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# Modeling Crude Oil Production Outlook: A Case Study of the Oil and Gas Industry in Nigeria

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## Abstract

In the past four decades, Nigeria has made impact on the global oil and gas exploration and production industry. As one of the lead exporters of crude oil and natural gas in Africa, an oil production model which tracks oil exploitation process is imperative to facilitate good national economic planning and industry strategy. The impact of technological advancement, policy incentives and economics can be estimated from such petroleum production model.

This paper reviews historical crude oil production in Nigeria; develops an empirical model to describe and explain the competing factors underlying its production patterns. The production model equations are formulated; with a non-linear curve fitting method to estimate the Hubbert's model parameters for Nigeria. The model is used to forecast future production outlook for Nigeria.

At the currently estimated reserves of 37.2 billion barrels, the model results suggest that production rate should have peaked at 2.70 MMSTB/D in year 2010, and forecasted that the estimated ultimate recovery, at year end 2050, will be 65 billion barrels (~ cumulative production of 31.25 billion barrels up till 2012 plus current proven reserves of 37.2 billion barrels). It suggests that the nation had just produced 50% of its currently estimated proved reserves. The Hubbert model was accurate for forecasting US crude oil production, but its strict symmetry has received criticism from experts (Lynch, 2002) (Cavallow, 2004) (Iledare, 2000) who believe that the model underestimates future production which our experiences also confirm. We specified the nature of the errors which resulted in considerable deviations of production trends from the Hubbert model.

We suggest however, alternative model for analysing the exploitation process in Nigeria in the form of successive curve re-fitting of Hubbert model to new production data from time to time to check the effect of new technology, economics or policy implementation on Nigeria's crude oil production.

## Introduction

Nigeria started crude oil production in 1958 with a modest production rate of 5,100 BPD. As of January 1, 2013, Nigeria had reached production capacity of 2.5 MMBPD and 2,996 BSCF for oil and natural gas, respectively, contributing 2.8% and 1.3% of global daily oil and gas production (Figure 1). However, Nigeria has not been able to meet its vision 2010 target of 4.0MMBPD. The booked gas reserves indicate that Nigeria appears to have greater potential for gas production than oil, but the sector is limited by lack of infrastructure to monetize the gas that is being flared. For this major reason, Nigeria has not been able to meet the zero flaring targets since 2008. Currently, 15.78% of total daily produced gas is still being flared (NNPC MPI figures, October, 2013).

The industry has not fully maximized its potential, they are hindered by insecurity and supply disruptions caused by crude oil theft, pipeline vandalization, community unrest, militancy, OPEC production quota (political constrain) and Petroleum Industry Bill (PIB) issues. Nevertheless, with improvement in technology, knowledge of the basin, economics, and policy incentives, Nigeria's crude oil production has increased steadily (Figure 1).

This paper describes the dynamics of crude oil production in Nigeria over the past four decades. We then discuss production forecasting and demonstrate the different approaches to modeling oil supply; and use a non-linear least squares curve fitting method to determine the parameters of Hubbert's model. The historical data used for this study was provided by the Department of Petroleum Resources (DPR), which is an agency in the Ministry of Petroleum Resources, charged with the regulatory responsibility and the supervision of all the E&P operations under licenses and leases in the Nigeria oil and gas industry.

