technical change on the
firm. In summary this analysis incorporates the view of the firm
facing a continuously changing spectrum of best-practice techniques
where many of the techniques are embodied in capital goods requiring
investment. Because of this common requirement for investment, the
adjustment process often is a lagged or step function where best-
practice techniques are chosen at the point of replacement or ex-
pansion of capital goods. At any point in time only the most recent-
ly constructed plants will reflect current best-practice techniques.
The productivity of the firm (or industry) will reflect a weighted
average of the techniques in use which in turn reflect, at least in
part, the best-practice techniques as of the date of installation of
the capital equipment associated with the techniques in use.

The path of useful knowledge has been traced from the unde-
veloped knowledge of pure science to best-practice techniques and
from best-practice techniques to techniques chosen by the firm.
These techniques chosen by the firm represent the technical changes that are of primary interest in this paper. Since it is difficult to obtain data on technical changes themselves, a surrogate of technical change, productivity, has been selected in this study to see if it lends itself to the investigation of the effects of technical change on the firm. The term productivity in this paper means the arithmetic index of output per unit of inputs. This definition is expanded later in this chapter.

Technical Change and Productivity

In this section of the paper the relationship between technical change and productivity will be discussed. As mentioned above, productivity is used in this study as a surrogate for technical change because of the difficulties inherent in the measurement and aggregation of technical change. These measurement and aggregation difficulties are discussed next and are followed by the discussion of the relationship between technical change and productivity.

In considering methods of measuring technical change, a paper by Simon Kuznets on the definition and measurement of technical change is relevant. He states,\(^1\)

The problem of measurement, of reducing these changes to a common denominator that would permit numerical comparisons, is therefore, largely the task of reconciling the need for identification of the changes, which calls for distinctiveness, with the need for anonymity, for the required homogeneity of countable units.

Thus, in an attempt to measure technical change a trade-off between specific measures, which are easy to measure but difficult to aggregate, and general measures, which are difficult to measure but easy to aggregate, can be expected.

In the specific measure of technical change, the object of count is kept specific and a narrowly defined aspect of technical change would be measured. For example, the replacement of some switchboard telephone exchanges with automatic exchanges is a technical change. If it is measured by a count of new exchanges, this could be termed a specific measure.

In a general measure of technical change a wide variety of technical changes are included in one measure which conceals this variety under some relatively artificial aggregating device. An example of a general measure of technical changes might be the dollar amount expended on the new telephone exchanges in the previous example. The use of dollar cost makes aggregation easy, but may not facilitate analysis of the technical changes.

In order to avoid the difficulties of measuring technical change directly, an indirect measure of technical change, productivity, is used in this study. An additional advantage to choosing productivity as a surrogate for technical change is that the needed data appear to be more readily available. A discussion of the extent to which measured productivity can be expected to include technical changes follows.

The specific formulation of the productivity index used in
the empirical part of this study is discussed in Chapter IV. Pro-
ductivity, so defined, is a measurement of results. As mentioned
above, Stigler has classified the potential causes of a change in
productivity into:

1. A technical change.
2. A change in the quality of inputs.
3. A change in economies of scale.
4. A change in the degree of utilization of facilities.

In this paper the change referred to will be an increase or an im-
provement unless otherwise indicated. The above four-way classifi-
cation will be incorporated in the following discussion of technical
changes and productivity.

In evaluating the effect of technical change on productivity,
it is convenient to consider the type of output unchanged. Concep-
tually this is desirable because, although the definition of techni-
cal change includes the possibility of a new or improved output, a
comparison of measured productivity between two periods with differ-
ent kinds of output is difficult. The measure of output must somehow
make two basically different outputs comparable. On a practical
level this problem is avoided in this study by choosing firms in an
industry whose output has not changed. The characteristics of kilo-
watt hours (kwh) of electricity provided by firms in the electric
power industry have not changed over time. Subsequent discussions
of technical change will incorporate the assumption of unchanged
output quality.

Stigler's classification indicates that productivity can be
characterized by the following functional relationships:

\[ Q = f(T, W, Z, U) \]

where \( Q \) is productivity, \( T \) is technical change, \( W \) is input quality change, \( Z \) is the change in returns to scale, and \( U \) is the change in utilization of capacity. If direct measurement were possible, the \( T \) variable, as defined in this paper, would be used in this study. However, of the four variables on the right-hand side of the above relationships only \( U \), the utilization variable, is directly measurable. In this study \( Q \) is used as a measure of technical change with effect of \( U \) held constant in the statistical model. This procedure leaves the influence of \( W \), input quality changes, and \( Z \), changes in returns to scale, in the model where they might distort the desired relationship. Each of the four influences represented above is discussed in the following sections with particular attention given to input quality changes and changes in returns to scale and their effect on this study.

Technical Change

In terms of results technical changes involving the use of a new method or input can be classified into (1) a change that saves inputs relative to outputs, (2) a change that increases output relative to inputs, (3) a change that takes advantage of shifts in factor prices, and (4) a change instituted for non-economic reasons. The first two classes directly affect productivity. The third class of change does not appear to have a necessary conceptual relationship to productivity. However, the definition of technical change in this
paper includes changes in techniques due to substitution effects. The productivity measure used in this paper (specified in detail in Chapter IV) is an index or relative change computation as follows:

\[
Q_{12} = \frac{\theta_2}{\theta_1} \left[ \frac{K_1P_{k1} + N_1P_{n1}}{K_2P_{k1} + N_2P_{n1}} \right]
\]

where \( \theta_1 \) is output in period 1, \( K_1 \) and \( N_1 \) are inputs in period 1, and \( P_{j1} \) is the price of input \( j \) in period 1. If in period 2 the price of \( N \) increases to the extent that a shift in inputs is desirable, then \( K_2 \) would be increased and \( N_2 \) would be decreased from what would otherwise be expected. The exact effect of this shift on \( Q_{12} \) is uncertain since the inputs move in opposite directions by unknown, weighted amounts. But it is likely that the effect on \( Q_{12} \) will be small unless the input shifts are large (a somewhat unlikely event over the one year time periods used in this study). The effect of the shift on \( Q_{2,3} \) and subsequent elements of the \( Q \) series is also minimal since the effect of the input and price changes will appear in both the numerator and denominator of the input function.

As the above discussion indicates, the proxy used for technical change in this study may not do a good job of reflecting the influence of price-motivated substitution of factors. This weakness is undesirable, but a solution is not readily available. As a practical matter, this apparent weakness may not exist. The adjustment of the firm to shifts in factor prices takes time. It is likely that \( P_{j1} \), which is an annual average price will reflect, at least in part, the price shift to which the firm is adjusting in period 2. In this
case the weighted inputs in the denominator in $Q_{12}$ would be smaller than the numerator resulting in the desired effect on productivity.

A technical change in the fourth classification above does not appear to have any necessary relationship to productivity. The result that the productivity series may not reflect this class of technical change is not considered important.

Changes in the Quality of Inputs

A change in input quality could affect productivity in any of the following ways:

1. A change in input quality might change the quality of output. If the output were price weighted, the expected change in output price would change productivity. This effect is relatively unimportant in this study since the output of the industry studied here has constant quality (see the discussion in Chapter IV).

2. A change in input quality might result in a change in the amount of input required per unit of output. This change would have a direct effect on the productivity computation.

3. A change in input quality might include a change in input price along with the effect indicated in 2 above. The expected direction of the price change would be the opposite of the change in unit input requirements. Again looking at the expression for $Q_{12}$ above, it can
be seen that a fall in $K_2$ due to an input quality improvement is weighted by the previous period's price. For this reason the productivity measure will reflect this change in input quality. $Q_{23}$ and subsequent elements of the series will not reflect the change.

The cause of a change in input quality may be either a decision by the firm's management or a change in the firm's environment. A combination of these causes is also possible. An example of a change in input quality due to changes in the firm's environment might be the overall improvement of the national labor force due to improving education and health. An example of a change in input quality due to a management decision might be the purchase of a better quality of fuel. A change in input quality due to a management decision is a technical change as defined in this paper. This implies that the definition used here differs from Stigler's definition. This difference may be due in part to the macroeconomic emphasis of his analysis.

In summary, the productivity measure can be expected to reflect changes in input quality. To the extent that these changes are not due to management decisions, the productivity measure is not reflecting precisely what is intended. However, a correction for this effect, which may not be too large over the twenty-one year period of this study, does not appear to be possible.

The comment that the productivity measure will reflect changes in input quality should be qualified to the extent that the Input
measurements reflect quality changes. The fuel input is measured in British Thermal Units (BTU) which are of constant quality. The capital and labor inputs are measured in units that are likely to reflect some changing quality. The labor input is measured in man-years and the capital input is measured in terms of deflated cost (these variables are specified in Chapter IV). To the extent that these input measures are not of constant quality, the effect of input quality changes will be reflected by the productivity measure.

In this study no attempt was made to remove the influence of input quality changes from the labor and capital inputs. This decision was based in part on the difficulty of obtaining a constant quality measurement of these inputs and the desire to include the effect of quality changes due to management decisions. A potential error is included to the extent that environmental caused changes are important. The fact that the fuel input measure holds input quality constant is not considered important since the fuel quality does not appear to have changed significantly over the period of study. The measurement technique for fuel was chosen to facilitate aggregation of different types of fuel.

Changes in Returns to Scale

Lloyd describes the scale phenomenon as having to do with the change in output that occurs when the firm increases its use of all factors in the same proportion.\(^1\) If the proportionate change in out-

put is less than the proportionate change in all factors, the firm is said to be producing under decreasing returns to scale; if the proportionate change in output is the same as the proportionate change in all factors, the firm is said to be producing under constant returns to scale; and if the proportionate change in output is greater than the proportionate change in all factors, the firm is said to be producing under increasing returns to scale.

As Stigler suggests, this scale phenomenon could have an effect on the arithmetic index computation of total factor productivity. For example, if the firm is producing under increasing returns to scale, an increase in productivity when output is increased will be due in part to the scale phenomenon.

For purposes of this study there are two relevant questions. First, is it necessary to control the effect of the scale phenomenon in this study? And secondly, if the effect of the variable is to be controlled, what data series would best measure the effect of the scale phenomenon? The following paragraphs consider these two questions.

The distinction between technical change and the scale phenomenon is not clear. It may be that in a particular case the proportionate increase in output is greater than the proportionate increase in all factors because management is able to make use of better techniques when the scale of operations expands. It appears that the scale phenomenon may be due, at least in part, to changes that are defined in this paper as technical changes. In commenting on Stigler's article, Solow points out that the effects of increasing scale and
technical change are mixed. Given this situation, there does not appear to be a clear answer to the first question.

The above comments are likely to doom any attempt to measure the scale phenomenon to failure. An indirect measurement of the scale phenomenon is likely to also measure technical change. A direct measurement of returns to scale is probably impossible since the condition of an increase in the use of all factors in the same proportion with no changes in techniques is very unlikely in an operating firm.

In summary, it seems reasonable that there should be no attempt to control the effects of the scale phenomenon in this study. Technical change, as broadly defined in this study, may be the cause of a major part of the phenomenon defined as returns to scale. In addition there does not appear to be any way of measuring the effect of the scale phenomenon to the extent that it does exist.

Changes in the Degree of Utilization

A change in the degree of utilization of facilities can also be expected to influence the measured productivity. The effect of this variable will be specifically accounted for in the experimental model. The variable will be specified in Chapter IV.

Summary

While the above discussion indicates that measured productivity is a reasonable measure of technical change in the firm, it does have

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some imperfections that could confuse relationships of interest to an experimenter. This makes a consideration of alternative measures of technical change worthwhile. Some possibilities considered for this study include expenditures for research and development, expenditures for research and development and employee development and training, and the number of new patent applications. The primary reason for rejecting these alternatives is that they appear to be approximating technical changes generated within the firm. For many firms the larger part of technical change will come from techniques and methods developed elsewhere. Measured productivity appears to be a better means of reflecting all the technical changes in the firm than these alternatives.

Productivity is commonly used as a measure of technical change in research in economics. Economists who have made use of this technique include Kendrick, Solow, Salter, and Fabricant. Fabricant makes the following comment regarding the use of productivity to measure technological change:

Probably the average economist, as distinct from the man in the street, would consider the index of output per unit of labor and capital input, with allowance made for education, as probably the best available measure of technological change that we have. In fact, economists usually call it the measure of technological change.

The qualifications on using productivity as a measure of technological change:

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change are more extensive than for its use as a measure of technical change. In addition to the influences on productivity other than technical change, the lack of relationship between changes in knowledge (technological changes) and productivity must be considered. The use of productivity measurement, given its apparent weaknesses, can be justified in part by the difficulty of finding acceptable alternatives, particularly at the level of macro-analysis where most economists operate.

