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Nigeria' Power Sector: Analysis of Productivity

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Abstract: This study analyzes the productivity change in Nigeria's power sector from 2004-2008, Applying the Malmquist index with the input technological bias. The results show that on average, the Nigerian power sector becomes both more efficient and experience technological improvements. Furthermore, the assumption of Hicks neutral technological change is not suitable and therefore the traditional growth accounting method is not appropriate for analyzing changes in productivity for Nigeria power sector. Policy implications are derived.

Key words: Power, Nigeria; productivity, technological change, policy implications.

1. Introduction

Nigeria needs to improve efficiency and reduce waste in the public sector, and strengthen the private sector as its engine of growth (Ebohon, 1996; Akinlo, 2008; Wolde-Rufael, 2009). It is generally accepted that this feature will only be achievable with an efficient electricity generation as the latter affects every gamut of the economy. Unfortunately, although the power sector is one of the most important industries supporting infrastructure of the country electricity generation had remained underdeveloped and in short supply. While the country is richly endowed with huge supply of gas, coal, as well as solar and hydro resources, these seemed to be only sparingly applied. Currently, power generation is mainly from thermal plants, which contribute about 60%, and hydro power plants which generate about 30%(Tallapragada, 2009; Adoghe, 2008; Okoro and Chikuni, 2007).

The motivation for the present research are the following. First, the context of the Nigerian electricity market, characterised by inadequate electricity generation framework, which is continues to be compounded by lack of timely routine maintenance, thereby resulting in significant deterioration in plant electricity output, a key reason for the lingering electric power crisis. More than two decades of underprivileged planning and underinvestment had left a vast supply deficit (Ikeme and Ebohon, 2005). Also, none of the new infrastructure in over a decade, unfortunately, comes in the market of the country despite rapid population growth and rising demand for power. The power sector was at the edge of fall down. Average daily generation was 1,750MW in 1999. The situation, after 10 years, is not really different as available capacity output is still less than 2.5GW. Various measures taken in the past to address the electricity generation and distribution problem seemed to have yielded little or no result. This apparently led government, in 2004, to embark on a reform that was meant to decentralize operations in the power sector. Conceptually, the reforms are to solve a myriad of problems, including limited access to infrastructure, low connection rates, inadequate power generation capacity, inefficient usage of capacity, and lack of capital for investment, ineffective regulation, high technical losses and vandalism, and insufficient transmission and distribution facilities (Adenikinju, 2003). In short, Nigeria seeks policies that can promote least-cost electricity generation while ensuring a constant increase in production. Second, to adopt a performance model aiming to analyse the production of Nigerian electricity plants to investigate whether there are improvements in efficiency and productivity in the sector after the reform. Therefore this study applies a data envelopment analysis (DEA) model to the Malmquist Index with biased technological change to frame the productivity change of Nigeria's power stations, Farrell (1957). Finally, this research aims to identify a sound energy policy that can assist Nigeria to improve its energy capacity through improved performance.

The remainder of the paper is organized as follows: Section 2 presents the contextual setting; Section 3 presents a literature survey. Section 4 details the methodology while Section 5 presents the data and the results. Section 6 discusses the results and section 7 concludes.

2. Contextual setting

Electricity generation in Nigeria started in the city of Lagos in 1896 some 15 years after that of Britain from which Nigeria obtained independence in 1960. In the northern part of the country, the Nigeria Electricity Supply Company (NESCO) began operations in 1929 as an electric utility company in Nigeria with the construction of a hydroelectric power station at Kurra near Jos. The first attempt to coordinate supply and development of electricity occurred in 1951 with the establishment of the Electricity Corporation of Nigeria (ECN) by an act of parliament. In 1962, the first 132KV line was constructed, connecting Ijora Power Station to Ibadan Power Station. The Niger Dams Authority (NDA) was established in 1962 and authorized to build up the hydropower prospects of the country. It sold electricity to ECN. However, ECN and NDA were merged in 1972 to form the National Electric Power Authority (NEPA), a company with exclusive monopoly over electricity generation, transmission, distribution and sales throughout the country.

Despite its long history, NEPA's development has been very slow and electricity generation in Nigeria had deteriorated over the years. This is rarely expected given the country's rich endowment in natural resources that could facilitate electricity production. The company from inception appeared to be faced with the problems of lack of adequate funding and managerial strategies resulting in the steady decline of the company (Adoghe, 2008). While the transmission and distribution deteriorated, the demand for electricity continued to increase. This is in spite of the fact that many corporate organisations have folded up as a result of harsh operating environment occasioned, in large part, by the poor and epileptic supply of electricity. The paradox is easily explained by the increasing demand in domestic requirement resulting from an ever-increasing population. Analysts (see Tallapragada, 2009; Adoghe, 2008; Okoro and Chikuni, 2007) have advanced some reasons for the continued problem in the sector. A huge investment was undertaken in the area of power generation without a corresponding investment in the transmission and distribution networks. Other reasons identified include weak governance, poor institutional capacities and inadequate investments. It is a classic example of the developmental paradox where there are tremendous resources but little dividends.

Nigeria's economy is characterized by a large informal sector many of whom depend on electricity for daily production and livelihood. As NEPA is almost never available many of them have been forced to buy generators to continue production. This immediately has the effect of increasing their cost of production. Those who cannot afford the luxury are forced to abandon the trade often for no visible alternative. The result is that the rate of unemployment continues to rise and rise. The experience in the formal sector is not much different, as corporate bodies have had to self-generate electricity in order to maintain production.

