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Application of Non-Linear Cobb-Douglas Production Function with Autocorrelation Problem to Selected Manufacturing Industries in Bangladesh

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ABSTRACT

In developing counties, efficiency of economic development has been determined by the analysis of industrial production. An examination of the characteristic of industrial sector is an essential aspect of growth studies. The growth of a country can be measured by Gross Domestic Product (GDP). GDP is substantially affected by the industrial output. Industrial gross output is mainly a function of capital and labor input. If the effect of labor and capital input to output is at a satisfactory level in an industry or in a group of industries, then industrial investment will increase. As a result, the number of industries will increase, which will directly affect GDP and also will decrease the unemployment rate. This is why, industrial input-output relationship is so important for any industry as well as for the overall industrial sector of a country. To forecast the production of a firm is necessary to identify the appropriate model. MD. M. Hossain *et al*. [1] have shown that Cobb-Douglas production function with additive errors was more suitable for some selected manufacturing industries in Bangladesh. The main purpose of this paper is to detect the autocorrelation problem of Cobb-Douglas production model with additive errors. The result shows that autocorrelation is presented in some manufacturing industries. Finally, this paper removes the autocorrelation problem and re-estimates the parameters of the Cobb-Douglas production function with additive errors.

Keywords: Cobb-Douglas Production Function; Autocorrelation; Manufacturing Industry; Bangladesh

1. Introduction

In the present times, production takes place by the combination forces of various factors of production such as land, labor, capital etc. In this connection, socialist countries are using different patterns of level of factors of production for their respective industrialization policy according to the taste, demand and nature of their country-wide population, its size, location and environment. Bangladesh is a developing country. It is essential for Bangladesh to go for mass industrialization to strengthen the economy of Bangladesh for this purpose; of course our policy for industrialization must be well planned, well defined and well thoughtful. The development of economy is dependent on the industrial polices of the country. By using production function we can get industrial policies especially indication about the nature of the production inputs used in the production function.

The growth of a country can be measured by Gross Domestic Product (GDP). GDP is substantially affected by the industrial output. Industrial gross output is a function of capital and labor input mainly. If the effect of labor and capital input to output is at a satisfactory level in an industry or in a group of industries, then industrial investment will increase. As a result, the number of industries will increase, which will directly affect GDP and also will decrease the unemployment rate. This is why, industrial input-output relationship is so important for any industry as well as for the overall industrial sector of a country.

Hoque [2], Bhatti [3], Baltagi [4], Bhatti and Owen [5], Bhatti [6], Bhatti *et al*. [7], Ingene and Lusch [8], Mok [9], Hossain *et al*. [10], Hajkova and Hurnik [11], Prajneshu [12], Antony [13], Hossain *et al*. [14], amongst others who have used linear regression models to measure the log-linear Cobb-Douglas (C-D) type production processes. Hoque [2] used the survey data for Bangladesh to examine the relationship between farm size and production efficiency. The author estimated two Cobb-Douglas-type production functions both by ordinary least squares with fixed and random coefficients. The stochastic term in Cobb-Douglas type models is either specified to be additive or multiplicative (See Stephen M. Goldfeld and Richard E. Quandt [15]). They developed a model in which a Cobb-Douglas type function is coupled with simultaneous multiplicative and additive errors. But MD. M. HOSSAIN *ET AL*. [1] have been shown that Cobb-Douglas production function with additive errors was more suitable for some selected manufacturing industries in Bangladesh. They used the annual industrial data collected from the recent publications of "Statistical Yearbook of Bangladesh" [16] published by Statistics division, Ministry of Planning, Dhaka, Bangladesh and "Report on Bangladesh Census of Manufacturing Industries (CMI)" [17] published by Planning division, Ministry of Planning, Dhaka, Bangladesh, for the major manufacturing industries of Bangladesh over the period 1978-1979 to 2001-2002 to estimate the Cobb-Douglas production function. This paper also considers these data sets. Moreover, this paper could not use the latest data of manufacturing industries simply because the relevant data are not up to date in the ministry. This paper considers the following manufacturing industries for the ongoing analysis:

i) Textile, ii) Leather & Leather products, iii) Leather footwear, iv) Wood & cork products, v) Furniture & fixtures (wooden), vi) Paper & paper products, vii) Printing & publications, viii) Drugs & pharmaceuticals, ix) Chemical, x) Plastic products, xi) Glass & glass products, xii) Iron & steel basic industries, xiii) Fabricated metal products, xiv) Transport equipment, xv) Beverage and xvi) Tobacco.

