A Study of Growth Factors of Electric Energy Production in Pennsylvania 1956–1971*

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Introduction

Electricity is the most preferred form of energy because it is versatile in its application, clean in its use, relatively safe and readily controlled. The United States currently utilizes about 23% of its energy in the form of electricity. This is expected to increase to 34% by 1980, and to 44% by 1990.

A recent study [21] pointed out that the consumption of electricity in Pennsylvania in 1971 was more than double that of 1956 and would almost double from 1971 to 1985. It seemed worthwhile to follow up with an examination of the reasons for this vigorous growth.

The three basic objectives of the present study are:

- —to derive the relative proportions of total increase in output that are caused by growth in labor and capital formation,
- —to characterize the manner in which changes in output occur apart from changes in the specified inputs, and
- —to investigate the question of returns to scale.

The explanation of the growth of total electric power production in Pennsylvania, 1956–1971 rests on the assumptions that, in the terminology of the theory of production, if quantities of output and input are measured accurately, growth in total output is largely explained by growth in total input and that the complexities and interdependencies between them can be described by the aggregate production function.

Previous studies of similar problems have concentrated their attention on analysis of technological progress in terms of the production function and have attempted to find out how much, if any, of the decline in the input requirements is attributable to each of the following three factors: (1) economies of scale; (2) factor substitution; and (3) the shift in the production function. These studies include those of Nerlove [14], Komiya [12], and Dhrymes and Kurz [3]. However, they are concerned exclusively with the nature of the production function itself as it relates to the United States steam electric power industry.

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Throughout Nerlove's paper he conducts his investigation on the firm level for the year 1955, using cross-section sample. Assuming the steam electric generating process to be described by the aggregate production function, Nerlove proceeds to estimate its parameters via the implied cost function under the hypothesis that firms act so as to minimize cost under an output constraint. His main conclusion is that the generating aspect of electricity supply is uniformly characterized by increasing returns to scale, the degree of such returns being a decisive function of the output level.

Komiya, analyzing data from the newly constructed electric generating plants in the United States over the period 1930–1956, tried to find out how much, if any, of the decline in the input requirements is attributable to each of the three above-mentioned factors. He begins by assuming a substitution model, in which fuel, capital, and labor inputs are assumed substitutable for each other. No assumption regarding the market conditions under which the economic unit operates is made. This attempt does not yield satisfactory results, quite likely because of multicollinearity of the input. In his second approach he introduces the Leontief Model, in which each of three major inputs is assumed as a logarithmic linear function of the output. He stratifies his sample by technological subclasses and then conducts an analysis of covariance, treating technology as the factor level.

Komiya's study led him to one main conclusion—that in steam power generation the scale effect is a far more important factor than the process of technological change.

We agree with Dhrymes and Kurz that Komiya's treatment of the number and size of generating units in explaining the dollar cost of a plant is questionable. Hence, a particularly advantageous purchase (very low price) of a generating unit will be interpreted by Komiya as a factor of increasing returns to scale in electricity generation. In turn, capital is assumed to be measurable by means of the deflated cost of the generating units. In conclusion, we cannot endorse Komiya's position.

An econometric investigation of the impact of technology and size on the characteristics of production in the steam electric generating industry was also undertaken by Dhrymes and Kurz. Using data related to newly constructed plants in the United States over the period 1937–1959, they investigated the question of returns to scale in electricity supply, and assessed the effects of technological change on returns to scale. In the process they employed the constant elasticity of substitution production function and proceeded to estimate its parameters under Nerlove's cost minimization hypothesis and the sample stratification technique of Komiya.

Dhrymes and Kurz[1] concluded that increasing returns to scale prevail throughout, and the main impact of technology was registered during the 50's.

In our analysis the Cobb-Douglas production function, with unconstrained returns to scale is used, and we simultaneously introduced a marginal productivity condition representing cost minimization in competitive factor markets. Time-series data related to the State of Pennsylvania total electric power generation over the period 1956–1971 are employed.