Productivity as a General Term

The term productivity is used in at least two ways. It is used in a qualitative sense to refer to quality or state of being productive. For instance, one might refer to the productivity of a farm and mean that the land is fertile. Productivity has also been given the more precise meaning of a quantitative relationship. Productivity used in this quantitative sense is usually a ratio between output and any or all of the associated inputs all in real (physical) terms. There is some variation possible in the exact form of this ratio with respect to the aggregation of the inputs. The most common form of this aggregation is the sum of price weighted inputs. This form is used in this study.

The meaning of measured productivity can vary depending on the specific inputs and output used. For example, the productivity of an individual machine operator can be computed using his labor hours as input and the number of units he completes as output. In con-

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trast, an overall measure of firm productivity should include all output including production and, if significant, other services such as product distribution.

The use of the output per unit of input technique has been popular in economics because it requires little prior knowledge of the production process. Barzel suggests that if economists were able to estimate a firm's production function accurately, the measurement of changes in productivity would be simple and precise. The change in productivity would be the observed shift in the production function over time. Barzel then argues that this point is of considerable importance in explaining the use of productivity analysis in economics.

It seems appropriate at this time to point out that if analysis of productivity is used as a substitute for analysis of production functions, then some assumptions about the form of the firm's production function are being made. For example, if productivity, Q, is conceptualized as the ratio between price weighted output and the sum of price weighted inputs as follows:

$$Q = \frac{\theta \cdot P_o}{\sum_{i=1}^{n} (I_i P_i)}$$

then it appears that Q is the technical coefficient in a price-weighted production function as follows:

$$\theta \cdot P_o = Q \left[ \sum_{i=1}^{n} (I_i P_i) \right]$$

Since production functions are usually in real terms without price weights and usually have inputs aggregated as products (exponentially weighted in the Cobb-Douglas production function), this is a rather unusual function. Also, the production function is usually viewed as a production "frontier" representing the maximum output possible for a given set of inputs and existing techniques. Salter comments that production functions with their implied emphasis on long-run static equilibrium analysis are particularly unsuited for the analysis of changes in productivity. His comment is based on the fact that the firm's measured productivity reflects a continuing process of adaptation to changing techniques and changing prices. The firm is very unlikely to achieve the static equilibrium implied by the ordinary microeconomic production function.

In this study the arithmetic index of total factor productivity is used. As the above comments indicate, this technique is not a means of avoiding an analysis of the firm's production function. An assumption about the firm's implied or operating production function is being made and, as Domar points out, this function has the weakness of assuming that the marginal products of the inputs are dependent only on a change in "other forces" and always in the same proportion, so that their ratios remain constant and independent of

the ratio of the quantities of the inputs.\textsuperscript{1,2} However, this apparent weakness is based on theoretical grounds. At this point there is no basis for picking a particular production function as being the best approximation of the operating production relationship for firms in the industry studied here. For this reason the use of the arithmetic index, which has been used on the selected industry with satisfactory results, seems reasonable.\textsuperscript{3}

When measuring productivity, the output measured should, in theory, be physical output but will often be approximated by using the real dollar value of output because of the heterogeneity of even one firm's output and the problem of obtaining data on physical output. Inputs are often approximated in the same manner. In measuring productivity for a firm, the two basic factors in the classical pro-


\textsuperscript{2}Given the function:

\[ Q = \frac{\theta \cdot P_o}{K P_k + N P_n} \]

\[ \theta \cdot P_o = Q K P_k + Q N P_n \]

\[ \theta = Q K \frac{P_k}{P_o} + Q N \frac{P_n}{P_o} \]

\[ \frac{\delta \theta}{\delta K} = Q \frac{P_k}{P_o} \quad \text{and} \quad \frac{\delta \theta}{\delta N} = Q \frac{P_n}{P_o} \]

\textsuperscript{3}Barzel, Op. Cit.
duction function, capital and labor, are included at a minimum. Additional inputs may be included depending on the characteristics of the economic unit under study.
CHAPTER III

THE EXPERIMENTAL HYPOTHESIS

The hypothesis for the empirical experiment reported in this paper is that:

The relative (or proportional) changes in total factor productivity will explain a significant part of the relative changes in reported performance when the effects of certain other variables (specified in Chapter IV) are held constant.

The estimation of the degree of explanation will be made using the regression model. A more detailed discussion of the estimation and related tests appears in Chapter IV.

To establish an a priori reason for this hypothesis, two relationships will be used, one describing earnings or reported performance \( Y \) and the other describing productivity \( Q \). The relationships are:

\[
Q = \theta P_o (K P_k + N P_n + F P_f)^{-1}
\]

\[
Y = \theta P_o - (K P_k + N P_n + F P_f)
\]

where \( \theta \) is output, the input variables are capital \( K \), labor \( N \), and fuel \( F \), and the \( P_i \)'s are the associated prices. There are operating costs excluded from \( Y \) in the above expression. This and other differences between these two expressions and those used in Chapter IV are discussed at the end of this chapter. In the following analysis the prices \( (P_i) \) are held constant and all output is assumed to be sold.
Since the changes to be studied here are across time, the relationships in the previous paragraph can be restated as a function of time \( t \) as follows:

\[
Q(t) = \theta(t) \cdot P_0 \left[ K(t) P_k + N(t) P_n + F(t) P_f \right]^{-1}
\]

\[
Y(t) = \theta(t) \cdot P_0 - \left[ K(t) P_k + N(t) P_n + F(t) P_f \right]
\]

Letting \( g(t) = K(t) P_k + N(t) P_n + F(t) P_f \),

\[
Q(t) = \theta(t) \cdot P_0 \cdot g^{-1}(t)
\]

\[
Y(t) = \theta(t) \cdot P_0 - g(t)
\]

The derivatives with respect to time are

\[
Q'(t) = \theta'(t) \cdot P_0 \cdot g^{-1}(t) - \theta(t) \cdot P_0 \cdot g^{-2}(t) \cdot g'(t)
\]

\[
Y'(t) = \theta'(t) \cdot P_0 - g'(t)
\]

The purpose of the following analysis is to show what conditions on the input and output variables are necessary for a change in productivity to imply a change in reported performance in the same direction. To accomplish this task, it is necessary to determine what conditions on the variables are needed to show that the existence of \( Q'(t) \) implies the existence of \( Y'(t) \) in the same direction. Pre-existing conditions on the variables are:

\[
0 < P_i \text{ for all } P_i \text{ and } P_i's \text{ are held constant}
\]

\[
0 \leq K, N, f
\]

\[
0 < \theta
\]

\[
0 < g(t)
\]

The results of the following analysis are summarized in Table 1 which shows the possible combinations of movements of the variables and the resulting conceptual effect on the hypothesis.
Table 1
RESULTS OF THE CONCEPTUAL ANALYSIS

<table>
<thead>
<tr>
<th></th>
<th>$Q'(t) &gt; 0$</th>
<th>$Q'(t) = 0$</th>
<th>$Q'(t) &lt; 0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Q(t)$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$&gt; 1$</td>
<td>$= 1$</td>
<td>$&lt; 1$</td>
<td></td>
</tr>
<tr>
<td>$&lt; 0$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The symbol $S$ indicates that the hypothesis is sustained and the symbol $CP$ indicates that a contradiction of the hypothesis is possible. The explanation of the other symbols is included in the preceding text.
The following analysis is used repeatedly in considering different conditions on the variables and is summarized here to minimize repetition. The variable conditions to be used in this analysis are (1) the direction in which productivity is changing indicated by the sign of \( Q'(t) \), (2) the direction in which output is changing indicated by the sign of \( \theta'(t) \), and (3) the arithmetic sign of earnings. This last condition will limit the range of \( Q(t) \) since if

\[
0 < Y(t)
\]

or

\[
0 < \theta(t) \cdot P_o - g(t)
\]

or

\[
g(t) < \theta(t) \cdot P_o
\]

then \( Q(t) = \theta(t) \cdot P_o \cdot g^{-1}(t) \) is in the range \((1, \infty)\). If earnings are negative, the same argument will result in \( 0 < Q(t) < 1 \).

Each step in the analysis will begin with a condition on the direction of the change in productivity as indicated by the sign of \( Q'(t) \). For example, when \( Q'(t) > 0 \)

\[
0 < Q'(t)
\]

or

\[
0 < \theta'(t) \cdot P_o \cdot g^{-1}(t) - \theta(t) \cdot P_o \cdot g^{-2}(t) \cdot g'(t)
\]

or

\[
0 < \theta'(t) \cdot P_o - \theta(t) \cdot P_o \cdot g^{-1}(t) \cdot g'(t)
\]

or

\[
0 < \theta'(t) \cdot P_o - Q(t) \cdot g'(t)
\]

(1)

Under some conditions additional analysis as follows is used.

\[
0 < \theta'(t) \cdot P_o - Q(t) \cdot g'(t)
\]

or

\[
\theta'(t) \cdot P_o > Q(t) \cdot g'(t)
\]

or

\[
\theta'(t) \cdot P_o > \theta(t) \cdot P_o \cdot g^{-1}(t) \cdot g'(t)
\]

or

\[
\frac{\theta'(t) \cdot P_o}{\theta(t) \cdot P_o} > \frac{g'(t)}{g(t)}
\]

(1i)
using the same approach, when \( Q'(t) < 0 \)

\[
0 > \theta'(t) \cdot P_0 - Q(t) \cdot g'(t) \tag{iii}
\]

and \( \frac{\theta'(t) \cdot P_0}{\theta(t) \cdot P_0} < \frac{g'(t)}{g(t)} \) \tag{iv}

**Increasing Productivity**

The first case to be considered when productivity is increasing \( (Q'(t) > 0) \) is where earnings are positive \( (1 < Q(t)) \) and output is increasing \( (\theta'(t) > 0) \). Using (i)

\[
0 < \theta'(t) \cdot P_0 - Q(t) \cdot g'(t)
\]

and since \( \theta'(t) \cdot P_0 - Q(t) \cdot g'(t) < \theta'(t) \cdot P_0 - g'(t) \) when \( Q(t) > 1 \) and \( g'(t) > 0 \)

\[
0 < \theta'(t) \cdot P_0 - g'(t)
\]

or \( 0 < \theta'(t) \cdot P_0 - g'(t) \)

and if \( g'(t) < 0 \)

\[
0 < \theta'(t) \cdot P_0 - g'(t)
\]

0 < \( \theta'(t) \cdot P_0 \)

These are the desired result, and they indicate that no contradictions of the hypothesis will occur under these conditions.

The second case to be considered is where earnings are positive \( (Q(t) > 1) \) and output is falling \( (\theta'(t) < 0) \). Using (ii)

\[
\frac{\theta'(t) \cdot P_0}{\theta(t) \cdot P_0} > \frac{g'(t)}{g(t)}
\]

or \( \frac{g(t)}{\theta(t) \cdot P_0} < \frac{g'(t)}{\theta'(t) \cdot P_0} \)

or \( 0 < \frac{g(t)}{\theta(t) \cdot P_0} \)

or \( 0 < \frac{g'(t)}{\theta'(t) \cdot P_0} \)
Since $\theta'(t) \cdot P_0 < 0$, $g'(t) < 0$. In this case to show that $Y'(t) = \theta'(t) \cdot P_0 - g'(t) > 0$, it is necessary to add the condition that $g'(t) < \theta'(t) \cdot P_0$. When $0 > g'(t) \geq \theta'(t) \cdot P_0$, the research hypothesis is contradicted since $Q'(t) > 0$ and $Y'(t) \leq 0$.

When earnings are positive ($Q(t) > 1$) and output is unchanged ($\theta'(t) = 0$) and using relationship (i),

$$0 < \theta'(t) \cdot P_0 - Q(t) \cdot g'(t)$$

or

$$0 < -Q(t) \cdot g'(t)$$

or

$$0 > g'(t)$$

and $Y'(t) = \theta'(t) \cdot P_0 - g'(t)$

or

$$Y'(t) = -g'(t)$$

or

$$Y'(t) > 0$$

This is the desired result indicating no contradiction of the research hypothesis. This result also holds when earnings are negative ($Q(t) < 1$).

When earnings are negative ($Q(t) < 1$) and output is increasing ($\theta'(t) > 0$), using relationship (ii)

$$\frac{\theta'(t) \cdot P_0}{\theta(t) \cdot P_0} > \frac{g'(t)}{g(t)}$$

or

$$\frac{g(t)}{\theta(t) \cdot P_0} > \frac{g'(t)}{\theta'(t) \cdot P_0}$$

provides no assurance that $g'(t) < \theta'(t) \cdot P_0$ because

$$\frac{g(t)}{\theta(t) \cdot P_0} > 1$$

When $g'(t) \geq \theta'(t) \cdot P_0$ and $Q'(t) > 0$, $Y'(t) \leq 0$ and the research hypothesis is contradicted.

