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The Two-level CES Production Function for the Manufacturing Sector of Pakistan

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Production functions have been widely studied in the relevant literature. In this paper, apart from labour and capital, we have used energy as a factor input and calculated the elasticity of substitution between these inputs, measured technical progress, and determined the returns to scale in the manufacturing sector of Pakistan. Since we have more than two factors of production, the standard Cobb-Douglas and CES production functions do not provide satisfactory results. Hence, two-level (nested) CES production function becomes the natural choice for the appropriate technology. Using this technology, we have found low elasticity of substitution between the three factors of production. Furthermore, the manufacturing sector is found to exhibit decreasing returns to scale, having experienced disembodied technical progress at the rate of 3.7 percent per annum.

I. INTRODUCTION

The concept of technical production function is central to economic analysis and is defined in the literature as a physical relationship between inputs and outputs of an economic process. The study of production function has a number of important direct and indirect implications for macro-theorist. First, it provides a link between the input markets and the commodities markets and thus has a key role to play in any generalization of the economy. Secondly, it is an input into the study of aggregate investment and, clearly, the choice of production technology influences the nature of investment function. Finally, it provides a basic ingredient to the study of income distribution because one can work back to the distribution of the proceeds of production from the production function itself.

Because of its central importance to economic analysis, the production function of various functional forms has been widely studied in the literature.[1] All of

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[1] The number of such studies is so large that it is impossible to list all of them. However, good summaries on theoretical and empirical development can be found in Fisher (1983).

these studies have been directed towards finding the degree of substitution between capital and labour besides investigating the returns to scale properties of the production function. Among the various classes of production relations, the most widely estimated functions are Cobb-Douglas (CD) and constant elasticity of substitution (CES). In the case of Pakistan, some attempts have been made to estimate the elasticity of factor substitution for different manufacturing industries. For example, [Kazi *et al.* (1976) and Battese and Malik (1987)] have estimated CES production function, while Kemal (1981) and Battese and Malik (1988) have estimated both the CES and variable elasticity of substitution (VES) production functions to determine the elasticity of substitution between labour and capital for different manufacturing industries. [Naqvi *et al.* (1983); Khilji (1982)] have estimated Cobb-Douglas production function for the manufacturing sector as a whole with labour and capital as factor inputs.

Ever since the first oil shock of 1973, energy has become an important factor of production, and there exists now a vast body of literature that has estimated the elasticity of substitution between energy and non-energy factor inputs. The elasticity of substitution between energy and non-energy factor inputs is crucial for understanding the macroeconomic impacts of energy price shock.[2] In recent years the shortage of energy has adversely affected the growth of manufacturing output in Pakistan. Although energy has widely been used as a factor of production in the production function studies of many countries, none of the studies listed above in the case of Pakistan has used energy as a factor input.[3] The purpose of this paper is threefold: first, to estimate a production function for the manufacturing sector of Pakistan with labour, capital and energy as factor inputs and calculate the elasticity of substitution between these factor inputs; secondly, to calculate the speed of adjustment between the desired and the actual level of factor inputs which will indicate the extent of structural rigidities in the economy; and finally, to determine the returns to scale and to measure technical progress in the manufacturing sector of Pakistan.

II. METHODOLOGY AND DATA

Consider a general production function where V_i $(i = 1, 2, \ldots\ldots n)$ are the n factor inputs which produce a vector of real aggregate output X

$$X = \phi\,(V_1, V_2, \ldots\ldots V_n) \qquad \ldots \qquad \ldots \qquad \ldots \qquad (1)$$

[2] See Solow (1987).

[3] Only Khan and Klein (1984) have estimated a Cobb-Dauglas production function with labour, capital and energy as factor inputs in the case of Pakistan.

Let us assume the existence of an aggregate firm which chooses the inputs level so as to minimize the cost of production of a given level of output, i.e., the aggregate firm minimizes cost subject to output constraint

$$\min \; C = \sum_{i=1}^{n} P_i V_i \qquad \ldots \qquad \ldots \qquad \ldots \qquad (2)$$

$$\text{s.t} \quad X = \phi(V_1, V_2, \ldots\ldots V_n)$$

where P_i are the factor prices.