THE PRODUCTION FUNCTION

Let the production process in a certain industry be characterized by the Cobb-Douglas production function.

$$Y_t = \beta_0 X_{1t}^{\beta_1} X_{2t}^{\beta_2} U_t \tag{1}$$

where Y_t—real output,
X_{1t}—labor input,
X_{2t}—capital input
β_0, β_1 and β_2—constant parameters,
U_t—multiplicative disturbance distributed independently of X_{1t} and X_{2t} with expectation unity.

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[1] Phoebus J. Dhrymes and Mordecai Kurz: Technology and Scale in Electricity Generation, Econometrica, Vol. 32, No. 3 (July 1964), p. 288.

This form has constant elasticities with respect to each of the conditioning variables:

$$(\partial Y_t/\sigma X_{Kt})(X_{Kt}/Y_t) = \beta_K$$

where $(K = 1, \ldots, K)$.

It has been widely used in theoretical and empirical analyses of production.

This function, with provision for disembodied neutral technical change at the rate of $10^{\lambda-1}$, may be written as:

$$Y_t = \beta_0 X_{1t}^{\beta_1} X_{2t}^{\beta_2} 10^{\lambda t} U_t \tag{2}$$

The productivity parameter λ helps to describe the manner in which changes in output occur apart from changes in the specified input.

Equations (1) and (2) are nearly always transformed into the log linear relationship.

$$\text{(3)}\quad \text{Log } Y_t = \text{Log } \beta_0 + \beta_1 \text{ Log } X_{1t} + \beta_2 \text{ Log } X_{2t} + \lambda t + \text{Log } U_t$$

Where log U_t is an additive disturbance, independent of X_{1t} and X_{2t} with expectation zero. In this form the function (2) is a single equation which is linear in the unknown parameters: Log $\beta_0, \beta_1, \beta_2, \lambda$.

If we simultaneously introduce a marginal productivity condition representing cost minimization in competitive factor markets, it can be described as:

$$\text{(4)}\quad \frac{WX_{1t}}{PX_{2t}} = \frac{\dfrac{\partial Y_{t*}}{\partial X_{1t}}}{\dfrac{\partial Y_{t*}}{\partial X_{2t}}} V_t = \frac{\dfrac{\partial Y_t}{\partial X_{1t}}}{\dfrac{\partial Y_t}{\partial X_{2t}}} V_t = \frac{\beta_1}{\beta_2} \cdot \frac{X_t}{X_{2t}} V_t$$

where Y_{t*} is the nonstochastic portion of total output (which might be interpreted as "planned output"), PX_{2t} is the price of capital services, WX_{1t} is the wage rate, and V_t is a random disturbance reflecting incomplete cost minimization. Equation (4), considered by itself, is a linear relationship in *ratio variables* with an unknown parameter $\frac{\beta_1}{\beta_2}$ which becomes evident when it is transformed to:

$$\text{(5)}\quad \text{Log } \frac{WX_{1t}}{PX_{2t}} = \frac{\beta_1}{\beta_2} + \text{Log } \frac{X_{1t}}{X_{2t}} + \text{Log } V_t$$

Estimates of equation (1) or (2) can be obtained by application of the least squares methods.

In order to avoid multicollinearity problems among inputs we can estimate $\beta_0, \beta_1, \beta_2$ and S_{ut} from the joint distribution of X_{1t} and X_{2t} (given WX_{1t}, PX_{2t}, and Y_t), which is based upon the system (2) – (4). Estimation is possible by the introduction of Professor L. R. Klein's[2] two step procedure. The two-step procedure estimates $\frac{\beta_1}{\beta_2}$ from equation (5) (by setting the sum of the log arithmic residuals equal to zero in the sample) and then regresses log Y_t in equation (3) on t and $\left(\frac{\beta_1}{\beta_2} \text{ Log } X_{1t} + \text{Log } X_{2t}\right)$ where $\frac{\beta_1}{\beta_2}$ is the previously obtained estimate of $\frac{\beta_1}{\beta_2}$. The coefficient of the combined variables in the regression is our estimate of β_2. From the estimate of β_2 and of $\frac{\beta_1}{\beta_2}$, we may obtain the estimate of β_1 as:

$$\text{est. } \beta_1 = \frac{\beta_1}{\beta_2} \cdot \beta_2$$

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[2] See L. R. Klein: A testbook of Econometrics, Illinois, and New York, 1953, 226–236, and also Ronald G. Bodkin and Lawrence R. Klein: Non-linear Estimation of Aggregate Production Function, The Review of Econometrics and Statistics, Vol. XLIX, (February 1967, No. 1).