There is a lot of suspicion and conflicts between NEPA officials as provider on the one hand and consumers on the other thereby encouraging illegitimate activities such as illegal connections to the national grid or the existing residential/industrial outfit, overbilling and under billing, payment via unscrupulous business collusion, and canalization of equipments which are then resold, in most cases, to private electricity institutions (Subair and Oke, 2008).

Often NEPA is confronted with reckless development of areas, which does not match its efforts. For example, small industries unexpectedly spring up in areas planned as residential. As a consequence, transformers and cables are overloaded until they are damaged. This is problematic since NEPA is not notified when new loads are added to existing ones.

The costs of power supply interruptions are fairly large because of the predominating utilization of private generators for homes and industries with its fire and health hazards, disturbance of scheduled productive activities and reductions in operation. Not only that, the unpredictable power supply often results in equipments malfunctioning (Subair and Oke, 2008).Currently, the National electricity grid presently consists of nine generating stations (3 hydro and 6 thermal). However, as stated, supply capacity largely lags behind demand of the country. Although some state capitals are connected to the national transmission grid system they are served only haphazardly. In the circumstance, the proposed national integrated rural development is elusive as disabilities are experienced in every facet of NEPA operations.

In 2000 government restructured the power sector by unbundling NEPA into eighteen separate companies composed of six electricity-generating companies, one Transmission Company and eleven distribution companies. The restructuring was designed to encourage private participation by breaking NEPA's monopoly and paving way for Independent Power Producers (IPPs). It is yet to be seen whether the reform will bring about the much desired changes as the new structure is yet to be fully operational.

3. Literature Survey

While there is extensive literature on benchmarking applied to a diverse range of economic fields, the scarcity of studies regarding African energy companies' bear's testimony to the fact that this is a relatively under-researched topic (Estache, Tovar and Trujillo, 2008).

Efficiency analysis in relation to electricity is concentrated on distribution networks (Jamasb, Nillesen and Pollitt, 2004; Farsi and Filippini, 2004; Estache, Rossi and Ruzzier, 2004; Jamasb and Pollitt, 2003). Papers analysing the efficiency of electricity generating plants include (Kleit and Terrell, 2001; Hiebert, 2002; Arocena and Wadams Price, 2002; Knittel, 2002; Raczka, 2001; Barros, 2008). Jamasb and Pollitt (2001) review the frequency with which different input and output variables are used to model electricity distribution. The most frequently used outputs are units of energy delivered, number of customers and size of the service area. The most widely used inputs are number of employees, transformer capacity and network length. For an extended up to date survey, see Jamasb, Mota, Newbery and Pollitt (2005).

Restricting the literature review to a sample of recent energy production papers, it is observed that they adopt one of two complementary efficiency methodologies: DEA, and the Stochastic Frontier Model. Table 1 displays our review of these works.

Table 1: Recent Papers on Energy Production

Stochastic Frontier Models				
Papers	Method	Units	Endogenous variable	Exogenous variables
Kleit and Terrell (2001)	Bayesian Cobb-Douglas cost stochastic frontier model.	USA, 78 steam plants, observed in 1996	Total cost	(i) Annual output (Mwh); (ii) peak output (Mwh); (iii) wage(dollars); (iv) price of fuel; (v) price of capital; (vi) log of relative wage; and (vii) log of relative fuel price.
Knittel (2002)	Cobb-Douglas stochastic production frontier model	USA, unbalanced data from 1981 to 1996 on investor-owned electricity coal, gas and oil utilities (5040 observations)	Output (Mwh)	(i) Capital; (ii) labour; (iii) coal; (iv) oil; (v) vintage; and (vi) vintage squared.
Hiebert (2002)	Translog cost frontier model USA	412 US municipal utilities observed from 1988-1997.	Total operating and maintenance costs are regressed in several explanatory variables	(i) Net electricity generation (in megawatt hours); (ii) price of fuel (in dollars per-million British thermal units); (iii) time trend; (iv) the vintage of the plant in years (calculated as the sum of the vintages of the units); (v) the age of the plant (in months); and (vi) the number of units comprising the plant. For coal, a dummy variable is included.
Farsi and Filippini (2004)	Cobb-Douglas cost frontier	Switzerland , 59 utilities observed from 1988 to 1996	Total annual costs per- Kwh	(i) Annual output in gwh; (ii) number of customers; (iii) load factor; (iv) service area; (v) average annual labour price per employee; (vi) average capital price per kva installed; (vii) average price of input power, (viii) high voltage network dummy; (ix) auxiliary revenues more than 25%; and (x) share of forest area more than 40%.
Data Envelopment Analysis papers				
Papers	Method	Units	Inputs	Outputs
Pollitt (1996)	Two-stage model DEA model. First stage a CCR DEA model. Second stage a battery of statistical tests (ANOVA, Tobit regression, etc.)	78 Nuclear power stations in the USA, UK, Canada, Japan and South Africa,	(i) Labour; (ii) capital;, (iii) fuel; (iv) price of labour; (v) price of capital; (vi) price of fuel, separated into historic and current; and (vii) other input descriptors (age and	Energy produced in KWh

