British Journal of Arts and Social Sciences
ISSN: 2046-9578, Vol.6 No.2 (2012)

http://www.bjournal.co.uk/BJASS.aspx

Towards Appropriate Energy Mix In The Generation Of The Nigerian Electricity Industry

Abstract

One of the greatest obstacles to the development of the Nigerian economy is the generation and distribution of electricity. The small, medium and the large-scale enterprises in Nigeria are all adversely affected by erratic power supply. The lackluster performance of the manufacturing sector in recent times is partly attributable to this problem. It has prevented these enterprises from attaining optimum production levels. It has also usually damaged essential machinery resulting in production stoppages. In addition, the adverse effect on the standard of living of the citizenry, the inflow of genuine foreign investment and balance of payment are quite enormous. These are serious economic problems that must be solved if the Nigerian economy is to attain potential growth rate. However, several efforts have been made to ameliorate this deplorable state

In 1988, the National Electric Power Authority (NEPA) was partially commercialized, supported by an upward review in tariffs. As part of the restructuring effort of the power sector, the Electric Power Sector Reform Act 2005 was enacted. Consequently, the defunct National Electric Power Authority (NEPA) is now known as Power Holding Company of Nigeria (PHCN). The law paved the way for the unbundling of NEPA into the 18 companies – 6 generating companies, 1 transmission company and 11 distributing companies. The generating companies are made up of 2 hydro and 4 thermal (gas based) stations. Can this arrangement ensure efficient generation of electricity in Nigeria? In other words can Egbin, a gas based power station or Jebba, an hydro power station stay on its own and still be efficient in supplying uninterrupted electric power in Nigeria? The experience of former reformers, for instance, Ontario in 2002 and Ghana 2006 on the over reliance on a single technology (hydro) has underscored the necessity for Nigeria to ensure appropriate energy mix in the generation of electricity.

Basically, restructuring electricity market is usually an oligopolistic market and the modern theory of oligopoly is grounded almost entirely in the theory of games as popularized by Neumann and Morgenstern, (1944); Schotter and Schwodlauer, (1980) and Iwayemi, (2007). This study therefore, describes and analyzes some game theoretic oligopoly models currently discussed in literature. This derives from the need to enable us explain the strategic behaviour of the participants in a restructuring regime. In addition, the special features of electricity, in terms of non-storability of product, capacity constraints and the need to constantly balance demand and supply underscore the relevant of game theoretic models.

The central focus of this paper is on the determination of an appropriate energy mix in the generation of electricity in Nigeria following the enactment of Electric Power Sector Reform Act 2005. A partial

equilibrium model in the style of Cournot game is employed to explain the likely strategic behaviour among the generators. Consequently, the model is solved by considering secondary data for benchmark year 2002 as the basis for simulation. The simulation starts by employing Lerner index to characterize the behaviour of the major supplier of electricity as a monopoly and observes the performance of the industry as the number increases from one to n-number of firms in terms of price and output. Two scenarios are considered, single technology which is characterised as a firm using either hydro or thermal in the process of generating electricity and mixed technology showing a situation where a firm combines both hydro and thermal in the process of generating electricity. The major sources of data include the Corporate Annual Report and Account of NEPA (2002), the NEPA Generation Report 2002, the World Bank Discussion Paper 2002 and the World Development Indicator (2005). The numerical solution of the model requires a nor-linear equation solution algorithm. The study made use of General Algebraic Modeling System (GAMS).

A comparison of the two scenarios seems to suggest that a mixed technology is more efficient than the single technology being suggested by the Electric Power Reform Act 2005. This derives from the fact that with mixed technology, a firm has larger elbow to operate efficiently as substitution of hydro for gas, and vice versa in the process of production is possible. During the wet season for instance, hydro stations can be employed cheaply than thermal (gas based). While thermal can be used reasonably during dry season than to close or reduce scale of production. The results of the simulation showed higher output and lower price under mix technology compared with single technology scenario. Perhaps this result might be helpful for policy options in Nigeria under the ongoing restructuring of the power sector.