To provide empirical content to the basic theory discussed above, it is necessary to choose an appropriate technology, i.e., the functional form for ϕ. The general practice has been to select the production function of Cobb-Douglas (CD), or the constant elasticity of substitution (CES) variety, with labour and capital as factor inputs. Since we have three factors of production (labour, capital and energy), the CD production function becomes uninteresting because of its property of unitary elasticity of substitution ($\sigma = 1$) among factor inputs. The CES production function becomes an abvious choice because it assumes a constant, but not necessarily unitary, elasticity of substitution. The extended version of CES production function with labour, capital and energy as factor inputs is specified as

$$Y_m = A \left[\delta_1 L_m^{-\rho} + \delta_2 K_m^{-\rho} + \delta_3 E_m^{-\rho} \right]^{-\mu/\rho} e^{\lambda_t} \qquad \ldots \qquad (3)$$

whereas A represents the total efficiency of production, $\delta_i (i = 1, 2, 3)$ are the distribution parameters; μ is the degree of homogeneity; ρ represents the elasticity of substitution which is given as $\sigma = 1/1 + \rho$; λ is the rate of disembodied technical progress; Y_m is the gross value of production in the manufacturing sector; while L_m, K_m and E_m are respectively the labour, capital and energy inputs in the manufacturing sector. The elasticity of substitution (σ) ranges from zero to infinity. Therefore, both the Leontief type production function when $\sigma = 0$ and the Cobb-Douglas production function when $\sigma = 1$ are seen as special cases of the more general CES function.

The CES production function specified in Equation (3) is not without limitations. Since we have three factors of production, the standard CES function has the awkward property of assuming that the elasticity of substitution for every pair of inputs is exactly the same. In the past, several attempts have been made to resolve this issue when there are more than two factors of production.[4] A more practical solution is provided by Sato (1967) who specifies a 'nested' CES production function, which extends the usefulness of the CES function by allowing a large number of factors and different elasticities of substitution among factor subsets. For the present

[4]See for example [Uzawa (1962); McFadden (1963); Mukerji (1963)].

purpose, we follow Sato (1967) and specify a 'nested' or two-level CES production function. The underlying assumption for this function is that the production function is strongly separable, i.e., the allocation of factors within each level is determined exclusively by the factor prices relative to that level.

We begin our modelling exercise by specifying a 'nested' CES combination of capital (K_m) and energy (E_m).[5] This is based on the consideration that capital and energy are likely to be complements, since the operation of capital equipment requires a certain amount of energy. On the second level, we then obtain a relationship between working capital (capital-energy combination) and labour input and estimate the elasticity of substitution between these two factors. Thus we write the two-level CES production function as

$$Y_m = A\left[b_1 (a_1 K_m^{-\rho_1} + a_2 E_m^{-\rho_1})^{\rho_2/\rho_1} + b_2 L_m^{-\rho_2} \right]^{-1/\rho_2} \quad \ldots \quad (4)$$

wherein all the parameters and variables are as defined earlier.

Following the cost-minimization approach, the steps of optimization are as follows.[6]

First Level

$$\min \; P_K K_m + P_E E_m$$

$$\text{s.t } J = Y_{KE} = \left[a_1 K_m^{-\rho_1} + a_2 E_m^{-\rho_1} \right]^{-1/\rho_1} \quad \ldots \quad \ldots \quad (5)$$

Solving for the first order condition we have

$$(E_m/K_m)^* = (a_2/a_1)^{\sigma_1} \; (P_K/P_E)^{\sigma_1} \quad \ldots \quad \ldots \quad (6)$$

where $\sigma_1 = 1/1+\rho_1$ and an asterisk (*) indicates the desired factor ratio. Taking logarithms on both sides of Equation (6) we have

$$\ell n(E_m/K_m)^* = \sigma_1 \; \ell n(a_2/a_1) + \sigma_1 \; \ell n(P_K/P_E) \quad \ldots \quad \ldots \quad (7)$$

Following Sato (1967), we assume that factor inputs do not adjust to their desired level instantaneously. Therefore, we specify an adjustment mechanism as

[5] As suggested in the literature [for examples, see Klein (1983); Prywes (1981)], nesting procedure requires that those factor inputs should be nested at the first level which are complementary in nature or have very low elasticity of substitution.

