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Technical Efficiency and Macroeconomic Determinants for the Greek Power Industry before liberalization: a Stochastic Frontier Approach

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Abstract

The derivation of efficiency estimates for the Power Industry is significant for policy design. This paper analyzes technical efficiency and its macroeconomic determinants for the case of the Greek Public Power Industry before liberalization. Technical efficiency is estimated by means of stochastic frontier analysis (S.F.A.) and its macroeconomic determinants are also evaluated. The industry's technical efficiency ranged between 83% and 100% with an average equal to 94% and achieving its maximum performance in 1974 and 1992. Important determinants of technical efficiency are the scale of operation and the country's incorporation in the wider European Union (E.U.) area.

Keywords: Power Industry, Technical Efficiency, Determinants, Greece

JEL Classification: L94

1. Introduction

Most European Union (E.U.) governments are preoccupied with how to introduce reforms in their electricity sectors given that power industry privatization gain international acceptance. Similarly, Greece as a member of the E.U. cannot ignore the Electricity Directives (96/92/EC and 17/04/EC) which have dictated great changes in the directions of liberalization, increased efficiency and competitiveness. This means that the estimation of technical efficiency of the electricity sector becomes an integral part of the overall restructuring strategy.

A number of studies on technical efficiency of the electricity sector in developed countries use frontier methodologies. However, the majority of them originate in the U.S.A. For instance, Kopp and Smith (1980), estimate stochastic frontier production functions for U.S. plants. Also, Ayres *et al.* (2005) analyze the efficiency of the U.S. electricity usage since 1990. An extended review of the literature on the electricity sector is provided in Pollitt (1995), where technical efficiency is investigated in an international context. Furthermore, Pollitt (1997) measured the efficiency of power generators in an international context. This study was followed by several other papers concerning electric utilities, such as (Zhang and Bartels, 1997) studying the cases of New Zealand, Australia and Sweden.

Although efficiency studies of the generation sector of developed countries abound, there has been little research on energy in small or developing countries. For example, Mayer (2000) used non-frontier methodologies to study reliability problems of small islands (Caribbean and Pacific islands) in electricity generation. Also, Koroneos *et al.* (2005) in a non-frontier framework, analyze the energy system and the use of renewable energy sources in Cyprus. Meibodi (1998) estimated technical efficiency in the electricity sector using data from World Bank and the main finding was that a significant part of the variation in efficiency, within the electricity sector in developing countries, is due to the scale of operation. In other words, the efficiency of the power plants is found to be positively related to the scale of operation. The results also demonstrate that increasing returns to scale prevail in the electricity generation of most developing countries. Also, Whiteman (1995), using World Bank data, benchmarked electricity systems of developing countries.

Efficiency studies and analyses on developing countries' generating systems such as Greece are lacking. A plethora of studies (e.g. Caramanis 1979, Samouilidis and Mitropoulos 1982, Vlachou and Samouilidis 1986, Donatos and Mergos 1989, Kintis and Panas 1989, Christopoulos 2000, Caloghirou *et al.*1997) investigate factor substitution in Greek manufacturing (including electricity). For instance, Christopoulos (2000) stated that the share of the three main sources of energy, crude oil, diesel and electricity increased significantly as a percentage of the total cost in the sector. Also, Caloghirou *et al.* (1997) argued that electricity consumption steadily increases for all Greek manufacturing, the process of electrification, whereas consumption of non-electric energy decreases. More precisely, electricity increases its expenditure share, while the share of non – electric energy decreases.

However, despite the fact that technical efficiency has been one of the most important concerns in the electricity sector of many developing countries in recent years (Pacudan and de Guzman 2002), there is no research in the existing literature on the technical efficiency of the electricity industry in Greece using S.F.A. and evaluating various determinants of efficiency in the 1970-1997 time span. In this spirit, the paper measures technical efficiency and analyzes its macroeconomic determinants for the Greek electricity sector in the 1970-1997 time span i.e. before liberalization. The technical efficiency results are compared with a previous study employing Data Envelopment Analysis (D.E.A.) to assess their consistency.

