DIGITALES ARCHIV

ZBW – Leibniz-Informationszentrum Wirtschaft
ZBW – Leibniz Information Centre for Economics

Al Mahish, Mohammed A.

Article

Economies of scale, technical change, and total factor productivity growth of the Saudi electricity sector

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Al Mahish, Mohammed A. (2017). Economies of scale, technical change, and total factor productivity growth of the Saudi electricity sector.

This Version is available at:
http://hdl.handle.net/11159/1218

Kontakt/Contact
ZBW – Leibniz-Informationszentrum Wirtschaft/Leibniz Information Centre for Economics
Düsternbrooker Weg 120
24105 Kiel (Germany)
E-Mail: *rights[at]zbw.eu*
https://www.zbw.eu/econis-archiv/

Standard-Nutzungsbedingungen:
Dieses Dokument darf zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden. Sie dürfen dieses Dokument nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, aufführen, vertreiben oder anderweitig nutzen. Sofern für das Dokument eine Open-Content-Lizenz verwendet wurde, so gelten abweichend von diesen Nutzungsbedingungen die in der Lizenz gewährten Nutzungsrechte.

https://zbw.eu/econis-archiv/termsofuse

Terms of use:
This document may be saved and copied for your personal and scholarly purposes. You are not to copy it for public or commercial purposes, to exhibit the document in public, to perform, distribute or otherwise use the document in public. If the document is made available under a Creative Commons Licence you may exercise further usage rights as specified in the licence.

ZBW Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Mitglied der Leibniz-Gemeinschaft

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2017, 7(3), 86-94.

Economies of Scale, Technical Change, and Total Factor Productivity Growth of the Saudi Electricity Sector

Mohammed Al-Mahish*

Department of Applied Economics, College of Agriculture and Food Science, King Faisal University, Al-Ahsa, Saudi Arabia.
*Email: malmahish@kfu.edu.sa

ABSTRACT

This paper aims to accomplish two objectives. The first is to extend the existing method of total factor productivity (TFP) growth decomposition by incorporating network characteristics. The second objective is to empirically evaluate technical change and productivity of the Saudi electricity sector. The results show that the Saudi electricity sector operates under the presence of economies of output density, economies of customer density, and diseconomies of scale. The technology used in the Saudi electricity sector is a cost saving technology. It is characterized as fuel using, capital neutral, and energy saving technology. The estimated average technical change term is positive. It indicates a cost increase during the timeframe of this study. The estimated average TFP growth is positive using both the proposed and existing method. Compared with the proposed method, the existing method overestimated TFP growth of the Saudi electricity sector. Furthermore, the paper estimated an optimal scale of output to be almost 11% larger than the maximum output level generated by the Saudi Electricity Company. The paper concludes that the Saudi Electricity Company needs to expand its size to reach the optimal output level.

Keywords: Energy, Total Factor Productivity Growth, Economies of Scale, Technical Change
JEL Classifications: Q40, D24, O33, L25, L94

1. INTRODUCTION

The electric sector in Saudi Arabia is fully regulated by the government. In 2000, the council of ministers issued a royal decree to restructure the electric sector that used to be fully owned and managed by the government. This resulted in the consolidation of unified electricity firms working in eastern, central, western, and southern regions in addition to ten companies working in the northern region into a vertically integrated utility company. Furthermore, the decree stipulated the listing of the company as Saudi Electricity Company (SEC) in the Saudi stock market. Currently, 74.3% of company stock is owned by the government, 6.92% is owned by the Saudi Arabian Oil Company (ARAMCO), and the remaining stocks are owned by the public. As stated in the company's website, the company supplies over 75% of the generation capacity and maintains a monopoly position in the transmission and distribution of electricity. The company purchases energy to cover the deficit in electricity generation from the water and electricity company, desalination plants, and other producers. Furthermore, since the establishment of the SEC, the company has enjoyed much governmental support and privileges such as interest free loans, loan payment deferral, and waiver of dividends on the government's shareholding.

The mission of the SEC is to optimize its resources in generating electricity to meet the increased demand for electricity from various users such as residential, industrial, and commercial. The company's aim is to reduce the cost of electricity production. Thus, it is very important to conduct an empirical examination of the company's mission and aim statement by examining how SEC uses its input efficiently in delivering its output to the final users. To my knowledge, there has not been a study that examines economic productivity and efficiency in the Saudi electricity sector. Therefore, the purpose of this paper is to examine the presence of economies of scale (EOS), technical change, and total factor productivity (TFP) growth. Also, the paper tries to extend the existing literature about the decomposition of TFP growth by deriving an equation that takes into account the impact of network characteristics in TFP decomposition. The other objective of the paper is to inform the decision makers in the SEC about the optimal scale of operation.

2. LITERATURE REVIEW

The studies that have analyzed the electricity industries can be generally classified into two groups with regard to their empirical methodology. The first group employs a non-parametric approach that usually uses the data envelopment analysis (DEA) and the second group employs a parametric approach mostly using a stochastic frontier approach, a cost function, a production function and a distance function.