			reactor type).	
Arocena and Waddams Price (2002)	Two DEA Models: (i)Graphyperbolic Malmquist; (ii) Malmquist Index	28 Spanish generating plants observed from 1984 to 1997	(i) Capital proxied by average capacity (mw); (ii) labour average number of workers); (iii) fuel (million of therms).	(i) Annual power produced (Mwh)
Raczka (2001)	DEA two-stage procedure: in the first stage, DEA allocative model is used; in the second stage, a Tobit model regresses the efficiency scores in explanatory variables.	41 heat plants from Wielkopolska, Poland observed in 1997.	(i) Labour; (ii) fuel; and (iii) pollution	(i) Heating production
Jamasb, Nillesen and Pollitt (2004)	DEA CCR models, input oriented. One base model and two strategic behaviour models: a gaming operating costs model and a model with restricted outputs	28 USA utilities observed in 2000	(i) Distribution operating costs.	(i) Units of electricity delivered; (ii) number of customers; (iii) length of network.
Estache, Rossi and Ruzzier (2004)	DEA distance function	84 South American companies, observed from 1994 to 2001	(i) Distribution lines: (ii) transformation capacity in MVA. Environmental variables: Residential sales/sales and GNP per-capita PPP units.	(i) Sales in Gwh; (ii) number of customers; (iii) service area in km2.

It is recognised in the literature that both methods give similar rankings. However, research has shown that, although, the DEA scores are, sometimes, inferior in value to econometric scores, the ranking is preserved (Bauer et al., 1998). Regarding the inputs and outputs, the literature review does not reveal a universally agreed set of input and output variables for modelling of electricity units (Jamasb, Nillesen and Pollitt, 2004).

The policy implications of the surveyed papers focus on the differences in efficiency scores and the drivers of efficiency, the role of alternative regulatory frameworks in efficiency, and the comparative analysis of efficiency of public and private companies. Other findings are: Deregulating electricity generation increases efficiency (Kleit and Terrell, 2000), alternative regulatory programs provide firms with an incentive to increase efficiency (Knittel, 2002), andprice controls and subsidies decrease technical efficiency (Raczka, 2001). Moreover, regulation and competition accompanied by privatisation promotes efficiency (Arocena and Waddams Price, 2002), while regulation without competition decrease efficiency (Barros and Peypoch, 2008). For competition to work, regulators must coordinate their policy throughout a multi country region, for example, South America, (Estache, Rossi and Ruzzier, 2004), Africa (Ramanathan, 2005; Estache, Tovar and Trujillo,2008, Barros and Managi 2009)

Privately-owned plants exhibit higher average efficiency than publicly-owned plants (Pollitt, 1996). Public firms are more efficient under cost-of-service regulation, compared with price-cap regulation (Arocena and Waddams Price, 2002). Another paper relying on an innovative cost function is Jara Diaz et al. (2004). Recent applications of DEA models in energy studies are Pombo and Taborda (2006) and Vaninski (2006), Nakano and Managi (2008) and Mukherjee (2002). Therefore, the present paper innovates in energy efficiency adopting the Malmquist DEA model with the input technological bias.

Research on Nigeria energy includes Ibitoye and Adenikinju (2007), Amobi (2007), Eti, Ogaji and Probert (2004), Ikeme and Ebohon (2005) and Adenikinju (2003), but none of this papers analysed productivity on Nigerian electricity plants.

4. The Model

We apply DEA to station-level data in order to measure changes in productivity in Nigeria's electricity industry for the period from 2004 to 2008. We separate measures of productivity change into various component parts to better understand the effect of technological advancement. Total factor productivity (TFP) includes all categories of productivity change, which can be decomposed into two components: 1) technological change (i.e., shifts in the production frontier) and 2) efficiency change (i.e., movement of inefficient production units relative to the frontier) Färe et al. (1994)

Production frontier analysis provides the Malmquist indexes (Malmquist, 1953; Caves; Christensen and Diewert, 1982), which can be used to quantify productivity change and can be decomposed into various constituents. Malmquist Total Factor Productivity is a specific output-based measure of TFP. It measures the TFP change between two data points by calculating the ratio of two associated distance functions (Caves; Christensen and Diewert, 1982) . A key advantage of the distance function approach is that it provides a convenient way to describe a multi-input, multi-output production technology without the need to specify functional forms or behavioural objectives, such as cost-minimization or profit-maximization.

The DEA method has been widely used to estimate the reciprocal of the Shephard (1970) input distance function. The reciprocal of this distance function serves as a measure of Farrell (1957) input efficiency and equals the proportional contraction in all inputs that can be feasibly accomplished given output, if the decision making unit (DMU) adopts best-practice methods. We link input efficiency indices across time in order to estimate the Malmquist productivity index. This index estimates the change in resource use over time that is attributable to efficiency change and technological change. Furthermore, we use the approach of Färe et all. (1997) and decompose technological change into an index of output-biased technological change, an index of input-biased technological change, and an index of the magnitude of technological change.

Holding outputs constant, the reciprocal of the input distance function gives the ratio of minimum inputs required to produce a given level of outputs to actual inputs employed, and serves as a measure of technical efficiency. Let $x^t = (x_1^t,...,x_N^t)$ represent a vector of *N* non-negative inputs in period *t* and let $y^t = (y_1^t,...,y_M^t)$ represent a vector of *M* non-negative outputs produced in period *t.* The input requirement set in period *t* represents the feasible input combinations that can produce outputs and is represented as

$$F^t(y) \quad = \quad \{x: \quad x \text{ can produce } y\}. \tag{1}$$

The isoquant for the input requirement set is defined as

$$ISOQ\ F^t(y) = \{x: \quad \frac{x}{\lambda} \notin F^t(y), \text{ for } \lambda > 1\}. \tag{2}$$

The Shephard input distance function is defined as

$$D_i^t(y,x) \quad = \quad \max\{\lambda: \quad \frac{x}{\lambda} \in F^t(y)\}. \tag{3}$$

The reciprocal of the Shephard input distance function equals the ratio of minimum inputs to actual inputs employed and serves as a measure of Farrell input technical efficiency. Efficient DMUs use inputs that are part of the $ISOQ\ F^t(y)$ and have $D_i^t(y,x) = 1$. Inefficient DMUs have $D_i^t(y,x) > 1$.