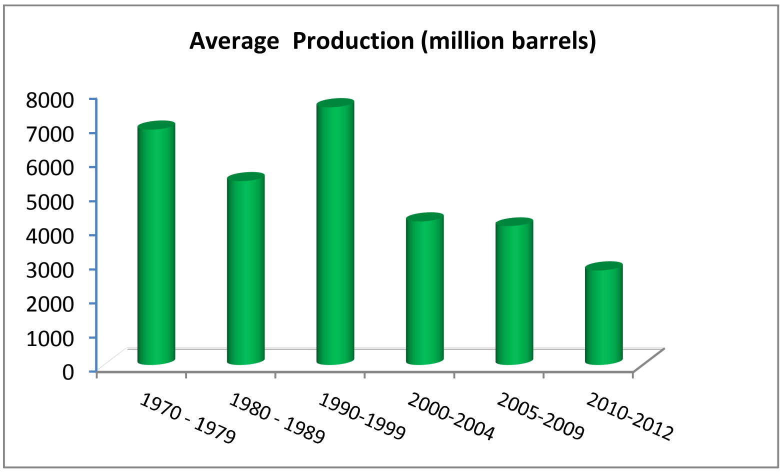


**Figure 1: Nigerian Average Annual Oil Production**

## Dynamics of Crude Oil Production in Nigeria

The summary of the major events that led to distinct trends in Nigerian oil production from 1970 till date is shown in **Table 1.0.** The advent of nine major IOCs marked an average growth of approximately 1 billion barrels per year in oil production between 1966 and 2005. During the years preceding 1966, the multinational companies who were involved in oil and gas exploration and production successfully completed 296 wells, out of the 352 appraisal and development wells drilled. Therefore, the gentle rise in oil production up till 1970 was as a result of the drilling efforts of the IOCs to boost production. Aggressive growth in oil production between 1970 and 1979 turn the Nigerian oil and gas industry into an attractive market for investors. The global crises in top oil producing nations added to the growth in Nigeria oil exports in the late 70s and by 1978 the nation's production has grown to 200% from previous decade. The global decline in crude oil supply between 1967 and 1979 led to significant oil price escalations, as OPEC recorded the rise of oil price from $3 per barrel to $12 by 1974 and $37 by 1980. Iledare (2007) appraised the impact of crude oil price changes on global Exploration and Production (E&P) industry and concludes that for every one dollar rise in real oil price, 29 new rigs will be engage worldwide. This hypothesis is evident in the Nigeria case and the rest of the OPEC members (Iledare and Pulsipher, 2000).

After 1980, global demand decreased and overproduction resulted to a glut on the world market, which caused six-year reductions in oil prices culminating with a 46% price drop in 1986. When real oil prices fell from $63.36 in 1981 to $17.95 in 1989, the global annual production fell by about 12.6 million barrels (Iledare, 2007). Further investigations show that Nigeria average annual production fell by 5.10 million barrels per dollar decline during this period.

1990-1999 saw major discoveries in the offshore locations of the Niger Delta, which caused oil productions to increase from 1.2 MMSTB/D to an average of 1.8MMSTB/D in 1999. In 1993, the government signed a Production Sharing Contract (PSC) with SNEPCO and Elf, and Odudu blend (offshore OML100) came on stream to boost oil supply. Production was maintained at about 2.2 MMSTB/D from 2000 to 2004 as forecasted in a study of rate of reserves depletion in the Nigeria's Niger Delta Basin (Iledare and Pulsipher 2000).

In 2005, the Nigerian government set a production target of 3MMSTB/D, but production hits barely 2.5MMSTB/D in 2005 and gradually decline to 2.2MMSTB/D in 2009. This shortfall was triggered by the suspension of SPDC activities in Ogoni land and about eighty-eight (88) oil wells were shut-in within that territory. Notwithstanding this setback, activities in the exploration and production industry increased as the industry completed 140 appraisal wells and 3,152 development wells between 2010 and 2012. This marked the highest drilling effort the industry had ever attended, but criminal activities of pipeline vandalism (figure 2), militancy in the Niger Delta creeks, and kidnapping of oil workers; sabotaged the expectation from this landmark. These criminal activities had shut down large volumes of Nigerian oil production.