Coelli et al. (2003) used translog stochastic frontier production function to estimate TFP change in Bangladesh agriculture. The results show 0.23% per year decrease in TFP. Huang et al., 2010 used a stochastic meta frontier approach to estimate the cost efficiency of Taiwan's electricity distribution units. Their results show that the high circuit density group is more efficient than low circuit density group due to the impact of network characteristics in determining the efficiency for the electricity distribution industry. Also, they find that the current scale of distribution is smaller than the optimal scale. Using an input distance function (Subal et al., 2015) analyzed Norwegian electricity distribution companies. They concluded that the smaller companies achieved EOS and some of them are technically efficient while they could not find evidence of EOS among larger firms. Also, the authors found that technical progress in the industry had no relationship between technical change and firm size. As for studies in the U.S. electric sector, Christensen and Greene (1976) found evidence of scale economics in the U.S. electric power generation in 1955, Atkinson and Halvorsen (1984) found the range of estimates of scale economies using total shadow cost in range of 54.0-1.7%, and Okunade (1993) found the average scale economies of 0.26 in a sample of privately regulated private steam-electric utilities in East-North-Central U.S. Gao et al. (2013) studied the US electric power industry and found that on average the industry had its highest TFP growth rate in 2005 and 2008 and negative TFP growth rate in 2002 and 2007. Andrikopulos and Vlachou (1995) found evidence of EOS and the average TFP growth rate is 0.017% in the Greek public electric power industry. Efthymoglou and Vlachou (1989) estimated that the TFP of the integrated Greek power system increase at an average annual growth rate of 1.76%. Filippini (1998) used a translog cost function approach on a sample of Swiss municipal utilities. He concluded that the Swiss utilities operate with economies of output density (EOD), economies of customer density (ECD), and EOS. Roberts (1986) used a translog cost function approach and rejected the hypothesis of no EOD and customer density at the 1% level. Additionally, he rejected the hypotheses of no economies of size at the 5% level. Tovar et al. (2011), analyzed Brazilian electricity distribution industry using a stochastic translogarithmic distance function. The results show a positive TFP with an annual growth of 0.9% during 1998-2005 and the average technical change growth is estimated to be 4.9%. Goto and Sueyoshi (2009) found evidence of EOS, negative technical change (due to large investment cost), and a negative TFP growth in the Japanese electricity distribution industry. The study also indicated that the network characteristics (load factor, customer density, and underground ratio of lines) influence the cost of distribution. See and Coelli (2013) found the average TFP growth in the Malaysian electricity generation industry of 0.5%, 0.94%, and 2.34% using Malmquist method, Törnqvist method, and stochastic frontier analysis, respectively. The authors attributed the differences because different methods use different explicit or implicit cost and revenue share to weight inputs and output variables components. Arcos and de Toledo (2009) concluded that the Spanish electricity utility industry exhibit diseconomy of scale. Akkemik (2009) found that the technical change in the Turkish electricity generation sector is energy using and labor and capital saving. Also, the results showed presence of EOS and a general trend for technological progress to deteriorate. Oh (2015) analyzed Korean fossil-fuel generation companies and found evidence of EOS, technical deterioration, average scale component of 1.459%, and, on average, a negative TFP growth rate of −0.697%. Burney (1998) estimated a translog variable cost function using a time series data on Kuwait electricity generation sector. The author found evidence supporting the presence of diseconomy of scale in electricity generation in Kuwait. Hisnanicka and Kymnb (1999) stressed the importance of additional research to investigate the impact of scale economies on productive behavior. Oh et al. (2014) extended TFP growth decomposition by relating technical change to return to scale. Therefore, in case of constant return to scale, TFP growth will equal the rate of technical change.

Studies on the electric sector that used non-parametric approach are many. For example, Lam and Shiu (2004) China's thermal power generation using a DEA approach. They found the average TFP growth rate is 2.1%. Abbott (2006) analyzed the Australian electricity supply industry using DEA approach and found an average technical progress growth rate of 1.8%, and a TFP average annual growth rate of 2.5%. Çelen (2013) estimated the mean TFP change of 1.033% in Turkish electricity distribution companies. See and Coelli (2014) use Törnqvist index to estimate TFP growth of Tenaga Nasional Berhad in Malaysia. The study found a TFP growth of 1.19% prior to the company's corporatization, 5.73% after the company corporatization, and 0.36 for the full period of study.

To my knowledge, this is the first paper that analyzes EOS, technical change, and TFP growth of the Saudi electricity sector. Also, this is the first study that includes network characteristics in TFP growth decomposition.

3. METHODOLOGY AND DATA

3.1. Theoretical Model

The model that will be used in this paper is the same model derived by Oh (2015). However, this paper will improve Oh's model by incorporating network characteristic into the decomposition of TFP. Thus, the approach is a dual approach that uses a cost function. The model assumes that firms minimize costs and that factor markets are competitive. The cost function is represented as:

$$C = C(w, y, N, t) \tag{1}$$

Where, C is the total cost, w represents input prices, y is firm's output, N is network characteristics such as customer density, length of transmission and distribution line, etc. and t is a time trend variable.

By taking the total differential, equation 1 becomes

$$\mathrm{dlnC} = \sum_i \frac{\partial \ln C}{\partial \mathrm{lnw}_i}\mathrm{dlnw}_i + \frac{\partial \ln C}{\partial \mathrm{lny}}\mathrm{dlny} + \frac{\partial \mathrm{lnC}}{\partial \mathrm{lnN}}\mathrm{dlnN} + \frac{\partial \mathrm{lnC}}{\partial t}\mathrm{dt} \quad (2)$$

By applying Shephard's lemma, we obtain the following cost share equation:

$$\frac{\partial \mathrm{lnC}}{\partial \mathrm{lnw}_i} = \frac{w_i x_i}{C} = S_i \quad (3)$$

S_i denotes input cost share. Inserting equation 3 into (2) yields the following

$$\frac{\mathrm{dlnC}}{\mathrm{dt}} = \sum_i S_i \frac{\mathrm{dlnw}_i}{\mathrm{dt}} + \frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}\frac{\mathrm{dlny}}{\mathrm{dt}} + \frac{\partial \mathrm{lnC}}{\partial \mathrm{lnN}}\frac{\mathrm{dlnN}}{\mathrm{dt}} + \frac{\partial \mathrm{lnC}}{\partial t} \quad (4)$$

The above logarithmic time derivatives, which denote rate of change, can be expressed as:

$$\dot{C} = \sum_i S_i\, \dot{w}_i + \frac{\partial \ln C}{\partial \ln y}\dot{y} + \frac{\partial \ln C}{\partial \ln N}\dot{N} + \frac{\partial \ln C}{\partial t} \quad (5)$$