Introduction

One of the greatest obstacles to the development of the Nigerian economy is the generation and distribution of electricity. The small, medium and the large-scale enterprises in Nigeria are all adversely affected by erratic power supply. The lackluster performance of the manufacturing sector in recent times is partly attributable to this problem (Adejugbe, 2006). It has prevented these enterprises from attaining optimum production levels. It has also usually damaged essential machinery resulting in production stoppages. In addition, the adverse effect on the standard of living of the citizenry, the inflow of genuine foreign investment and balance of payment are quite enormous. These are serious economic problems that must be solved if the Nigerian economy is to attain potential growth rate. However, several efforts have been made to ameliorate this deplorable state

In 1988, the National Electric Power Authority (NEPA) was partially commercialized, supported by an upward review in tariffs. As part of the restructuring effort of the power sector, the Electric Power Sector Reform Act 2005 was enacted. Consequently, NEPA is now known as Power Holding Company of Nigeria (PHCN). The law paved the way for the unbundling of NEPA into the 18 companies – 6 generating companies, 1 transmission company and 11 distributing companies. The generating companies are made up of 2 hydro and 4 thermal (gas based) stations. Can this arrangement ensure efficient generation of electricity in Nigeria? In other words can Egbin, a gas based power station or Shiroro, a hydro power station stay on its own and still be efficient in supplying uninterrupted electric power in Nigeria? The experience of former reformers, for instance, Ontario in Canada in 2002 and Chana 2006 on the over reliance on a single technology (hydro) has underscored the necessity for Nigeria to ensure appropriate energy mix in the generation of electricity. The rest of this paper is structured as follows: In section 2 an attempt is made to discuss the evolution of the Nigerian Electricity Industry in Nigeria and international experience. Some empirical and theoretical expositions formed the bases of discussion in section 3. The methodology of the study is discussed in section 4, while the results are presented in section 5. Lastly, the conclusion

2 Structural Evolution of the Nigerian Electricity Industry and the International experience

An historical scrutiny of the electricity industry in Nigeria will reveal a movement from a fragmented ownership of generating plants to one of unified ownership and control by government fiat, involving virtually absolute monopoly. The on–going reform, which was introduced in 2005, was therefore a U-turn, or a policy reversal. Gross inefficiency of the industry, the heavy dependence on government treasury, rapid technological development in the industry and trends in the management of electricity industry in other countries are the major motivating factors for the reform.

Traditionally, electricity industry presents some features which make large scale production inevitable. A key feature of the electricity sector is the existence of scale economies in segments of generation, transmission, and distribution (Soto, 1998). Decreasing average costs are achieved through massive investments that are mostly irreversible (for example, generating plants, transmission lines, and distribution networks). A second characteristic is that electricity is largely a homogeneous good; the cost of storage is prohibitive, inventory cannot be profitably kept. The market must rely on equating supply and demand in every instance. A third feature is that demand and supply exhibit marked variability due to weather conditions in consumption. Consequently, there are important advantages derived from building interconnected systems and setting long-term contracts. These features suggest that the electricity industry should be structured to foster large firms, to permit scale economies and risk aversion. The consequence is that competition is jeopardized, and by implications efficiency may be adversely affected.

These technical realities appeared to have encouraged the horizontal integration of the various power stations in Nigeria to give birth to the Electricity Corporation of Nigeria (ECN) and ultimately the National Electric Power Authority. The economics of the power system in the 1970s in Nigeria implied that because of economies of scale in production, it was more economical to have fewer but bigger-sized plants than to maintain a geographical spread (Iwayemi, 1975; 1984). Based on the economies of scale argument in production of electricity, (Taiwo, 1982) compared the most efficient period between the ECN era and NEPA era. The result was inconclusive because of inadequate data. In 1940s, 1950s and 1960s major economies of scale in electricity generation in the UK came from the use of larger and lager generators: 30MW generating sets in 1948; 100MW sets in 1956; 200MW set in 1959; and 500MW set 1966. The 1970s and 1980s witnessed a decline in the size of generators occasioned by decline in demand for electricity and improvement in technology. The new method of realizing economies of scale was reduction in the number of power stations, each station having several generators. As a result, the average generating capacity of each station rose significantly, symbolising a different type of economy of scale. (Lipsey and Chrystal, 2005)

Furthermore, advancement in technology provided the impetus for the current reform programme of the federal government. In recent years, technological improvement in gas turbines and the developments of combined – cycle gas turbines have recast economies of scale in electricity industry reversing a 50-year trend towards large, centralised power stations (Bayless, 1994; Casten, 1995). For instance, combine-cycle gas turbines can be brought on line faster (within 2 years) and at more modest scale (50 -500 megawatts) than coal or nuclear plants (5-10 years and 1,000 megawatts). Aero – derivatives gas turbines can be efficient at scales as small as 10 megawatts (Balzhiser, 1996). Technological progress in the industry has thus paved the way for the entry of small and medium- scaled firms into the industry. These firms can be efficient and profitable. This shows that a smaller firm can still operate efficiently.