The paper is structured as follows: Section 2 sets out the stochastic frontier methodology. Section 3 describes the data and the variables. Section 4 presents the empirical results. Finally, section 5 concludes.

2. Methodological Framework

Farrell (1957) was probably the first to provide us with the definition of technical efficiency. However, Aigner *et al.* (1977), introduced the stochastic frontier production function, and Meeusen and van den Broeck (1977) considered the Cobb-Douglas production function with a composed disturbance term. Since then, three main approaches have been developed for the measurement of technical efficiency: parametric (deterministic and stochastic), non-parametric based on D.E.A. and productivity indices based on growth accounting and index theory principles (Coelli *et al*., 1998). D.E.A. and S.F.A. are the most popular methods for calculating the technical efficiency of a firm.

The S.F.A. approach requires a functional form to estimate the frontier production function and is based on the idea that the data is contaminated with measurement errors and noise. See Bauer (1990). The conventional D.E.A. approach uses linear programming techniques and cannot discriminate between inefficiency and noise. Thus, it tends to produce overestimated inefficiency measures, a fact which is the most important disadvantage of D.E.A. in comparison to S.F.A. See Bauer (1990).

We start with the assumption that the technology applied in the production process can be described by a twice differentiable production function which relates the flow of output with various inputs of production. In algebraic terms the stochastic production frontier (S.P.F.) can be expressed as:

$y = f(\boldsymbol{X},\boldsymbol{\beta})\exp(\varepsilon),\ \varepsilon = (v-u),\ u>0 \qquad (1)$

where: y is the observed output quantity; f is the deterministic part of the frontier production function, $\boldsymbol{X}$ is a vector of the input quantities used by the firm, $\boldsymbol{\beta}$ is a vector of parameters to be estimated, v is a symmetrical random error and u is a one-sided non-negative random error term representing technical efficiency. It is assumed that f is finite for every $\boldsymbol{X}$, and continuous for all nonnegative y and $\boldsymbol{X}$. The elements of v represent the conventional normal distribution of random elements including measurement errors, minor omitted variables, and other exogenous factors. The elements of u indicate shortfalls of the firm's production units from the efficient frontier.

The rationale is that production is subject to two disturbances of different origin. The positive disturbance u expresses the fact that each firm's output lies on or below its frontier. Any deviation is the result of factors, such as the capability of the producer and his/her employees, the defective and damaged products, etc. However, the frontier itself may vary randomly over time for the same firm and consequently the frontier is stochastic, with random disturbance v, which expresses external to the firm events, such as statistical noise, observation and measurement error, and exogenous shocks beyond the control of the production unit. Thus, technical efficiency is measured by:

$$\mathrm{TE} = y \,/\, [f(\boldsymbol{X})\exp(v)] = \exp(-u)$$

and has a value between 0 and 1, with 1 defining a technically efficient firm or year.

Given a parametric functional form for f and distributional assumptions about u and v, equation (1) can be estimated using Ordinary Least Squares (O.L.S.).[1]

More specifically, equation (1) is written as:

[1] Equation (1) could be estimated using Maximum Likelihood (Aigner *et al.* 1977). However, the O.L.S. estimators have statistical properties at least as desirable as those of the ML estimators (Olson *et al.* 1980), are easier to obtain and tend to provide encouraging results (Kumbhakar and Lovell, 2000).

$$\ln(y) = \ln[f(\boldsymbol{X})] + v - u \qquad (2a)$$
$$\ln(y) = -\mu + \ln[f(\boldsymbol{X})] + (v-u+\mu) \qquad (2b)$$

where: $\mu = E(u)>0$.