Since the logarithmic time derivatives of cost[1] and the Divisia index of TFP growth are expressed as:

$$\dot{C} = \Sigma_i\, S_i\, \dot{X}_i + \Sigma_i\, S_i\, \dot{w}_i \quad (6)$$

$$T\dot{F}P = \dot{y} - \Sigma_i\, S_i\, \dot{X}_i \quad (7)$$

By inserting equation 6 into (7), we obtain

$$T\dot{F}P = \dot{y} - (\dot{C} - \Sigma_i\, S_i\, \dot{w}_i) \quad (8)$$

Where $\dot{y}$ is the growth rate of output. Then by inserting equation 5 into equation 8, we obtain the final decomposition of $T\dot{F}P$ growth that takes into account the impact of network characteristics as below:

$$T\dot{F}P = \dot{y} - (\Sigma_i\, S_i\, \dot{w}_i + \frac{\partial \ln C}{\partial \ln y}\dot{y} + \frac{\partial \ln C}{\partial \ln N}\dot{N} + \frac{\partial \ln C}{\partial t} - \sum_i S_i\, \dot{w}_i) \quad (9)$$

$$T\dot{F}P = \left(1 - \frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}\dot{y}\right) + \left(\frac{\partial \mathrm{lnC}}{\partial \mathrm{lnN}}\dot{N}\right) + \left(1 - \frac{\partial \mathrm{lnC}}{\partial t}\right) \quad (10)$$

$$T\dot{F}P = SC + (-\varepsilon_N \dot{N}) + TC \quad (11)$$

Where SC denotes scale component. ε_N is the elasticity of total cost with respect to the network variable and $\dot{N}$ is the growth rate in the network variable. TC is the technical change.

Some authors who did not include network characteristics in their analysis, such as Akkemik (2009) and Oh (2015) have defined EOS as the elasticity of total cost with respect to output, $\frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}$. On the other hand, Christensen and Greene (1976) have defined EOS as unity minus the elasticity of total cost with respect to output $1 - \frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}$.

The scale components shows how a firm adjusts its size to approach or deviate from the optimal size. As mentioned by Oh, if a firm is operating under the EOS (or EOD for authors who include network characteristics) and increasing its size, then the scale component is positive. Also, a positive scale component can occur if a firm is operating under dis EOS and decreasing its firm size. Conversely, a negative scale component indicates that the firm is deviating far from the optimal size.

The technical change term, which equals the negative of the elasticity of total cost with respect to time, shows the reduction in firm's cost over time.

Therefore, the proposed TFP growth in this paper equals the summation of scale component, the negative of the elasticity of network variables times their growth, and technical change.

3.2. Econometric Model

Stochastic frontier methodology cannot be used in this paper because it requires panel data (See and Coelli, 2014). However, translog cost function approach has been widely used with time series data in the economic literature (Seldona et al., 2000; Mohammed and Burney, 2006; Wang and Liao, 2006; Andrikopulos and Vlachou, 1995; Burney, 1998; Onghena et al., 2014). This paper will use translog cost function approach since it has been widely used in the literature to estimate empirically the cost function in the electricity industry, for example Akkemik (2009) and Filippini (1998). The model is written as:

$$\ln C = a_c + a_y \ln y + \frac{1}{2}a_{yy}(\ln y)^2 + a_t t + \frac{1}{2}a_{tt}t^2 + a_{yt}(\ln y)t +$$
$$\Sigma_i\, \delta_i \ln P_i + \frac{1}{2}\Sigma_i\, \Sigma_j\, \gamma_{ij} \ln P_i \ln P_j + \Sigma_i\, \gamma_{iy} \ln P_i \ln y + \Sigma_i\, \gamma_{it} \ln P_i t + \varphi_i N_i \quad (12)$$

Where, C denotes total cost, y is output, t is a time trend variable, P_i and P_j is the price of the ith and jth input (f = fuel, e = purchased energy, and k = capital), and N is a variable accounting for network characteristics. α_c is the intercept for the cost function. a_t, a_{tt}, a_{yt}, γ_{ij}, γ_{iy}, γ_{it}, δ_i and φ_i are parameters to be estimated. The network variable is specified in a linear way following Goto and Sueyoshi (2009). Also, I include a dummy variable in the model to distinguish the time period prior to SEC incorporation in 2000 from the period after SEC incorporation.

Homogeneity condition in input prices requires $\sum_i\delta_i = 1$, $\sum_{ij}\gamma_{ij} = 0$, $\sum_i\gamma_{yi} = 0$, and $\sum_i\gamma_{it} = 0$. By normalizing total cost and input prices by a chosen input price, we impose the homogeneity condition. There are many studies in the electricity sector that followed this approach (Filippini, 1998; Huang et al. 2010; Fetz and Filippini, 2010; Oh, 2015). In this paper, I will follow the same approach. The symmetry condition ($\gamma_{ij} = \gamma_{ji}$) is imposed in the estimation. Also, the translog cost function requires the approximation of the

---

[1] For further details regarding the derivation of the logarithmic time derivatives of cost equation (6), please refer to Oh (2015).

underling cost function to be made at a local point. Thus, this paper will normalize all data by their means (Filippini, 1998; Goto and Sueyoshi, 2009; Hartarska et al., 2013).

By applying Shephard's lemma, taking the partial derivatives of the cost function with respect to input prices $(\frac{\partial \mathrm{lnc}}{\partial \mathrm{lnP_i}})$, we obtain the following cost share equation:

$$S_i = a_i+\sum_j\gamma_{ij}\mathrm{lnP}_j+\gamma_{yi}\mathrm{lny}+\gamma_{it}t \qquad (13)$$

Where S_i is the cost share equation and a_i is the intercept for the share equations (f = fuel, e = purchased energy, and k = capital). The scale component of TFP growth in equation 11 can be calculated from the translog cost function as below:

$$\mathrm{SC}=\left(1-\frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}\right)\dot{y} = (1-a_y+a_{yy}\mathrm{lny}+a_{yt}t+\sum_{i}^{3}{}_{yi}\mathrm{lnP_i})\dot{y} \qquad (14)$$

The incorporation of network characteristics in the econometric model allows for distinguishing between EOD, ECD, and EOS. EOD will be calculated using the following equation:

$$\mathrm{EOD}=\left(\frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}}\right)^{-1} \qquad (15)$$

Roberts, 1986; Filippini, 1998; Wang and Liao, 2006. EOD occur when EOD is bigger than one and dis EOD occur when EOD is <1. This means that the average cost decreases as the electricity output sold to a fixed number of customers and service area increases. Filippini (1998) and Roberts (1986) stated that EOD occur when there is an increase in the demand for electricity from a fixed number of customers in a fixed service area.