Besides technical considerations, the state has remained a central player in the industry for two other reasons, bordering on strategic factors. First, the industry commands enormous market influence not only because the service is a very essential one, but also because electricity cannot be stored and consequently, the consumer depends significantly on the supplier (Bernard, 1997). Second, the industry depends overwhelmingly on public assets such as rivers, land accessibility, and mineral or petroleum resources; therefore, it has far-reaching impact on the environment (Bradbrook, 1996). Theses reasons appear to justify the state participation in the Nigerian electricity industry particularly before the current reform. Even as a network utility, state participation is equally important under the reform programme, particularly in the transmission and distribution segments and policy regulations.

Economic factors provided another stimulus for government intervention in the industry. Largely propelled by the oil wealth of the earlier 1970s, coupled with the increase in demand for electricity, the federal government accorded high priority to the electricity sub-sector by developing several hydro-electricity plants and thermal plants, particularly during the 1970s. Apart from Kanji dam, which was commissioned in 1968 under the first development plan, there were major developments during the subsequent development plans. The thermal power stations were accelerated during the second development plans. For instance, with the expansion of the completion of Delta 11, the total capacity of the Delta power station rose from a mere 72MW in 1966 to 192MW during the second development plan (1970 – 1975). The Ogorode thermal station was commissioned in 1980 while the phase four of Afam power station was commissioned in 1982 raising the installed capacity to 427.5MW. The 578MW Jebba hydro – electric station and Egbin power station were commissioned in 1986 under the third national development plan. The Shiroro hydro-electric dam with 600MW capacity was commissioned in 1989.

Thereafter, the power sector witnessed a period of stagnation. For instance, there was no increase in the installed generation capacity between 1990 and 1999. Hence, in recent times, the industry has been unable to meet the electricity supply requirements for domestic, commercial and industrial purposes; and this has adversely affected the country's socio – economic development and consequently the need for a reform.

3 Some theoretical and Empirical Considerations

Theoretical economic models, such as perfect competition and monopoly models, are too general to be applied directly to the electricity industry since they do not take into account many fundamental aspects of actual electricity markets. Current developed models combine the technical characteristics of electricity based on operational models and the modeling of firms behaviours based on oligopoly competition theory. A survey of the most relevant models is presented in this section focusing on the technical characteristics they take into account, the economic model they use and the purpose they serve.

It is well recognized that, given the concentrated nature of the electricity market, oligopoly competition models are the most suitable models for analyzing electricity markets. The choice between Bertrand and Cournot competition represents the two major alternatives (Blake, 2003). Depending on the purpose of the model and the type of market, one approach might be more relevant than another. In general, and especially in period of high demand, it appears that the Cournot paradigm corresponds more closely to electricity markets (Borenstein and Bushnell, 1999). The use of Cournot competition is supported by the fact that electricity suppliers have limited capacity. In the Bertrand approach, any firm can capture the entire market by pricing below other competitors but, since electricity producers have increasing marginal costs and limited installed capacity, Bertrand's assumptions regarding behaviour appear less realistic (Hobbs, 1986). However, in some circumstances, for instance, periods of low demand, it has been argued that Bertrand model might be a relevant approach (Green and Newbery, 1992; Wolfram, 1999). Hence, the nature of demand and the level of capacity constraints are fundamental variables that need to be taken into account to choose between Cournot and Bertrand competition.

The third model for the analysis of imperfect competition is the supply function equilibrium model (SFE) in which firms compete with each other through the simultaneous choice of supply functions. Klemperer and Meyer (1989) developed SFE in order to model competition in the presence of demand uncertainty. The idea behind their model is that even if an oligopolist knows its competitors' output the presence of demand uncertainty implies that the oligopolist faces many possible demand profiles. Accordingly, management's decisions about size, structure, corporate values, and decision rules of the firm implicitly determine a supply function that identifies the outputs that the firm will sell at prices that the market will accept. Such a supply function provides the firm with flexibility in adapting to changing business conditions.