The estimation of the S.P.F. by the O.L.S. leads to consistent estimators for all the parameters, μ included, under the assumption that v is normally and u is half-normally distributed. The rationale behind normality is convenience at estimation plus the fact that we lack information upon which to base alternative assumptions.[2]

Estimation of equation (2) gives the residuals e_i , i = 1, 2, …, N. The second and third central moments of the residuals, $m_2(e)$ and $m_3(e)$ respectively, are calculated, as known, as follows:

$$m_2(e) = [1/(N-k)]\cdot \Sigma e_i^2 \qquad (3a)$$
$$m_3(e) = [1/(N-k)]\cdot \Sigma e_i^3 \qquad (3b)$$

where: N is the number of observations and k is the number of regressors, the constant term included. Then, we estimate σ^2_u and σ^2_v using the formulae (Georganta 1993):

$$\sigma^2_u = [(\pi/2)[(\pi/(\pi-4)]m_2(e)]^{2/3} \qquad (4a)$$
$$\sigma^2_v = m_2(e) - [(\pi-2)/\pi)]\ \sigma^2_u \qquad (4b)$$

Following Battese and Coelli (1988), the point measure of technical efficiency is:

$$TE_i = E(\exp\{-u_i\}/\varepsilon_i) = [[1-F[\sigma_{\cdot}-(M_i^*/\sigma_{\cdot})]/[1-F_{\cdot}(-M_i^*/\sigma_{\cdot})]\exp[-M_i^* + (\sigma_{\cdot}^2/2)] \qquad (5)$$

where F denotes the distribution function of the standard normal variable. Also:

$$M_i^* = (-\sigma^2_u\varepsilon_i)(\sigma^2_u + \sigma^2_v)^{-1} \qquad (6a)$$
$$\sigma_{\cdot}^2 = \sigma^2_u\ \sigma^2_v\ (\sigma^2_u + \sigma^2_v)^{-1} \qquad (6b)$$

The technical inefficiency effects are frequently estimated in a first step and the determinants of inefficiency are obtained in a second-stage regression. However, efficiency effects can be simultaneously conditioned on several factors and estimated using the parameterization (Battese and Coelli, 1995):

[2] Half-normal and exponential distributions are traditionally employed for *u*. However, these two assumptions lead to very similar estimates (Caves and Barton 1990).

$$TE_i = \delta_o + z_i\delta \qquad (7)$$

where z_i is a vector of explanatory variables, and δ_o and δ are respectively a parameter and a vector of parameters to be estimated. Most authors use hypothesis testing to evaluate the model (Curtiss 2000, Morrison 2000, Abdulai and Eberlin 2001). This involves testing whether the coefficients δ in equation (7) are significantly different from zero. Accordingly, the hypothesis H_0 $\{\delta_k=0\ \forall k\}$ is also tested.

3. Data and Variables

The empirical investigation covers the period 1970-1997 before liberalization and has been subject to data availability. All variables entering the production function (i.e. output, labour, capital stock, energy) are expressed in monetary units (1995 prices) that come from corporate sources (balance sheets, etc). The estimates of the capital stock come from a previous study (Roboli and Tsolas 2003). Practically, our approach can be regarded as a (sub)case of panel data and thus the usual assumptions about the errors are in force. Obviously, our analysis indicates the year(s) that the industry enjoyed its most efficient operation and can, thus, be used for benchmarking.

As discussed earlier, explanatory variables for efficiency could be included in the model. The choice of the variables in the final model has been subject to data availability and the fact that the corporation was a state corporation. In this sense, general macroeconomic variables (e.g. interest rate, etc) express the external environment that the corporation faces. Meanwhile, its scale of operation coincides with the size of the country's economy. After all, the performance of a public enterprise is, by nature, related to the macroeconomic theories of competitiveness (Reve and Mathiesen 1994, Preeg 1994, Krugman 1994).

The proposed model for estimating the macroeconomic determinants of technical efficiency in the Public Electricity Corporation in Greece includes the following variables:

i. Gross Domestic Product of Greece in billions of drachmas (1995 prices) published by the European Commission (2000).
ii. Gross Fixed Capital Investment in billions of drachmas (1995 prices) published by the European Commission (2000).

iii. Real Lending Interest Rate (%) for trading capital published in the *Statistical Bulletin* by the Bank of Greece and the European Commission (2000).
iv. The Profit Rate (%) by Maniatis *et al.* (1999).
v. A dummy variable that takes the value of 1 during the military rule and 0 elsewhere, and is used to account for the military rule in Greece.
vi. A dummy variable that takes the value 1 during the crisis and 0 elsewhere, and is used to account for the first oil crisis.
vii. A dummy variable that takes the value 1 during the crisis and 0 elsewhere, and is used to account for the second oil crisis.
viii. A dummy variable that takes the value of 0 before 1992 and 1 afterwards, and is used to account for the country's incorporation in the E.U. financial area.

