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Original Research Article

Application of auto-regressive time series model to marginal oil field production in Nigeria

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ABSTRACT

Some concern has been expressed over the continuous low production from Marginal oil field. This production problem has been ascribed to multitude of hindrances occasioned by the nature of earth formation in the zone. Attempts to ascertain the character or complexion of such problems have often eluded researchers and operators of the field. This study adopts the use of auto-regressive time series model to find out the root cause or the mechanism that generate high output or low output in marginal field. The correlogram that captures the memory of the mechanism that generated the output process was established. And by judiciously picking and choosing the right lags from the correlogram, model that replicates the production process mechanism was also established. The result obtained shows that there is a close tracking of the forecast with the actual. Evidently, the Mean absolute percentage error (MAPE) obtained is 5.07% showing that the errors in forecast are marginal suggesting that the forecast is robust if not sure-fire.

Keywords: Auto-regression; Forecast; Marginal field; Oilfield; Time series

1. Introduction

Marginal field often have low crude oil production. This production problem has been ascribed to multitude of hindrances occasioned by the nature of earth formation in the zone. Attempts to ascertain the character or complexion of such problems have often eluded researchers and operators of the field. The country in which the marginal field is located tends to show more concern about factors that hinder continuous production from these marginal fields. For economic reasons, they tend to research the mechanics of the cause of low yield from marginal fields. It is therefore important that a research of this nature be conducted. Accordingly, many researches have been conducted to find out why yields in marginal fields are marginal. The proposed solution to tracing the mechanics of low production centers on the application of auto-regressive model. It uses the correlation between adjacent observations in a time-series to find out the root cause or the mechanism that generate high output or low output as the case may be. It starts by having an outlay of possible lags giving the spread or length of the time series data and by using a special tool called auto-correlation function r_k, given by;

$$r_k = \frac{\sum_{t=1}^{T-K}(y_t - \bar{y})(y_{t+k} - \bar{y})}{(y_t - \bar{y})^2} \quad (1)$$

With the auto-correlation function r_k correlogram that captures the memory of the mechanism that generated the output process can be established. This correlogram can be referred to as a statistical black box, comparable to the black box that records flight's incidents. And by judiciously picking and choosing the right lags from the correlogram, model that would replicate the production process mechanism can also be established. If the choice of these lags is done with sagacity, a robust or sure-fire model that acts like the original production process mechanism which generated the data will be re-generated. This model even acts better than artificial intelligence.

Research work on marginal field exploration dates back to early 1950s when Shell Petroleum Development Company (SPDC) started oil exploration in the Niger Delta of Nigeria and continues up to 1970s. Some of the researchers reported that there were many wild-cats well that were explored. Some of them yielded marginal well output and therefore classified as marginal fields. Notable among such papers are: [1-4]. Oil exploration also continue when majority of the explorations snowballed which contributed to oil boom of that era. See for example, [5-8]. Similar studies include: [9-11].

Contemporary researches on marginal field started gaining importance when the International Oil Companies (IOCs) started showing disinterest in this fields and Nigerian investors and venture capitalist that didn't have the stock of capitals the IOC yields showed renewed interest in the field. One outstanding fact about their discovery is that the marginal fields are replete with high risk and therefore they try to study the risk return profile to evaluate when it is desirable to invest. Research studies such as [12-15] evaluated some of the risks. Others include: [16-21]. A number of studies have been conducted also on the technological [22-25] and economic factors [26-30], affecting oil and gas field development across the globe and Nigeria in specific. The overview of the emergence of marginal oil fields in Nigeria and their contribution to the country's oil production was considered by [31] while [32] examined the controversy surrounding the development of marginal oilfields in Nigeria as well as [33] who assessed the critical success factors of marginal oil field development in Niger Delta region of Nigeria. The foregoing sample review revealed that there is a balance of literature on marginal oil field production but a dearth on the use of auto-regressive model to forecast yield from the representative well of the marginal fields. The aim of this study therefore is to use auto-regressive model to describe the mechanisms that tend to generate yields in marginal field production. Such knowledge could characterize the nature and complexion of production in marginal field.