The SFE model is more intuitively appealing than the Bertrand and Cournot models because it allows for a strategy space in which competing firms choose entire supply functions. The strategies of the Bertrand and Cournot models are limited because firms choose either prices or quantities. Consistent with the Nash equilibrium solution concept that the three models share, each firm's choice of supply function occurs simultaneously. In general, SFE price equilibra are generally between the Bertrand and Cournot extremes. A further discussion of the models have been carried out elsewhere (see Isola, 2006). This study makes use of the Cournot model which is discussed as follows:

The problem facing the firm under Cournot oligopoly can be set up as follows. The pay-off function is given as the profit function Π stated as:

$$\Pi^i(q^i) = \sum \left(\sum p\, q^i - C^i(Q^i) \right) \quad \text{with} \quad Q^J = \sum q^i \qquad (1)$$

In equation (8), the first two terms in the square brackets are revenues from electricity sales to the unregulated market segments. By assumption, production costs are convex.

Each firm has to predict the behaviour of other firms in making its output decision, if all coincide simultaneously with what the rivals will do, the supply by each firm to maximize profit Π can be set up as a non-linear programming as follow:

$$\text{Max} \quad \Pi^J(q^j) = \sum \left(\sum p\, q^j - C^j(Q^j) \right)$$

$$\text{s.t.} \quad Q_t^j \le h_t \bar{Q}^j$$

$$Q^j = \sum q^j \qquad (2)$$

This results in the following first-order conditions for firm q^j :

$$\frac{\partial L^j}{\partial q^j} = p + \sum q^j \frac{\partial p}{\partial q^j} - \frac{\partial C^j}{\partial q^j} - g^j \le 0 \qquad q^j \frac{\partial L^j}{\partial q^j} = 0 \qquad (3)$$

$$\frac{\partial L^j}{\partial g_T^j} = h_T \bar{Q}^j - Q_T^j \ge 0 \qquad g^j \frac{\partial L^j}{\partial g^j} = 0 \qquad (4)$$

These are the traditional first-order conditions for profit maximization, i.e. marginal revenue equals marginal cost. Equation (3) is the reaction function of the firm j. Equation (3) can be rewritten as:

$$\frac{p(q) - MC}{p(q)} = \frac{1}{n\xi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where the price elasticity faced by the firm (n_i) is equal to $n\xi$. As a benchmark to compare the outcome of Cournot and Monopoly, a presentation of perfect market model, therefore becomes relevant.

4 Methodology

A partial equilibrium model in the style of Cournot game is employed to explain the likely strategic behaviour among the generators. Consequently, the model is solved by considering secondary data for benchmark year 2002 as the basis for simulation. The simulation starts by employing Lerner index to characterize the behaviour of the major supplier of electricity as a monopoly and observes the performance of the industry as the number increases from one to n-number of firms in terms of price and output. Two scenarios are considered, single technology which is characterised as a firm using either hydro or thermal in the process of generating electricity and mixed technology showing a situation where a firm combines both hydro and thermal in the process of generating electricity. The major sources of data include the Corporate Annual Report and Account of NEPA (2002), the NEPA Generation Report 2002, the World Bank Discussion

Paper 2002 and the World Development Indicator (2005). The numerical solution of the model requires a nor-linear equation solution algorithm. The study makes use of General Algebraic Modeling System (GAMS).

5 The result

First, we considered a single technology reflecting the present disposition of the Electric Power Sector Reform Act 2005. Under this case, there are six generating companies using either hydro or gas. The second scenario is a mixed technology where a firm combines both hydro and thermal (gas based). The base year solution and the various scenarios were obtained using GAMS.