4. Results and Discussion

In this paper, the functional form of the production function for S.F.A. was specified as a Cobb-Douglas. Specifications such as the translog provide the opportunity to characterize the data in a more flexible way, however, with limited data as in our case it tends to be seriously over-parameterized. As Coelli *et al.* (1998) noted the translog estimates are likely to suffer from degrees of freedom and multicollinearity problems resulting in inefficient estimates. Thus, the adopted functional form, corresponding to equation (1), is:

$$\ln Y = a_o + a_1 \ln K + a_2 \ln L + a_3 \ln E + v - u \qquad (8)$$

where: Y denotes output, K denotes capital stock, L denotes labour, and E denotes energy. Table 1 presents the estimate of the production function based on equation (8).

Table 1: *Production function estimate*

Determinant	Value	T-statistic
Intercept	-7.94	-6.30*
a_1	-0.05	-0.93
a_2	1.49	11.77*
a_3	0.43	4.90*
R^2	0.96	
D.W.	1.75	
S.E.E.	0.09	

Note: * significance at the 1% level

Turning now to the regression results reported in Table 1, we can see that the estimated coefficients are highly significant for all parameters, except for the capital stock whose coefficient is equal to -0.05 and not significant at the 1% level. This result, which is related to capital's utilization is consistent with the findings of other researchers (see Battese and Coelli 1995).

This result is important in explaining that capital is not a significant constraint on production efficiency, compared to more important labour and energy (i.e. fuel) inputs, which are actually combined with capital to produce electricity. In other words, adding more capital to a fixed (and/or small) generating capacity does not necessarily contribute positively to total output. More precisely, this fact is related to the characteristics of the technical equipment and facilities in Greek firms during the last decades (Kintis 1982), where a large part of the machinery owned by the firms is old and, consequently, non productive. The regression explains a very high 96% of the variability of output, and there is no evidence of autocorrelation of the residuals. These results show that the model used provides very good fit to the data.[3]

Since the total production and the regressors are expressed in logarithms, the coefficients are interpretable as output elasticities. As known, returns to scale are calculated from the sum of the inputs' coefficients as[4]:

$$a_1 + a_2 + a_3 = 1.87 > 1$$

This result is consistent with the findings by other researchers since the electricity industries are, usually, found to experience economies of scale (see, for instance, Meibodi 1998, Filippini *et al.* 2002, Filippini *et al.* 2001).

The next step is, through equation (5), to estimate annual technical efficiency (T.E.) for the 1970-1997 time span. Summary statistics for technical efficiency are presented in Table 2. The same data was employed to estimate technical efficiency by means of D.E.A. (Roboli and Tsolas 2003). The efficiency estimates computed by D.E.A. are used for the comparison with the S.F.A. estimates (Table 2).

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[3] We specify a production function without technological progress. After all, findings by other researchers indicate that the technological level has remained, almost, unchanged for a great part of the period investigated for the country as a whole, as well as for the electricity sector in Greece (see e.g. Belegri-Roboli and Michaelides 2006, Bosworth and Kollintzas, 2001).

[4] Note that if: (i) $a_1 + a_2 + a_3 = 1$, then there are constant returns to scale, (ii) $a_1 + a_2 + a_3 < 1$, decreasing returns to scale and (iii) $a_1 + a_2 + a_3 > 1$, increasing returns to scale.

Table 2: *Efficiency estimates*

	S.F.A.	D.E.A.
Average	0.94	0.91
Standard Deviation	0.047	0.073
Minimum	0.83	0.80
Maximum	1	1

P.P.C. demonstrates technical efficiency measures ranging from 83% to 100%. Using a simple arithmetic average we obtain an average annual technical efficiency equal to about 94%. Also, the firm's technical efficiency measure reached its highest levels in 1974 and 1992. The estimated technical efficiency measures of the present paper are, in general terms, consistent with the findings by Roboli and Tsolas (2003). First, their findings show that P.P.C. experienced increasing returns to scale during the period 1970-1997, except for the last two years. Second, their findings demonstrate that technical efficiency ranged from 80% to 100%. Third, using a simple arithmetic average on the measure presented in their paper, we obtain an average annual technical efficiency equal to 91%. Finally, the firm's maximum score found within each method is equal to unity and achieved in 1974 and 1992.