When earnings are negative ($Q(t) < 1$) and output is decreasing
\( (\theta'(t) < 0) \), using relationship (ii)

\[
\frac{\theta'(t) - P_O}{\theta(t) - P_O} > \frac{g'(t)}{g(t)}
\]

or \( \frac{g(t)}{\theta(t) - P_O} < \frac{g'(t)}{\theta'(t) - P_O} \)

or \( 1 < \frac{g(t)}{\theta(t) - P_O} \)

or \( 1 < \frac{g'(t)}{\theta'(t) - P_O} \)

or \( g'(t) < \theta'(t) - P_O \)

or \( \gamma'(t) > 0 \)

The last expression is the desired result indicating that no contradictions of the hypothesis will occur under these conditions.

**Decreasing Productivity**

To complete this analysis, the cases where productivity is declining \( (Q'(t) < 0) \) must be considered. These cases are included in spite of relevant industry statistics showing consistent annual increases in productivity because of the possibility that a particular firm selected for study here may vary from the industry pattern.\(^1\)

When earnings are positive \( (Q(t) > 1) \) and output is increasing \( (\theta'(t) > 0) \), using relationship (iv)

\[
\frac{\theta'(t) - P_O}{\theta(t) - P_O} < \frac{g'(t)}{g(t)}
\]

or \( \frac{g(t)}{\theta(t) - P_O} < \frac{g'(t)}{\theta'(t) - P_O} \)

or \( 0 < \frac{g(t)}{\theta(t) - P_O} \)

From the formulation of \( Y'(t) = \theta'(t) \cdot P_o - g'(t) \), it can be seen that \( Y'(t) < 0 \), as desired, when \( g'(t) > \theta'(t) \cdot P_o \). However, a contradiction to the hypothesis occurs when \( 0 < g'(t) < \theta'(t) \cdot P_o \) and this event is possible under subject conditions on the variables.

When the firm has positive earnings (\( Q(t) > 1 \)) and output (\( \theta'(t) < 0 \)), using relationship (iv)

\[
\frac{\theta'(t) \cdot P_o}{g(t) \cdot P_o} < \frac{g'(t)}{g(t)}
\]

or 
\[
\frac{g(t)}{\theta(t) \cdot P_o} > \frac{g'(t)}{\theta'(t) \cdot P_o}
\]

or 
\[
1 > \frac{g(t)}{\theta(t) \cdot P_o}
\]

or 
\[
1 > \frac{g'(t)}{\theta'(t) \cdot P_o}
\]

or 
\[
g'(t) > \theta'(t) \cdot P_o
\]

or 
\[
0 > \theta'(t) \cdot P_o - g'(t)
\]

or 
\[
0 > Y'(t)
\]

Since this is the desired result, no contradictions to the research hypothesis are indicated under this set of conditions.

As under the condition of increasing productivity, when output is constant (\( \theta'(t) = 0 \)), it does not matter whether earnings are positive or negative. The hypothesis is sustained under either condition as follows; using relationship (iii)

\[
0 > \theta'(t) \cdot P_o - Q(t) \cdot g'(t)
\]
or \( 0 > -Q(t) \cdot g'(t) \)

or \( 0 > g'(t) \)

or \( Y'(t) = \theta'(t) \cdot P_o - g'(t) \)

or \( Y'(t) = -g'(t) \)

or \( Y'(t) < 0 \)

When earnings are negative \((Q(t) < 1)\) and output is increasing

\((\theta'(t) > 0)\), using relationship (iii)

\[ 0 > \theta'(t) \cdot P_o - Q(t) \cdot g'(t) \]

\[ \theta'tP_o - Q(t) \cdot g'(t) > \theta'(t) \cdot P_o - g'(t) \]

\[ 0 > Y'(t) \]

when \(g'(t) > 0\). A contradiction will occur when \(g'(t) < 0\).

When earnings are negative \((Q(t) < 1)\) and output is falling

\((\theta'(t) < 0)\), using relationship (iii)

\[ 0 > \theta'(t) \cdot P_o - Q(t) \cdot g'(t) \]

will imply \(0 > \theta'(t) \cdot P_o - g'(t)\)

or \(0 > Y'(t)\)

when \(g'(t) > 0\). When \(g'(t) < 0\), a contradiction to the hypothesis will exist when \(g'(t) \leq \theta'(t) \cdot P_o\).

No Change in Productivity

When \(Q'(t) = 0\),

\[ 0 = \theta'(t) \cdot P_o - Q(t) \cdot g'(t) \]

This result will imply \(Y'(t) = 0\) only when \(Q(t) = 1, \theta'(t) \cdot P_o = 0\), or \(g'(t) = 0\). In all other cases, \(Y'(t)\) will vary around \(Q'(t)\) depending on the size of \(Q(t)\) and the sign of \(\theta'(t)\) and \(g'(t)\). The possibility of \(Q'(t) = 0\) in a selection of years from a firm seems
very small. Even if the dynamic nature of the U.S. economy is ignored, the remoteness of the possibility would exist because of measurement errors.

Summary

The conditions under which contradictions of the research hypothesis can exist are:

1. When the change in productivity is positive, either the combination of positive earnings and falling output or negative earnings and increasing output can result in a contradiction of the hypothesis.

2. When the change in productivity is negative, either the combination of positive or negative earnings and increasing output or negative earnings and falling output can result in a contradiction of the hypothesis.

3. When there is no change in productivity, the hypothesis will be contradicted unless \( Q(t) = 1 \), \( \theta'(t) = 0 \), or \( g'(t) = 0 \).

The conditions in case three above are very unlikely to exist. Some change in productivity is almost certain to occur over time in a real firm. The conditions under cases one and two are possible. If they occur in the subject firms, some reduction in the measured relationship can be expected.

The conditions that seem most likely to occur in a regulated utility in the period, 1947-1967, are increasing productivity, positive earnings, and increasing output. This set of conditions sus-
tained the hypothesis in the above analysis. The increasing output and positive earnings seem particularly reasonable due to the expansion of the national economy and the stable, regulated earnings of these companies. The increasing productivity, while likely to occur most of the time, is not quite as secure an observation since measured productivity could fluctuate depending on the rate at which the firm utilizes new techniques. This set of conditions where productivity is falling, output is increasing, and earnings are positive, can result in a contradiction of the research hypothesis.

Differences Between the Conceptual and the Experimental Model

The above analysis is based, in part, on some simplifying assumptions which do not hold in the experimental data used to obtain the results reported in Chapter V. In the following discussion the effect of these assumptions is considered.

The relationships between first derivatives used in the analysis are not precisely the same as the relative change relationships that are discussed in the next chapter. However, the two approaches are equivalent. This equivalence can be seen by considering that the relative change can be stated as \( \frac{Q + \Delta Q}{Q} \) while the derivative can be stated as \( \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = Q'(t) \). In theory the sign of \( \Delta Q \) and \( Q'(t) \) is the same if it is assumed that the firm maintains the same direction of change throughout the time period, \( t \), associated with \( \Delta Q \). The relative change will fluctuate around one in the same directions that \( Q'(t) \) will fluctuate around zero.
In the conceptual arguments above, $g(t)$ was assumed to have the same content in both the computation of productivity, $Q(t)$, and performance, $Y(t)$. This condition is not true in the experimental data. In the following discussion the differences and their expected size and direction are identified, the reasons for these differences are considered, and their effect on the set of conditions in the above conceptual analysis considered most likely is discussed.

As stated previously, the conceptual $g(t) = K(t)P_k + N(t)P_n + F(t)P_f$. The prices used are held constant between periods in the experimental data. The discussion of the variables in the next chapter illustrates that the price weights used in the computation of productivity are held constant in each computation. The prices used in the computation of performance are held constant by including an independent variable reflecting the year to year variation in input prices. The differences that do exist in $g(t)$ in the experimental data are:

1. The prices of fuel and labor used in the productivity variable are different from those used in the performance variable.

2. The depreciation used in the computation of performance is not the same as the capital input used in computing productivity.

3. The $g(t)$ used in the performance measure includes costs or inputs not included in the productivity measure.
The first and second differences exist, in large part, because of the difference in the intent of the two variables, performance and productivity. In this study the performance variable of interest is the figure reported by the firm. The effect of the year to year variation of prices should be included in this variable and, to a large extent, is included. The productivity variable, if its conceptual relationship to technical change is to be maintained, should reflect only the variation of physical quantities. For this reason the price weights used in the productivity variable are deflated by specific price indexes.

The third difference exists because the excluded inputs (primarily purchased goods and services and taxes other than income taxes), while important in the computation of performance, are both difficult to measure and interpret as physical inputs and are unlikely to be major contributors of technical change. For these reasons no attempt was made to include them in the productivity variable.

At this point the researcher is in somewhat of a dilemma. To adjust the two variables to the extent necessary to make the above conceptual analysis hold may assure very good experimental results but it also results in an uninteresting experiment. The "concept" best approximated in the above analysis is the productivity measure. The experiment where the performance variable is adjusted to conform to the above analysis is less interesting because the resulting performance measure is not comparable to any figure actually reported by the firm. If an attempt was made to adjust the productivity measurement to conform with the reported performance, two major
problems arise. First, the measurement of "other" inputs would present severe problems and second, the resulting figure would be more difficult to relate to technical change. The following analysis considers the result of going ahead with the more interesting experiment where the variables are not adjusted to conform with the conceptual analysis.

The prices of labor and fuel used in the computation of productivity are deflated by a specific price index. The purpose of this deflation is to remove the effect of input price changes from the productivity series. The productivity series should reflect only changes in physical inputs. These prices are held constant between years in the performance measure by the use of the independent variable, but this procedure is not equivalent to deflation. The specific indexes used were based on a center year from the time period studied, 1958. For the eleven years in the series prior to 1958, the deflated prices will tend to be higher than the undeflated prices. This would lead to the expectation that the input function for the computation of productivity, \( g_q (t) \), will be larger than input function for the computation of performance, \( g_y (t) \). No difference would be expected in the base year, 1958. In the remaining years of the series, the input function \( g_q (t) \) can be expected to be less than \( g_y (t) \) since the deflated price weights will be less than the undeflated prices.

The cost of capital input used in computing performance is equivalent to a low percentage, between two and three per cent, of the undeflated gross capital. The capital input used in computing productivity is a moderate percentage, averaging approximately 10%.\]
of the deflated net capital of the firm. The price weighted capital input in $g_q(t)$ was, on average, about three times the size of the capital input in $g_y(t)$. This difference would lead to the expectation that $g_q(t)$ will be larger than $g_y(t)$.

The input function for computing performance, $g_y(t)$, includes costs or inputs that were not included in $g_q(t)$. These other costs include taxes other than income taxes and purchased goods and services. The expected effect of these differences is that $g_y(t)$ will be greater than $g_q(t)$.

It is of interest to consider the effects of these differences on the most likely case discussed in the conceptual analysis. If the effect of the difference in capital inputs on $g(t)$ is approximately equal to the effect of the costs not included in the productivity computation, it is expected that $g_y(t) < g_q(t)$ in the first half of the time series and $g_y(t) > g_q(t)$ in the second half of the time series due to the influence of $P_n$ and $P_f$.

In the conceptual analysis of the most likely condition we have $\theta'(t)P_0 - Q(t)g'(t) < \theta'(t)P_0 - g'(t)$ when earnings are positive. In adjusting this formulation to $g_y(t) \neq g_q(t)$ there are two main points to consider. First, the condition of positive earnings does not insure that $Q(t) > 1$.

$$0 < Y(t)$$
$$0 < (t)P_0 - g_y(t)$$
$$g_y(t) < \theta(t)P_0$$

does not imply $g_q(t) < \theta(t)P_0$ except when $g_q(t) \leq g_y(t)$ which in this case would occur in the second half of the time period. Secondly
$g_y'(t)$ does not have to equal $g_q'(t)$ since price weights are different. The $g(t)$ with the larger price weights can be expected to have the larger absolute value of $g'(t)$. In this case $|g_y'(t)| < |g_q'(t)|$ in the earlier years and $|g_y'(t)| > |g_q'(t)|$ in the later years.

Returning to the formulation $\theta'(t) \cdot P_0 - Q(t) \cdot g'(t) < \theta'(t) \cdot P_0 - g'(t)$ and replacing the $g(t)$'s and $g'(t)$'s with $g_i(t)$ and $g_i'(t)$,

$$\theta'(t) \cdot P_0 - \left[ \frac{g(t) \cdot P_0}{g(t)} \right] \cdot g'(t) < \theta'(t) \cdot P_0 - g'(t)$$

or

$$\theta'(t) \cdot P_0 - \left[ \frac{g(t) \cdot P_0}{g(t)} \right] \cdot g_q'(t) < \theta'(t) \cdot P_0 - g_q'(t)$$

we see that this relationship during the second half of the time series where $g_q(t) < g_y(t)$ insuring $\theta(t) \cdot P_0 / g_q(t) > 1$, must be true only when $g_y'(t) < g_q'(t)$. This is true when the $g_i'(t)$'s are negative or zero, a somewhat unlikely condition when $\theta'(t) > 0$. Otherwise $\theta(t) \cdot P_0 / g_q(t)$ must be large enough to offset the difference between $g_y'(t)$ and $g_q'(t)$. This is a much more likely situation since the firms in this industry have stable, good earnings over the time series and the differences between $g_y(t)$ and $g_q(t)$ and between $g_y'(t)$ and $g_q'(t)$ are not likely to be large.