Application to Electric Power Generation in Pennsylvania 1956-1971

THE INPUT-OUTPUT RELATIONSHIP[3]

Production of electric energy (in KWH) in the State in 1971 was about double that of 1956. Using 1956 = 100.0 as the statistical base, its relative index in 1971 was 200.2, with an annual average growth rate of 4.8%.

The basic fuel source pattern has not been altered over the period analyzed. The four sources of electricity are: coal, gas and fuel oil, hydro, and nuclear power. Among them, the main one is still coal.

The total electric energy production contributed by coal has had, with some faltering, an upward trend between 1956 and 1971. The relative index in 1971 was an estimated 177.6, with 1956 = 100.0. Coal contributed 91.2%–94.2% to the total electricity production between 1956 and 1965. Since 1966 we observe a gradual distinct decline in its contribution. In 1971 it was 80.9%.

The second source used by generating plants, according to fuel type, is gas and fuel oil.[4] Between 1956 and 1966 about 2.3%–6.8% of total electric production was attributable to gas and fuel oil. For the other years of the period analyzed there has been a steady rapid increase in its contribution to total electric energy production. In 1971 its fraction was 18.1%.

Hydro generation contribution to total electric power production, until 1956, was insignificant in the analyzed period (In 1956, 6.5%). Between 1957 and 1960, it was rather constant (2.1%–2.2%). Since 1961, there has been a gradual decrease in the hydro generation contribution. In 1971, it was only 0.4%.

Nuclear power contributed 0.02% to the total electric power production in 1957. Between 1958 and 1967, it had an upward trend, except in 1964 and 1966, because of changes in technology. It ranged from 0.4% in 1958 to 1.0% in 1967. In 1971, it was only 0.6%.

Let us now relate the above described growth tendencies of output to the trends of input-productive factors: labor, capital and technological progress.

Labor, capital and technological progress are usually considered as the major growth factors of electric energy production. Electric power generation is a highly automated process and labor input enters the productive process in three ways: operation and supervision of the plant which entails work of control and adjustment; maintenance; and clerical and office work. Labor requirements move more or less with the output and number of units in operation.

The average number of employees or manhours are used as measures of labor input. However, the average number of employees does not take into account the length of the work week, the operation of double shifts, and similar practices. For that reason, when manhour measures are available, they are preferable from an econometric point of view. In this case it is a flow variable in the same dimensions as output.

In the long range the technological progress in electricity generation (as in most manufacturing industries where fixed capital equipment plays an important role) requires from labor less physical effort and more knowledge and experience.

In order to take these two components of labor input into consideration, we have corrected the annual average number of employees, and the annual average number of manhours by the relative index of total wages and salaries of employees in thousands of constant dollars, 1958 = 100.0.

The annual average number of employees engaged in electricity generation in Pennsylvania between 1956 and 1971 decreased about 3.8%. From 1966 to 1971, there was a slight increase in the annual average number of employees but it never exceeded that of 1956.

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[3] The detailed data discussed in this section are available from the authors.

[4] Approximately 80% fuel oil; 20% natural gas.

Almost the same growth tendency can be observed for the annual average number of manhours employed in Pennsylvania's electric power generation industry in the same period. Its relative index in 1971 was 97.9, with 1956 = 100.0.

In the same period, the annual average number of employees and the annual average number of manhours corrected by the relative index of total wages and salaries of employees had quite different growth tendencies. The annual average number of employees between 1956 and 1963, except for 1959 and 1960, was less than that of 1956; from 1964 to 1971, there was a steady and proportionate tendency of growth. The relative index for 1971 was 138.3, with 1956 = 100.0. The average annual rate of growth between 1956 and 1971 was 140.8—an annual average growth rate of 2.2%.