In considering the single technology scenario, the model was initially run as a one person game. The GAMS solution replicated the baseline data for the year 2002, thus confirming the validity of the model for simulation. The result showed that as a monopoly, the price that cleared the market was N11.60 per kilo watt hour as against N7 per kilo watt hour ceiling price set by the government. This is an obvious signal of sub-optimal pricing. In addition, it was found that as the number of players increased, the price that cleared the market declined continuously up to the seventh firm. For instance, as a two-person game, the price that cleared the market for firm using hydro was N3.69 per kilo watt hour while for a firm employing thermal (gas based) it was N6.22 per kilo watt hour. By the time the number of firms increased to seven, the prices fell to N2.66 per kilo watt hour and N4.45 per kilo watt hour respectively for hydro and thermal (gas based) firms. Beyond seven firms, the model becomes infeasible as the difference between marginal cost and price becomes so small to permit entry of additional firm.

By the same token, as the number of operators increased, the composite output correspondingly increased. From the production output of 2,500MW as a monopoly, the composite output has steadily increased to 54,000MW following the entry of the seventh firm, using either hydro or gas.

The second scenario was carried out based on the assumption of a firm using both hydro and thermal (gas based) in the process of production. As a monopoly, the result of GAMS simulation replicated the initial baseline data thus validating the model for stimulation. Like the previous scenario, as the number of players increased, the price that cleared the market similarly declined, but this continued up to the twenty eighth firm. When the number of operators in the industry rose to two, that is, duopoly; the price that cleared the market fell to N5.22 per kilo watt hour reflecting about fifty per cent reduction. As the number of the players rose to twenty eight, the price that cleared the market fell considerably to N3.45 per kilo watt hour.

There result also showed that a positive relationship could be observed between number of firms and the composite output. The composite output was about 11,108MW with two players in the industry. As at the point the number of players rose to twenty eight, the composite output has reached almost 234,805MW. However, beyond this point, the model becomes infeasible.

As could be observed from above analysis, as the number of firm increases, there is also a corresponding increase in output; and a decline in price.

In order to convey a vivid picture of our analysis, charts 1 to 5 clearly illustrate the relationship between price, output and number of firms for single and mixed technology scenarios.

Chart 1: Single Technology Number of firms against Price(Nkwh)

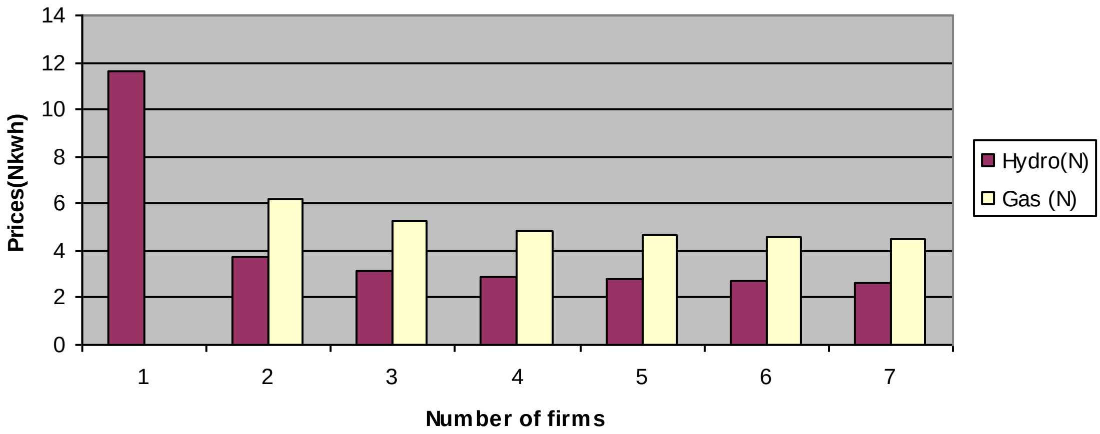


Chart 2: Single Technology Number of firms against composite output(mw)