[6] The advantages of following the cost minimization approach rather than the profit maximization approach are discussed at length in Hornstein *et al.* (1981).

$$\left[\frac{(E_m/K_m)}{(E_m/K_m)_{-1}}\right] = \left[\frac{(E_m/K_m)^*}{(E_m/K_m)_{-1}}\right]^{\Theta} \qquad \ldots \qquad \ldots \qquad (8)$$

where Θ is the adjustment parameter ranging from zero to one. Substituting Equation (7) in Equation (8) and re-arranging term we get

$$\ell n(E_m/K_m) = \Theta\sigma_1 \; \ell n(a_2/a_1) + \Theta\sigma_1 \; \ell n(P_K/P_E)$$

$$+ (1-\Theta)\, \ell n\, (E_m/K_m)_{-1} \qquad \ldots \qquad \ldots \qquad (9)$$

Estimating Equation (9), we obtain $\hat{\sigma}_1$, $\hat{\rho}_1$, $\hat{a}_1$ and $\hat{a}_2$. With the help of these estimated parameters, we construct the quantum and price indices as[7]

$$J = Y_{KE} = \left[\hat{a}_1 K_m^{-\hat{\rho}_1} + \hat{a}_2 E_m^{-\hat{\rho}_1}\right]^{-1/\hat{\rho}_1} \qquad \ldots \qquad \ldots \qquad (10)$$

$$P_J = P_{KE} = \left[\hat{a}_1^{\hat{\sigma}_1} P_K^{(1-\hat{\sigma}_1)} + \hat{a}_2^{\hat{\sigma}_1} P_E^{(1-\hat{\sigma}_1)}\right]^{\frac{1}{(1-\hat{\sigma}_1)}} \qquad \ldots \qquad (11)$$

Equation (10) is the index of working capital while Equation (11) is the first level dual cost function. P_{KE} is the imputed minimum cost of producing a unit of Y_{KE}. Notice that P_{KE} is independent of the levels of K_m and E_m.

Second Level

On the second level we obtain a relationship between working capital (capital-energy combination) and labour. Following again the cost-minimization approach we have

$$\min \; P_{KE}\, Y_{KE} + P_L\, L_m$$

$$\text{s.t } J = Y_{KEL} = \left[b_1\, Y_{KE}^{-\rho_2} + b_2\, L_m^{-\rho_2}\right]^{-1/\rho_2} \qquad \ldots \qquad \ldots \qquad (12)$$

where P_L is price of labour, i.e., the wage rate. Solving for the first-order condition we get

$$(L_m/Y_{KE})^* = (b_2/b_1)^{\sigma_2}\; (P_{KE}/P_L)^{\sigma_2} \qquad \ldots \qquad \ldots \qquad (13)$$

where $\sigma_2 = 1/1+\rho_2$ and an asterisk (*) indicate the desired level of factor ratio. Taking logarithms on both sides of Equation (13) we have

[7] The normalization condition $a_1 + a_2 = 1$ is used in order to obtain both $\hat{a}_1$ and $\hat{a}_2$ from Equation (9).

$$\ln(L_m/Y_{KE})^* = \sigma_2 \ \ln(b_2/b_1) + \sigma_2 \ \ln(P_{KE}/P_L) \quad \ldots \quad (14)$$

Again assuming that factor inputs do not adjust to their desired level instantaneously, we specify an adjustment mechanism as

$$\left[\frac{(L_m/Y_{KE})}{(L_m/Y_{KE})_{-1}}\right] = \left[\frac{(L_m/Y_{KE})^*}{(L_m/Y_{KE})_{-1}}\right]^{\Psi} \quad \ldots \quad \ldots \quad (15)$$

where Ψ is the adjustment parameter ranging from zero to one. Substituting Equation (14) in Equation (15) and re-arranging term we get

$$\ln(L_m/Y_{KE}) = \Psi\sigma_2 \ \ln(b_2/b_1) + \Psi\sigma_2 \ \ln(P_{KE}/P_L) + (1-\Psi)\ln(L_m/Y_{KE})_{-1} \quad \ldots \quad \ldots \quad (16)$$