Not surprisingly, the average technical efficiency estimated by D.E.A. is lower than the one estimated by S.F.A., as D.E.A. cannot discriminate between inefficiency and noise. Actually, most of the studies using both D.E.A. and S.F.A. report similar findings (see, for instance, Bruemmer 2001). Finally, in contrast to D.E.A., only two years were found to be totally efficient using S.F.A. This difference stems from the different methodology used, i.e. in D.E.A. the frontier is determined by the best practice observed.

Furthermore, in this section, the estimation of a firm's technical efficiency allows further investigation of the sources of efficiency, and hence inefficiency, which could be of great importance to the implementation of policies to deal with it (Cote 1989). For instance, Timmer (1971) analyzed technical efficiency of U.S. agriculture. In 1981, Pitt and Lee (1981) studied the determinants of technical (in)efficiency by regressing the (in)efficiencies yielded from a stochastic frontier, upon various factors, including the scale of operation, etc.[5]

[5] However, there is a problem in this sort of approaches. Analytically, in the first stage, the inefficiency is assumed to be independently and identically distributed, while in the second stage it is assumed to be depending on a vector of factors (such as scale of operation, etc), implying that they are not identically distributed (Coelli 1995). Because of this problem, the D.E.A. efficiency

Thus, our analysis tests for the significance of the factors, which presumably influence the efficiency of the public power corporation in Greece (1970-1997) before liberalization when data were available. The results of the regression demonstrated no evidence of multicollinearity. So, in the basic specification, we use all of them simultaneously. Table 3 reports the results for the efficiency effects model.

Table 3: *Efficiency determinants*

Determinant	Value	T-statistic
Constant	0.79	14.19*
G.D.P.	$7 \cdot 10^{-6}$	2.86*
E.U. entrance	$-7 \cdot 10^{-2}$	-2.95*
R^2	0.31	
D.W.	1.81	
S.E.E.	0.04	
$H_0\{\delta_k=0\ \forall k\}$	rejected	

Note: * significance at the 1% level

Several models have been estimated and in the model presented the coefficients are significant for all determinants and the hypothesis H_0 is rejected. The result of the final specification is broadly in line with expectations. More precisely, the model explains up to 31% of the variation in efficiency variable which is considered as satisfactory for this sort of investigations. Also, all of the signs related to the efficiency determinants are as expected, and we can see that the estimated coefficients are highly significant.

Moreover, the efficiency measure is positively related to the firm's scale of operation, given the fact that the corporation was a state corporation and practically a monopoly. The bigger the size of the economy as a whole, the bigger the scale of operation and the more efficient the corporation is since the potential (monopolistic) market is also bigger. This result is consistent with the findings by various researchers that the scale of operation is usually a significant factor in determining efficiency (see, among others, Pitt and Lee 1981, Mayes *et al.* 1994, Yunos and Hawdon 1997).

scores are used as the independent variable in recent models for a second stage regression (see, for example, Pollitt 1996, Majumdar 1996).

As far as the negative sign linked to the country's entrance in the E.U. financial area is concerned, it is also characterized as expected. It may appear strange that the country's entrance in the E.U. financial area in 1992 is a determinant of efficiency for P.P.C. However, the greater the support from E.U. funds, given the monopoly position of the corporation in the domestic market, the less efficient the firm needed to be in order to survive in the monopolistic market.

After all, the Greek economy, including the electricity sector, was supported by important inflows of the E.U. structural funds. In fact the E.U. funds (Structural funds plus Framework Program) started gaining in importance in the financing of activities in Greece in the 1990s. Links between national and E.U. policies have been strengthened during this last period and reached their highest levels in the 1990s following the 2nd Community Support Framework (1994-1999).