ECD is calculated as:

$$\mathrm{ECD}=\left(\frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}+\partial \mathrm{lnN}_1}\right)^{-1} \qquad (16)$$

Where N_1 denotes the number of customers. EOD is a measure of the cost of selling more electricity to a fixed area as its population density increases (Filippini,1998). ECD occur when ECD is >1. Conversely, diseconomies of customer density occur when ECD is <1.

Economies of scale shows the change in average costs of selling more electricity to an increased number of customers and an increased service territory. EOS is expressed as:

$$\mathrm{EOS}=\left((\frac{\partial \mathrm{lnC}}{\partial \mathrm{lny}+\partial \mathrm{lnN}_1+\partial \mathrm{lnN}_2})\right)^{-1} \qquad (17)$$

When N_2 denotes a variable accounting for the service area. If EOS is >1, then a firm utilizes EOS. On the other hand, if EOS is <1, then a firm operates under diseconomy of scale.

Furthermore, the translog cost function allows the calculation of own price elasticity of demand and cross price elasticity of substitution. I will follow the convention in the literature in calculating own and cross price elasticities. Thus, the own price elasticity of demand can be calculated as:

$$\eta_{ii}=\frac{\gamma_{ii}}{S_i}+S_i-1 \qquad (18)$$

Cross price elasticity of demand is calculated as below:

$$\eta_{ij}=\frac{\gamma_{ij}}{S_i}+S_j \qquad (19)$$

Hicks-Allen elasticity of substitution, which some authors refer to as Allen-Uzawa elasticity of substitution, can be calculated by the following equation:

$$\theta_{ij}=\frac{1}{S_iS_j}a_{ij}+1 \qquad (20)$$

For all i = j.

$$\theta_{ii}=\frac{1}{S_i^2}a_{ii}S_i^2-S_i \qquad (21)$$

For all i.

Morishima elasticity of substitution can be computed as:

$$\sigma_{ij}=\eta_{ij}-\eta_{jj} \qquad (22)$$

3.3. Data

Data prior to the incorporation of SEC come from the Saudi Arabian Monetary Agency (SAMA) national statistics. Data after SEC incorporation come from the SEC annual report, annual financial statement, and electricity data report. The data is a time-series data from 1970 to 2014. The output (y) is the electricity sold in Gigawatt hours. The inputs are fuel price (P_f), purchased energy price (P_e), labor price (P_l), and capital price (P_k). Fuel price since SEC incorporation is calculated as total fuel expenses divided by total consumed quantity. Purchased energy price since SEC incorporation is calculated as the total purchased energy expenses divided by the total quantity of purchased energy, and labor price is the total payment to employees divided by the total number of employees. Prior to SEC incorporation, I used local fuel price index, local energy price index, and goods and other services price index published by SAMA as proxies for fuel price, energy price, and labor price, respectively. I followed the published literature in calculating capital price. Thus, capital price is calculated as residual cost divided by capital stock (Farsi et al., 2008; Fetz and Filippini, 2010; Oh, 2015). The network variables in this study are the number of subscribers and energy transmission network length. There were some missing observations for labor price, fuel price, purchased energy price, and transmission network length. The missing observations for those input prices and the transmission network length were recovered using the average annual growth rate as reported by SEC. Table 1 shows descriptive statistics of the key variables.

As shown in the Table 1, the lowest input price is capital price due to the facts mentioned in the introduction and the company's

Table 1: Descriptive statistics of the model key variables

Variable	Mean±SD	Minimum	Maximum
Output (Gigawatt hrs)	87941.07±77454.42	1690.00	274502.00
Fuel price	104.22±14.02	77.84	124.00
Purchased energy price	168.33±133.48	33.22	519.23
Labor price	109.62±21.24	70.08	163.82
Capital price	0.08±0.03	0.02	0.16
Transmission network length (km-sq)	23664.32±14360.26	6767.06	59797.00
Customers number	2859271.30±2096116.45	216000.00	7602279.00

SD: Standard deviation, all prices are in (1000) Saudi Riyal

strong credit rating (AA - and A1 according to Fitch, Standard $ poor's, and Moodey's respectively). This allows it to issue Sukuk (Islamic bonds) and obtain credit from export credit agencies and loans from local and international banks with low interest rates. In addition, the company increased its capital twice in 2002 and 2003. Also, since Saudi Arabia is one of the largest oil producers in the world, the company enjoys reduced fuel prices. The company uses natural gas, crude and heavy oil, and diesel in generating electricity. The output is the total electricity delivered to the subscribers. The total number of subscribers includes residential, agricultural, industrial, and governmental, since the company serves all types of electricity users.

4. MODEL ESTIMATION AND DISCUSSION

4.1. Estimation Procedures and Results

The data were normalized by labor price and the labor share equation was dropped to avoid the singularity in the variance covariance matrix. Since the data described in the previous section are time-series data, autocorrelation correction was needed. Thus, I followed (Seldona et al., 2000) procedures in correcting autocorrelation, who applied the method developed by Berndt and Savin (1975). The method also was applied by other authors to correct for autocorrelation in the translog cost function, such as Onghena et al. (2014). As stated by Seldona et al. (2000), care should be taken when correcting for autocorrelation while estimating the cost function and the share equations simultaneously. This is because the share equation includes the lagged error of the cost function and the cost function includes the lagged errors for the share equations, taking into account that the share equation has to sum up to one (adding-up restriction). Therefore, I used a first-order autoregressive error model. The error term for the cost function and the three share equations in this paper case are specified as:

$$U_{c,t} = \rho_{c,c}U_{c,t-1}+(\rho_{c,f}-\rho_{c,l})U_{f,t-1}+(\rho_{c,e}-\rho_{c,l})U_{e,t-1}+(\rho_{c,k}-\rho_{c,l})U_{k,t-1}+v_{c,t} \tag{23}$$

$$U_{f,t} = \rho_{f,c}U_{c,t-1}+(\rho_{f,f}-\rho_{f,l})U_{f,t-1}+(\rho_{f,e}-\rho_{f,l})U_{e,t-1}+(\rho_{f,k}-\rho_{f,l})U_{k,t-1}+v_{f,t} \tag{24}$$

$$U_{e,t} = \rho_{e,c}U_{c,t-1}+(\rho_{e,f}-\rho_{e,l})U_{f,t-1}+(\rho_{e,e}-\rho_{e,l})U_{e,t-1}+(\rho_{e,k}-\rho_{e,l})U_{k,t-1}+v_{e,t} \tag{25}$$

$$U_{k,t} = \rho_{k,c}U_{c,t-1}+(\rho_{k,f}-\rho_{k,l})U_{f,t-1}+(\rho_{k,e}-\rho_{k,l})U_{e,t-1}+(\rho_{k,e}-\rho_{k,k})U_{k,t-1}+v_{k,t} \tag{26}$$