Estimating Equation (16) we obtain $\hat{\sigma}_2$, $\hat{\rho}_2$, $\hat{b}_1$ and $\hat{b}_2$ and with the help of these estimated parameters we construct the quantum and price indices as

$$Y_{KEL} = \left[\hat{b}_1 \ Y_{KE}^{-\hat{\rho}_2} + \hat{b}_2 \ L_m^{-\hat{\rho}_2}\right]^{-\frac{1}{\hat{\rho}_2}} \quad \ldots \quad \ldots \quad (17)$$

$$P_m = P_{KEL} = \left[b_1^{\hat{\sigma}_2} \ P_{KE}^{(1-\hat{\sigma}_2)} + b_2^{\hat{\sigma}_2} \ P_L^{(1-\hat{\sigma}_2)}\right]^{-\frac{1}{(1-\hat{\sigma}_2)}} \quad \ldots \quad (18)$$

where P_m is the imputed minimum cost of producing a unit of extended value added, Y_{KEL}. Alternatively, using the equation for $P_J = P_{KE}$ (Equation (11)), the second-level dual cost function can be written as

$$P_m = P_{KEL} = \left[\hat{b}_1^{\hat{\sigma}_2} \left(\hat{a}_1^{\hat{\sigma}_1} P_K^{(1-\hat{\sigma}_1)} + \hat{a}_2^{\hat{\sigma}_1} P_E^{(1-\hat{\sigma}_1)}\right)^{\frac{(1-\hat{\sigma}_2)}{(1-\hat{\sigma}_1)}} + \hat{b}_2^{\hat{\sigma}_2} P_L^{(1-\hat{\sigma}_2)}\right]^{\frac{1}{(1-\hat{\sigma}_2)}} \quad \ldots \quad \ldots \quad (19)$$

Third Level

The third level involves the estimation of returns to scale, efficiency parameter, and the rate of technical progress. The functional form is given as

$$\ln Y_m = \ln A + \mu \ln Y_{KEL} + \lambda t \ \ldots \quad \ldots \quad \ldots \quad (20)$$

where A is the efficiency parameter; μ represent returns to scale and λ measures the rate of technical progress.

Data

The quality of empirical research depends on the quality of the data base. In a developing country like Pakistan one would expect serious deficiencies in the basic quality of economic data. In recent years, however, the data base of Pakistan has improved considerably. For our purposes, the data regarding value added in manufacturing is taken from *Pakistan Economic Survey, 1984-85* at constant prices of 1959-60. As regards the labour force in the manufacturing sector, the data on these are obtained on the basis of total labour force calculated from the information about the labour force participation rate given in the various issues of *Pakistan Economic Survey (PES).* The total labour force is then distributed to the manufacturing sector on the basis of percentage reported in the various issues of *PES*. Data regarding the capital stock in manufacturing sector are calculated from the investment series in this sector. To get the initial value of capital stock we use capital-output ratio as three, and for the subsequent years an assumption of 5 percent depreciation rate has been used.

As regards the variable, to represent energy we use petroleum consumption in industry, and these data are taken from the various issues of *Energy Year Book.*[8] The data regarding the price of energy are taken from Naqvi *et al.* (1983) for the period 1959-60 to 1978-79; and thereafter these are taken from *PES 1984-85.* Price of capital is obtained as $P_K = R + \beta$ where R is the rate of interest and β is the rate of depreciation. Price of labour is the wage rate taken from the various issues of *Yearbook of Labour Statistics.*

III. RESULTS

The two-level CES production function for the manufacturing sector of Pakistan is estimated with the help of ordinary least squares estimation technique covering the time period from 1959-60 to 1982-83. Wherever deemed necessary, the equations that suffer from serial correlation are corrected by using the Cochrane-Orcutt iteration method. The results are reported in Equations (1) to (7) in Table 1. Since the production function is estimated on three different levels, the results corresponding to the first level of estimation is reported in Equation (1). The result reveals very low substitutability between capital and energy. The elasticity of substitution between capital and energy ($\hat{\sigma}_{KE}$) is 0.175 which lends credence to our assumption regarding the choice of factor to be nested at the first stage. The low elasticity of substitution between capital and energy indicates a near-fixed proportions relation between the two factors. Capital and energy requirements are often built into the machinery with relatively little room for ex-post substitution. The

[8] Energy is a composite factor that includes electricity, gas and petroleum. However, the non-availability of consistent time series for electricity and gas used in industrial sector from 1959-60 has constrained us to use only petroleum to represent energy as a factor of production.