We assume that there are *k*=1,…,*K* DMUs. The DEA piece-wise linear constant returns to scale input requirement set takes the form:

$$F^t(y) = \{x: \sum_{k=1}^{K} z_k^t x_{kn}^t \le x_n, n = 1,...,N, \sum_{k=1}^{K} z_k^t y_{km}^t \ge y_m, m = 1,...,M, z_k^t \ge 0, k = 1,...,K\}. \tag{4}$$

The DEA input requirement set takes linear combinations of the observed inputs and outputs of the K DMUs using the K intensity variables, z_k^t, to construct a best-practice technology. The N+M inequality constraints associated with inputs and outputs imply that no less input can be used to produce no more output than a linear combination of observed inputs and outputs of the K DMUs. Constraining the K intensity variables to be non-negative allows for constant returns to scale.

To compute input technical efficiency for DMU "o" we solve the following linear programming problem:

$$
\begin{aligned}
1/D_i^t(y_o^t, x_o^t) = \max_{z,\lambda} \{\lambda^{-1} : \sum_{k=1}^{K} z_k^t x_{kn}^t \le \lambda^{-1} x_{on}^t,\ n = 1,\dots,N, \\
\sum_{k=1}^{K} z_k^t y_{km}^t \ge y_{om}^t, m = 1,\dots,M,\ z_k^t \ge 0, k = 1,\dots,K\}.
\end{aligned} \tag{5}
$$

Following Färe et al. (1997) , total factor productivity growth can be estimated using the Malmquist input-based index of total factor productivity growth. This index can be decomposed into separate indexes measuring efficiency change and technological change. Efficiency change measures "catching up" to the frontier isoquant, while technological change measures the shift in the frontier isoquant from one period to another. Dropping the subscript "o" the Malmquist input-based productivity index ($MALM$) takes the form

$$
MALM = \sqrt{\frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^t, x^t)} \times \frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^t(y^t, x^t)}}\ . \tag{6}
$$

Rearranging equation 6 yields

$$
MALM = \frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^t(y^t, x^t)} \times \sqrt{\frac{D_i^t(y^t, x^t)}{D_i^{t+1}(y^t, x^t)} \times \frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})}}\ , \tag{7}
$$

Where efficiency change (i.e., movements towards the production frontier) is represented by $EFFCH = \frac{D_i^{t+1}(y^{t+1}, x^{t+1})}{D_i^t(y^t, x^t)}$ and technological progress is represented by $TECH = \sqrt{\frac{D_i^t(y^t, x^t)}{D_i^{t+1}(y^t, x^t)} \times \frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})}}$. The TECH, EFFCH and other indexes are components of Malmquist TFP index. Values of *MALM*, *EFFCH*, or *TECH* greater than one indicate productivity growth in efficiency, and technological progress.

Färe et al. (1997) show how the technological change index can be further decomposed into the product of three separate indexes of output-biased technological change (*OBTECH*), input-biased technological change (*IBTECH*), and the magnitude of technological change (*MATECH*). These indexes take the form:

$$OBTECH = \sqrt{\frac{D_i^t(y^{t+1}, x^{t+1})}{D_i^{t+1}(y^{t+1}, x^{t+1})} \times \frac{D_i^{t+1}(y^t, x^{t+1})}{D_i^t(y^t, x^{t+1})}},$$
$$IBTECH = \sqrt{\frac{D_i^{t+1}(y^t, x^t)}{D_i^t(y^t, x^t)} \times \frac{D_i^t(y^t, x^{t+1})}{D_i^{t+1}(y^t, x^{t+1})}}, \tag{8}$$
$$\text{and } MATECH = \frac{D_i^t(y^t, x^t)}{D_i^{t+1}(y^t, x^t)},$$

where $TECH = OBTECH \times IBTECH \times MATECH$.

Figure 1 illustrates the construction of the input distance function and the components of the Malmquist input based productivity index. The input requirement set in period 1 includes all points to the northeast of the isoquant $F^1(y)$. We assume that technological progress occurs from period 1 to period 2 with the input requirement set in period 2 including all points to the northeast of the isoquant $F^2(y)$. The DMU for which we calculate efficiency and productivity change employs an input vector. In period 1 and in period 2 it employs input vector E. In both periods the DMU produces the same level of output (*y*), but uses excessive inputs and is technically inefficient. The input distance function in period 1 is $D_i^1(y,x^1)=\dfrac{0A}{0B}$ and in period 2 the input distance function is $D_i^2(y,x^2)=0E/0D$. The two inter-period input distance functions are calculated as $D_i^1(y,x^2)=\dfrac{0E}{0F}$ and $D_i^2(y,x^1)=\dfrac{0A}{0C}$. The Malmquist index is calculated as $MALM=\sqrt{\left(\dfrac{0E/0D}{0A/0C}\right)\times\left(\dfrac{0E/0F}{0A/0B}\right)}$. Efficiency change is calculated as $EFFCH=\dfrac{0E/0D}{0A/0B}$ and technological change is calculated as $TECH=\sqrt{\left(\dfrac{0A/0B}{0A/0C}\right)\times\left(\dfrac{0E/0F}{0E/0D}\right)}=\sqrt{\dfrac{0C}{0B}\times\dfrac{0D}{0F}}$.