2. Methodology

This is an applied research involving the collection of 68-day daily production data from a marginal oil field in the Niger Delta. In other to replicate or describe the mechanism that gave rise to this production, the time-series obtain was analyze with auto-regressive model described in equation 1. Autocorrelation functions r_k were computed using lags developed from the time-series. Following this, a correlogram, which as earlier said, is like a black box detailing the incidents of the production process was obtained. Influential lags were accordingly used to develop auto-regressive model and the set of subsequent normal equations were solved by MATLAB software R2013a. The auto-regressive model that emerged was very simple in form and structure. A set of errors arising from the difference between actual and predicted were used as a check for model adequacy. The set of normal equations developed for this study is given below:

$$
\begin{aligned}
\sum y_t &= n\beta_0 + \beta_1\sum x_1 + \beta_2\sum x_2 + \beta_3\sum x_3 + \beta_4\sum x_4 + \beta_5\sum x_5 + \ldots + \beta_8\sum x_8 + \beta_9\sum x_9 + \beta_{10}\sum x_{10} \\
\sum x_1 y_t &= \beta_0\sum x_1 + \beta_1\sum x_1^2 + \beta_2\sum x_1x_2 + \beta_3\sum x_1x_3 + \beta_4\sum x_1x_4 + \ldots + \beta_9\sum x_1x_9 + \beta_{10}\sum x_1x_{10} \\
\sum x_2 y_t &= \beta_0\sum x_2 + \beta_1\sum x_1x_2 + \beta_2\sum x_2^2 + \beta_3\sum x_2x_3 + \beta_4\sum x_2x_4 + \ldots + \beta_9\sum x_2x_9 + \beta_{10}\sum x_2x_{10} \\
\sum x_3 y_t &= \beta_0\sum x_3 + \beta_1\sum x_1x_3 + \beta_2\sum x_2x_3 + \beta_3\sum x_3^3 + \beta_4\sum x_3x_4 + \ldots + \beta_9\sum x_3x_9 + \beta_{10}\sum x_3x_{10} \\
\sum x_4 y_t &= \beta_0\sum x_4 + \beta_1\sum x_1x_4 + \beta_2\sum x_2x_4 + \beta_3\sum x_3x_4 + \beta_4\sum x_4^4 + \ldots + \beta_9\sum x_4x_9 + \beta_{10}\sum x_4x_{10} \\
\sum x_5 y_t &= \beta_0\sum x_5 + \beta_1\sum x_1x_5 + \beta_2\sum x_2x_5 + \beta_3\sum x_3x_5 + \beta_4\sum x_4x_5 + \ldots + \beta_9\sum x_5x_9 + \beta_{10}\sum x_5x_{10} \\
\sum x_6 y_t &= \beta_0\sum x_6 + \beta_1\sum x_1x_6 + \beta_2\sum x_2x_6 + \beta_3\sum x_3x_6 + \beta_4\sum x_4x_6 + \ldots + \beta_9\sum x_6x_9 + \beta_{10}\sum x_6x_{10} \\
\sum x_7 y_t &= \beta_0\sum x_7 + \beta_1\sum x_1x_7 + \beta_2\sum x_2x_7 + \beta_3\sum x_3x_7 + \beta_4\sum x_4x_7 + \ldots + \beta_9\sum x_7x_9 + \beta_{10}\sum x_7x_{10} \\
\sum x_8 y_t &= \beta_0\sum x_8 + \beta_1\sum x_1x_8 + \beta_2\sum x_2x_8 + \beta_3\sum x_3x_8 + \beta_4\sum x_4x_8 + \ldots + \beta_9\sum x_8x_9 + \beta_{10}\sum x_8x_{10} \\
\sum x_9 y_t &= \beta_0\sum x_9 + \beta_1\sum x_1x_9 + \beta_2\sum x_2x_9 + \beta_3\sum x_3x_9 + \beta_4\sum x_4x_9 + \ldots + \beta_9\sum x_9^2 + \beta_{10}\sum x_9x_{10} \\
\sum x_{10} y_t &= \beta_0\sum x_{10} + \beta_1\sum x_1x_{10} + \beta_2\sum x_2x_{10} + \beta_3\sum x_3x_{10} + \beta_4\sum x_4x_{10} + \ldots + \beta_9\sum x_9x_{10} + \beta_{10}\sum x_{10}^2
\end{aligned} \quad (2)
$$