**Table 1.0 Summary of the major events associated with distinctive trend.**

| Dates | Events |
|---|---|
| Before 1970 | Efforts of operating companies (IOCs) to boost production |
| 1970-1979 | High oil prices of the 70's |
| 1980-1989 | World oil glut of the 80's |
| 1990-1999 | Nigerian deep offshore major discoveries, Guaranteed notional margin of $2.00/bbl, policy incentives |
| 2000-2004 | Production from the large oil and gas fields in deep offshore |
| 2005-2008 | Niger Delta militancy, global economic recession |
| 2009-till date | Production contribution from marginal and indigenous operators |

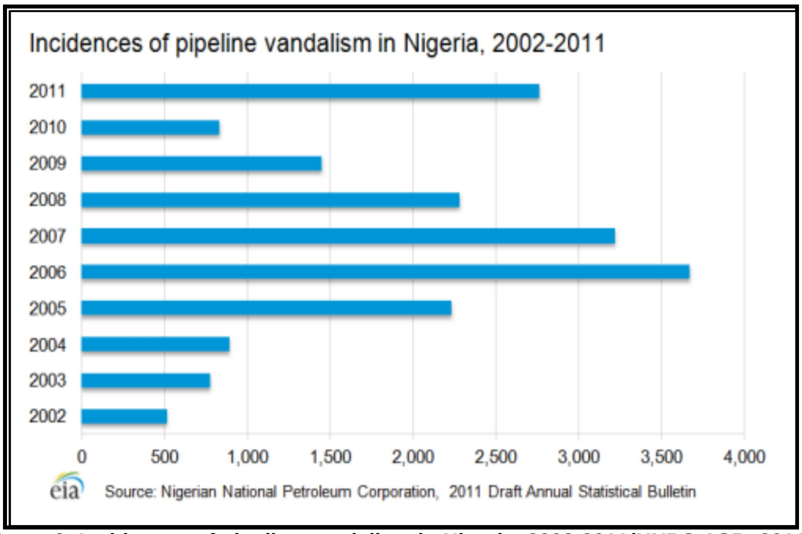


**Figure 2: Incidences of pipeline vandalism in Nigeria, 2002-2011(NNPC ASB, 2011)**

## Oil Production Modeling

There are several methods adopted in the industry to evaluate oil production trends and forecasts of ultimate oil reserves. Forecast can be based on geology and engineering, econometrics or formulating trends using curve fitting procedures (Al-Jarri, 1997). Among the models applied in the global forecasts of oil reserves are the Hubbert curve fitting model of 1956 and the application of Arps and Roberts (1958) decline model (Iledare, 1995). Others are Ryan (1973), Attanasi et al. (1981), Davis and Haubaugh (1981), Kaufmann (1986), and Cleveland and Kaufmann (1991). The geological models are based on the theory that everything in the world follows the natural process of rise-grow-mature-decay, whereas econometric models are based on the fact that supply is responsive to price. The first economic theory of exhaustible resource exploitation is developed by Harold Hotelling (1931). Hotelling's model, though simple, was based on several assumptions that are plainly contrary to known facts. Experts confirmed that his model is not "wrong"; it is simply not applicable for explaining the prices of exhaustible resources in the real world- Heal and Barrow (1980), Miller and Upton (1985), Halvorsen and Smith (1991), Watkins (1992), Adelman and Watkins (1995).

Hubbert model proved particularly popular in forecasting ultimate recoverable oil reserves in the US and elsewhere because of the availability of the data it required. However, the use of the Hubbert approach is subject to a number of shortcomings which is discussed subsequently.

## Applications of Hubbert's Model

The classical model which has been shown to be reliable was modeled by Hubbert's in 1956. The model predicted peak oil in the lower forty-eight states of America between 1965 and 1970 and the emergent decline that followed in USA oil production trend after 1970. Al-Jarri et al (1997) used Hubbert model to review historical crude oil production of 67 countries including Nigeria. Polynomial trends were established for countries that has substantially developed their reserves. However, for countries that have not optimized their reserves enough, the Hubbert's model did not fit the production data accurately, but indicates clear differences between model and observed production data. Some of these "unmatched" trends are caused by the economic, political actions and technology that had influenced the activities of oil production within the region under study.

## Model Formulation

The main assumptions around Hubbert's model are as shown below.

1) Oil production rate begins with zero.
2) Oil production will pass through a maximum and decline again to zero.
3) The area under the production rate-time curve equals the expected ultimate oil recovery within the study period.