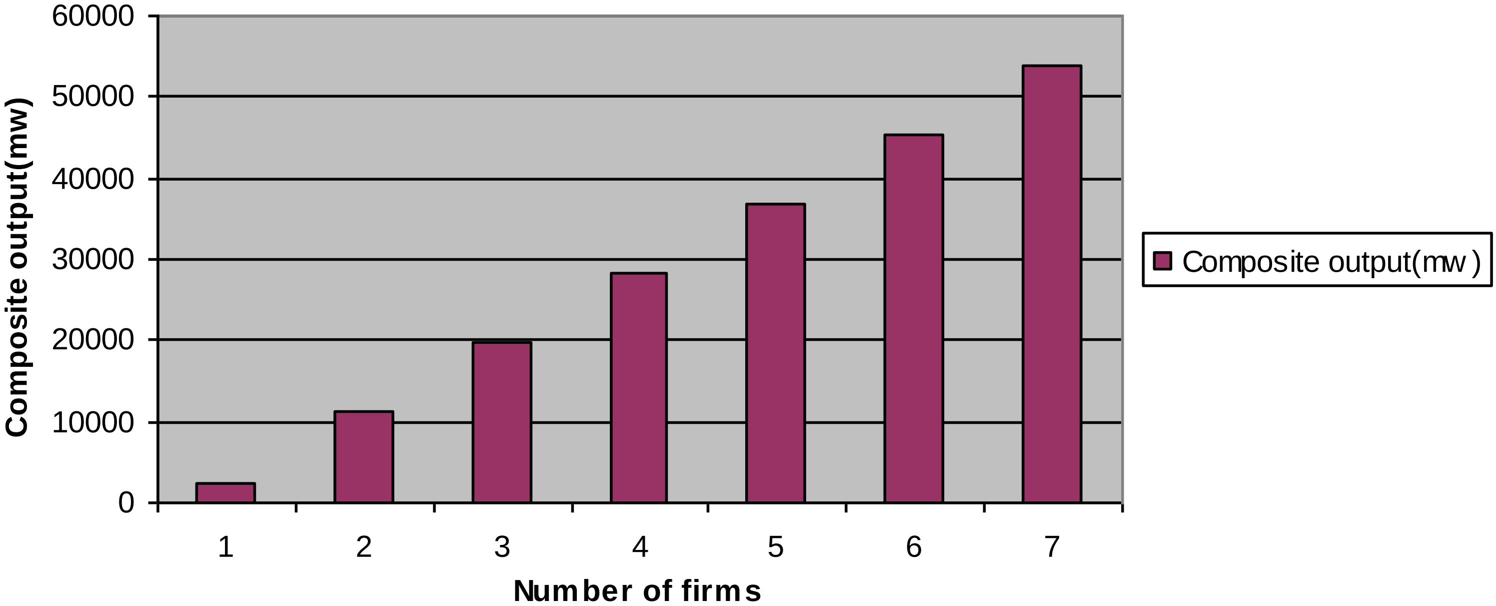


Chart 3: Single Technology **Number of firms against output of Hydro and Gas(mw)**