During the first part of the time period, $g_y(t) < g_q(t)$. This condition makes it possible for $\theta(t) \cdot P_0 / g_q(t) < 1$ even though earnings are positive. However, since large stable earnings are expected and the difference between $g_q(t)$ and $g_y(t)$ is not expected to be large, the likelihood of $Q(t) < 1$ is not large and in the event it did occur
the result is likely to be a value close to one. Given also that
\( g_\gamma'(t) < g_q'(t) \) is likely during this time period when output changes
are positive, the expression
\[
\left[ \frac{g(t) \cdot P_0}{g_q(t)} \right] \quad g_q'(t) > g_\gamma'(t)
\]
is likely to be true.

It is also possible for the joint effect of differences due to
capital inputs and excluded inputs, assumed to offset above, to in­
fluence \( g(t) \). If the effect of the excluded inputs dominates the
effect of the difference between the capital inputs, \( g_\gamma(t) > g_q(t) \)
insuring that \( Q(t) > 1 \). If the effect of the capital inputs is domi­
nate, then \( g_\gamma(t) < g_q(t) \) making it possible for \( Q(t) < 1 \). Since the
difference between capital inputs involves both a larger input and a
higher price in \( g_q(t) \) than in \( g_\gamma(t) \), the expected effect of this dif­
ference is that \( |g_q'(t)| > |g_\gamma'(t)| \). When the changes in the inputs
are positive as expected when output is expanding, then the expected
relationship is \( g_q'(t) > g_\gamma'(t) \). The exclusion of inputs from \( g_q(t) \)
leads to the expectation of \( g_q'(t) < g_\gamma'(t) \) when output is expanding.

Again using the relationship
\[
\left[ \frac{g(t) \cdot P_0}{g_q(t)} \right] \quad g_q'(t) > g_\gamma'(t)
\]
and first considering when excluded inputs are dominated in \( g_\Gamma(t) \)
and \( g_\Gamma'(t) \) so that \( g_\gamma(t) > g_q(t) \) and \( g_q'(t) < g_\gamma'(t) \), a contradiction
is possible unless \( \theta(t) \cdot P_0 / g_q(t) \) is large enough to offset the dif­
fERENCE between \( g_q'(t) \) and \( g_\gamma'(t) \). Again, if the difference between
\( g_q'(t) \) and \( g_y'(t) \) is small, as expected, the prosperity of firms in this industry makes a contradiction unlikely.

If excluded inputs dominate the \( g_i(t) \) and the difference in capital inputs dominate \( g_i'(t) \) then the expected relationship's are \( g_y(t) > g_q(t) \) and \( g_q'(t) > g_y'(t) \). Under these conditions, there is no contradiction of the hypothesis.

When the difference in the capital inputs dominates the \( g_i(t) \) then \( g_y(t) < g_q(t) \). Under this condition \( Q(t) \) may be less than or equal to one when earnings are positive. As mentioned above, the stable, strong performance of firms in the electric utility industry make it unlikely that \( g_q(t) \geq g(t) \cdot P_o \). In this situation, the above analysis regarding \( g_q'(t) \) and \( g_y'(t) \) still holds.

In summary the most likely set of conditions on the variables and on the differences between the conceptual variables and experimental variables tend to support the research hypothesis. There is no question that there is more risk that the expected relationship will be obscured, but this risk seems worth taking in view of the purpose of this study.
CHAPTER IV

THE EXPERIMENTAL DESIGN

In this chapter the experiment to test the hypothesis discussed in Chapter III is presented. Included in the presentation are a discussion of the experimental variables including those representing influences on the firm to be held constant, a discussion of the regression model used to explore the relationship between the variables, and a discussion of the data used in the experiment.

The subjects chosen for this experiment are three privately owned, electric utility companies; The Columbus and Southern Ohio Electric Company, The Detroit Edison Company, and The Public Service Company of Indiana. The firms were chosen from the private sector of the electric utility industry because of the previous research on a productivity measure for this industry\(^1\) and the readily available data on firms in this industry. Also, the output of firms in the electric utility industry is homogeneous across time. This homogeneity of output makes the changes in productivity across time easier to interpret since the basis of comparison, output, does not change.

The use of data from three different firms in this experiment should not be viewed as an attempt to suggest a random sample from the industry. The results of this experiment should not be viewed as necessarily representative of the industry and are, strictly speak-

\(^1\)Barzel, Op. Cit.
ing, not generalizable. The use of three firms should be viewed as replications of the experiment to obtain some representative indications of the problems of using the chosen productivity measure on members of the electric utility industry as a measure of technical change.

Experimental Variables

The experimental variables in this study are the two variables of primary interest, reported performance and productivity and other variables chosen to hold constant certain effects which can be expected to obscure the a priori relationship between reported performance and productivity discussed in Chapter III. These other variables are presented along with their purpose in the experiment in the following discussion.

All of the variables used in this experiment are expressed as ratios representing the relative change over a time period of one year. The primary purpose of this specification is to make all the variables consistent with the productivity variable which is specified in this form. Additional benefits from the use of the relative change specification include the fact that the variable series represent changes which are the phenomenon of interest in this study and that relative change specification tends to remove the influence of changing magnitude from the variable series.

Reported Performance

The ratio of the current year's reported performance to that of the previous year will be used as the dependent variable. Reported
performance is defined as operating earnings before federal income taxes. Two alternative definitions of reported performance, operating earnings after federal income taxes and net earnings plus after tax bond interest, were considered, but because of the possible effects of extraordinary and other gain and loss items, they were not used. These extraordinary and other items were considered undesirable in the performance variable because they do not reflect the operating performance of the firm.

An individual item in the reported performance series may be specified as:

$$R_{t,t-1} = \frac{Y_t}{Y_{t-1}}$$

$R_{t,t-1}$ - the reported performance variable in period $t$.

$Y_t$ - the reported operating earnings before taxes in period $t$.

This variable ($R_{t,t-1}$) will be used as the dependent variable or the variable whose variation is to be explained.

Productivity

The productivity series will be computed from four time series; adjusted output in kilowatt hours (kwh) and three input series, capital usage, labor, and fuel. Each of these four series is discussed in the following paragraphs. At the end of this discussion the formula for computing productivity is specified.

Output. — The output series is the basic output of the electric utility, kwh, adjusted for the differences in distribution output to different classes of consumers. The consumption by each
category selected in kwh is multiplied by a weight computed as follows:¹

1. For a calendar year in the time period, 1947-1967, monthly kwh sales and average price per kwh are plotted on graph paper to obtain an indication of the forms of the relationship, \( p_i = f(q_i) \) where \( p_i \) is the average rate per kwh for class \( i \) and \( q_i \) is the monthly consumption in kwh for class \( i \).

2. The least-squares method is used to estimate the coefficients of the relationship suggested by the plots in step one.

3. The equation obtained in the above is used to compute \( p_i \)'s for each class selected in the series. These \( p_i \)'s are the weights to be used in weighting output in the form, \( \theta = A p_a + B p_b \), where \( \theta \) is

¹The method described in the text can be summarized as the selection of some year during the 21 year time period during which no significant changes have occurred; estimate the function:

\[ p_{it} = a_i + \beta_i q_{it} \quad i = 1, 2, 3 \]
\[ t = 1, \ldots, 12 \]

\( p_{it} \) - average rate per kwh for class \( i \) in month \( t \).
\( q_{it} \) - consumption in kwh for class \( i \) in month \( t \).

using a plot of the data to justify the form of the function; and then using the estimates \( \hat{a}_i \) and \( \hat{\beta}_i \) to compute the price weights as follows:

\[ \hat{p}_{ij} = \hat{a}_i + \left[ \hat{\beta}_i q_{ij} / 12 \right] \quad i = 1, 2, 3 \]
\[ j = 1, \ldots, 21 \]

\( \hat{p}_{ij} \) - computed price weight per kwh for class \( i \) in year \( j \).
\( q_{ij} \) - annual consumption in kwh for class \( i \) in year \( j \).
weighted output, A and B are the annual consumption figures for each of two classes, and the $p_j$'s are the respective weights.

The use of the weights computed from one year's experience on all twenty-one years of data assumes that the relative distribution output to the major classes of consumers has not changed over the time period. This assumption would seem reasonable for most electric utilities, in part due to their rather stable operating characteristics. Years in which the utilities obtained or made rate changes were avoided in step number 1 above.

The weighting technique described here implies that differences between average rates for the different classes are good indicators of the differences in distribution costs which in turn are good indicators of differences in distribution output. The last step seems plausible since the costs represent the effort the firm is putting into this activity and there is no need to impute a return. In any case distribution output differs between consumers in terms of service and probably is not directly measurable.

The first implication, that differences in rates reflect differences in cost, is not quite so clear, particularly if the firm is using differential rates to discriminate between consumer classes. In an industry-wide study of productivity in the electric power industry, Barzel found some evidence indicating that weighting output in the outlined manner results in a better measure of productivity,
but he did not feel that his results were conclusive.\(^1\,\!\!^2\) For this reason he used both weighted and unweighted output in order to compare the results.

The weighted output will be used in this study. This choice is based on two points. First, from a conceptual standpoint it seems that output weighted for differences in distribution output is a better measure of the firm's total output than just production output. Secondly, as mentioned above, the evidence Barzel did present did favor the weighted output measure.

**Capital Input.** — The first input variable, capital, is the most arbitrary since the consumption of capital is not directly measureable. The measurement suggested by Barzel is an allocation of 1/37 of each year's additions to utility plant to each of 37 years beginning with the year of the addition.\(^3\) This method is equivalent to straight-line depreciation. The 37 year life is an industry average for utility plant life.

Since the other two inputs, labor and fuel, are measured in physical quantities, price weights are necessary to aggregate the inputs. Barzel's capital price weight is a rate of return on capital; the sum of net profits, income taxes, interest, and depreciation over

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\(^2\)Barzel's evidence essentially consisted of some tests for indications that electric utilities exercise monopoly powers, particularly in discriminating between classes of consumers. His results indicate that monopoly powers were not being used.

\(^3\)Ibid., pp. 12-13.
the stock of capital (measured on a basis consistent with the consumption series). Depreciation is added back to the performance measure since it is a provision for the cost of the assets on which a return is being computed. Including depreciation in the computation of this return is incorrect in the same sense that it is incorrect in capital budgeting.

Barzel used Ulmer's method of estimating capital consumption. The combination of Ulmer's method of measuring the quantity of input and Barzel's price weight is difficult to understand. It is, essentially, the multiplication of depreciation by a rate return on the stock of capital assets. However, it is not entirely clear in Barzel's paper whether he actually uses Ulmer's measure of consumption or, instead, uses the measure of capital stock implied by Ulmer. The use of rate of return as a price weight for capital stock makes more sense as a computation since the result is a rent or return to capital.

In this study the capital input will be obtained by computing the measure of capital stock implied by Ulmer. The price weight will be Barzel's internal rate of return. The input may be specified as:

$$K_i = \sum_{j=1-(n-1)}^{i} \left[ A_j - A_j \left( \frac{i-j}{n} \right) \right]$$

---

$K_i$ - the stock of capital assets in year $i$.

$A_j$ - the price adjusted addition to the stock of capital in year $j$.

$n$ - the weighted average life of utility plant for the subject company.

There is no a priori reason why a straight-line pattern of capital asset consumption should be correct or in any sense superior to alternative patterns. The straight-line pattern will be used in this study in part because the choice of a correct or "best" pattern is not a part of this experiment and also because Barzel found that his productivity measure was not very sensitive to changes in the pattern of capital asset consumption. In following paragraphs some of the literature on measuring capital stocks and flows is discussed.

Griliches suggests that an ideal measure of the flow of capital services would be machine hours where hours from different machines would be weighted by their respective rents.¹ This suggestion would seem to be better approximated by a stock of capital weighted by its rent than by depreciation weighted by the rate of return to capital. It should be added that the gross (undepreciated) stock of capital may be an even better approximation of machine hours since it is an approximation of the quantity of capital in use. Also, the use of an internal book rate of return is only a rough estimate of the market determined rent suggested by Griliches.

As the above discussion may indicate, the measurement of capital stocks and flows is a problem area to which no really satisfying answers have been devised. This lack of progress has been attributed by some authors to the extreme heterogeneity of capital in terms of quantity and quality and across time.¹

Richard and Nancy Ruggles suggest that even though analysis of questions relating to the efficiency of capital implies an interest in the services of capital rather than capital stock, many analysts use capital stock data because going from capital stock to capital services results in even more difficult measurement problems.² The use of capital stock as a measure of capital inputs seems to imply that capital makes its contribution to production by being available for use rather than its actual use. This suggestion also supports the possibility that Barzel used capital stock as his measure of the input quantity of capital.