Productions of a manufacturing industry during a specific period constitute time series data. In this situation autocorrelation is present. Thus in order to develop a model for production this paper consider autocorrelation problem. That is why the main purpose of this paper is detecting the autocorrelation problem of Cobb-Douglas production model with additive errors to measure the production process of some selected manufacturing industries in Bangladesh.

The rest of this paper is organized as follows. Section 2 briefly discusses the theoretical concepts of the Cobb-Douglas production function with additive errors. Section 3 discusses the estimation procedure of this model. Results and discussion have been presented in Section 4. Section 5 concludes the paper.

2. Cobb-Douglas Production Function

The Cobb-Douglas production function is the widely used function in Econometrics. A famous case is the well-known Cobb-Douglas production function introduced by Charles W. Cobb and Paul H. Douglas, although anticipated by Knut Wicksell and, some have argued, J. H. Von Thünen [18]. They have estimated it after studying different industries in the world, for this it is used as a fairly universal law of production.

The Cobb-Douglas production function with additive error term can be represented as,

$$p_t = \beta_1 L_t^{\beta_2} K_t^{\beta_3} + u_t \tag{2.1}$$

where, p_t is the output at time t; L_t is the Labor input; K_t is the Capital input; β_1 is a constant; u_t is the random error term. β_2 and β_3 are positive parameters.

3. Estimation Procedure

In the case of Equation (2.1), the minimization of error sum squares $\sum_{t=1}^{T} u_t^2 = S(\beta)$ is no longer a simple linear estimation problem. To estimate the production function we need to know different types of non-linear estimation. In non-linear model it is not possible to give a closed form expression for the estimates as a function of the sample values, *i.e.*, the likelihood function or sum of squares cannot be transformed so that the normal equations are linear. The idea of using estimates that minimize the sum squared errors is a data-analytic idea, not a statistical idea; it does not depend on the statistical properties of the observations (see Christensen [19]). Newton-Raphson is one of the popular methods to estimate the parameters in non-linear system.

Newton-Raphson Method

Newton-Raphson is one of the popular Gradient methods of estimation. In Newton-Raphson method, we approximate the objective function $g(\beta)$ at β^t by Taylor series expansion up to the quadratic terms

$$g(\beta) \approx g(\beta^t) + G(\beta^t)(\beta - \beta^t) + \frac{1}{2}(\beta - \beta^t)' H(\beta^t)(\beta - \beta^t)$$

where, $G(\beta^t) = \left[\frac{\partial g}{\partial \beta_i}\right]_{\beta^t}$ is the gradient vector and $H(\beta^t) = \left[\frac{\partial^2 g}{\partial \beta_i \partial \beta_k}\right]_{\beta^t}$ is the Hessian matrix. This Hessian matrix is positive definite, the maximum of the approximation $g(\beta)$ occurs when its derivative is zero.

$$G(\beta^t) + H(\beta^t)(\beta - \beta^t) = 0$$

$$\beta = \beta^t - \left[H(\beta^t)\right]^{-1} G(\beta^t)$$

This gives us a way to compute β^{t+1}, the next value in iterations is,

$$\beta^{t+1} = \beta^{t} - \left[H\left(\beta^{t}\right)\right]^{-1} G\left(\beta^{t}\right)$$

The iteration procedures continue until convergence is achieved. Near the maximum the rate of convergence is quadratic as define by

$$\left|\beta_i^{t+1} - \hat{\beta}_i\right| \le c\left|\beta_i^{t} - \hat{\beta}_i\right|^2$$

for some $c \ge 0$ when β_i^t is near $\hat{\beta}_i$ for all i. Thus we get estimates $\hat{\beta}_i$ by Newton-Raphson methods.