A mathematical basis that relates oil production rate and the cumulative oil production developed by Hubbert is written as (Al-Jarri, 1997):

$$q(t) = \frac{dN_p}{dt} = aN_p + bN_p{}^2 \tag{1}$$

where $N_p$ is the cumulative oil production and a and b are multiplicative constants. The oil rate written as q, or $\frac{dN_p}{dt}$ = 0 at time t = 0, and at t→ ∞, $N_p$=$N_{p,u}$,. $N_{p,u}$, is the estimated ultimate recovery of crude oil. If we substitute the boundary conditions, equation (1) is then transformed to equation (2) below.

$$\frac{dNp}{\left(Np - \frac{N_p{}^2}{N_{p,u}}\right)} = a\,dt \tag{2}$$

Integrating Eq. 2 from t = $t_0$ to t→ ∞ yields the following logistic cumulative oil production curve as a function of time:

$$N_{p,l} = \frac{N_{p,u}}{(1 + N_o e^{-a(t-t_o)})} \tag{3}$$

where

$$N_o = \frac{N_{p,u} - N_{p,o}}{N_{p,o}} \tag{4}$$

$N_{p,o}$ is the cumulative oil production at an arbitrary time, $t_o$

Therefore, the crude oil production rate ( $\frac{dN_p}{dt}$ ) is obtain by differentiating Eq. 3 to give the following equation written below.

$$q(t) = N_{p,u} \frac{aN_o e^{-a(t-t_0)}}{(1 + N_o e^{-a(t-t_o)})^2} \tag{5}$$

Equation (5) is solved through a trial and error calculation. Guess values of the parameters a, $N_{p.u}$ and $N_o$ iteratively estimates the ultimate reserves and forecast the time to reach ultimate reserves.

## Application Procedure

The following procedures are applied to generate the cumulative distribution curve in the application of Hubbert production trend model.

(1) Given the annual production from the national data centre, daily rate and cumulative production are estimated.
(2) Arbitrary cumulative production and corresponding time is selected for $N_o$ and $t_o$.
(3) Equations (4) and (5) are coded to represent Hubbert model for daily rate and cumulative curve.
(4) The root mean square (RMS) is used to analyze the "goodness of fit".