The presence of technical change complicates the measurement of capital input. In a world of progress, it is difficult to measure, at successive instants of time, an aggregate of capital stock or input flow, where the different components of the aggregate consists of highly durable pieces of non-uniform quality. The different vintages of capital goods have different technical attributes. The series on capital stock is constructed from the conventional national income accounts. Statistics on capital stock for the industrial sector are obtained from series on gross investment in fixed capital and capital consumption or depreciation. In terms of these statistics, net investment in constant price system is computed and accumulated to give capital stock values.

In some studies, direct physical estimates, such as horsepower ratings of equipment, can be used as an alternative capital measure.

In highly capitalized industries measures of productive capacity may serve as a measure of capital stock.

We have examined:

- —Net investment in thousands of constant dollars, 1958 = 100.0,
- —capital expenditures in thousands of constant dollars, 1958 = 100.0, and
- —total installed capacity in KW.

Net investment has increased about 68.6% in the state electric power industry over the past sixteen years. Its average annual rate of growth between 1956 and 1971 was 3.5%.

There was substantial growth in capital expenditures. In 1971 they were over five times as large as those of 1956. Capital expenditures had, with some faltering, an upward trend between 1956 and 1971. An intensified growth tendency in new capital formation can be observed particularly from 1962 to 1971. The annual average growth rate between

This intensified growth tendency of capital formation suggests a rather striking impact of technological improvement on the degree of mechanization. The reduction in labor and capital requirements due to these changes is very substantial.

During the sixteen year period from 1956 to 1971, the labor and capital requirements per unit of produced electric power declined by 26.7% and 15.8% respectively.

They are reflected in a significant increase in total installed capacity. Total installed capacity for the same period increased approximately 138.9%, with an annual average growth rate of 6.0%.

The basic fuel source pattern of the total installed capacity to generate electric energy in Pennsylvania, 1956–1971, was practically unchanged between 1956 and 1966. About 93.1%–96.0% of the total installed productive capacity was for coal plants; 0.4%–1.0% for gas and fuel oil plants; about 2.9%–2.0% (between 1957 and 1966, in 1956—6.6%) for hydroelectric plants; and 1.3%–1.0% for atomic plants.

Between 1967 and 1971 the basic installed capacity pattern was subject to substantial changes. In 1967 coal accounted for 88.1% of electric generation, gas and fuel oil 4.2%, hydroelectric 6.7% and nuclear 1.0%; in 1971, coal capacity dropped to 60.0% of the total; oil and gas rose to 33.1%; hydroelectric dropped slightly to 6.1% and nuclear dropped slightly to 0.8%.

The long-run trend seems to be substitution of capital for fuel and labor inputs.

The quantitative expressions of the complexities and interdependencies between input and output in these relationships are discussed in the following section.

Estimation

FIRST PHASE OF ESTIMATION

Using a productive input–output relation like (2), the following set of variables was taken for consideration:

Y_t—The total electric energy production (in KWH),

X_{1t}—An annual average number of employees,

$\overset{*}{X}_{1t}$—An annual average number of employees corrected by relative index of total wages and salaries of employees (in thousands of constant dollars, 1958 = 100.0).

X_{1ht}—An annual average number of manhours,

$\overset{*}{X}_{1ht}$—An annual average number of manhours corrected by relative index of total wages and salaries of employees (in thousands of constant dollars, 1958 = 100.0),

X_{2t}—The total installed generating capacity (in KW),

The variable for time appears in our regression models to characterize the impact of technical change on the production function. It will be seen that under the phrase "technical change" we have in mind Solow's special case of neutral technical change. This "neutral" type is expressed by a shift in the production function. "Shifts in the production function are defined as neutral if they leave marginal rates of substitution untouched but simply increase or decrease the output attainable from given inputs."[5]

Introducing data described in the last section, four variants of equation (2) have been estimated corresponding to different labor input measures:

I. 1) $$\operatorname{Log} Y_t = \operatorname{Log} \beta_0 + \beta_1 \operatorname{Log} X_{1t} + \beta_2 \operatorname{Log} X_{2t} + \lambda \cdot t + \operatorname{Log} U_t$$