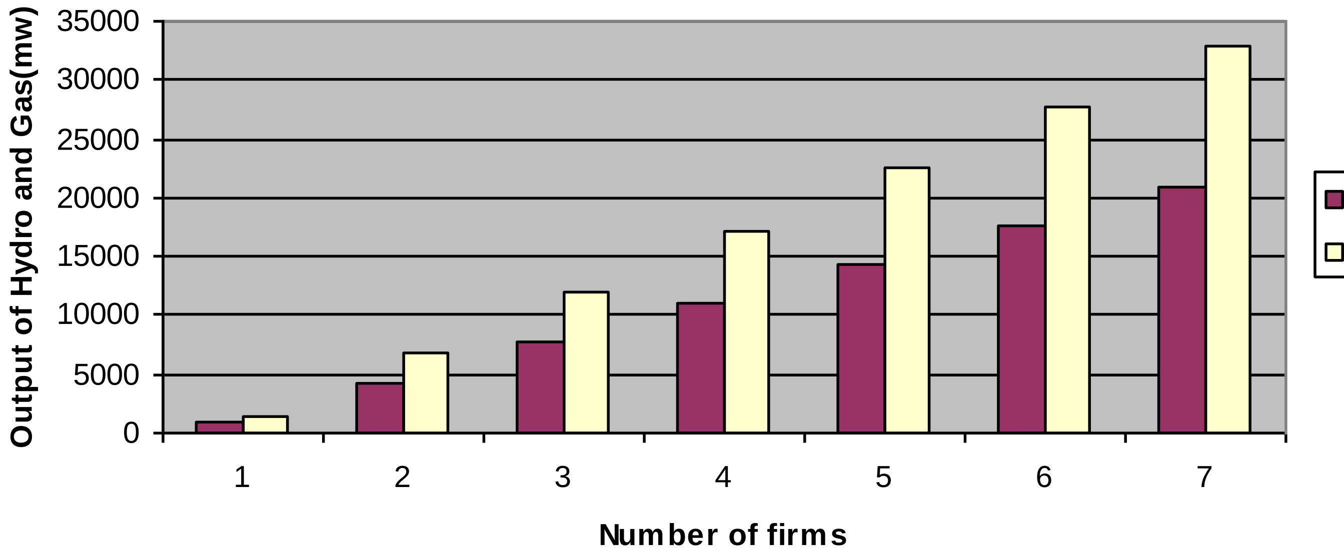


Chart 4: Mixed Technology **Number of Firms against price(Nkwh)**

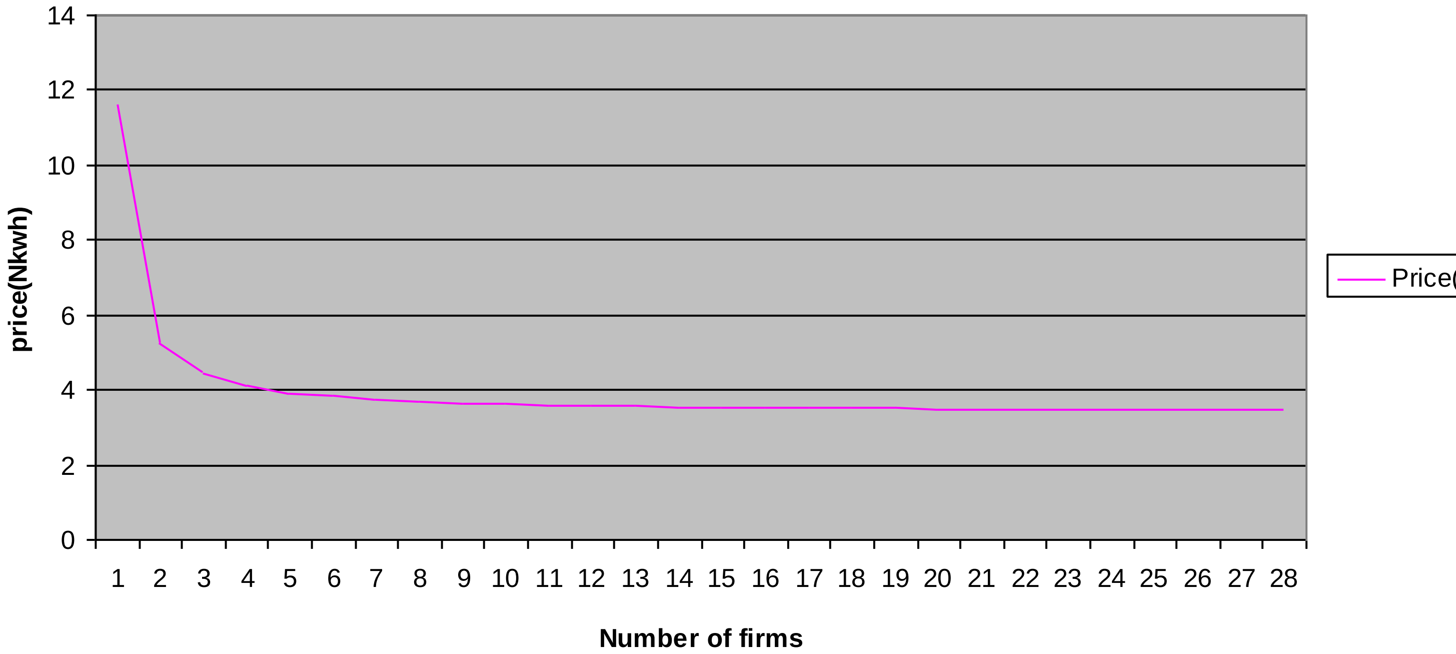
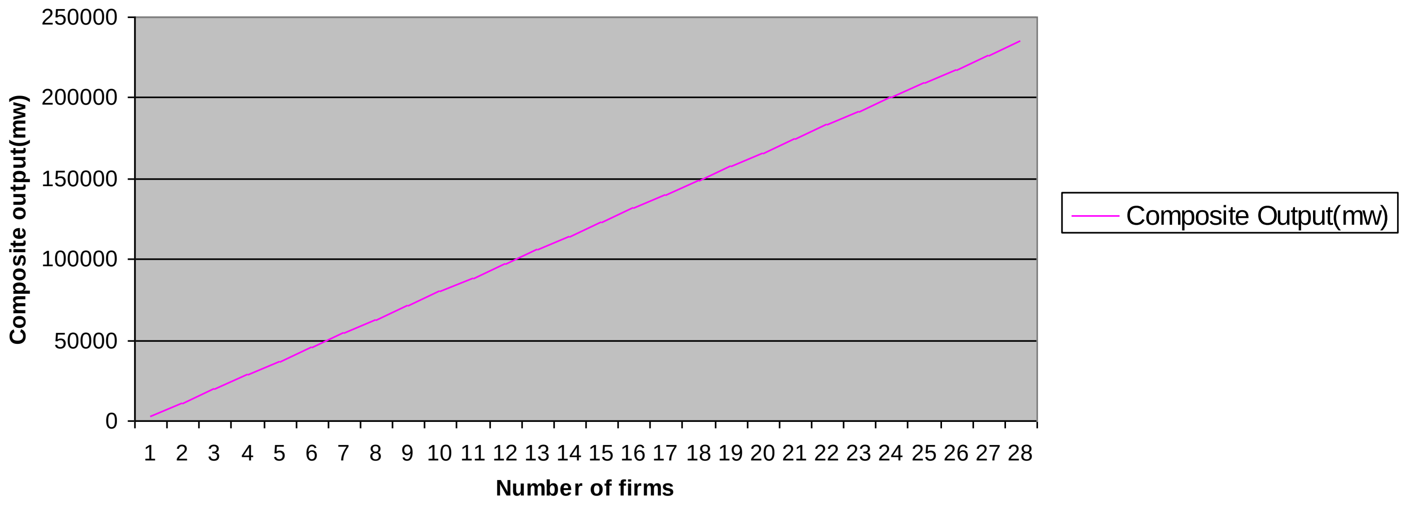