In considering alternative measures of capital stock, the Ruggles¹ draw on a previous paper by Denison who proposes three alternative measures of capital; 1) cost, 2) capacity of the system as a


whole, and 3) marginal contribution to capacity by each individual machine. Method 3 is discarded as being impossible to measure. Method 2 is given some consideration, but is also dropped. The Ruggles point out that to base the measurement of capital on output or capacity seriously impairs the usefulness of the results "For the study of efficiency — since actual capacity or output is used as the measure of quantity, there can be no change in the productivity of capital." This leaves the measure of capital by cost, method one, which is advocated by Denison. In discussing the use of cost, Denison discusses the problem of separating in the price index series the effect of changes in the productivity of producing capital goods and changes in the productivity of capital. The productivity of the capital-using firm would ideally include only the latter, but the separation of the effects is seldom possible.

It is likely that the best approach to dealing with the problem of measuring a capital input is Griliches' suggestion that alternative measures be used. If the different methods cause significantly different results in the study, some attempt should be made to evaluate the causes of the differences. Some alternative measures that can be used include both the flow and the stock concepts attributed to Ulmer above, alternative measures of stock such as "one-horse


shay measurement of net capital stock, and alternative measures of depreciation such as those suggested by Griliches. ¹ His cited paper is concerned with measures of capital to fit an investment function.

In this study one of the primary purposes of the productivity series is to provide a means of comparing technical change and changes in the accountant's measure of performance. This explicit purpose of the productivity series does not appear to dictate a choice for the capital input measure other than that it should be the best possible approximation given a desire to measure changes in physical efficiency.

Since the measurement of capital inputs must be an estimate of some type, the possibility of excluding capital from both the performance variable and the productivity variable should be considered. The implications of this procedure on each variable will be considered separately, then the joint implication in the context of this study will be discussed.

The stated purpose of this study is to investigate the relationship between the reported performance of the firm and technical change. The reported performance of the firm is ordinarily accounting profit after depreciation, but it is relatively simple for a financial statement reader to add back depreciation to obtain a performance figure that excludes a capital input cost. There have been suggestions for this technique in the financial literature as a means of avoiding the effects of different depreciation methods in cross-sectional comparisons. These suggestions have been disputed in

¹Ibid., p. 121
accounting literature on the grounds that a performance measure that excludes the cost of capital is deficient. While the conceptual correctness of the performance measure is not a primary issue in this study, it is preferable to use a conceptually superior measure if the price to be paid is not too high. The price paid is the introduction of measurement error. The seriousness of this effect will be considered after the importance of the capital input to the productivity measure is considered.

The exclusion of the capital input from the productivity variable results in a substantial change in the meaning of productivity. Its conceptual relationship to technical change is obscured. For example, an increase in output made possible by an increase in capital, as described in the next paragraph, would be reported as an increase in productivity. This increase in the partial productivity has no relationship to technical change. It is due to an increase in the factor excluded from the productivity measure.

The effect of the exclusion of capital inputs on the relationship between the two variables will be discussed in two steps. First, the effect will be discussed ignoring measurement error, and second, the effect of measurement error on the relationship will be considered. It is possible for an increase in capital to be a major source of an increase in output and revenue (e.g., the installation of an additional generator in an existing plant requiring only marginal increases in other factors). This event is likely to increase both reported performance before depreciation and the partial productivity (excluding a capital input). The measured relationship between the two variables
may be strengthened, and this strengthened relationship would not have to have any dependence on technical change.

The measures of capital inputs used in the productivity and the performance variables can be described as measurements subject to measurement error. It is convenient to view such measurements as random samples from some probability distribution. The effect of the measurement error on the relationship between productivity and performance can then be discussed in terms of likely results given certain relationships between the "true" values being approximated and the parameters of the measurement error distribution.

The "true" value referred to in the previous paragraph is some theoretical measure of capital. If this measurement was operationally defined, it would appear in both the performance and the productivity variable as the same amount except that the capital input in the performance variable would be weighted by an appropriate price.

The question to be dealt with here is what characteristics of the measurement error would lead to an expectation of obscuring or spurious significance effects on the relationship between the performance and productivity variable? Since each measurement of capital input in both variables is viewed as a random sample, it is possible in small samples for a real relationship to be obscured or for a spurious relationship to be indicated due to chance. In this study the experiment was replicated three times in an attempt to minimize this possibility. If the results are consistent in all three replications, confidence in the results should be increased.
It is possible for the measurement error distribution to have characteristics such that a systematic deviation from the true value can be expected. It is possible for this situation to result in an obscuring or spurious significance effect on the relationship between performance and productivity. These effects are not likely to be caused by differences in the systematic deviations between the inputs used in the performance and productivity variables since the capital input measures used are likely to vary in the same direction. The obscuring or spurious significance effects are possible because the measured variables could systematically move in the wrong directions when input substitution is occurring.

Since the results reported in Chapter V are significant for all three replications, the possible effect of a systematic deviation that is more important to consider is spurious significance. This effect might occur when the capital input measurements systematically vary in the opposite direction from the movement of real capital inputs and the result of this movement in some way artificially strengthens the measured relationship between the performance and productivity variables.

Previous discussion has indicated that there is no operational definition of real capital inputs. For this reason it is impossible to show that this systematic deviation is or is not occurring. However, if the reader accepts some change in stock or change in capital available concept as the appropriate approximation of true capital usage, the possibility of a systematic deviation is small. Both the depreciation figure used in the performance measure and the capital
input figure used in the productivity variable are likely to move in the same direction as a stock approach to capital consumption. If the reader's belief as to an appropriate measure of capital consumption is such that he expects a systematic deviation or believes that it is likely, he may want to restrict his interpretation of the results of this experiment.

In order for an incorrect variation in the measured capital inputs to cause spurious significance in the relationship of interest, it is necessary to state that the correct variation would have resulted in an insignificant relationship. The arguments in Chapter III imply that such an insignificant relationship, at least conceptually, is unlikely.

The occurrence of spurious significance due to systematic variation of the capital input measurement from its true value requires that both the existence of systematic variation and the existence of an insignificant true relationship. Since it appears that each of these events is somewhat unlikely, their joint occurrence may be even less likely. This fact coupled with the importance of the capital input to the measurement of technical change in the productivity variable supports the use of capital inputs in this study.

Labor Input.— The labor input is measured either by the average number of employees for the year or by labor hours. Labor hours is the more desirable measure since it is more sensitive to changes in effort. However, labor hours were not available for the whole time series in two of the companies. The labor price weight is obtained by dividing total labor cost for the year by the quantity measure.
The resulting average pay rate is then adjusted for price changes using a specific index. As was discussed previously, no attempt is made to adjust the labor input for changes in quality across time.

The Fuel Input. — The fuel input is measured in terms of British Thermal Units (BTU). The price weight for fuel is obtained directly and is adjusted by a specific price index before being used as a weight in the computation of productivity. There is no problem with changes in the quality of this input since the measuring unit, BTU, is of constant quality.

Summary. — The formula used to combine these four variables to obtain the productivity series is: \[ Q_t, t-1 = \frac{\theta_t}{\theta_{t-1}} \left[ \frac{\sum_{i} (l_{t-1, i} P_{t-1, i})}{\sum_{i} (l_{t, i} P_{t-1, i})} \right] \]

- \( Q_{t, t-1} \) — the productivity index defined as productivity in year \( t \) relative to productivity in year \( t-1 \).
- \( \theta_t \) — the output (adjusted) in year \( t \).
- \( l_{t, i} \) — the quantity in year \( t \) of input \( i \).
- \( P_{t, i} \) — the price in year \( t \) of input \( i \).

The prices used in weighting the inputs in the productivity measure were all adjusted by specific price indexes to minimize the effect of price changes on the productivity measure. The effect of

\[ \text{Barzel, Op. Cit., p. 4} \]

2The productivity formula is a Laspeyres quantity index and is subject to the familiar index number bias, probably in a downward direction. This constant bias would not have any serious effect on this study since changes in the index will not be biased by this technique.
this adjustment is not large since the resulting weights are used in
the computation of a chained productivity index series. The price
indexes chosen are the regional Handy-Whitman index for steam elec­
tric plant construction costs for capital assets,\(^1\) the Handy-Whitman
index for electric labor costs,\(^1\) and the wholesale price index for
coal.\(^2\) These types of indexes have been criticized on occasion for
not reflecting changes in the quality of the subject of the index.
For purposes of this study this weakness is a benefit since the
changes in quality referred to are often the technical changes that
are to be reflected. If an index reflected these changes, their in­
fluences on the productivity measure would be removed. As the dis­
cussion in Chapter II indicated, changes in the quality of inputs due
to exogenous effects should be excluded from the variables, but it is
not possible to accomplish this separation. The exogenous quality
changes are not removed by the specific price index deflations.

In the process of selecting price weights a choice was made
between specific indexes and general price indexes. The purpose of
the price indexes in the computation of productivity is to hold con­
stant the effect of changing input prices on the product of the input
price and the input quantity. The best index for this purpose is
likely to be the index that most closely follows the prices of the
firm inputs. For this reason specific indexes as closely related to

\(^{1}\)Handy-Whitman Index of Public Utility Construction Costs,
No. 81 (Baltimore: Whitman, Requart and Associates, 1968)

\(^{2}\)Business Statistics, A Supplement to the survey of Current
the specific inputs of the firm as possible were used.

Other Variables

The first other variable is a measure of the degree of utilization of capacity; specifically, the relative change in the ratio of output to average available capacity. This variable may be specified as:

\[
U_{t,t-1} = \frac{O_t}{C_t} / \frac{O_{t-1}}{C_{t-1}}
\]

- \( U_{t,t-1} \) - the degree of utilization variable for period \( t \).
- \( O_t \) - the unweighted output in period \( t \).
- \( C_t \) - the average available capacity in period \( t \).

The degree to which capacity is used is an influence on the changes in productivity that is not a technical change. As was discussed in Chapter II, this variable is included to hold constant this effect on the productivity measure and performance.

The second other variable is an approximation of the effect of input price levels on the performance variable. The measure used is the relative change in the prices of the labor and fuel inputs used in the productivity measure. This variable may be specified as:

\[
S_{t,t-1} = \frac{\sum_{i} \left[ l_{t-1,i} P_{t_1} \right]}{\sum_{i} \left[ l_{t-1,i} P_{t-1,i} \right]}
\]

- \( S_{t,t-1} \) - the input price change variable in period \( t \).
- \( l_{t_1} \) - the quantity of input \( i \) in period \( t \).
- \( P_{t_1} \) - the price of input \( i \) in period \( t \).
The prices used in this variable are not adjusted for changes in the price level.

The third other variable is an approximation of the effect of output price changes on performance. The variable may be specified as:

\[ V_{t,t-1} = \frac{\theta_{t-1} P_{to}}{\theta_{t-1} P_{t-1,0}} \]

- \( V_{t,t-1} \) - the output price variable in period \( t \).
- \( P_{to} \) - the average price of output in period \( t \).
- \( \theta_t \) - the unweighted output in period \( t \).

The use of this variable makes consideration of the effect of price regulation in the electric utility industry unnecessary.

There are other expected influences on the performance variable that are not controlled by the other variables specified above. These influences include 1) shifts in the composition of output to more or less profitable combinations, 2) changes in factors not included in the productivity and input price variables such as taxes other than income taxes and purchased goods and services, 3) influences excluded from the measured variables due to measurement errors. While influences in category one and two represent measurable phenomenon, influences in category three cannot be specified.

It is possible to specify additional other variables to attempt to control the influences in categories one and two in the previous paragraph. However, this procedure is undesirable unless the additional contribution of these variables is expected to be large. In an experiment with small samples it is desirable to keep the number
of variables to a minimum since the possibility of multicollinearity is increased when financial variables closely related to the Q variable are added to the model. It is not expected that any one of the possible other variables not previously specified will be important enough to include in the model.

Experimental Model

The experimental model used in this study is the ordinary linear regression model specified as:

$$ R_{t,t-1} = \beta_0 + \beta_1 Q_{t,t-1} + \beta_2 U_{t,t-1} + \beta_3 S_{t,t-1} + \beta_4 V_{t,t-1} + \eta $$

where the experimental variables are those discussed in the previous section of the paper, the $\beta_j$'s are the coefficients to be estimated, and $\eta_t$ is the random disturbance term. This expression can also be stated in matrix notation as:

$$ R = X\beta + \eta $$

where $R$ is an $(n \times 1)$ vector of values of the performance variable, $X$ is an $(n \times p)$ matrix of values of the $(p - 1)$ independent variables and $\eta$ is an $(n \times 1)$ vector of the disturbance terms.