Substituting the respective values of the parameters in equation (2) we have equation 3:

$$
\begin{aligned}
188771 &= 68\beta_0 + 186017\beta_1 + 183252\beta_2 + 180487\beta_3 + \ldots + 65765\beta_{10} \\
516768118 &= 186017\beta_0 + 517374151\beta_1 + 509153308\beta_2 + \ldots + 177816120\beta_{10} \\
508465718 &= 183252\beta_0 + 509153308\beta_1 + 509728926\beta_2 + \ldots + 177616939\beta_{10} \\
&\ldots\ldots \\
&\ldots\ldots \\
&\ldots\ldots \\
178068121 &= 65765\beta_0 + 177816120\beta_1 + 177616939\beta_2 + \ldots + 188203957\beta_{10}
\end{aligned} \quad (3)
$$

This set of normal equations in beta (β) had its coefficients extracted to form a coefficient or adjoint matrix that was solved with Matlab software R2013a. Table 1 depicts the correlation coefficients obtained from the Matlab solution.

Table 1. Correlation coefficients

Correlation Coefficient	Correlation Coefficient Value
β_0	2792.6
β_1	0.1000
β_2	-0.0000
β_3	0.0000
β_4	-0.1000
β_5	0.1000
β_6	-0.0000
β_7	-0.0000
β_8	-0.1000
β_9	0.0000
β_{10}	0.0000

The resulting autoregressive model is given by

$$\hat{y}_t = \beta_0 + \beta_1 y_{t-1} + \beta_2 y_{t-2} + \beta_3 y_{t-3} + \beta_4 y_{t-4} + \beta_5 y_{t-5} + \beta_6 y_{t-6} + \beta_7 y_{t-9} + \beta_8 y_{t-35} + \beta_9 y_{t-36} + \beta_{10} y_{t-45} \quad (4)$$

Where 1, 2, 3, 4, 5, 6, 9, 35, 36, 45 are the most influential lags selected from the correlogram as outlined in Figure 1.

Substituting the respective correlation coefficients

$\beta_0,\ \beta_1,\ \beta_2,\ \beta_4, \beta_5 + ... + \beta_9, \beta_{10}$ obtained into equation (4) yields model prediction given as

$$\hat{y}_t = 2792.6 + 0.1y_{t-1} - 0.1y_{t-4} + 0.1y_{t-5} - 0.1y_{t-35} \quad (5)$$

Where $\beta_2, \beta_3, \beta_6, \beta_7, \beta_9, \beta_{10} = 0$

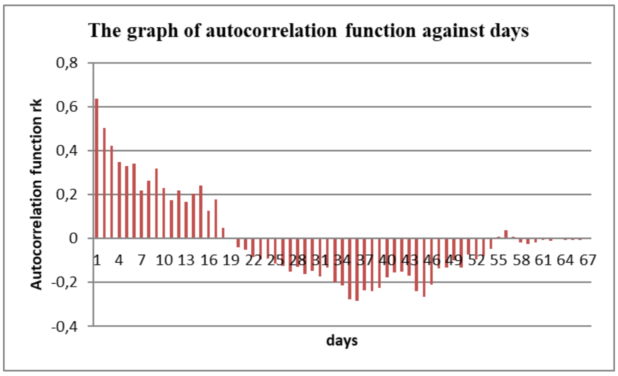

Fig. 1. Graph of auto-correlation function against days

3. Results and Discussion

Table 2 shows the forecast along with the actual data and the associated errors.

If we eyeball the forecast against the actual as well as the residuals, it will be seen that there is a close tracking of the forecast with the actual as shown in Figure 2.

Figure 2 depicts the chart of the daily oil well production data forecast tracking the actual data.

Evidently, the errors are marginal suggesting that the forecast is robust if not sure-fire. As expected all forecast are always imprecise. The mean absolute percentage error (MAPE) is 5.07% showing that the error in forecast is marginal. Again out of sample forecast was conducted for 5days; the associated errors are shown below:

Table 2. In-sample forecast and associated errors

t	y_t	$\hat{y}_t$	e_t	t	y_t	$\hat{y}_t$	e_t	t	y_t	$\hat{y}_t$	e_t
1	2851	2792.6	58.4	**22**	2756	3094.9	-338.9	**43**	2765	2774.6	-9.6
2	2958	3077.7	-119.7	**23**	2735	3060.2	-325.2	**44**	2667	2775.7	-108.7
3	2918	3088.4	-170.4	**24**	2634	3069.2	-435.2	**45**	2656	2756.5	-100.5
4	2897	3084.4	-187.4	**25**	2963	3054	-91	**46**	2676	2766.2	-90.2
5	2765	2797.2	-32.2	**26**	2867	3096.7	-229.7	**47**	2656	2779.9	-123.9
6	2975	3058.4	-83.4	**27**	2846	3081.4	-235.4	**48**	2598	2789.5	-191.5
7	2873	3094.1	-221.1	**28**	2954	3087.3	-133.3	**49**	2676	2774.5	-98.5
8	2943	3082	-139	**29**	2903	3055.1	-152.1	**50**	2687	2778.8	-91.8
9	2856	3100.1	-244.1	**30**	2845	3092.5	-247.5	**51**	2675	2763.8	-88.8
10	2934	3057.2	-123.2	**31**	2945	3079.2	-134.2	**52**	2553	2770.5	-217.5
11	2985	3096.2	-111.2	**32**	2770	3076.3	-306.3	**53**	2654	2763.6	-109.6
12	2743	3084.1	-341.1	**33**	2705	3074.7	-369.7	**54**	2564	2772.4	-208.4
13	2785	3075.6	-290.6	**34**	2765	3068.9	-303.9	**55**	2564	2768.8	-204.8
14	2790	3063.3	-273.3	**35**	2667	3059.1	-392.1	**56**	2565	2777.8	-212.8
15	2794	3066.5	-272.5	**36**	2656	2791.7	-135.7	**57**	2867	2763.4	103.6
16	2995	3096.2	-101.2	**37**	2676	2768.9	-92.9	**58**	2876	2814.8	61.2
17	2954	3087.9	-133.9	**38**	2656	2762.4	-106.4	**59**	2887	2816.8	70.2
18	2765	3087.5	-322.5	**39**	2598	2778.3	-180.3	**60**	2765	2784.9	-19.9
19	2845	3068.7	-223.7	**40**	2676	2777	-101	**61**	2677	2752.2	-75.2
20	2814	3057	-243	**41**	2770	2760.7	9.3	**62**	2776	2774.8	1.2
21	2834	3078.1	-244.1	**42**	2705	2784.3	-79.3	**63**	2779	2773.7	5.3

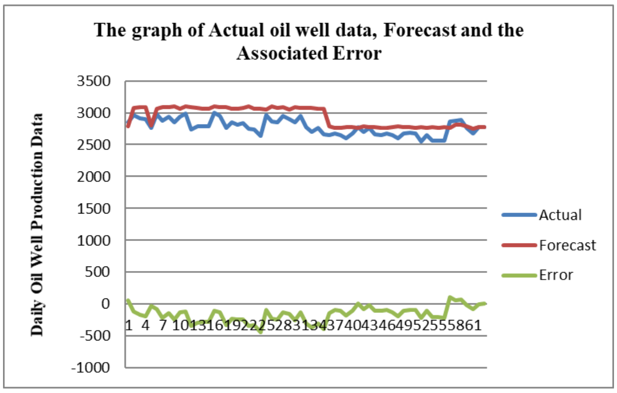

Fig. 2. Graph of Actual oil well production data, Forecast and the associated Error

Table 3. Out of sample forecast and associated errors

t	y_t	$\hat{y}_t$	e_t
64	2758	2792.4	-34.4
65	2780	2796.14	-16.14
66	2765	2766.2	-1.2
67	2765	2791.8	-26.8
68	2754	2800.7	-46.7

4. Conclusion

The auto-regressive model developed in this study has been able to track the 68-day daily production data obtained from marginal oil field in the Niger Delta region of Nigeria. The model has successfully replicated and describes the mechanism that gave rise to the yields in marginal field.

Using auto-regression analysis, the study revealed the nature of marginal oil field daily production data considered in this study. Such knowledge could characterize the nature and complexion of production in marginal field. The problems of marginal field development are not confined to just one constraint, although the mixture of constraints that marginal field operators face varies from one country to another. Some of the major factors hindering marginal field development in the country are low level of support infrastructure, funding constraints, high operational and capital expenditure, insufficient policy, and institutional framework.

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Nomenclature

y_t	: Actual data
$\hat{y}$	: Forecast
$\bar{y}$	: Mean
r_k	: Auto-Correlation function
β	: Correlation coefficient
e_t	: Error
IOC	: International Oil Companies
MAPE	: Mean absolute percentage error
SPDC	: Shell Petroleum Development Company

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