2) $$\operatorname{Log} Y_t = \operatorname{Log} \beta_0 + \beta_1 \operatorname{Log} \overset{*}{X}_{1t} + \beta_2 \operatorname{Log} X_{2t} + \lambda \cdot t + \operatorname{Log} U_t$$

II. 1) $$\operatorname{Log} Y_t = \operatorname{Log} \beta_0 + \beta_1 \operatorname{Log} X_{1ht} + \beta_2 \operatorname{Log} X_{2t} + \lambda \cdot t + \operatorname{Log} U_t$$

2) $$\operatorname{Log} Y_t = \operatorname{Log} \beta_0 + \beta_1 \operatorname{Log} \overset{*}{X}_{1ht} + \beta_2 \operatorname{Log} X_{2t} + \lambda \cdot t + \operatorname{Log} U_t$$

We proceeded to estimate the parameters by regressing the logarithms of output, on logarithms of capital, logarithms of labor, and time, by the ordinary least squares method. No marginal productivity condition was assumed.

The results are summarized in Table I.

TABLE I

ESTIMATES OF THE PARAMETERS OF THE COBB-DOUGLAS PRODUCTION FUNCTION, WITH UNCONSTRAINED RETURNS TO SCALE

	LOG β_0	β_1	β_2	λ	R	S_u	F	d
I. 1)	1.38241	0.318	0.260	0.017	0.978	0.02267	178.90	1.82
Standard Error		(0.537)	(0.247)	(0.043)				
t.		0.593	1.053	0.385				
2)	1.57452	0.176	0.317	0.015	0.978	0.02289	175.46	1.79
Standard Error		(0.361)	(0.222)	(0.038)				
t.		0.487	1.430	0.396				
II. 1)	1.99790	0.233	0.226	0.015	0.979	0.02243	182.87	1.87
Standard Error		(0.191)	(0.234)	(0.028)				
t.		1.221	0.928	0.527				
2)	1.95033	0.128	0.296	0.014	0.978	0.02281	176.76	1.79
Standard Error		(0.172)	(0.232)	(0.028)				
t.		0.748	1.276	0.503				

Source: See text

Note: A) For a significance level of 5 per cent and $n - k - 1 = 16 - 3 - 1 = 12$ degrees of freedom, the value of t is $t = 1.782$.

B) Critical f value at the 0.05 level of confidence and 12 degrees of freedom is $f = 3.41$.

C) Critical d_L and d_U values (for the Durbin-Watson Test at the 0.05 level of confidence, $n = 16$, and $k = 3$ independent variables are $d_L = 0.86$ and $d_U = 1.54$.

The statistical picture which emerges shows that this attempt to fit the Cobb-Douglas production function, with unconstrained returns to scale (with provision for disembodies neutral technical change at the rate of $10^{\lambda-1}$) to our empirical observations did not give satisfactory results. Let us now turn to the statistical significance of individual parameter estimates. The generally high values of the Durbin-Watson statistic indicates that they are not significant, and we accepted the null hypothesis that the residuals of the production function equations are not autocorrelated. Next, we consider the question of the significance of the partial regression coefficients. Our t statistics for each of the considered equations, are generally low. We conclude that the partial regression coefficients are not individually significant. The very high values of the F statistics for each of our production function equations suggest that the regression is significant, even though individual coefficients are not.

The problem with the estimate may be that the multicollinearity of the input and time factors obscures the separate contributions of these variables.

SIMPLE CORRELATION COEFFICIENTS

	Y_t	X_{1t}	$\overset{*}{X}_{1t}$	X_{1ht}	$\overset{*}{X}_{1ht}$	X_{2t}	t
Y_t		−0.153	0.903	−0.164	0.886	0.975	0.957
X_{1t}	0.153	—	—	—	—	0.020	0.308
$\overset{*}{X}_{1t}$	0.903	—	—	—	—	0.882	0.867
X_{1ht}	−0.164	—	—	—	—	0.062	0.239
$\overset{*}{X}_{1ht}$	0.886	—	—	—	—	0.924	0.858
X_{2t}	0.975	0.020	0.882	0.062	0.924	—	0.966
t	0.957	0.308	0.867	0.239	0.858	0.966	—

Source: See text

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[5] R. M. Solow: Technical Change and the Aggregate Production Function, *Review of Economics and Statistics*, Vol. 39, 1957, p. 314.