The purpose of the regression model in this experiment is to provide an estimate of $\hat{\beta}_1$, $\hat{\beta}_1$, the coefficient of the productivity variable in the model and the statistical significance of $\hat{\beta}_1$, using the $t$ test statistic. The estimate of $\beta_1$, $\hat{\beta}_1$, is obtained by using the ordinary least-squares technique. An estimate of all the regression coefficients, in matrix notation, is obtained by the fol-
lowing matrix computation:¹

\[ \hat{\beta} = (X'X)^{-1}X'R \]

\( \hat{\beta}_1 \) is the coefficient of primary interest since it represents the slope of the regression line in the RQ plane of the model. This slope is a measure of the relationship between R, the change in performance, and Q, the change in productivity. The null hypothesis of this experiment is that this slope is zero. The alternative hypothesis is that this slope is greater than zero, indicating a one-tailed test.

A test of the statistical significance of \( \hat{\beta}_1 \), will be made in the following manner. There is a function of \( \hat{\beta}_1 \) and its estimated standard error, \( s_{\beta_1} \), that is approximately distributed as a t distribution with \( n-p \) degrees of freedom specified as:²

\[ t(n-p) = \frac{\hat{\beta}_1 - \beta_1}{s_{\beta_1}} \]

By setting \( \beta_1 \) in this formulation at zero, a statistical test of whether or not the estimate of \( \hat{\beta}_1 \), is significantly different from zero is obtained. The resulting t statistic is:

\[ t(n-p) = \frac{\hat{\beta}_1}{s_{\beta_1}} \]

In this experiment \( n \), the number of observations on the variables, will be twenty and \( p \), the number of variables, will be four.

The use of Student's t test requires certain assumptions. These assumptions may be summarized using the matrix notation as:³

²Ibid., p. 120.
³Ibid., p. 109.
1. \( X \) is an \((n \times p)\) matrix of known fixed quantities.

2. \( X \) has rank of \( p < n \).

3. \( \eta \), the disturbance term, is distributed \( N(0, \sigma^2 I) \) where \( \sigma^2 \) is unknown.

In a formal sense then, this model should be used only in estimating the parameters, \( \beta \), of a model where the independent variables are fixed and known and departures from a fixed mathematical relationship are due only to equation errors and the independent, normally distributed disturbance term.

It is very unlikely that economic data such as the data used in this study will exactly meet the above assumptions. For a representative discussion of the effects of the possible violations of the assumptions see Johnston.\(^1\) A discussion of the effects of likely violations on this study will be included with the discussion of the results of the experiments in the next chapter.

The Data

The data used for the empirical part of this study come from three primary sources. They are (1) the Federal Power Commission's annual \textit{Statistics of Electric Utilities in the United States}, (2) \textit{Moody's Public Utility Manual} for various years, and (3) data provided by the subject firms. The physical input data came directly from the firms or from Moody's. The annual FPC statistics and internal statistical summaries provided most of the financial data.

Because of the uniform accounting requirements of the Federal Power Commission, the data series in the electric utility industry tend to be of relatively good quality. This statement is particularly true of the data for the twenty-one year period under study, 1947-1967. Changes in data content have been minimal over this time period. However, for the capital input series it was necessary to obtain data from up to forty-one years prior to 1947. Some of this data was unavailable in a directly usable form and had to be estimated.\(^1\)

As outlined in a previous section of this chapter, the data input to the least-squares computation is five variables. In order to get the raw data into appropriate form, a computer program was written. The output of this program is a set of punched cards including the five variables in a form usable in a pre-programed regression routine. In order to debug the computational program the first company regression inputs were computed by hand. Errors in the computer computational program were discovered by comparing the results of the two alternative computations. For the remaining two companies, at least one computation of each of the five variables was

\[ A_j = B[D_j / C] \]

where \( A_j \) is the estimated addition in year \( j \), \( B \) is the January 1, 1947 gross capital assets, \( D_j \) is the change in gross capital assets in year \( j \), and \( C \) is the change in gross capital assets between date \( i \) and January 1, 1947. Date \( i \) is obtained by subtracting the average life of capital assets for the subject firm from 1947.
checked by hand to provide assurance that the program was operating properly.
CHAPTER V

THE RESULTS OF THE EXPERIMENTS

The results of the three three replications of the experiment support the hypothesis of the study. In the following discussion these overall results are presented first. The remainder of this chapter is concerned primarily with an evaluation of the results.

Results and the Hypothesis

The results relevant to the hypothesis are presented in Table 2. For each company the relationship between performance and productivity is statistically significant at at least the 97.5% level, indicating that the research hypothesis is supported by these experiments. The other variables whose influences are held constant are the input price variable, the output price variable, and the degree of utilization variable. The performance measure is operating earnings before income taxes. The productivity measure is based on the capital stock approach to measuring capital inputs. The signs of the regression coefficients for productivity are positive, as expected, and the partial correlation coefficients are large.

In Table 2 it is apparent that the regression coefficients for the three companies are different. While the Columbus and Southern Ohio Electric Company (CSOE) and the Public Service Company of Indiana (PSCI) have quite similar regression coefficients, the coefficient
TABLE 2

THE RESULTS OF THE EXPERIMENTS-

THE REGRESSION COEFFICIENT ON CHANGES IN PRODUCTIVITY

<table>
<thead>
<tr>
<th>Company</th>
<th>Regression Coefficient</th>
<th>Standard Error</th>
<th>t Statistic</th>
<th>Partial Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&gt; The Columbus and Southern Ohio Electric Company</td>
<td>1.619</td>
<td>.7426</td>
<td>2.180 a&gt;</td>
<td>.4905</td>
</tr>
<tr>
<td>2&gt; The Detroit Edison Company</td>
<td>3.750</td>
<td>.8715</td>
<td>4.303 b&gt;</td>
<td>.7433</td>
</tr>
<tr>
<td>3&gt; The Public Service Company of Indiana</td>
<td>1.317</td>
<td>.4510</td>
<td>2.921 b&gt;</td>
<td>.6021</td>
</tr>
</tbody>
</table>

a> Significant of the 97.5% Level.
b> Significant of the 99.5% Level.
for the Detroit Edison Company (DEC) is larger. One possible reason for this difference in the size of the regression coefficients might be the operating characteristics of the companies.

The Detroit Edison Company is an urban company, concentrated in one metropolitan area with over fifty per cent of its output going to industrial consumers. It is approximately twice as large in total assets as the other two companies. Both the Columbus and Southern Ohio Electric Company and the Public Service Company of Indiana are spread over relatively large geographical areas with substantial parts of their output going to small commercial and geographically dispersed rural and residential customers. Sales to industrial consumers are a smaller portion of output for these latter two companies.

The described differences in operating characteristics can affect the magnitude of the regression coefficients in at least two ways. First, these differences can result in differences in the relative importance of the five variables included in the model. A variable that is relatively less important can be expected to have a smaller regression coefficient and vice versa. Secondly, these differences in operating characteristics can, along with other factors, increase the size of both the positive and the negative coefficients estimated by the technique. This increase might be due in part to greater variation in data from that particular firm. A comparison of the coefficients in Table 4 across firms seems to support the second possibility.

The differences between the subject companies pointed out above are relevant in explaining the differences in the regression weights,
but these differences in operating characteristics would not imply any necessary reason why the significance of the regression coefficients or the partial correlation coefficients should differ. In fact, a logical extension of the experimental hypothesis might be that the significance of the relationship between changes in productivity and changes in performance would not differ across firms in the same industry. Using a test for the significance of differences between partial correlations suggested by Graybill,\(^1\) the differences between the three partial correlation coefficients are not significant.\(^2\)

The Assumptions of the Model

The use of the regression model involves certain assumptions about the data used (or the observations on the variables) and the relationship between the variables. These assumptions were mentioned in Chapter IV. Before any implications can be drawn from the data, the effects of these assumptions on this study should be considered. The following list is equivalent to the assumptions discussed in Chapter IV and are oriented toward practical evaluation.

1. Linear model
2. Heteroscedasticity
3. Normality
4. Autocorrelation
5. Multicollinearity


\(^2\)A chi square statistic with .25 < \(p\) < .50 was obtained testing the null hypothesis that all three partial correlation are equal.

The use of a linear statistical model presumes that the relationship between the variables under study is linear or can at least be transformed to a linear relationship.¹ The primary means of evaluating violations of this and the other assumptions of the model in this study is the examination of residuals technique suggested by Draper and Smith.² While statistics for examination of the residuals do exist, "... in practical regression situations a detailed examination of the corresponding residual plots is usually far more informative and the plots will almost certainly reveal any violations of assumptions serious enough to require corrective action."³

Linear Model

In a regression of time series data as in this study, a serious violation of the assumption of a linear relationship between the variables should result in an abnormal pattern in a time sequence plot of the residuals. The computer program used to compute the regression statistics in this study provides this time sequence plot of the residuals. The plots for the three firms in this study are shown in Figure 1. There is no apparent pattern in these plots indicating departures from a linear relationship. If a simple linear model is used when the true relationship is not well approximated by this model, 


²Ibid., pp. 86-99.

³Ibid., p. 92.
The Columbus and Southern Ohio Electric Company

The Detroit Edison Company

The Public Service Company of Indiana

FIGURE 1
TIME SEQUENCE PLOTS OF THE REGRESSION RESIDUALS
the resulting estimates of the coefficients are likely not to be significant and the residual plot is likely to have unusual patterns in it.

The fact that the simple linear model works well in this study does not imply that the result would necessarily hold true in other firms. There is no theory, at this point, that states that a simple linear combination of the relative changes in productivity, input prices, output prices, degree of utilization of capacity, and economic activity should explain the relative changes in performance. Alternative functional relationships are conceivable, and much more evidence is needed before such a relationship could be suggested.

Heteroscedasticity

Heteroscedasticity is the existence of non-constant variance in the model, i.e., the variance of the error term in the model is not constant. The existence of this violation does not bias the estimate of the regression coefficient, but it can increase the variance of the estimate reducing the significance of the results and the partial correlations. Also, the t test statistic is not strictly correct as normally computed. The time sequence plot of the residuals will usually disclose the existence of heteroscedasticity.

The pattern in the residual plots that typically indicates non-constant variance in the residuals is a fan-shaped plot. This pattern would indicate a significant trend for increasing or decreasing residual variance. Again looking at Figure 1, the residual plots for these three firms do not appear to indicate any serious violation of the
constant variance assumption.

Normality

The use of the t test for the significance of the regression coefficients is based on the assumption of normal distributions for the disturbance terms and the assumption that these distributions are independent.\(^1\) If these assumptions are seriously violated, the significance test used in this study might be meaningless. To test the assumption of normal distributions, Draper and Smith suggest an overall plot of the residuals.\(^2\) These overall plots for the three subject firms are illustrated in Figure 2. None of these plots appear to indicate a serious violation of the normality assumption.

An alternative means of testing the normality assumption would be the use of a chi-square test. However, the use of this test on a regression with only twenty observations is questionable since the use of the chi-square test requires the division of the observations into cells and for tests including more than two cells there should be at least five observations in each cell. In this study the best possible design is the rather poor situation of 4 cells with 5 observations each and only one degree of freedom.\(^3\)

Autocorrelation

A lack of independence in the disturbance terms is often de-


The Columbus and Southern Ohio Electric Company

The Detroit Edison Company

The Public Service Company of Indiana

FIGURE 2
OVERALL RESIDUAL PLOTS
scribed as autocorrelation or serial correlation in the residuals. This violation of the model does not bias the estimates of the coefficients, but does result in inefficient estimates, i.e., estimates with inflated sampling variances. In this study the Durbin-Watson d Statistic is used to test for the existence of autocorrelation. The computed d's for the firms are

1. Columbus and Southern Ohio Electric Company 2.04
2. Detroit Edison Company 2.23
3. Public Service Company of Indiana 1.41

At the 95% level \( d_L = .90 \) and \( d_U = 1.83 \). The null hypothesis of no serial correlation cannot be rejected for firm one. The computed d's for firms two and three are in the inconclusive range (between \( d_U \) and \( d_L \)). No conclusion is possible in this case. However, the computed statistic for firm two is so close to \( 4 - d_U \) that it is very likely that if the true cut-off value were known, the null hypothesis would not be rejected for firm two.

The inconclusive results reported in the previous paragraph are common when the Durbin-Watson test is used with relatively small samples. An alternative test using the von Neumann ratio has been proposed by Theil and Nagar. Their test does not have an inconclusive range on the test statistic. However, their alternative does not appear to be appropriate in this study. Theil and Nagar state that

when using their tables, "... the first and second differences of the explanatory variables should be small relative to the range of the variable itself." This condition does hold for the variables used in this study.

Since the computed statistic for firm two is close to $d_y$, it is likely that firm three is the only case where serious autocorrelation might exist. Because the model violation can only be suspected in one out of the three replications and the results on the productivity variable are consistent, no attempt to improve the estimates will be made.