Consequently, this article suggests that Greek G.D.P. and the country's incorporation in the E.U. financial area are important determinants of efficiency. The results of this article suggest that policy measures that can facilitate an economy size increase might have beneficial effects on efficiency due to the positive size-efficiency relationship. In addition, the country's entrance in the E.U. financial area has a negative impact on efficiency. Obviously, certain structural interventions are needed in order for the organization to preserve its dominant position in the liberalized market which will signify a new era for the corporation, since the E.U. support funds - on which the corporation seems to rely - might soon cease to exist.

5. Conclusions and Policy Insights

This paper estimated technical efficiency measures for the Greek Public Power Corporation (P.P.C.) in the time period 1970-1997 when data were available. Formally, technical efficiency refers to the ability of a firm to minimize input use in the production of a given output vector, or the ability to obtain maximum output from a given input vector. In other words, the measurement of technical efficiency indicates the ability of a firm to survive in a competitive environment. As a result, reliable measures of technical efficiency in power corporations and other enterprises in Greece are of great interest because they can assist in addressing important issues. For instance, inefficient operation of firms - in the sense that if a firm is inefficient it does not produce at minimum cost - could lead to higher prices and losses (GPPC 2007).

The methodological framework used was the stochastic frontier approach (SFA) and the functional form followed the popular Cobb-Douglas specification. The results showed that the corporation has been experiencing increasing returns to scale whereas technical efficiency ranged between 83% and 100% with an average equal to about 94% per annum and achieving its maximum performance in 1974 and 1992. These results are, in general terms, consistent with findings by other researchers.

The P.P.C. was, practically, *the* Greek electricity sector. P.P.C. was a state-owned corporation until January 2001, when it became a *société anonyme* (S.A.). It was vertically integrated into all aspects of the electricity sector. Only about 2% of electricity was generated by others and was used by the industrial companies that generated it. The Greek P.P.C. faced no serious competition from abroad given that Greece had no significant direct electricity connections with other European Union (E.U.) or International Energy Agency (I.E.A.) members. The existing links to other Balkan countries were used only for balancing and back-up transactions. Also, there was no connection with Turkey, but P.P.C. and T.E.A.S. (i.e. the Turkish utility), have planned one under the Trans-european Energy Networks Program of the E.U. Finally, after 2001, a small link to Italy provides limited competition, co-owned by P.P.C. and E.N.E.L. These reforms in the Power Sector have increased competition and are said to have brought substantial benefits for consumers. However, if P.P.C. does not minimize its inefficiency in the long run, it will have problems surviving in a liberalized market.

The derivation of efficiency estimates of the Greek P.P.C. could have significant policy implications in the strategic planning of the Greek electricity sector. Our findings could assist the enterprise in better adjusting its operation. For instance, the critical assessment of the prevailing conditions during the "best" years (i.e. benchmark years) will permit the enterprise to face the conditions of the liberalized market. In this spirit, we have provided quantitative information on the magnitude of efficiency. Also, we have provided information on the determinants of technical efficiency and this information could be used to identify the sources of positive (or problematic) performance.

The economic objectives of the electricity sector are to satisfy demand, to promote competition and efficiency, and to protect consumers as regards prices and quality. Meanwhile, the reduction of entry barriers, creation of competing generating companies, and strengthening of the regulatory regime, provide a way toward the objectives of greater efficiency. Competition has delivered efficiency gains in some countries while other countries have created competing generating companies (e.g. United Kingdom, New Zealand, Australia, some States of the U.S.A., Argentina, etc). Competition is feasible in

Greece, too, but regulatory authority could be placed as a regulatory body, under the auspices of the government, independent of the regulated companies.

No doubt, such a process needs continuous reforms. Therefore, the government should review the sector in order to check whether rigorous competition is developing. If not, then inefficient operation of firms could lead to higher prices which could induce industry to substitute away from electricity toward some other source of energy. This is consistent with the findings by G.P.P.C. (2007).

Clearly, more extended research on the subject would be of great interest. Besides widening the database there is one more consideration that would be desirable to explore in the near future. More specifically, an additional dummy variable could be used to extend our model in order to account for the liberalization effect on the Power Sector.

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