SECOND PHASE OF ESTIMATION

Since the single-equation, least squares method in estimating the above equations did not yield satisfactory results, we introduced Klein's two-step approach. Following this, we first estimated the parameters of the marginal productivity side condition and then proceeded to estimate the remaining parameters from the production function relation.

Further computational manipulation yields the estimates of parameters β_0, β_2 and λ for each equation:

I. 1)

$$\begin{array}{lll} \beta_0 = 2.074 & \beta_2 = 0.279 & \lambda = 0.013 \\ \quad (6.977) & \quad (0.787) & \quad (0.023) \end{array}$$

2)

$$\begin{array}{lll} \beta_0 = 0.307 & \beta_2 = 0.542 & \lambda = 0.014 \\ \quad (9.962) & \quad (1.123) & \quad (0.028) \end{array}$$

II. 3)

$$\begin{array}{lll} \beta_0 = 1.851 & \beta_2 = 0.299 & \lambda = 0.014 \\ \quad (7.934) & \quad (0.882) & \quad (0.022) \end{array}$$

4)

$$\begin{array}{lll} \beta_0 = 2.192 & \beta_2 = 0.262 & \lambda = 0.014 \\ \quad (6.988) & \quad (0.778) & \quad (0.023) \end{array}$$

The standard errors of these numerical estimates of parameters β_0, β_2 and λ in each equation persuaded us not to proceed with the calculation of the estimate of β_1.

The uncertainty of these results is caused by the inter-correlation between the smoothed-out time trend representing neutral technical progress and the combined variable. A further, quite likely explanation may be that the electric power industry was, as we pointed out in the second section, one of the most stable and tranquil industries in the entire economy of the State over the last sixteen years. We have not observed any kind of extra slow-downs or speed-ups in the trend of the total electric energy production during the period analyzed.

Accordingly we re-estimated the equations without time trends without time. The new equations and the estimates of their parameters are shown in Table 3. For the cells of each column the upper figure is the parameter estimate itself, while the figure below it in parentheses is (where given and/or appropriate) the associated standard error.

TABLE 3

ESTIMATES OF THE PARAMETERS OF THE COBB-DOUGLAS PRODUCTION FUNCTION, WITH UNCONSTRAINED RETURNS TO SCALE

Equation	Estimates	Log β_0 (1)	β_1 (2)	β_2 (3)	$\beta_1 + \beta_2$ (4)	S_U (5)	R^2 (6)	F. (7)
I. 1)	$\text{Log } Y_t = \text{Log } \beta_0 + \beta_1 \text{Log } X_{1t}$ $+ \beta_2 \text{Log } X_{2t} + \text{Log } U_t$	−2.87162 (3.21600)	0.381 (0.237)	0.838 (0.355)	1.219	0.02663	0.937	3.20
2)	$\text{Log } Y_t = \text{Log } \beta_0 + \beta_1 \text{Log } \overset{*}{X}_{1t}$ $+ \beta_2 \text{Log } X_{2t} + \text{Log } U_t$	−1.80349 (2.61228)	0.326 (0.191)	0.717 (0.287)	1.043	0.02445	0.947	3.84
II. 1)	$\text{Log } Y_t = \text{Log } \beta_0 + \beta_1 \text{Log } X_{1ht}$ $+ \beta_2 \text{Log } X_{2t} + \text{Log } U_t$	−3.12941 (3.31452)	0.389 (0.241)	0.854 (0.361)	1.243	0.02673	0.937	3.33
2)	$\text{Log } Y_t = \text{Log } \beta_0 + \beta_1 \text{Log } \overset{*}{X}_{1ht}$ $+ \beta_2 \text{Log } X_{2t} + \text{Log } U_t$	−1.82352 (2.67424)	0.323 (0.193)	0.710 (0.290)	1.033	0.02519	0.944	3.20

Source: See text.