For the model (2.1), to estimate the parameters we minimize the following error sum squares

$$S\left(\beta\right) = \sum_{t=1}^{n}\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)^2$$

In case of nonlinear estimation we use the score vector and Hessian matrix. The elements of score vector are given below:

$$\frac{\partial S(\beta)}{\partial \beta_1} = -2 * \sum_{t=1}^{T}\left[\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(L_t^{\beta_2} K_t^{\beta_3}\right)\right]$$

$$\frac{\partial S(\beta)}{\partial \beta_2} = -2 * \sum_{t=1}^{T}\left[\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(L_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right]$$

$$\frac{\partial S(\beta)}{\partial \beta_3} = -2 * \sum_{t=1}^{T}\left[\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(K_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right]$$

Also the elements of Hessian matrix are given below:

$$\frac{\partial^2 S(\beta)}{\partial \beta_1^2} = 2 * \sum_{t=1}^{T}\left(L_t^{\beta_2} K_t^{\beta_3}\right)^2$$

$$\frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_2} = 2 * \sum_{t=1}^{T}\left[\left(\left(\ln\left(L_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(L_t^{\beta_2} K_t^{\beta_3}\right)\right) - \left(\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(L_t\right)\right) * \left(L_t^{\beta_2} K_t^{\beta_3}\right)\right)\right]$$

$$\frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_3} = 2 * \sum_{t=1}^{T}\left[\left(\left(\ln\left(K_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(L_t^{\beta_2} K_t^{\beta_3}\right)\right) - \left(\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(K_t\right)\right) * \left(L_t^{\beta_2} K_t^{\beta_3}\right)\right)\right]$$

$$\frac{\partial^2 S(\beta)}{\partial \beta_2^2} = 2 * \sum_{t=1}^{T}\left[\left(\left(\ln\left(L_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right)^2 - \left(\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(L_t\right)\right)^2 * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right)\right]$$

$$\frac{\partial^2 S(\beta)}{\partial \beta_2 \partial \beta_3} = 2 * \sum_{t=1}^{T}\left[\left(\left(\ln\left(K_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(L_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right) - \left(\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(K_t\right)\right) * \left(\ln\left(L_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right)\right]$$

$$\frac{\partial^2 S(\beta)}{\partial \beta_3^2} = 2 * \sum_{t=1}^{T}\left[\left(\left(\ln\left(K_t\right)\right) * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right)^2 - \left(\left(p_t - \beta_1 L_t^{\beta_2} K_t^{\beta_3}\right) * \left(\ln\left(K_t\right)\right)^2 * \left(\beta_1 L_t^{\beta_2} K_t^{\beta_3}\right)\right)\right]$$

Hence the Score vector is

$$G(\beta) = \left[\frac{\partial S(\beta)}{\partial \beta_1}, \frac{\partial S(\beta)}{\partial \beta_2}, \frac{\partial S(\beta)}{\partial \beta_3}\right]'$$

and Hessian matrix is

$$H(\beta) = \begin{bmatrix} \frac{\partial^2 S(\beta)}{\partial \beta_1^2} & \frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_2} & \frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_3} \\ \frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_2} & \frac{\partial^2 S(\beta)}{\partial \beta_2^2} & \frac{\partial^2 S(\beta)}{\partial \beta_2 \partial \beta_3} \\ \frac{\partial^2 S(\beta)}{\partial \beta_1 \partial \beta_3} & \frac{\partial^2 S(\beta)}{\partial \beta_2 \partial \beta_3} & \frac{\partial^2 S(\beta)}{\partial \beta_3^2} \end{bmatrix}$$

4. Results and Discussion

The parameters of the Cobb-Douglas production function with additive errors have been estimated by using optimization subroutine for different manufacturing industries considered in this study. The results are summarized in the **Table 1**.

There are economies of scale in the manufacturing of Drugs & pharmaceuticals, Furniture & fixtures (wooden), Iron & steel basic, Leather footwear, Fabricated metal products, Plastic products, Printing & publications, Tobacco since $\gamma < 1$ for these industries and there are diseconomies of scale in the Beverage, Chemical, Glass & glass products, Leather & leather products, Paper & paper products, Textile, Wood & crock products industries, Transport equipment since $\gamma > 1$ for these industries.