Table 1

Estimated Results of Two-level CES Production Function for the Manufacturing Sector of Pakistan

First Level

(1) $\ln(E_m/K_m) = -0.76 + 0.175 \ln(P_K/P_E) - 0.01\ D$
$\qquad (2.79)^* \quad (2.80)^* \qquad\qquad (0.08)$

$\bar{R}^2 = 0.36;\ \hat{\ell} = -0.42\ (2.68)^*$ (ARI-OLS)

$\hat{\sigma}_{KE} = 0.175;\ \hat{\rho}_1 = 4.71;\ \hat{a}_1 = 0.53;\ \hat{a}_2 = 0.47$

$$(2) \qquad P_{KE} = \left[0.53^{0.175} \times P_K^{(1-0.175)} + 0.47^{0.175} \times P_E^{(1-0.175)}\right]^{\frac{1}{1-0.175}}$$

$$(3) \qquad Y_{KE} = \left[0.53\, K_m^{-4.71} + 0.47\, E_m^{-4.71}\right]^{-\frac{1}{4.71}}$$

Second Level

(4) $\ln(L_m/Y_{KE}) = 0.19 + 0.10 \ln(P_{KE}/P_L) + 0.79 \ln(L_m/Y_{KE})_{-1} + 0.22\ D$
$\qquad (0.51)\ (2.53)^* \qquad (4.54)^* \qquad (3.22)^*$

$\bar{R}^2 = 0.70;\ DW = 1.96;\ F = 17.97$

$\hat{\sigma}_{KE,\,L} = 0.48;\ \hat{\rho}_2 = 1.08;\ \hat{b}_1 = 0.39;\ \hat{b}_2 = 0.61$

$$(5) \quad P_m = P_{KEL} = \left[0.39^{0.48} \times P_{KE}^{(1-0.48)} + 0.61^{0.48} \times P_L^{(1-0.48)}\right]^{\frac{1}{(1-0.48)}}$$

$$(6) \qquad Y_{KEL} = \left[0.39\, Y_{KE}^{-1.08} + 0.61\, L_m^{-1.08}\right]^{-\frac{1}{1.08}}$$

Third Level

(7) $\ln Y_m = 1.34 + 0.82 \ln Y_{KEL} + 0.037\ t$
$\qquad (0.83) \quad (3.91)^* \qquad (5.33)^*$

$\bar{R}^2 = 0.98;\ DW = 1.63;\ F = 624.99$

shares of capital and energy on the first level of nesting represented by $\hat{a}_1$ and $\hat{a}_2$ respectively are 0.53 and 0.47. Since capital and energy indicate a near-fixed proportion relation, the variations in their relative prices would be expected to have little effect on the energy – capital ratio. This is confirmed by the low adjusted R^2 ($\bar{R}^2 = 0.36$). It may be noted that Equation (1) is estimated under the assumption that factor inputs adjust to their desired level instantaneously. In other words, the discrepancies between the desired and the actual levels of factor inputs are completely eliminated in one year [or Θ, the adjustment coefficient is equal to unity].[9]

[9]We also estimated Equation (1) assuming that factor inputs do not adjust to their desired level instantaneously i.e. $\Theta \neq 1$ but the results were unsatisfactory. Particularly, the coefficient of lagged dependent variable was very low and it was also found statistically insignificant.

The result corresponding to the second level of estimation is reported in Equation (4). However, to estimate the result for the second level we need an estimate of price (P_{KE}) and quantum (Y_{KE}) indices. The price and quantum indices are obtained on the basis of the estimated parameters from the first level and are reported in Equations (2) and (3) respectively. On the second level, the elasticity of substitution between working capital (Y_{KE}) and labour is found less than unity ($\hat{\sigma}_{KE,\ L}$ = 0.48) which is consistent with the CES production function.[10] A dummy variable (D) is also included in the second level of estimation to take into account the post-1973 energy crises. It can be seen that the coefficient of the dummy variable is statistically significant with the positive sign. This suggests that the rise in energy prices after 1973 induced manufacturers to save energy, with output held constant, only by increasing labour and lowering capital stock. This is because, as stated above, capital and energy requirements are often built into the machinery with little possibility of ex-post substitution. The share of working capital represented by $\hat{b}_1$ is 0.39 while the share of labour measured by $\hat{b}_2$ is 0.61. The adjustment coefficient (Ψ) calculated as 1 minus, the coefficient of lagged dependent variable is 0.21 (1−0.79 = 0.21), which suggest that 21 percent of the discrepancies between the desired and the actual levels of factor inputs are eliminated in one year on the second level of nesting. It may be noted that the speed of adjustment (21 percent per annum) is rather slow because of the structural rigidities that prevail in the economies of developing countries.