Table 2: Parameter definition

Parameter	Definition
$\alpha_c, \alpha_f, \alpha_e, \alpha_k$	Intercept for the cost function, purchased energy, fuel, and capital
a_y, a_t	First order output parameter and first order technology parameter effect
$\delta_f, \delta_e, \delta_e$	Input price parameters
γ_{ij}	Parameters denoting interaction among the variables
$\rho_{i,j}$ and $(\rho_{i',j}-\rho_{i',j})$	Autocorrelation parameters

As indicated by Seldona et al. (2000), the ρ differences are estimated as one parameter because we cannot estimate them individually and we are not interested in them.

I estimated the cost function and the share equation simultaneously using seemingly unrelated regression method (SUR). Tables 2 and 3 show parameter definition and parameters estimate, respectively. As shown in Table 3, most of the autocorrelation parameters are significant at the 1% level, indicating the correct use of Berndt and Savin's (1975) methodology. Also, Shapiro-Wilk Normality test shows that normality assumption hold for the cost function and for the capital share equation. Moreover, the average R^2 for the cost function and the cost share equations is 0.97. This indicates that the selected variables have explained on average about 97% of the variation in the cost function and the share equation.

The primary first order effect of technology (a_t) is negative and significant at the 1% level, indicating that the technology used is cost saving. Akkemik (2009) interpreted the coefficient (a_{tt}) as the speed of technological progress. Thus, in this case it implies acceleration of technological progress at a rate of 0.003% annually. Table 4 shows that the average technical change from 1971 to 1974 has been almost constant at a rate of 11%. After 1975, the technical change rate had been gradually increasing. However, in 1991 the technical change started to fall, due to the Gulf War. Moreover, the technical change rate started to increase gradually after the SEC incorporation in 2000, but it started to decrease from 2008 until 2010 due to the global financial crisis. In relative terms, the parameter γ_{ft} indicates that SEC technology is fuel using, which is due to the subsidized fuel prices it receives from the government, which encourages the company to rely on fuel as a source of input in generating electricity. However, the parameter γ_{et} indicates that SEC technology is a saving technology with respect to purchased energy, and γ_{kt} indicates it is neutral with respect to capital. As stated by Norsworthy and Jang (1992), in absolute term ($a_t+\gamma_{it}$)

Table 3: Parameter estimates

a_c	20.634***(0.594)	γ_{kt}	−0.002 (0.003)	a_t	−0.208*** (0.029)
a_f	0.152 (0.202)	Dummy	−0.530*** (0.067)	a_{tt}	0.003*** (0.001)
a_e	0.328*** (0.097)	Customers	−0.096 (0.075)	γ_{fy}	0.078 (0.048)
a_k	−0.029 (0.094)	Transmission length	2.163*** (0.310)	γ_{ey}	0.040* (0.023)
δ_f	−0.217 (0.153)	$\rho_{c,c}$	−1.361*** (0.263)	γ_{ky}	−0.015 (0.024)
δ_e	0.659*** (0.095)	$(\rho_{c,f}-\rho_{c,l})$	−2.247*** (0.439)	γ_{ft}	0.039*** (0.005)
δ_k	0.109 (0.101)	$(\rho_{c,e}-\rho_{c,l})$	−1.210*** (0.402)	γ_{et}	−0.019*** (0.003)
γ_{ff}	0.047 (0.044)	$(\rho_{c,k}-\rho_{c,l})$	−1.488*** (0.497)	$\rho_{k,c}$	−0.690*** (0.168)
γ_{fe}	−0.097*** (0.021)	$\rho_{f,c}$	1.481*** (0.271)	$(\rho_{k,f}-\rho_{k,l})$	−0.493** (0.185)
γ_{fk}	0.179*** (0.012)	$(\rho_{f,f}-\rho_{f,l})$	2.268*** (0.296)	$(\rho_{k,e}-\rho_{k,l})$	0.082 (0.178)
γ_{ee}	0.097*** (0.021)	$(\rho_{f,e}-\rho_{f,l})$	0.281 (0.315)	$(\rho_{k,e}-\rho_{k,k})$	0.458** (0.180)
γ_{ek}	−0.033*** (0.008)	$(\rho_{f,k}-\rho_{f,l})$	1.031*** (0.339)		
γ_{kk}	−0.098*** (0.009)	$\rho_{e,c}$	−0.602*** (0.185)		
a_y	1.222*** (0.205)	$(\rho_{e,f}-\rho_{e,l})$	−0.612*** (0.187)		
a_{yy}	0.287*** (0.052)	$(\rho_{e,e}-\rho_{e,l})$	0.699*** (0.173)		
a_{yt}	−0.016*** (0.006)	$(\rho_{e,k}-\rho_{e,l})$	−0.486** (0.174)	R^2	0.97

Standard errors are in parenthesis. ***Significant at 1%, **significant at 5%, and * significant at 10%

Table 4: Economies of scale, technical change, and total factor productivity growth

Term	Estimate
EOD	1.541***
	(0.219)
ECD	1.810***
	(0.202)
EOS	0.368***
	(0.043)
TC	0.129***
	(0.017)
SC	0.037***
	(0.010)
Suggested growth	0.069***
	(0.004)
Literature growth	0.166***
	(0.015)

EOD: Economics of output density, ECD: Economics of customer density, EOS: Economies of scale, TC: Technical change, SC: Scale component, TFP: Total factor productivity, Standard errors are in parenthesis. ***Significant at 1%, significant at 5%, and significant at 10%

the Saudi electric sector technology is absolutely fuel, purchased energy, and capital saving. The Saudi electric sector with sample mean characteristics operates with decreasing return to scale because the coefficient (a_y) is >1 and significant at the 1% level. As interpreted by Friedlaender et al. (1981), the positive value of (a_{yy}) indicates (asymmetric) U-shaped average cost curve in the Saudi electric sector. The dummy variable is negative and significant at the 1% level indicating that the consolidation of public firms to operate as a one entity (SEC) results in reducing the total cost of electricity generation. Also, an increase in energy transmission network length increases total cost.