Note: For a significance level of 5 percent and $m - k - 1 = 16 - 2 - 1 = 13$ degrees of freedom, the critical value of F is $F = 3.80$.

Critical d_L and d_u values (for the Durbin-Watson Test) at the 0.05 level of confidence, $n = 16$, and $K = 2$ independent variables are $d_L = 0.86$ and $d_u = 1.54$.

The statistical picture which can be drawn is one of a very tight fit of the selected production function. This is hardly surprising, in view of the strong trend in the output variable. We shall be more interested in the statistical significance of individual parameter estimates. In general, the residuals of the production function equations are significantly autocorrelated, as indicated by the low values of the Durbin-Watson statistic. Thus, our statistical tests of significance are somewhat vitiated by the presence of this phenomenon; although in the case of equation (I. 1) the F ratio is relatively higher than its critical value and in the case of the rest of the studied production function equations it is high enough that one might still be willing to place a fair amount of confidence in the statistical tests under examination.

We may now proceed to a discussion of the picture of the economic structure which emerges. It is quite interesting. The numerical values of the estimates of the labor and capital input parameters show that approximately one-third of the total increase in electric energy production is Pennsylvania over the considered time-series sample is attributable to growth in labor and two-thirds to growth in capital.

Next, we may turn to the problem of the measure of labor input, in terms of the aggregated production function which we raised in section II. There are quite small and insignificant differences between the parameter estimates of the equations (I. 1) and (II. 1). The same statistical picture can be seen regarding the parameter estimates of the equations (I. 1) and II. 1). Yet there are significant differences between the parameter estimates of the equation (I. 1) and (I. 2), and of the equations (II. 1) and (II. 2). It means that the both measures—an annual average number of employees (X_{1t}) and an annual average number of manhours (X_{1ht})—of labor input, i.e., its physical effort engaged in electricity generation in Pennsylvania, 1956–1971, describes, almost identically, the relative share of total increases in output that are caused by growth in labor. Nevertheless, an annual average number of employees ($\overset{*}{X}_{1t}$) and an annual average number of manhours ($\overset{*}{X}_{1ht}$) corrected by relative index of total wages and salaries of employees (in thousands of constant dollars, 1958 = 100.0), including physical and mental components of labor input, employed in Cobb-Douglas production function yield better results. The coefficients of multiple determination are slightly higher and the standard errors of their parameters estimates are more statistically significant, by conventional criteria.

For all equations in column (4) we have point estimates of returns to scale. In all cases, increasing returns to scale are the prevailing phenomena in electric power generation in Pennsylvania, 1956–1971.

For the above discussed reasons our preferred production function equation is equation (I. 2). Although its residuals are significantly autocorrelated, one might still be willing to predict Y_t by its application with some degree of confidence in its relative accuracy.

In terms of the aggregate production function, we conclude that the substantial growth of total electric energy production during a sixteen-year period from 1956 to 1971 in the State occurred under the impact of technological improvement.

The decline in the labor and capital requirements per unit of produced electric energy by 26.7% and 15.8% respectively is attributable to the intensified growth tendency of capital formation.

The electric power industry required, under the impact on the degree of mechanization, more qualified labor input over the last sixteen years.

The substantial changes in the basic fuel source pattern during the last six years of the analyzed period are due to the air pollution/technological improvement problems.

The great increase in total installed capacity is to be considered as the major achievement of technological progress in this industry.

There have not been any observed extra "slowdowns" or "speedups" in the trend of total electric energy production in the State over the last sixteen years.

The Cobb-Douglas production function, with unconstrained returns to scale (with provision for disembodied neutral technical progress at the rate of $10^{\lambda-1}$ fit to our empirical observations, did not yield satisfactory results. The single-equation, least squares method of estimating its parameters was used, and no marginal productivity condition was assumed.

Klein's two-step approach in parameters estimation of the assumed aggregate production function also did not give satisfactory results. The uncertainty of those results may be due to the intercorrelation between the smoothed-out time trend representing neutral technical progress and the combined variables.

Among the three possible explanatory factors of the growth of total electric production—labor, capital, and the smoothed-out time trend, the time factor was dismissed, because its associated parameter estimates were not statistically significant.