Chart 5:Mixed Technology Number of firms against Composite Output(mw)



A comparison of the two scenarios seems to suggest that a mixed technology is more efficient than the single technology being suggested by the Electric Power Reform Act 2005. This derives from the fact that with mixed technology, a firm has larger elbow to operate efficiently as substitution of hydro for gas, and vice versa in the process of production is possible. During the wet season for instance, hydro stations can be employed cheaply than thermal (gas based). While thermal can be used reasonably during dry season than close or reduce scale of production.

6. Conclusion

In conclusion, by using single technology optimum solution is attainable at the point when there are seven firms each operating hydro or thermal (gas based) in the process of producing electricity in Nigeria with a composite maximum production capacity of 54,000MW and an average wholesale price of N3.56 per kilo watt hour. Similarly, with mixed technology, optimum solution is attainable with twenty eight firms producing about 234,805MW and equilibrium price of N3.45 per kilo watt hour.

The study has shown that mixed technology is more efficient than single technology as increase in output and decline in price could be realised more rapidly at minimum cost. This is a pointer to the various Independent Power Producers that aside from gas based thermal plants; other sources like coal, solar, wind, hydro should be used as primary source of generating electricity in Nigeria. It is even worrisome to observe that almost all the generation expansion programmes of the federal government are thermal-gas based, except the Mambilla hydro station. According to Kupolokun (2006), the federal government has promised to complete 22 gas fired plants by 2010 to improve the nation’s electricity generating capacity. The constant vandalisation of gas pipe lines in the Niger Delta region, with the attendant shortage of gas supply to generate electricity has made the need to diversify very germane at this material time. According to Ibiyemi (2006), the generation of power supply in Nigeria suffered a major setback in the year 2006 as a result of a disruption of gas supplies to the Egbin station from the Niger Delta.

The experience of Ontario in Canada, which relied considerably much on hydro, has confirmed that weather condition plays a significant role in driving prices higher during the summer; reliance on hydro may, therefore, instigate importation of electricity at higher cost (Trebilcock, and Hrab, 2005). This has empirically demonstrated that single technology, is not the best option even in the advanced economy. The problem of over- reliance on single technology with the attendant energy crisis has compelled Ghana, in the recent times, to explore alternative sources of generating electricity from solar energy and biogas to support the Akosombo dam (Dike, 2006).

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