The information about returns to scale and Hick's neutral technical progress are obtained at the final level of estimation. However, to arrive at these results we need information about second level quantum and price indices. These are obtained on the basis of estimated parameters from the second level and are reported in Equations (5) and (6). The results corresponding to returns to scale and technical progress are reported in Equation (7). The coefficient for Y_{KEL} represents the returns to scale, and it can be seen from the equation that manufacturing activity in Pakistan exhibits decreasing returns to scale (the coefficient is below unity, i.e., 0.82) with its factor inputs. This finding is consistent with Kemal (1978), who also found decreasing returns to scale for total manufacturing at the two-digit level of industrial classification.

As regards the technical progress, the equation revealed that manufacturing sector did experience disembodied technical progress at the rate of 3.7 percent per annum. The coefficient of time trend is found statistically significant with the positive sign. This rate of technical progress is quite consistent with the recent findings of Khan and Siddiqui (1988), whose measures of technical progress in the

[10] The problem of simultaneity due to adjustment in Equation (4) in Table 1 was realized at the time of estimation and as such we had used Instrument Variable method of Two Stage Least Squares. The results were not different from the one reported in Equation (4) in Table 1.

manufacturing sector range from 3.2 percent to 3.7 percent depending upon the choice of technology.

IV. CONCLUDING REMARKS

The purpose of this paper has been manifold. First, to estimate a production function for the manufacturing sector of Pakistan, with labour, capital and energy as factor inputs, and to calculate the elasticity of substitution between these factor inputs. Secondly, to measure the speed of adjustment between the desired and the actual level of factor inputs. And, finally, to determine the returns to scale in the manufacturing sector of Pakistan.

As regards the first objective, the standard CES production function does not provide satisfactory results when there are more than two factor inputs, because it assumes that the elasticity of substitution for every pair of inputs is exactly the same. In order to get around this problem, we used a 'nested' or two-level CES production function under the assumption that the production function is strongly separable. On the first level, we nested capital and energy under the assumption that these two inputs are likely to be complements, and we estimated a CES function. The elasticity of substitution between capital and energy is found to be very low ($\hat{\sigma}_{KE} = 0.175$) which indicates a near-fixed proportions relation between the two factors. This finding is not altogether surprising because capital and energy requirements are often built into the machinery with relatively little room for ex-post substitution. However, the issue whether capital and energy are complements or substitutes is still debated.[11] In his recent papers, Griffin (1981, 1981a) has observed that capital and energy are substitutes if cross-sectional data are used, while these are complements when time-series data are used. Our study, since it uses the time-series data, shows a very low elasticity of substitution. However, in a recent paper, Solow (1987) has argued that the issue of complements or substitutes is not likely to be reconciled with aggregate data. Factor substitution is a microeconomic phenomenon, and is best examined by looking at microeconomic data.

On the second level, we nested working capital (capital-energy combination) with labour input and obtained the elasticity of substitution between these two factors. The elasticity of substitution is found to be less than unity ($\hat{\sigma}_{KE,\,L} = 0.48$).

The low elasticity of substitution between working capital and labour confirms the argument that the process of industrialization in Pakistan brought in increasingly capital-intensive techniques of production, and there is not much scope of employment-generation in this sector.[12]

As regards the second objective, the adjustment between the desired and the actual levels of the ratio of labour to working capital is found to be rather slow. The

[11] For a good summary of the debate, see Solow (1987).

[12] See Khan (1988).

slow speed of adjustment (21 percent per annum) reflects the structural rigidities that prevail in most of the economies of developing countries.

As regards the third objective, this paper finds that the manufacturing sector in Pakistan exhibits decreasing returns to scale, which indicates inefficient use of factors of production and mismanagement in this sector. It is also found that the manufacturing sector did experience disembodied technical progress at the rate of 3.7 percent per annum.

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