4.1.1. EOS, technical change, and TFP growth

Table 4 shows the estimate of economics of output density, ECD, EOS, technical change, and TFP growth at the sample mean.

Since the estimates of EOD and ECD are larger than one and significant at the 1% level, this indicates that the Saudi electricity sector operates under EOD and ECD, which is consistent to the results found in Filippini (1998) and Roberts (1986). However, the Saudi electric sector operates under dis EOS. The technical change is positive and significant, but <1 which indicates a cost increase during the average sample period. Furthermore, since the Saudi sector operates with EOD, and the estimated scale component is positive and significant, this gives evidence that SEC is increasing its firm size in an attempt to approach the optimal size. Table 4 also shows average TFP growth calculated using the proposed method in this paper, equation 13. The Saudi sector has a positive and significant TFP growth with a value of 0.069. However, if we decompose TFP growth by summing SC and technical change as it is done in the literature, the TFP growth would be 0.166. Thus, failure to account for network characteristics in the decomposition of TFP will overestimate the value of TFP growth of the Saudi sector. This gives evidence to support the derived equation 11 in providing a more accurate estimate of the value of TFP growth.

Table 5 shows that the average value of EOS decrease with increase in firm size which is consistent with (Filippini, 1998) findings. Also, the table shows a comparison between TFP growth using the method described in the literature and the proposed method in this paper. The comparison between the two methods reassures the importance of including network characteristics in TFP growth decomposition. It is clear from the table that the conventional method overestimates TFP growth rate. Using the proposed method, the company had three negative TFP growth rates in 2009-2010, 2010-2011, and 2013-2014, respectively. The average growth rate of technical change, conventional TFP, and the proposed TFP from SEC incorporation until 2014 is 0.09%, 0.02%, and −1.49%, respectively.

Moreover, the conventional method can underestimate TFP growth depending on the sign and magnitude of the elasticity of cost with respect to the network variables.

4.2. Own Price Elasticity of Demand and Cross Price Elasticity of Substitution

All own price elasticities of demand in Table 6 and Allen-Hicks elasticities in Table 7 are negative inelastic, except the price of capital has negative elastic own price elasticity of demand.

Surprisingly, the purchased energy has insignificant positive own price elasticity ($\eta_{ee} = 0.454$ and $\theta_{ee} = 0.027$). Despite the fact that the own price elasticity of purchased energy is statistically insignificant, this result is consistent with (Cho et al., 2004) who found positive own price elasticity of energy and (Gao et al., 2013) who used the dynamic translog model and found positive Allen elasticity of energy. To be consistent with the literature, I focused on the analysis of cross price elasticities of Hicks-Allen and Morishima elasticities in Tables 7 and 8, respectively.

Table 5: Estimated average annual rate of EOS, technical change, and TFP over time

Year	EOS	TC	SC	TFP literature	Suggested TFP
1971-1972	0.470	0.113	0.116	0.229	0.131
1972-1973	0.463	0.113	0.142	0.254	0.156
1973-1974	0.453	0.113	0.167	0.280	0.186
1974-1975	0.445	0.113	0.134	0.247	0.155
1975-1976	0.436	0.114	0.147	0.262	0.170
1976-1977	0.425	0.116	0.160	0.275	0.185
1977-1978	0.416	0.117	0.137	0.253	0.166
1978-1979	0.401	0.120	0.174	0.294	0.209
1979-1980	0.387	0.124	0.147	0.271	0.185
1980-1981	0.380	0.126	0.088	0.214	0.127
1981-1982	0.372	0.127	0.075	0.202	0.112
1982-1983	0.367	0.129	0.060	0.188	0.097
1983-1984	0.363	0.130	0.042	0.172	0.080
1984-1985	0.360	0.131	0.035	0.167	0.073
1985-1986	0.358	0.134	0.031	0.165	0.069
1986-1987	0.358	0.140	0.025	0.165	0.068
1987-1988	0.359	0.146	0.016	0.162	0.064
1988-1989	0.358	0.149	0.016	0.165	0.066
1989-1990	0.357	0.149	0.017	0.167	0.067
1990-1991	0.355	0.149	0.017	0.166	0.066
1991-1992	0.355	0.146	0.016	0.162	0.063
1992-1993	0.354	0.143	0.017	0.161	0.061
1993-1994	0.352	0.141	0.021	0.162	0.062
1994-1995	0.351	0.137	0.015	0.152	0.053
1995-1996	0.351	0.135	0.009	0.144	0.044
1996-1997	0.351	0.133	0.008	0.141	0.040
1997-1998	0.351	0.131	0.008	0.140	0.039
1998-1999	0.350	0.130	0.014	0.144	0.043
1999-2000	0.346	0.128	0.014	0.142	0.043
2000-2001	0.342	0.126	0.010	0.137	0.076
2001-2002	0.339	0.127	0.007	0.134	0.066
2002-2003	0.338	0.127	0.008	0.134	0.036
2003-2004	0.340	0.128	0.006	0.135	0.075
2004-2005	0.343	0.130	0.006	0.135	0.077
2005-2006	0.344	0.129	0.010	0.138	0.054
2006-2007	0.345	0.130	0.009	0.138	0.060
2007-2008	0.345	0.128	0.009	0.137	0.054
2008-2009	0.345	0.124	0.011	0.135	0.016
2009-2010	0.346	0.127	0.013	0.140	−0.007
2010-2011	0.346	0.133	0.011	0.144	−0.009
2011-2012	0.346	0.133	0.010	0.143	0.022
2012-2013	0.344	0.132	0.012	0.144	0.055
2013-2014	0.345	0.130	0.011	0.141	−0.001