The statistical picture which emerges shows that all four equations corresponding to the considered labor input measures have a satisfactory close fit to actual sample data.

The recognized substantial autocorrelation in the estimated residuals from the production function relationships of our equations may be reduced by "improvement" of the sample and introduction of the alternative capital and labor input measures.

One-third of the total increase in electric energy production in Pennsylvania is attributable to growth in labor and two-thirds to growth in capital.

For all cases an increasing return to scale is the prevailing phenomenon.

The fixed capital equipment played an important role.

REFERENCES

[1] Arrow, K. J., B. Minhas, M. Chenery, and R. Solow: "Capital-Labor Substitution and Economic Efficiency," *The Review of Economics and Statistics, Vol. XL III, No. 3* (1961), 225–250.

[2] Bodkin, R. G., L. R. Klein: "Nonlinear Estimation of Aggregate Production Functions," *The Review of Economics and Statistics Vol. XLIX, No. 1* (1967), 28–44.

[3] Dhrymes, P. J., M. Kurz: "Technology and Scale in Electricity Generation," *Econometrica, Vol. 32, No. 3* (July 1964) 287–315. Solow, R. M.: "Technical Change and Aggregate Production Function," *Review of Economics and Statistics,* Vol. 39, (Aug. 1957), 312–320.

[4] Energy and Public Policy—1972, Edited by John J. Murphy, *A Conference Report from the Conference Board,* New York, 1972.

[5] "Energy Technology To The Year 2000," Technology Review, Cambridge, Mass., 1972.

[6] Guidelines For Growth of The Electric Power Industry, The 1970 National Power Survey, Federal Power Commission, Part I, Washington, 1971.

[7] Hottel, H. C. and J. B. Howard: New Energy Technology, Some Facts and Assessments, Cambridge, Mass. 1971.

[8] Iulo, W.: Electric Utilities—Costs and Performance: Bureau of Economic and Business Research. Pullman, Washington: Washington State University Press, 1961.

[9] Johnston, J.: Statistical Cost Analysis. New York: McGraw-Hill, 1960.

[10] Klein, L. R.: *A Textbook of Econometrics,* Illinois and New York, 1953.

[11] Klein, L. R.: *An Introduction to Econometrics,* Prentice-Hall, Inc., Englewood Cliffs, N.J., 1962.

[12] Komiya, R.: "Technological Progress and the Production Function in the United States Steam Power Industry," *Review of Economics and Statistics,* 44, No. 2 (1962), 156–166.

[13] Lomax, K. S.: "Cost Curves for Electricity Generation," *Economica,* 19, New Series (1952), 193–197.

[14] Nerlove, M.: "Returns to Scale in Electricity Supply," Technical Report No. 96, Institute of Mathematical Studies in the Social Sciences, Serra House, Stanford University, May 25, 1961.

[15] Nordin, J. A.: "Note on a Light Plant's Cost Curves," *Econometrica,* 15, No. 3 (1947), 231–235.

[16] *Outlook for Energy in The United States to 1985,* The Chase Manhattan Bank, New York, 1972.

[17] *Pennsylvania Statistical Abstract, A Statistical Fact Book, Harrisburg,* 1956–1972.

[18] President's Report, Presented by Howard M. Swartz at PEA's 65th Annual Meeting in Philadelphia, 1972.

[19] Remick, F. J.: Nuclear Power, Threat or Promise?, The Pennsylvania State University, Philadelphia, 1973.

[20] Smigel, A. E.: Comments on the Energy Problem, Department of Commerce, Harrisburg, December, 1972.

[21] Smigel, A. E., and Krawiec, F.: "Past and Future Electric Energy Demands for Pennsylvania, 1956–1985," *Wharton Quarterly,* Winter, 1973.

[22] Statistical Abstract of The United States, National Data Book and Guide to Sources, Washington, D.C., 1956–1972.

[23] Statistics for Electric Utilities, Department of Commerce, Pennsylvania Public Utility Census Series, Release Number U—1956–1971.

[24] "The Time For Action Is Now," *Nuclear Industry,* October, 1972.