<Figure 1 about here>

Figure 2 illustrates the construction of the index of input-biased technological change. The isoquant in period 1 is represented by $F^1(y)$. We again assume technological progress and draw two alternative isoquants represented by $F^{21}(y)$ and $F^{22}(y)$. Technological progress is Hicks' neutral if the MRS (marginal rate of substitution) between two inputs remains constant, holding the input mix constant. Hicks' neutral technological change is given by the parallel shift in the input requirement set to $F^{HN}(y)$. Technological progress is x_1-saving and x_2-using if the MRS between the two inputs increases, holding the input mix constant. Technological progress is x_1-using and x_2-saving if the MRS between the two inputs decreases, holding the input mix constant. The isoquant $F^{21}(y)$ represents an x_1-saving and x_2-using bias. The isoquant $F^{22}(y)$ represent an x_1-using and x_2-saving bias. From period 1 to period 2 the ratio of the two inputs changed such that $\left(\dfrac{x_1}{x_2}\right)^{t+1}>\left(\dfrac{x_1}{x_2}\right)^{t}$. If technological progress shifts the isoquant to $F^{21}(y)$ in period 2 the index of input bias is $IBTECH = \sqrt{\frac{0B}{0C} \times \frac{0D}{0F}} = \sqrt{\frac{0B/0C}{0F/0D}}$. Therefore, by construction we have $0B/0C > 0F/0D$ implying that *IBTECH*>1. Additionally, x_1-saving and x_2-using bias is indicated by $\left(\frac{x_1}{x_2}\right)^{t+1} > \left(\frac{x_1}{x_2}\right)^{t}$ and IBTECH>1. If instead technological progress shifted the isoquant to $L^{22}(y)$ in period 2, the index of input bias would be $IBTECH = \sqrt{\frac{0B}{0C} \times \frac{0G}{0F}} = \sqrt{\frac{0B/0C}{0F/0G}}$. In this case, we have $0B/0C < 0F/0G$ so that *IBTECH*<1 and the technology exhibits an x_1-using and x_2-saving bias.

<Figure 2 about here>

To investigate output-biased technological change, we represent the technology by the output possibility set: $P^t(x) = \{y: \quad x \text{ can produce } y\}$. The output possibility set is an alternative to the input requirement set for representing the technology since $x \in F^t(y)$ if and only if $y \in P^t(x)$. The Shephard output distance function takes the form:

$$D_o^t(x^t, y^t) = \min\{\theta: \quad (y/\theta) \in P^t(x)\}. \tag{9}$$

Under constant returns to scale the Shephard input distance function equals the reciprocal of the Shephard output distance function. Färe et al. (1985). That is, $D_i^t(y^t, x^t) = D_o^t(x^t, y^t)^{-1}$. Therefore, given constant returns to scale we can write the index of output-biased technological change as

$$OBTECH = \sqrt{\frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^{t+1}, y^{t+1})} \times \frac{D_o^t(x^{t+1}, y^t)}{D_o^{t+1}(x^{t+1}, y^t)}}. \tag{10}$$

Figure 3 illustrates the construction of the index of output-biased technological change assuming technological progress between period 1 and 2. The output possibility set in period 1 is given by $P^1(x)$. Technological progress with respect to outputs is Hicks' neutral if the marginal rate of transformation between two outputs is constant, holding the mix of outputs constant. Hicks' neutral technological progress is illustrated by the parallel shift of the production possibility set to $P^{HN}(x)$. Technological progress is biased in favour of output 1 (y_1-producing) if the marginal rate of transformation between outputs 1 and 2 increases, holding the mix of outputs constant. Technological progress is biased in favour of output 2 (y_2-producing), if the marginal rate of transformation between the two outputs is less in period 2 holding the output mix constant. The output possibility set given by $P^{21}(x)$ illustrates an y_1-producing output bias and the output possibility set given by $P^{22}(x)$ illustrates an y_2-producing output bias.

In period 1 a DMU is observed to produce an output vector represented by point A. The output distance function is calculated as $D_o^1(x,y^1)=\frac{0A}{0B}$. In period 2, the DMU is observed to produce output vector E. If the technology shifts to $P^{21}(x)$ in period 2, the output distance function in period 2 is $D_o^2(x,y^2)=\frac{0E}{0F}$ and the index of output-biased technological change is $OBTECH=\sqrt{\frac{0E/0F}{0E/0D}\times\frac{0A/0B}{0A/0C}}=\sqrt{\frac{0D/0F}{0B/0C}}>1$. Thus, since $\frac{y_1^{t+1}}{y_2^{t+1}}<\frac{y_1^t}{y_2^t}$ and *OBTECH*>1, the technology is y_1-producing, relative to y_2. If the technology shifted to $P^{22}(x)$ in period 2, the output distance function would be calculated as $D_o^2(x,y^2)=\frac{0E}{0G}$ and output-biased technological change is $OBTECH=\sqrt{\frac{0E/0G}{0E/0D}\times\frac{0A/0B}{0A/0C}}=\sqrt{\frac{0D/0G}{0B/0C}}<1$. Given that $\frac{y_1^{t+1}}{y_2^{t+1}}<\frac{y_1^t}{y_2^t}$ and *OBTECH*<1, the technology is y_2-producing.