EOS: Economies of scale, TC: Technical change, SC: Scale component, TFP: Total factor productivity

Allen-Hicks elasticities show fuel and energy are complements with Morishima cross price elasticity of $\sigma_{fe} = -0.610$ and $\sigma_{ef} = -0.498$. Fuel and capital are substitutes with elastic cross price elasticity. Also, fuel and labor are substitute with inelastic cross price elasticity. Energy and capital have a strong complementary relationship using Allen- Hicks elasticity. However, Morishima cross price elasticity indicates that the price of purchased energy is elastic substitute with respect to the price of capital, indicating that the increases in the price of energy induces the firm to seek more capital to implement projects that reduces its dependence on purchased energy in generating electricity. Furthermore, the Morishima elasticity shows price of capital has an inelastic complementary relationship with price of purchased energy indicating that the firm uses part of its capital in purchasing energy. Also, Morishima elasticity shows that increases in the price of purchased energy forces the firm to substitute purchased energy to demand more labor for its own operation to reduce its reliance on purchased energy. The results also show that the firm uses labor as a complementary factor with purchased energy to generate electricity. Allen-Hicks elasticity shows that capital and labor are complements and Morishima elasticity shows the same relation. However, when the price of labor increases, the firm uses more capital to procure a technology that substitutes its need for labor.

5. OPTIMAL SCALE

Huang et al., 2010 used the fundamental theory of minimum efficient scale in industrial economics in order to find the minimum point of the long run average cost function. The authors stated that the optimal scale can be found by taking the partial derivatives of the cost with respect to output and setting it equal to 1, $\left(\frac{\partial \ln C}{\partial \ln y} = 1\right)$. Also, Hartarska et al. (2013) used the same approach to find the optimal scale. In this paper, I followed the same approach to find the optimal size of SEC. It is important to note that the calculation of optimal scale holds the effect of network characteristics constant. Thus, I recommend for future research to develop an equation for optimal scale that takes into account the impact of network characteristics.

The results show that the optimal scale of output is 303404 Gigawatt hours. The optimal scale is about 3.5 times larger than the sample mean of 87941 Gigawatt hours. Also, the optimal scale is almost 1.7 times larger than the average output produced since SEC incorporation, 181100 Gigawatt hours. The largest output produced in the sample of study as shown in Table 1 is 274502

Table 6: Own price and cross price elasticity of demand evaluated at the mean

	j=f	j=e	j=k	j=l
i=f	−0.460*** (0.103)	−0.156*** (0.049)	0.479*** (0.028)	0.137* (0.079)
i=e	−0.958*** (0.302)	0.454 (0.308)	−0.418*** (0.109)	0.922*** (0.266)
i=k	3.373*** (0.196)	−0.479*** (0.125)	−2.551*** (0.148)	−0.343** (0.150)
i=l	0.134* (0.078)	0.147*** (0.042)	−0.048** (0.021)	−0.234*** (0.083)

Standard errors are in parenthesis. ***Significant at 1%, **significant at 5%, and *significant at 10%

Table 7: Allen-Hicks elasticity of substitution evaluated at the mean

Elasticity	Estimate
θ_{fe}	−2.228*** (0.701)
θ_{fk}	7.843*** (0.457)
θ_{fl}	0.313* (0.181)
θ_{ek}	−6.850*** (1.790)
θ_{el}	2.100*** (0.606)
θ_{kl}	−0.781** (0.342)
θ_{ff}	−0.383*** (0.044)
θ_{ee}	0.027 (0.022)
θ_{kk}	−0.159*** (0.009)
θ_{ll}	−0.295*** (0.036)

Standard errors are in parenthesis. ***Significant at 1%, **significant at 5%, and * significant at 10%

Table 8: Morishima elasticity of substitution evaluated at the mean

	j=f	j=e	j=k	j=l
i=f	0.000	−0.610*	3.030***	0.371**
		(0.341)	(0.167)	(0.154)
i=e	−0.498	0.000	2.133***	1.156***
	(0.372)		(0.176)	(0.303)
i=k	3.833***	−0.933***	0.000	−0.109
	(0.252)	(0.312)		(0.193)
i=l	0.595***	−0.307	2.504***	0.000
	(0.171)	(0.331)	(0.154)	

Standard errors are in parenthesis. ***Significant at 1%, **significant at 5%, and *significant at 10%

Gigawatt hours, and it belongs to 2014. This largest level of output is still smaller than the long run optimal scale. The optimal scale is approximately 1.11 times larger than the output level produced in 2014.

6. CONCLUSION

The paper has examined Saudi electricity sector's productivity using a translog cost function approach. The results show that the technology employed in the Saudi electricity sector is a cost saving technology. In relative terms, the technology is fuel using, energy saving, and capital neutral. The incorporation of SEC results in cost reduction of power generation. Also, the average cost curve in the Saudi electricity sector is characterized as an asymmetric U-shaped average cost curve. The results also show the presence of EOD and ECD. However, the industry operates under the presence of dis EOS. The paper has proposed an extension to the current method of TFP growth decomposition. The proposed method extends the original method by incorporating the network characteristics in the decomposition of TFP growth. The estimated technical change is positive and <1, indicating a cost increase during the average sample of study. Also, the estimated average TFP growth is positive using both the original method in the literature and the proposed method. However, the proposed method shows that the original method used in the literature generally overestimates TFP growth of the Saudi sector. From 2009 to 2011, the original method estimated a positive TFP growth while the proposed method estimated a negative TFP growth.

The results show that the own price elasticity of fuel and purchased energy is negative inelastic and negative elastic for capital. The cross price elasticities show that fuel and energy are complementary, fuel and capital are substitutes with elastic cross price elasticities, and fuel and labor are substitute with inelastic cross price elasticity.