Results of Autocorrelation

The present study considers Durbin-Watson *d* test procedure to detect the presence of autocorrelation. In some

Table 1. The estimates of Cobb-Douglas production function with additive errors for different industries under study.

Industry name	Intercept $(\hat{\beta}_1)$	S.E. $(\hat{\beta}_1)$	Labor elasticity $(\hat{\beta}_2)$	S.E. $(\hat{\beta}_2)$	Capital elasticity $(\hat{\beta}_3)$	S.E. $(\hat{\beta}_3)$	Return to scale $(\hat{\beta}_2+\hat{\beta}_3)$	$\hat{\gamma}=\frac{1}{(\hat{\beta}_2+\hat{\beta}_3)}$
Beverage	5.848951	3.004	0.230199	0.109	0.683362	0.055	0.913561	1.094618
Chemical	6.552999	3.459	0.239483	0.086	0.567255	0.081	0.806738	1.23956
Drugs	1.418816	0.506	0.583740	0.254	0.578490	0.257	1.16223	0.860415
Furniture	0.136145	0.150	0.323816	0.061	1.583382	0.251	1.907198	0.524329
Glass	10.858785	3.447	0.267905	0.145	0.446118	0.087	0.714023	1.400515
Iron	5.432328	9.418	0.825566	0.346	0.317029	0.162	1.142595	0.875201
Leather footwear	9.975966	0.000	0.851867	0.129	0.168618	0.107	1.020485	0.979926
Leather products	149.5248	38.372	0.396121	0.155	0.273520	0.117	0.669641	1.493337
Fabricated metal	1.560328	1.006	0.979802	0.205	0.282128	0.151	1.26193	0.792437
Paper	36.90303	49.711	0.593256	0.132	0.154744	0.230	0.748	1.336898
Plastic	10.04537	0.000	0.962046	0.187	0.081875	0.136	1.043921	0.957927
Printing	0.761334	0.264	0.215724	0.054	1.062223	0.070	1.277947	0.782505
Textile	33.44288	31.332	0.237309	0.132	0.503446	0.052	0.740755	1.349974
Tobacco	5.828218	3.761	0.257396	0.055	0.867991	0.069	1.125387	0.888583
Transport	35.21922	46.842	0.873132	0.319	0.037898	0.147	0.91103	1.097659
Wood	45.73787	24.762	0.566334	0.084	0.054236	0.127	0.62057	1.611422

of the cases d statistic fails to detect autocorrelation. The limits of d are obtained at 5% level of significance. Here, for $k=2, n=24, d_L=1.188$ and $d_U=1.546$, where, k is the number of explanatory variables excluding the constant term and n is the total number of observations.

In many situations, however, it has been found that the upper limit d_U is approximately the true significance limit and therefore, in case the estimated d values lies in the indecision zone, one can use the modified d test procedure (See D. N. Gujarati [20]). By using these test procedures the present analysis found that, there exists positive autocorrelation of some manufacturing industries considered in this study.

The results given in **Table 2** indicates that, the autocorrelation is present in Beverage, Drug, Furniture, Iron, Leather footwear, Leather products, Paper, Plastic, Textile, Transport and Wood industry for Cobb-Douglas model with additive error terms. In order to remove this autocorrelation at first it is essential to estimate the value of ρ. Theil-Nagar procedure is used to estimate the value of ρ in this study.

Theil and Nagar have suggested that in small samples ρ can be estimated as

$$\hat{\rho}=\frac{n^2\left(1-\frac{d}{2}\right)+k^2}{n^2-k^2}$$

where, n = total number of observations, d = Durbin-Watson d, and k = number of coefficients (including the intercept) to be estimated (See D. N. Gujarati [20]).

Table 2. Result for testing autocorrelation for the Cobb-Douglas production function with additive errors for selected industries under study.