<Figure 3 about here>

In the next section we calculate input technical efficiency and the components of the Malmquist input-based productivity index for Nigeria's energy plants and examine the bias in the use of inputs and production of outputs found in the technological change index.

5. Data and Results

5.1. Data

We compiled our dataset on nine Nigerian electricity plants from 2004 -2008 from several sources (Federal Ministry of Power and Steel, 2006; NEPA Annual Accounts 2001 – 2008, Okoro and Chikuni, 2007). In addition, private information was obtained from professionals in the industry in Nigeria. These stations are Kainji Hydro Power, Jebba Hydro Power, Shiroro Hydro Power, Afam Thermal Power, Delta Thermal Power, Egbin Thermal Power, Sapele Thermal Power, Ijora Thermal Power, and Oji Thermal Power. Output is defined as gross (MWh) and capacity (MW), Maloney et al. (1996). Inputs are employees (person), operational expenditure (million Naira), and assets (million Naira). This study measures and decomposes productivity change over time in Nigeria power sector. Then, the geometric mean of each station-level index is provided to show the annual average of the indices.

<Table 2 about here>

5.2 Total Factor Productivity

Table 2 and Table 3 present the results for annual average change in TFP, and changes in the TFP decomposed into the technological change and efficiency change. The rate of TFP is larger than 1.0077. The rate of the TFP, however, drops from 1.092 and 1.023 in 2004-2005 and

2005-2006, respectively, to 0.978 and 0.937 in 2006-2007 and 2007-2008, respectively. A similar trend appeared in TECH change with an average of 1.0178.

<Table 2 and 3 about here>

In contrast, the changes in EFFCH are always opposite direction indicating the TECH dominates EFFCH on average. The magnitude of the change in EFFCH, however, is increasing over study periods on average. That is, inefficient stations are catching up to the frontier. In summary, we find TECH is the main source of TFP growth in Nigeria though there are catching up effects (i.e., efficiency improvement) on average.

As a consequence of innovation, technological change occurs, That is, the adoption of new technologies by best-practice power plant. The technological change index is greater than one for all except three plants, which indicates technological improvement (TECH>1), while others experienced technological regress ($TECH<1$).

We note that the power plants that defined the frontier in from 2004 and 2008 experienced positive change in efficiency. The $EFFCH=1$ only for Egbin Thermal Power and Sapele Thermal Power. Most of the other plants experienced improvement in efficiency ($EFFCH>1$). The technical efficiency change is defined as the diffusion of best-practice technology in the management of the activity. This is attributed to investment planning, technical experience, and management and organization in the plants.

The results for further TFP decompositions are also presented in Table 2. By closely looking at the results, it can be seen that six out of the nine stations experienced positive productivity change over time. These include Jebba Hydro Power, Shiroro Hydro Power, Afam Thermal Power, Delta Thermal Power, Sapele Thermal Power, and Oji Thermal Power. For these plants, we find that the corresponding two indices for TECH and IBTECH have very similar results. These indicate input biased technological change contribute to increase in the production frontier and also TFP. The productivity measurement (i.e., MALM) in Table 3 also indicates, on average, a positive productivity growth of MALM is largely induced by IBTECH.

For the input bias index, most of the plant experienced technological improvement in the use of inputs used to produce the vector of outputs (IBTECH>1). However, for the magnitude of technological change, only Afam Thermal Power experienced input progress (*MATECH*>1). We note that Afam Thermal Power operated on the frontier isoquant (MALM>1), and experienced technological progress (TECH>1) driven by the magnitude of technological change. This result can be explained by the amount of investment implemented. Afam Thermal Power also had IBTECH>1 during the study period, indicating a bias in favour of employment relative to operation expenditure and assets. The results here illustrate that assumption of Hicks neutral technological change is not valid because of existence of biased technological change. Therefore, the traditional growth accounting method is not appropriate for analyzing changes in productivity for Nigeria's power sector.

All of the following plants experience positive technological change. Jebba Hydro Power Station is the station located in Kwara State down stream of the Kainji Hydro Power Station. Afam Thermal Power Station uses natural gas and is located on the outskirts of Port Harcourt in Rivers State. It started operation in 1965 when its 18 units were commissioned. Delta Thermal Power Station which began operation in 1966 uses natural gas and is located in Ughelli, Delta State. The 20 units were commissioned but EFFCH is less than one. Sapele Thermal Power Station is located in Ogorode, Delta State. It uses both steam and gas turbines. Oji Thermal Power Station is located on the Oji River, Oji, in Enugu State. Though presently non – functional, it is the only coal-powered station in the country. Furthermore, among the nine plants, Shiroro Hydro Power is the only plant showing negative change in IBTECH. Shiroro Hydro Power Station is located in Niger State on the Shiroro Gorge along the Kaduna River. It has four generating units. However, TECH, for this station, is less than one although EFFCH has a high level of 1.086. The existence of a deviation in TC and EC show differences subsist in plant difference. For example, Shiroro Hydro Power Station is highest on TC but third lowest in EC. The availability of new technology and resource availability, among others, are expected to be a basis of these differences. Among the three hydro power plants, Shiroro Hydro Power is the only one performing better than average of productivity. Proper account needs to be taken to reduce the dependence on hydro-electricity and encourage more use of coal and gas for power generation.