The paper estimates the optimal scale of output to be 303404 Gigawatt hours, which is almost 11% larger than the maximum output level produced by the company in 2014. Thus, the paper concluded that SEC operates less than the optimal size and it needs to expand its output to reach the optimal scale.

REFERENCES

Abbott, M. (2006), The productivity and efficiency of the Australian electricity supply industry. Energy Economics, 28(4), 444-454.

Akkemik, A. (2009), Cost function estimates, scale economies and technological progress in the Turkish electricity generation sector. Energy Policy, 37(1), 204-213.

Andrikopulos, A., Vlachou, A. (1995), The structure and efficiency of the publicly owned electric power industry of Greece. The Journal of Energy and Development, 19(1), 57-79.

Arcos, A., de Toledo, P. (2009), An analysis of the Spanish electrical utility industry: Economies of scale, technological progress and efficiency. Energy Economics, 31(3), 473-481.

Atkinson, S., Halvorsen, R. (1984), Parametric efficiency tests, economies of scale, and input demand in U.S. Electric power generation. International Economic Review, 25(3), 647-662.

Berndt, E., Savin, N. (1975), Estimation and hypothesis testing in singular equation systems with autoregressive disturbances. Econometrica, 43(5-6), 937-958.

Burney, N.A. (1998), Economies of scale and utilization in electricity generation in Kuwait. Applied Economics, 30(6), 815-819.

Çelen, A. (2013), Efficiency and productivity (TFP) of the Turkish electricity distribution companies: An application of two-stage (DEA&Tobit) analysis. Energy Policy, 63(1), 300-310.

Cho, W., Nam, K., Pagan, J. (2004), Economic growth and interfactor/interfuel substitution in Korea. Energy Economics, 26(1), 31-50.

Christensen, L., Greene, W. (1976), Economies of scale in U.S. Electric power generation. Journal of Political Economy, 84(4), 655-675.

Coelli, T., Rahman, S., Thirtle, C. (2003), A stochastic frontier approach to total factor productivity measurement in Bangladesh crop agriculture, 1961-92. Journal of International Development, 15(3), 321-333.

Efthymoglou, P., Vlachou, A. (1989), Productivity in the vertically integrated system of the Greek electricity utility, 1970-85. Energy Economics, 11(2), 119-126.

Farsi, M., Fetz, A., Filippini, M. (2008), Economies of scale and scope in multi-utilities. The Energy Journal, 29(4), 123-143.

Fetz, A., Filippini, M. (2010), Economies of vertical integration in the Swiss electricity sector. Energy Economics, 32(6), 1325-1330.

Fllippini, M. (1998), Are municipal electricity distribution utilities natural monopolies? Annals of Public and Cooperative Economics, 69(2), 157-174.

Friedlaender, A., Spady, R., Chiang, S. (1981), Regulation and the structure of technology in the trucking industry. In: Cowing, T., Stevenson, R., editors. Productivity Measurement in Regulated Industries. New York, NY: Academic Press. p77-106.

Gao, J., Nelson, R., Zhang, L. (2013), Substitution in the electric power industry: An interregional comparison in the eastern US. Energy

Economics, 40(1), 316-325.

Goto, M., Sueyoshi, T. (2009), Productivity growth and deregulation of Japanese electricity distribution. Energy Policy, 37(8), 3130-3138.

Hartarska, V., Shen, X., Mersland, R. (2013), Scale economies and input price elasticities in microfinance institutions. Journal of Banking and Finance, 37(1), 118-131.

Hisnanicka, J., Kymnb, K. (1999), Modeling economies of scale: The case of US electric power companies. Energy Economics, 21(3), 225-237.

Huang, Y.J., Chen, K.H., Yang, C.H. (2010), Cost efficiency and optimal scale of electricity distribution firms in Taiwan: An application of meta frontier analysis. Energy Economics, 32(1), 15-23.

Lam, P.L., Shiu, A. (2004), Efficiency and productivity of China's thermal power generation. Review of Industrial Organization, 24(1), 73-93.

Norsworthy, J., Jang, S. (1992), Empirical Measurement and Analysis of Productivity and Technological Change: Applications in High-Technology and Service Industries. New York, NY: North-Holland.

Oh, D. (2015), Productivity growth, technical change and economies of scale of Korean fossil-fuel generation companies, 2001-2012: A dual approach. Energy Economics, 49(1), 113-121.

Oh, D., Heshmati, A., Lööf, H. (2014), Total factor productivity of Korean manufacturing industries: Comparison of competing models with firm-level data. Japan and the World Economy, 30(1), 25-36.

Okunade, A. (1993), Economies of scale in steam-electric power generation in East-North-Central U.S. Journal of Economics and Finance, 17(1), 149-156.

Onghena, E., Meersman, H., Van de Voorde, E. (2014), A translog cost function of the integrated air freight business. Transportation Research Part A: Policy and Practice, 62(1), 81-97.

Roberts, M. (1986), Economies of density and size in the production and delivery of electric power. Land Economics, 62(4), 378-387.

See, K., Coelli, T. (2013), Estimating and decomposing productivity growth of the electricity generation industry in Malaysia: A stochastic frontier analysis. Energy Policy, 62(1), 207-214.

See, K.F., Coelli, T. (2014), Total factor productivity analysis of a single vertically integrated electricity utility in Malaysia using a Törnqvist index method. Utilities Policy, 28(1), 62-72.

Seldona, B., Jewellb, R., O'Briena, D. (2000), Media substitution and economies of scale in advertising. International Journal of Industrial Organization, 18(8), 1153-1180.

Subal, C.K., Amundsveen, R., Kvile, H., Lien, G. (2015), Scale economies, technical change and efficiency in Norwegian electricity distribution, 1998-2010. Journal of Productivity Analysis, 43(3), 295-305.

Tovar, B., Ramos-Real, F., Almeida, E. (2011), Firm size and productivity. Evidence from the electricity distribution industry in Brazil. Energy Policy, 39(2), 826-833.

Wang, S.E., Liao, C.H. (2006), Cost structure and productivity growth of the Taiwan railway. Transportation Research Part E: Logistics and Transportation Review, 42(4), 317-339.