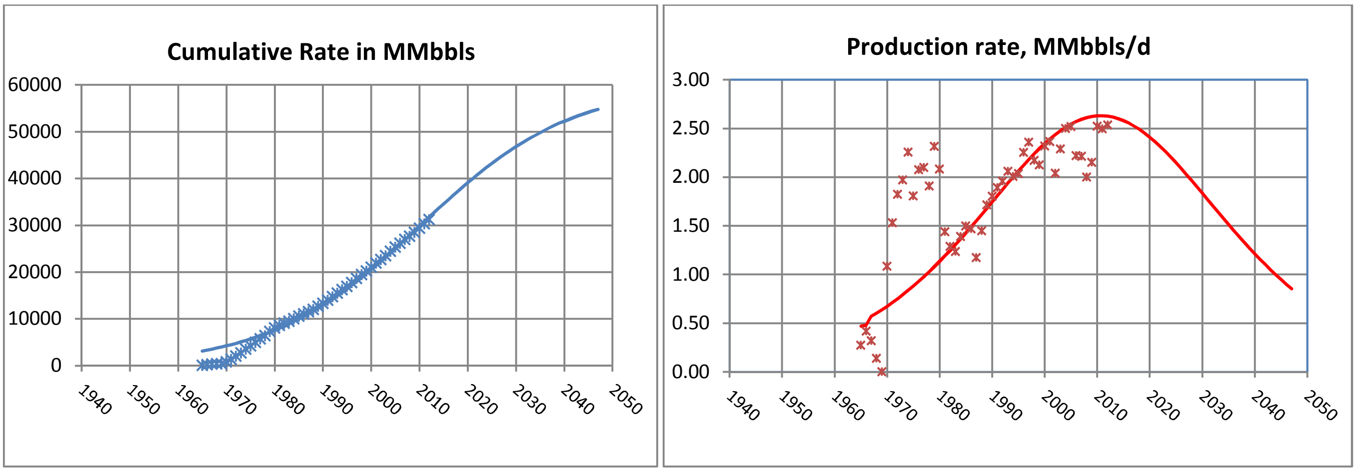


**Figure 3: Result of Nigeria Actual Production trend fitted with Hubbert Model.**

## Discussion of Results

Figure 3 shows the updated results of several iterations of the Hubbert model in the Nigeria case. The model forecasted an estimated ultimate oil recovery of 65 billion barrels at year end 2050, and should have peaked at 2.70 MMSTB/D in year 2010. The Hubbert model deviated from the production trend, thus, can be considered a “poor fit”. The corresponding rate curve shows that high residuals may be affected by external factors (political influence, fiscal regimes, technology) that have overridden the dominant factor (geology and engineering) in Hubert’s model.

Most OPEC and Non-OPEC third world crude oil production region is one which has not been heavily exploited to date (Lynch M.C. 2002), drilling density in this sedimentary basins is about 2% that of the US. Therefore, Hubbert’s model is not likely to be a very effective forecasting tool in regions where a large proportion of the ultimately recoverable reserves remain unexplored (Al-Jarri et al, 1997). Supply forecasts for these regions have been too low compare to the actual, and there was a consistent tendency to predict a peak within a few years, and a decline. As this peak was surpassed, the correction was not to remove the peak, but to raise it and move it out, always a few years into the future. (Feng Lianyong et al 2008, Al-Jarri et al 1997)

Though Hubbert’s assumptions translate to the basic principle that you can only produce proved reserves and not total resources, it is logical that estimated ultimate reserve should increase over time, as technological advances raise the proportion of oil that can be recovered economically in a field. Secondly, changes in effective pipeline networks, adequate production facilities and low costs of crude oil separations make it economical to produce fields which were ranked uneconomical. Thirdly, Nigeria is still in the era of easy oil, its unconventional resources (31 million barrels of oil in Tar Sand deposit in Ondo State) are untapped and EOR of several low pressure reservoirs are not yet harnessed. Actually, UR estimates do grow with time, according to the Nigeria’s published estimate in 1997, Iledare and Pulsipher 2000, and this paper (Table 2).

**Table 2: Nigeria peak oil forecast**

| Model year | Peak year | Peak production MMSTB/D | Estimated URR MMMSTB |
|---|---|---|---|
| Al-Jarri et al, 1997 | 1995 | 2.25 | 37.2 |
| Iledare et al, 2000 | - | 2.20 | 43.7 |
| This paper | 2010 | 2.70 | 65 |

By ignoring the effects of price and cost changes on exploration and development of new oil reserves- just as it was the case in the 1970s (see figure 3), Hubbert’s model, and other pure curve-fitting methods, may also exaggerate the rate of reserve depletion, and hence underestimate the energy resources that are ultimately recoverable. These techniques ignore important political constrains by OPEC prorationing, from 1980 to 2010.

The effects of technology advancements are not easy to measure using an aggregate model like Hubberts’. The impact of technology in expanding resources can be seen in UK case. In the British North Sea, many small fields that were discovered in the early days of exploration were not produced because they were not economic. Later, however, as other discoveries and other infrastructure were put in place in nearby locations and as new technologies such as subsea templates were developed, it became much cheaper to develop small fields and connect them to nearby pipelines and platforms. Thus, in 1995, approximately 16% of production in the UK came from fields that had been discovered before 1980, but not put into production until after 1990. This is so similar to the current situation in Nigeria where several projects that extensively add promote reserves addition may have been neglected by the Hubbert (Table 3). Some of the economic and political factors necessary for Hubbert's model to be applicable- just like in the US case are stable markets, political, policy and stable operational conditions-these elements are not guaranteed in the case of Nigeria.