All other plants have TFP less than one. Kainji Hydro Power Station, with eight generating units commissioned, is located in Niger State; along the River Niger.It is the first Hydro Power Station in the country. However, its efficiency change is less than one. Egbin, the largest Thermal Power Station in the country, is located on the outskirts of Lagos State. . Finally, Ijora Thermal Power Station, located in central Lagos uses AGO fuel and has 3 units. The predicament of PHCN is better appreciated from the observation of the CEO of PHCN, that the company’s capacity to generate electricity is dependent on the level of the lakes that are only filled around October or November of every year (Labo, 2009). It is therefore crucial for PHCN to cope with the periodic low level of water at Kainji and other dams especially during the dry season. In contrast, OBTECH is close to one and there is very little change over time and over plants. That is, *OBTECH*=1 for seven out of nine plants, and therefore we can conclude no substitution happens.

6. Discussion and Conclusion

As seen previously, productivity increased on average in the period analysed. In table 2, we can see that technical efficiency change and technological change contribute positively to this result. However, there are some plants that experience a negative productivity change. Furthermore, the average output bias (obtech) is negative signifying that the plants are not using their capacity in a meaningful way. The average input bias (ibtech) is positive signifying that there is a tendency to use labour, which results in an average Malmquist bias (matech). Therefore the managerial implications of these results in the following policy prescrition: First, there is some homogeneity in the Nigerian electricity plants which display productivity improvement explained by technical efficiency change and technological change. Based on this result it is important for managers to anticipate future changes in technology. The risk is in the obsolescence of their plant. Managers who actively participate in the technology planning process will be able to identify new uses of technologies and manage them for improved competitive advantage. For examples, wind and solar energy are now becoming increasingly common, Barros and Sequeira (2011). Second, performance analysis should be undertaken on a yearly basis and those plants with lower than average productivity indexes, should adopt stringent managerial procedures to overcome it in next year. Finally, in a deregulated energy market the electricity production changes the most productive plants contribute more to social wellbeing than the least performing plants, justifying the adoption of an active regulatory framework to increase plant performance. Managers can also try to change the energy plants strategy in ways that will allow it to rise above the average. Examples of the way forward include the adoption of pro-active strategies that capitalize on the growth of new market segments, including international markets in the West African sub-region.

How can we explain the efficiency rankings? These are endogenous results of the model, which can be explained by location, managerial tradition and ownership. Other factors, such ethnic effects, which are not investigated in the present research, may explain part of the observed inefficiency.

In comparison with the previous literature in this area, our research overcomes the bias the restriction on the analysis of technological change which has been previously adopted the Luenberger indicator (Briec, Peypoch and Ratsimbanierana, 2011).

Therefore the general conclusion is that the Federal Government needs to take into account their proposals underlined in the National Development Plans in relation to the performance of the industry. Obviously, it is important to increase labour productivity by better utilizing the specialized skills including power plant engineers, system planners and specialists in the installation and maintenance of equipment. However, more importantly, it is crucial for Nigeria power plant to consider total factor productivity for their performance analysis. For the future implementation of the national energy policy, such as deregulation, for instance, there is need to take proper account of the comparative economies of utilizing the various alternative sources.

Further research is needed to confirm the present conclusions. Research linking spatial location and ethnic regions should be analysed.

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Table 1: Descriptive Statistics

Variables	Minimum	Maximum	Mean	Stand. dev.
Outputs				
Capacity (MW)	30	1320	632.12056	419.24886
Production (MWh)	21.3	880	315.6339	248.07064
Inputs				
Employees	60	650	364.38868	190.86239
Operational Expenditure (Million Naira)	143	1741	968.91291	527.67798
Assets (Million Naira)	1812905	26452532	14467791	7640480

Table 2. Average Technical Efficiency Change and Technological Change for the Nigeria's Energy Station: 2004-2008

	Energy Station	MALM	EFFCH	TECH	OBTECH	IBTECH	MATECH
1	Kainji Hydro Power	0.993458	0.993929	1.002510	1	1.044858	0.959543
2	Jebba Hydro Power	1.018954	1.002153	1.020389	0.999877	1.022046	0.999336
3	Shiroro Hydro Power	1.085077	1.086390	0.990363	1	0.988022	0.999250
4	Afam Thermal Power	1.004992	1.001063	1.008270	1	1.001515	1.006336
5	Delta Thermal Power	1.015771	0.995437	1.020002	1	1.056830	0.967747
6	Egbin Thermal Power	0.973571	1	0.973571	1	1.165780	0.838563
7	Sapele Thermal Power	1.008765	1	1.008765	1	1.046604	0.964370
8	Ijora Thermal Power	0.963352	1.032013	0.960516	1	1.032402	0.949178
9	Oji Thermal Power	1.005697	0.992814	1.017756	1	1.025863	0.992979
	Mean (arithmetic)	1.007738	1.011533	1.000238	0.999986	1.042658	0.964145
	Median	1.005697	1	1.008270	1	1.032402	0.967747
	Std. Dev	0.034507	0.030426	0.021309	0.000041	0.051076	0.051370

Notes

1. *MALM* = *EFFCH* x *TECH*

2. *TECH* = *OBTECH* x *IBTECH* x *MATECH*

Numbers may not multiply because of rounding error.