Name of industry	Durbin Watson (d)	$(4-d)$	Comment based on Durbin-Watson d test	Comment based on modified d test
Beverage	0.984	3.016	Yes	Yes
Chemical	1.822	2.178	No	No
Drugs	1.432	2.568	No decision	Yes
Furniture	0.774	3.226	Yes	Yes
Glass	1.585	2.415	No	No
Iron	0.299	3.701	Yes	Yes
Leather footwear	0.588	3.412	Yes	Yes
Leather products	1.112	2.888	Yes	Yes
Fabricated Metal	1.802	2.198	No	No
Paper	1.112	2.888	Yes	Yes
Plastic	1.070	2.93	Yes	Yes
Printing	1.719	2.281	No	No
Textile	1.495	2.505	No decision	Yes
Tobacco	1.715	2.285	No	No
Transport	0.601	3.399	Yes	Yes
Wood	0.745	3.255	Yes	Yes

After estimating the value of ρ, observation is transformed as $y^*=\boldsymbol{P}y$ and $X^*=\boldsymbol{P}X$ where $\boldsymbol{P}$ a matrix defined as

$$\boldsymbol{P}=\begin{bmatrix}\sqrt{1-\rho^2} & 0 & 0 & \cdots & 0 & 0\\ -\rho & 1 & 0 & \cdots & 0 & 0\\ 0 & -\rho & 0 & \cdots & 0 & 0\\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots\\ 0 & 0 & 0 & \cdots & 1 & 0\\ 0 & 0 & 0 & \cdots & -\rho & 1\end{bmatrix}$$

The present study fit again the model for transformed data by using Newton-Rapson method and obtained the following estimates.

The results provided in **Table 3**, indicates that the problem of autocorrelation successfully removed by taking suitable steps. After removing the autocorrelation problem, again the parameters of the Cobb-Douglas production function with additive errors is estimated. The estimates are given in **Table 4**.

5. Conclusion

Nowadays, businessmen as well as industrialists are very much concerned about the theory of firm in order to make correct decisions regarding what items, how much and how to produce them. To forecast the output of some selected manufacturing industries in Bangladesh it is necessary to the estimate the parameters of Cobb-Douglas production function with additive errors. This paper detects the autocorrelation problem of Cobb-Douglas production model with additive errors which is used to measure the production process of some selected manufacturing industries in Bangladesh. The results of this study show that the autocorrelation is presented in Beverage, Drug, Furniture, Iron, Leather footwear, Leather products, Paper, Plastic, Textile, Transport and Wood industry for Cobb-Douglas model with additive error terms. Finally, after removing the autocorrelation problem, the parameters of the production function is estimated.

Table 3. Result for testing autocorrelation for the Cobb-Douglas production function with additive error in different industries for transformed data.

Name of industry	$\hat{\rho}$	Durbin Watson (d)	Comment
Beverage	0.631937	1.795	No Autocorrelation
Drugs	0.304381	1.860	No Autocorrelation
Furniture	0.638603	1.606	No Autocorrelation
Iron	0.879873	2.054	No Autocorrelation
Leather footwear	0.733079	2.476	No Autocorrelation
Leather products	0.466921	1.883	No Autocorrelation
Paper	0.466921	1.554	No Autocorrelation
Plastic	0.488254	1.600	No Autocorrelation
Textile	0.272381	1.969	No Autocorrelation
Transport	0.726476	1.317	No positive autocorrelation
Wood	0.653333	1.507	No positive autocorrelation

Table 4. Results of Cobb-Douglas production function with additive errors for transformed data.

Name of industry	Intercept $(\hat{\beta}_1)$	Labor elasticity $(\hat{\beta}_2)$	Capital elasticity $(\hat{\beta}_3)$
Beverage	6.931431	0.040001	0.776079
Drugs	1.151152	0.354476	0.807721
Furniture	0.797887	0.438352	1.239404
Iron	10.072814	0.984515	0.152960
Leather footwear	1.207653	0.919913	0.383542
Leather products	111.718274	0.338288	0.327641
Paper	5.074710	0.383715	0.572144
Plastic	6.363687	0.824554	0.249335
Textile	40.834681	0.193782	0.514988
Transport	128.990246	0.156192	0.352445
Wood	9.117616	0.779040	0.102175

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