Multicollinearity

When two or more of the independent variables in the experimental model are highly related, the least squares estimation technique may be seriously weakened, i.e., the estimation technique may not be able to separate the influences of the different variables and provide estimates of relative effects. Analytically, the data matrix (the $X'X$ matrix discussed in Chapter IV) is either singular or so closely approaching singularity that accurate inversion of the data matrix to obtain the $\hat{\beta}$ vector ($\hat{\beta} = (X'X)^{-1}X'Y$) is not possible. This problem is termed multicollinearity. In discussing this problem area, Johnston points out some disagreement in the literature as to the effects of multicollinearity. He comes to the conclusion that the existence of

---


this problem may be reflected in an unsatisfactorily low degree of precision (high sampling variance) in the estimated coefficients.

A more precise test for the existence of multicollinearity is suggested by Farrar and Glauber. In this study the relatively low sampling variance of the estimated coefficients for productivity changes appears to indicate that there is no need for more precise tests. Such tests would be useful if it were necessary to determine the cause of large sampling variance in a coefficient of interest.

The size of the simple correlations between the variables is sometimes an indication of multicollinearity, but high (any greater than .80) simple correlations are not a sufficient condition. These simple correlations are presented for the interested reader in Table 3.

Errors in Variables

Another problem in the use of the least-squares technique is the possibility of measurement errors on one or more of the independent variables. Since financial information from the firm is likely to be subject to measurement errors to at least some extent, it is important that this problem be considered here. In discussing measurement errors in the variables, it usually assumed that these errors amount to a stochastic disturbance term around the "true" value of the variable. Even with this assumption, the effect of the violation is


## TABLE 3
THE SIMPLE CORRELATION COEFFICIENTS BETWEEN THE VARIABLES

### The Detroit Edison Company

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Productivity</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Input Prices</td>
<td>-.0672</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Output Prices</td>
<td>-.7239</td>
<td>.2714</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>4. Utilization</td>
<td>.4919</td>
<td>.0974</td>
<td>-.6589</td>
<td>1.000</td>
</tr>
<tr>
<td>5. Performance</td>
<td>.4911</td>
<td>-.2392</td>
<td>-.0955</td>
<td>.2136</td>
</tr>
</tbody>
</table>

### The Public Service Company of Indiana

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Productivity</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Input Prices</td>
<td>.5010</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Output Prices</td>
<td>-.3809</td>
<td>-.0923</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>4. Utilization</td>
<td>.4836</td>
<td>.5080</td>
<td>-.3181</td>
<td>1.000</td>
</tr>
<tr>
<td>5. Performance</td>
<td>.5160</td>
<td>.1415</td>
<td>.0571</td>
<td>.0796</td>
</tr>
</tbody>
</table>

### The Columbus and Southern Ohio Electric Company

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Productivity</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Input Prices</td>
<td>-.0954</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Output Prices</td>
<td>-.2885</td>
<td>-.1857</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>4. Utilization</td>
<td>.7005</td>
<td>-.1787</td>
<td>-.2478</td>
<td>1.000</td>
</tr>
<tr>
<td>5. Performance</td>
<td>.1587</td>
<td>-.5492</td>
<td>.0651</td>
<td>-.1548</td>
</tr>
</tbody>
</table>
that the ordinary least-squares estimates of the regression coefficients may be biased.

There are a number of procedures suggested in the literature to attempt to remove or reduce the effect of the errors in variables problem. However, the most satisfactory approaches involve making assumptions about the relationships between the variables that do not appear appropriate in a "first look" at the relationships. One of these approaches, based on Theil's two-stage least-squares method, is discussed later in this chapter in considering alternative means of formulating the model. This method is not a feasible solution to the measurement error problem in this study since it requires information from outside the model on variables such as technical change and input quality change. This information is not available. Since the regression coefficients are not suggested as structural parameters in this study, a consistent bias in the regression coefficients may not be a serious problem.\(^2\)

### Evaluation of Estimated Relationships on all Variables

In this section the regression equation as a whole for each company will be discussed. Particular emphasis is placed on the significance or lack thereof in the explanatory model. The estimated equations for all three firms are presented in Table 4.

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2 Note that the term, consistent, is not used here in its statistical sense. Statistically, estimates subject to measurement errors are likely to be inconsistent.
### TABLE 4

THE REGRESSION EQUATIONS ON REPORTED OPERATING EARNINGS

<table>
<thead>
<tr>
<th>Independent Variables(\text{a})</th>
<th>The Columbus and Southern Ohio Electric Company</th>
<th>The Detroit Edison Company</th>
<th>The Public Service Company of Indiana</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression Coefficient</td>
<td>Standard Error</td>
<td>(t) Statistic</td>
</tr>
<tr>
<td>Productivity</td>
<td>1.619</td>
<td>0.7426</td>
<td>2.180</td>
</tr>
<tr>
<td>Input Price</td>
<td>-3.210</td>
<td>0.9494</td>
<td>3.381</td>
</tr>
<tr>
<td>Output Price</td>
<td>-0.1933</td>
<td>0.6365</td>
<td>0.304</td>
</tr>
<tr>
<td>Utilization</td>
<td>-0.7839</td>
<td>0.2976</td>
<td>2.634</td>
</tr>
<tr>
<td>Constant</td>
<td>3.733</td>
<td>1.523</td>
<td>2.405</td>
</tr>
</tbody>
</table>

\(R^2\) = 0.530  \(F\) = 4.234  \(F_{\text{c}}\) = 6.146  \(F_{\text{c}}^{\text{2}}\) = 2.291

\(\text{a}\) As previously defined, all variables enter the model as proportions or relative changes.
\(\text{b}\) The \(t(15)\) statistic must have a value of 2.131 at the 97.5% level and 2.947 at the 99.5% level.
\(\text{c}\) The \(F(4,15)\) statistic must have a value of 3.06 at the 97.5% level and 4.89 at the 99.5% level.
While the coefficient of productivity and its statistical significance are of primary interest in this study, a consideration of the influence of the other independent variables is important. The choice of these other variables may be important in discerning the influence of productivity on performance and, taken as a group, the independent variables appear to be a set of variables that would do a good job explaining the changes in reported performance.

The first and most important point in viewing these relationship equations is that, as previously pointed out, the productivity variable is highly significant in all three companies. A rough measure of the importance of using the model proposed in this study to obtain these results is the difference between (1) the simple correlation between changes in productivity and changes in performance and (2) the partial correlation between changes in productivity and changes in performance where the variation in the performance variable and the productivity variable explained by the other variables is held constant. The simple correlation coefficient and the partial correlation coefficient for each company are as follows:

<table>
<thead>
<tr>
<th>Company</th>
<th>Simple $r$</th>
<th>Partial $r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Columbus and Southern Ohio Electric Company</td>
<td>.1587</td>
<td>.4905</td>
</tr>
<tr>
<td>The Detroit Edison Company</td>
<td>.4911</td>
<td>.7433</td>
</tr>
<tr>
<td>The Public Service Company of Indiana</td>
<td>.5142</td>
<td>.6021</td>
</tr>
</tbody>
</table>

In every case there is an increase in the coefficient. For one com-
pany, the Columbus and Southern Ohio Electric Company, the increase is very large. The implication here is that the importance of using the model proposed in this study will vary from firm to firm. In the three firms studied the strength of the relationship was increased by using the model in every case.

Utilization Variable

An interesting occurrence in Table 4 is the significant negative coefficient for the utilization variable in the Columbus and Southern Ohio Company results. It would seem reasonable to expect that with other influences removed, high utilization of capacity would imply high performance. A review of this company's operating statistics and financial reports suggested that when the utility is averaging over approximately 60% utilization of capacity on average over the year, peak load demands are often close to or over the capacity of the company's generating plant. In this situation maintenance of the generating plant becomes more expensive and higher cost standby generating units are brought into service. These higher costs are likely to cause a negative partial correlation between performance and utilization when the level of utilization is high. Since the utilization variable was not significant for the other two firms, this analysis was not extended to include them.

An alternative utilization variable based on the load factor was considered. The load factor approach to a utilization variable was not used for the Columbus and Southern Ohio Electric Company and the Public Service Company of Indiana because data for the first ten
years in the time series was missing. The load factor is usually defined as the percentage of generating capacity in use during periods of peak demand (usually one-half hour periods). The load factor data was available for the Detroit Edison Company and produced results that were approximately the same as those obtained using the generating capacity approach to this variable.

Alternative Means of Incorporating Variables in the Model

The variables included in the experimental model, other than changes in performance and changes in productivity, all have a specific purpose. This purpose is to hold constant variation in either one or both of the variables of primary interest that may conceal the hypothesized relationship between them. The other independent variables intended to hold constant variation in the productivity variable, also an independent variable, can be expected to be correlated with the productivity variable. If this correlation is high enough, the previously discussed problem of multicollinearity could be introduced. In the three firm's selected this problem, if present, did not prevent the identification of a significant relationship between the two principal variables, productivity and performance.

If this problem of highly correlated independent variables did become a problem, a technique of "purging" unwanted variation proposed by Miller and Modigliani might be useful. This technique, described

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as a formally equivalent to Theil's two-stage least-squares method,\(^1\) was used by Miller and Modigliani to deal with measurement error in an independent variable. They hypothesize that the least-squares estimate of this variable by certain other variables in the model would be purged of the measurement errors. The basis for this hypothesis lies in a theory that the variation in the certain other variables will predict the 'true' value of the independent variable being estimated. The desirable result of using this approach is to eliminate the measurement error included in the direct measurement of an independent variable where this measurement error is expected to be correlated with the error term of the original model.

The use of this technique in this study would be reversed from that of Miller and Modigliani. Whereas they were interested in eliminating an error term in an independent variable to avoid biased coefficients, the purpose in this study would be to remove that part of the variation of an independent variable of primary interest explained by other variables to avoid having the whole model founder on multicollinearity. For example, the experimental model in this study includes changes in the degree of utilization of capacity as an independent variable. One of the purposes of this variable is to remove or hold constant its effect on the productivity variable so that the remaining variation in the productivity variable will more closely approximate the variation due to technical change. The least-squares

estimate of the coefficients of the model:

\[ Q = \gamma_0 + \gamma_1 U + \varepsilon \]

where \( Q \) is the productivity variable and \( U \) is the utilization variable, would be obtained. The adjusted productivity variable used to explain performance, then would be \( Q - \hat{\gamma}_0 - \hat{\gamma}_1 U \). Letting \( T \) represent this adjusted productivity variable, the final estimation equation would be:

\[ R = \beta_0' + \beta_1' T + \beta_2' U + \beta_3' S + \beta_4' V + \eta' \]

where the variables are those previously defined in this paper. Since variable \( U \) is orthogonal to variable \( T \), the omission of \( U \) from the above equation would not change \( \hat{\beta}_1' \).

The coefficient of \( T, \hat{\beta}_1' \), might be viewed as more interesting than the coefficient of the productivity variable, since with the influence of the degree of utilization removed, it is a closer approximation of technical change. However, the least-square technique accomplishes the same task without going through two stages. The coefficients of \( T \) and \( Q \) will be the same. This equivalence is shown in Appendix B. Since the coefficients are the same, this approach cannot offer a solution to a multicollinearity problem.
CHAPTER VI
SUMMARY AND IMPLICATIONS

The positive results of this study discussed in the previous chapter encourage further development of the idea of using the arithmetic index of productivity as a proxy for technical change in accounting research. The relationship hypothesized in this study was discernible in the three electric utility companies. In this concluding chapter the implications of the results for the study of technical changes and alternative approaches to the problem area attacked in this study will be presented. The chapter concludes with a discussion of some potential extensions of the present study for future research projects.

Implications for Technical Change

The results of this experiment indicate that a significant part of the variation in changes in performance not explained by the variation of the other variables in the model is explained by changes in productivity for the three firms studied. The other variables were changes in input prices, output prices, and the degree of utilization of capacity. The use of the term "explained" with its causal implications is justified in part by the theoretical arguments in Chapter III and in part by knowledge of the components of the linear computation of performance. As previously discussed, the model was con-
structured in such a way that the measured relationships between changes in performance and changes in productivity are an indication of the influence of technical changes on changes in performance as reported by the firm's accounting system. The favorable results of the experiment indicate, at least for these three firms, that the hypothesized relationship between technical change and reported performance can be discerned empirically.

While this favorable result is encouraging, it does not mean that this result can be extended to other firms even if they are drawn from the same industry. Several additional favorable replications of the experiment in the electric power industry chosen to include firms that used hydro-generated power, that are from other geographical regions, and that are of different sizes than the firms included in this study would be required to make generalized statements about the industry as a whole. Extending the model used in this study to other industries can be expected to present a host of definitional and measurement problems.