## Conclusions

The use of Hubbert model as a production forecast tool was very helpful in the analysis of Nigerian historical production data. Though the model is data sensitive, frequent curve fitting is required as new data become available to check the effect of new technology or policy implementation such as infill drilling or enhanced oil recovery programs. This does not however prove that the model is inherently misspecified. At the currently estimated reserves of 37.2 billion barrels, the model results suggest that production rate should have peaked at 2.70 MMSTB/D in year 2010, and forecasted that the estimated ultimate recovery, at year end 2050, will be 65 billion barrels (~ cumulative production of 31.253 billion barrels up till 2012 plus current proven reserves of 37.2 billion barrels). This suggests that the nation has just produced 50% of its currently estimated proved reserves. We think this estimate is low for a country like Nigeria that its basin has not been heavily exploited.

Although the industry is faced with some challenges lately, yet, the future is bright with a lot of untapped potentials. Of course, we can recommend the use of this model in monitoring the past, present and short term production forecast but it's certainly not reliable for long future forecast. This is because of industry dynamics with other factors (geologic and operational uncertainties) that affect both the reliability and accuracy of production forecasts. Crude oil supply is closely linked to reserve size, technology and fiscal/policy incentives, and with several new offshore projects scheduled to come online (see table 3), Nigeria's oil production will continue to increase in the medium-term, but the timing of these startups will depend heavily on a much-debated Petroleum Industry Bill in Nigeria and the impact changes in fiscal/regulatory terms will have on the oil industry.

**Table 3: Nigeria's expected near term capacity additions (OPEC 2011)**

| Country | Project / Field Name | Operator | Est. Year Onstream | Est. Gross addition (kb/d) | Type of Liquid |
|---|---|---|---|---|---|
| Nigeria | Satellite Projects | Esso (EEPNL) | 2011 | | CRUDE |
| Nigeria | Usan Field Development | Total E&P Nigeria Ltd | 2012 | 180 | CRUDE |
| Nigeria | Ofon Phase 2 Field Development | Total E&P Nigeria Ltd | 2012 | | CRUDE |
| Nigeria | Nkarika | Elf Petroleum Nigeria Ltd | 2012 | | CRUDE |
| Nigeria | Egina Field Development | Total E&P Nigeria Ltd | 2014 | 200 | CRUDE |
| Nigeria | Bonga Northwest Field Development | Shell Nigeria E&P Co Ltd | 2014 | 50 | CRUDE |
| Nigeria | Bosi Field Development | Esso (EEPNL) | 2014 | 140 | CRUDE |
| Nigeria | Uge Field Development | Esso (EEPNL) | 2014 | 85 | CRUDE |
| Nigeria | Erha North Phase 2 Field Development | Esso (EEPNL) | 2014 | 50 | CRUDE |
| Nigeria | Bonga Southwest/Aparo Field Dev. | Shell Nigeria E&P Co Ltd | 2016 | 200 | CRUDE |
| Nigeria | Bonga North Field Development | Shell Nigeria E&P Co Ltd | 2016 | 100 | CRUDE |
| Nigeria | Bolia Chota Field Development | Shell Nigeria E&P Co Ltd | | | CRUDE |
| Nigeria | Nsiko Field Development | STARDEEP | | 100 | CRUDE |
| Nigeria | Nwadoro/Hilah Field Development | STATOIL/HYDRO | | | CRUDE |
| Nigeria | Gbara Ubie | Shell Nigeria E&P Co Ltd | | | CRUDE |

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Any opinions, findings, conclusions and recommendations expressed in this paper are those of the authors and do not reflect the views of their respective institutions.

## Nomenclature

DPR = Department of Petroleum Resources
MMMSTB = Billion Stock Tank Barrels
MMSTB = Million Stock Tank Barrels
BPD = Barrels Per Day
BSCF = Billion Standard Cubic Feet
PIB = Petroleum Industry Bill

NNPC = Nigerian National Petroleum Corporation
MPI = Monthly Petroleum Information
OML = Oil Minning License

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