Table 3. Average Technical Efficiency Change and Technological Change for the Nigeria's Energy Station: 2004-2008 (Each Year)

Year	MALM	EFFCH	TECH	OBTECH	IBTECH	MATECH
2004	1.092055	0.971922	1.124074	1	1.067666	1.063828
2005	1.023098	0.99098	1.032064	1	1.017692	1.014205
2006	0.978398	1.078345	0.911838	1	1.024202	0.898526
2007	0.937398	1.004887	0.932976	0.999945	1.061071	0.880021

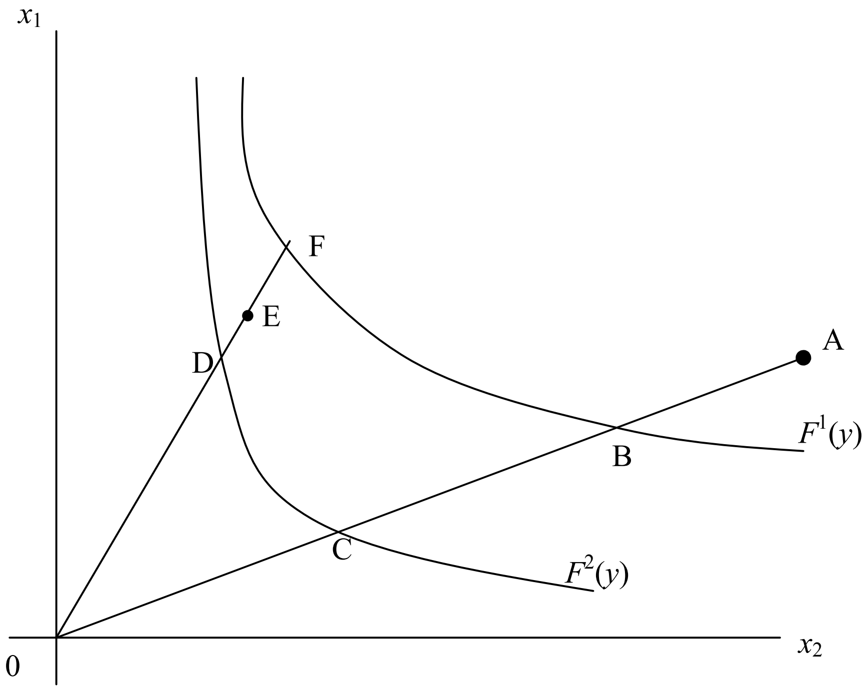

Figure 1. Input requirement sets and the input based productivity index.

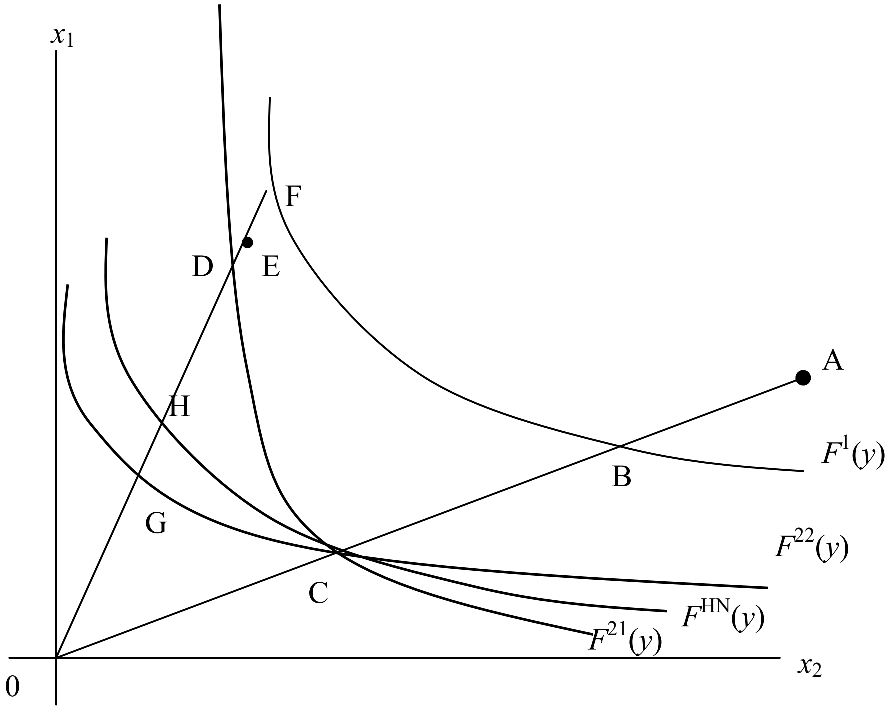

Figure 2. Input Requirement Sets (F(y)) and Input Biased Technological Change

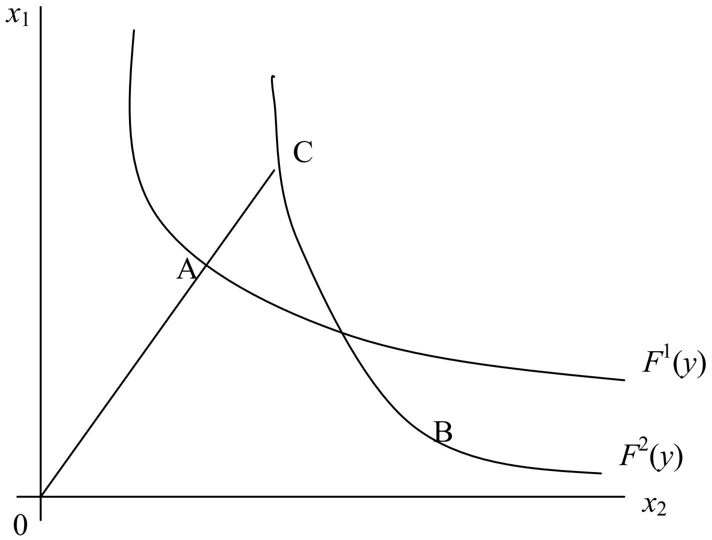

Figure 3. Illustration of Technological Regress for Frontier in Power Sector