What if the technique used in this paper or some other technique developed from this work is clearly successful in identifying the influence of technical change on performance? The answer to this question is basically the implication of this study for additional research or practical application. This subject will be considered in some detail in the concluding sections of this chapter.
Alternative Approaches

The basic research problem considered in this paper is the development of a means of describing and studying the effects of technical change on the reported performance of the business firm. One alternative to the approach used in this paper might be a simulation study. A simulation approach would first require the construction of a mathematical model that reasonably approximates the behavior of a firm in some particular industry. The parameters of the model should be proxies for variables typically believed to influence the behavior of the firm so that the behavior of the model, when these parameters are varied, will have some meaning in describing the behavior of the firm. This type of model could be used to generate data for an experiment such as that performed in this study.

The type of research presented in this study might be viewed as a first step in an alternative simulation study since some idea as to the form of the appropriate model and the important parameters might be obtained by examining the results of the empirical experiment. Information of this type may also be obtainable from industry studies and surveys of the theoretical literature on the industry.

The simulation approach to this study was not chosen because of the writer's interest in whether or not the hypothesized relationship could be discerned empirically. The extension of this study to the examination of management decisions, discussed later, is likely to involve, in part, attempts to obtain reliable estimates of the regression coefficients. These coefficients could then be used in a simulation model predicting the effect of a management decision involving a tech-
Another alternative approach to the research problem in this study might be a cross-section analysis of the industry. Using a recent two-year period of time, the relationship between changes in performance and changes in productivity holding the other variables constant could be estimated. If reliable estimates were obtained, the industry could be partitioned to investigate the consistency of the estimates across the different segments. For example the electric utility industry might be partitioned into its water-powered and fuel-powered segments.

The investigation of a cross-section of the industry was rejected for this study because of the strong possibility that the firms would be so heterogeneous that the relationship between productivity and performance variables could not be identified. A hydro-electric utility in the Pacific Northwest with its sprawling distribution system may be quite difficult to compare to a large, steam-electric utility in an eastern metropolitan area. Also, given the writer's interest in the behavior of the individual firm, a study of the firm's behavior across time seemed to be a more interesting beginning than the study of the industry at one or a few points in time.

Extensions of the Research

Knowledge of the behavior of the business firm is limited. This study is intended to make some addition to this knowledge. To be a really effective addition to knowledge of a particular field, the
normally modest findings of any single study should suggest the next step of inquiry. Should the line of investigation be continued or discarded as not worth pursuing? The remainder of this chapter presents some potential extensions of the present study that may be worth investigation.

The results of this study are limited in their scope because the subject firms are a very small portion of the industry, selected in a non-random manner from one geographical section of the country. Since the present investigation is successful, an important extension of this study is to extend it to electric utilities of different sizes, geographical location, and power sources. If the results of such an extension are intended to be generalized to any firm in the industry, the sample of firms should be selected in a manner consistent with the principles of random sampling theory. The result of a successful extension of the techniques used in this paper would establish the usefulness of the techniques in the electric utility industry.

The extension of the techniques used in this study to other industries, particularly those with heterogeneous output, is likely to present many serious problems of measurement and interpretations. A logical extension of this study, however, is the study of firms in other industries. There are other industries where the problems may not be too serious. For example, the radio broadcasting industry and some elements of the transportation industry have the relatively homogeneous output that facilitates interpretation of computed productivity over time. For example, the airline industry is essentially producing ton-miles of air transportation and has been subject to very visible
technical changes. Firms in the electric utility industry were chosen for this study because, in addition to the desirable behavior characteristics, the needed data on firms in this industry are particularly accessible.

Once the researcher has a useful technique for empirically identifying the relationship between changes in performance and technical changes (and possibly the structural coefficient of technical change in explaining performance), he should consider means of utilizing the technique. Up to this point, the primary focus of attention has been on using the techniques in this paper to investigate and expand our knowledge of the firm's behavior. There are at least two potential applications of the technique that extend beyond the present scope. The technical changes whose effects are studied in this paper are often the result of management decisions. The end result of the decisions, the technical changes and their effect on performance are considered in this paper. A logical extension of this study is to consider the relationships and time lags between decisions and technical changes. The completion of this step would provide a framework for empirical analysis of one particular class of management decisions — those considering, directly or indirectly, the technical changes to be implemented by the firm.

There has been considerable ferment in accounting literature in recent years concerning the usefulness and practicability of alternative measures of reported performance. A researcher might be interested in evaluating the sensitivity of different measures of performance to the components of performance used as variables in this study. Also,
an interesting line of accounting research would be to compare the behavior of the model used in this study across time between a successful firm and an unsuccessful firm in one industry. One logical result of the successful identification of important indicators of success and failure might be to include the indicator's in reports to interested persons outside the business firm.
APPENDIX A

Since the literature of technology suggests that the terminology of this complex subject is quite varied, the following definitions, most of which are suggested by Jacob Schmookler, will be used here:

1. Technology - the social pool of knowledge of the industrial arts (as is common in economics literature, this definition excludes human technology such as medicine and those parts of organizational technology that do not relate directly with industrial arts).

2. Technological capacity - that portion of existing technology which a nation's people commands, weighted by its distribution among the labor force.

3. Rate of technological progress - the rate at which new technology is produced in any period.

4. Rate of replication - the rate at which technology in existence at the beginning of a period is disseminated.

5. Technique - a method of producing a given good or service.

6. Technical change - when an enterprise produces a good or service or uses a method or input that is new to it (in this paper it will be assumed that any technical change made by a firm is a technical improvement).

7. Innovator - the first enterprise to make a given technical change. Its action is innovation.

8. Imitator - an enterprise making a technical change after the innovator.
In this study an alteration of the model equation based on the Miller and Modigliani purging technique was considered. The alteration involved the substitution of the residual from the estimation of the productivity variable by the utilization variable for the original productivity variable. This alteration was motivated by an interest in removing the influence of the utilization variable from the productivity variable. The purpose of this appendix is to show that the coefficient of the residual variable will be identical to the coefficient of the productivity variable in the original equation.

The basic model equation in this study is

\[ R = \beta_0 + \beta_1 U + \beta_2 Q + \beta_3 S + \beta_4 V + \epsilon \]

or in matrix notation, \( R = X\beta + \epsilon \) where

\[
X = \begin{pmatrix}
1 & U_1 & Q_1 & S_1 & V_1 \\
1 & U_2 & Q_2 & S_2 & V_2 \\
\vdots & \vdots & \vdots & \vdots & \vdots
\end{pmatrix}
\]

The variables are those defined in Chapter IV. The matrix \( X \) can be partitioned to result in the following model equation:

\[ R = X_1\beta_{1.23} + X_2\beta_{2.13} + X_3\beta_{3.12} + \epsilon \]
where

\[
X_1 = \begin{pmatrix}
1 & U_1 \\
1 & U_2 \\
\vdots & \vdots \\
\vdots & \vdots \\
\end{pmatrix}
\quad X_2 = \begin{pmatrix}
Q_1 \\
Q_2 \\
\vdots \\
\vdots \\
\end{pmatrix}
\quad X_3 = \begin{pmatrix}
S_1 & V_1 \\
S_2 & V_2 \\
\vdots & \vdots \\
\vdots & \vdots \\
\end{pmatrix}
\]

The residual variable of interest in this appendix is \(X_{2.1}\) resulting from the following least-squares estimation:

\[X_2 = X_1 \hat{\beta}_{21} + X_{2.1}\]

where

\[X_{2.1} = X_2 - X_1 (X_1'X_1)^{-1}X_1'X_2\]

A fact that will be useful in the following derivations is that

\[X_1'X_{2.1} = X_{2.1}'X_1 = 0.\] This can be shown as follows:

\[X_1'X_{2.1} = X_1'[X_2 - X_1(X_1'X_1)^{-1}X_1'X_2]\]
\[= X_1'X_2 - X_1'X_1(X_1'X_1)^{-1}X_1'X_2\]
\[= X_1'X_2 - X_1'X_2 = 0\]

\[X_{2.1}'X_1 = [X_2 - X_1(X_1'X_1)^{-1}X_1'X_2]'X_1\]
\[= X_2'X_1 - X_2'X_1(X_1'X_1)^{-1}X_1'X_1\]
\[= X_2'X_1 - X_2'X_1 = 0\]

The normal equations for the original model in matrix notation is

\[(X'X)\hat{\beta} = X'R.\] Using the above partitioning of the \(X\) matrix:

\[
\begin{pmatrix}
X_1'X_1 & X_1'X_2 & X_1'X_3 \\
X_2'X_1 & X_2'X_2 & X_2'X_3 \\
X_3'X_1 & X_3'X_2 & X_3'X_3
\end{pmatrix}
\begin{pmatrix}
\hat{\beta}_{1.23} \\
\hat{\beta}_{2.13} \\
\hat{\beta}_{3.12}
\end{pmatrix}
= \begin{pmatrix}
X_1'R \\
X_2'R \\
X_3'R
\end{pmatrix}
\]

Assuming the existence of the appropriate inverses, the solution for \(\hat{\beta}_{2.13}\) may be written:

\[
(Z_1 - Z_2Z_3^{-1}Z_4)\hat{\beta}_{2.13} = (Z_5 - Z_2Z_3^{-1}Z_6)
\]
where

\[ Z_1 = x_2'x_2 - x_2'x_1(x_1'x_1)^{-1}x_1'x_2 \]
\[ Z_2 = x_2'x_3 - x_2'x_1(x_1'x_1)^{-1}x_1'x_3 \]
\[ Z_3 = x_3'x_3 - x_3'x_1(x_1'x_1)^{-1}x_1'x_3 \]
\[ Z_4 = x_3'x_2 - x_3'x_1(x_1'x_1)^{-1}x_1'x_2 \]
\[ Z_5 = x_2' - x_2'x_1(x_1'x_1)^{-1}x_1' \]
\[ Z_6 = x_3' - x_3'x_1(x_1'x_1)^{-1}x_1' \]

Since the use of the residual variable is equivalent to replacing the vector \( X_2 \) with the vector \( X_{2.1} \) in the above formulations, the purpose of this appendix is accomplished if it can be shown that the \( Z_i \)'s do not change when \( X_{2.1} \) is substituted for \( X_2 \). In the following \( Z_i \) will represent the above \( Z_i \) where \( X_{2.1} \) has been substituted for \( X_2 \).

Beginning with \( Z_1 \), we have

\[ \hat{Z}_1 = x_{2.1}'x_{2.1} - x_{2.1}'x_1(x_1'x_1)^{-1}x_1'x_2 \]

Since \( x_{2.1}'x_1 = 0 \),

\[ \hat{Z}_1 = x_{2.1}'x_{2.1} \]
\[ \hat{Z}_1 = [x_2 - x_1(x_1'x_1)^{-1}x_1'] \cdot [x_2 - x_1(x_1'x_1)^{-1}x_1'] \]
\[ = [x_2' - x_2'x_1(x_1'x_1)^{-1}x_1'] \cdot [x_2 - x_1(x_1'x_1)^{-1}x_1'x_2] \]
\[ = x_2'x_2 - x_2'x_1(x_1'x_1)^{-1}x_1'x_2 \]
\[ - x_2'x_1(x_1'x_1)^{-1}x_1'x_2 \]
\[ + x_2'x_1(x_1'x_1)^{-1}x_1'x_1(x_1'x_1)^{-1}x_1'x_2 \]
\[ \hat{Z}_1 = Z_1 \]

Next we have

\[ \hat{Z}_2 = x_{2.1}'x_3 - x_{2.1}'x_1(x_1'x_1)^{-1}x_1'x_3 \]
\[ = x_{2.1}'x_3 \]
\[ = [x_2' - x_2'x_1(x_1'x_1)^{-1}x_1']x_3 \]
\[ Z_2 = Z_2 \]

For \( Z_3 \) there is no change since \( X_2 \) does not appear in its formulation. Thus \( \hat{Z}_3 = Z_3 \).

For \( Z_4 \) we have
\[
\hat{Z}_4 = X_3'X_2.1 - X_3'X_1(X_1'X_1)^{-1}X_1'X_2.1
\]
\[
= X_3'X_2.1
\]
\[
= X_3'[X_2 - X_1(X_1'X_1)^{-1}X_1'X_2]
\]
\[
= X_3'X_2 - X_3'X_1(X_1'X_1)^{-1}X_1'X_2
\]
\[ \hat{Z}_4 = Z_4 \]

For \( Z_5 \) we have
\[
\hat{Z}_5 = X_2.1' - X_2.1'X_1(X_1'X_1)^{-1}X_1'
\]
\[
= X_2.1'
\]
\[
= X_2' - X_2'X_1(X_1'X_1)^{-1}X_1'
\]
\[ \hat{Z}_5 = Z_5 \]

For \( Z_6 \) there is no change since \( X_2 \) does not appear in its formulation. Thus \( \hat{Z}_6 = Z_6 \).

The above analysis shows that the substitution of the residual variable, \( X_{2.1} \), in the model equation will not change the coefficient of productivity. This same approach can also be used to show that \( \hat{b}_{3.12} \) would not change. However, the coefficients in \( \hat{b}_{1.23} \) would change.
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