ANALYSIS OF PRODUCTIVITY AND TECHNICAL EFFICIENCY IN GRANITE AGGREGATE PRODUCTION IN SELECTED QUARRIES IN SOUTH-WESTERN, NIGERIA

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Abstract

This research analysed the productivity and technical efficiency in the granite aggregate production and also investigated the causes of inefficiencies in selected quarries across the south western region of Nigeria using stochastic frontier production function which incorporates a model of inefficiency effect. This was achieved through the collection of secondary data with a careful and thoughtful review of literature. The technical efficiency was estimated using Software for Statistics and Data Science (STATA). It was determined that the mean monthly granite production is 17,854.23 tonnes and about 86% of Mean production was influenced by the factors of production used in the study. The result also shows that 100% of the variation in quarries' output was due to inefficiencies on the part of the production processes rather than random variability. Variables such as total number of equipment, mean days of weekly use, number of skilled staff and quantity of fuel used per month, are factors which positively influence the output of the quarries, an investment on equipment would increase productivity and allows for continuity of operation against possible breakdown. The mean efficiency estimate of 68.4% is an indication that there is a chance to improve production. The implication of the study is that efficiency in granite aggregate production among the quarries could be increased by 31.6%. Factors such as age of equipment, availability of engineers for repair and number of working hours per day were found to be the sources of technical inefficiency. It is recommended that provision should be made by stakeholders investing in the quarries to provide access to affordable production inputs for an effective improvement in the level of efficiency among quarries.

Key Words: Technical Efficiency, Granite, Quarry, Productivity, stochastic frontier.

1. Introduction

Quarrying is the process of cutting or digging of stones, and related materials from an extraction site or pit. The different between mining and quarrying is that mining involves taking an economically useful material from the ground while quarrying involves obtaining quarry resources usually rocks, found on or below the land surface (Banez *et al.,* 2010). However, quarry project is a capital intensive investment with many uncertainties (Opafunso and Ajaka, 2004) and the survival of a mine is determined by how efficient it is technically and in terms of cost.

The main concern of the extractive industry includes the productivity, effective use and maintenance of all types of machinery possessed by the company (Jaroslaw and Magdelena, 2018). Productivity is a basic and intuitive measure of performance (Machek and Hnilica, 2012).The effective utilization of mine machines is of utmost importance for the granite quarries as this is one of the major dictators of productivity despite the availability of all other input. This has motivated the managers of mining enterprises to take a series of measures, including activities aimed at enhancing effectiveness of the entire process of mining production. Consequently, this will result in the identification of areas which offer the possibility of increasing the effectiveness of the technical resources owned by mining enterprises. Conventional methods of granite quarrying are becoming increasingly expensive due to the sequence of diverse operations involved. Irrespective of the amount of granite aggregates produced, a quarry can operate technically efficiently only if the production is maximized with optimal use of input factors.

Technical efficiency measures the percentage of actual output relative to the potential output that is produced from the same set of inputs from a fully efficient firm (Aigner, 1968). This definition means that increase of technical efficiency can lead to profit maximization and improvement of the firm performance. Consequently, many granite aggregate quarries in Nigeria regards raising productivity as one of their main priorities because it is an important indicator to measure the developmental level of production systems. It reflects the utilization degree of various kinds of production factors such us resource, environment, capital, technology and energy sources (Liu *et al.*, 2016). However, little has been done on how technically efficient is their operation. The above observations necessitated this research work in order to analyze the technical efficiency in the quarry operations in some selected quarries in Nigeria.

The quarry firm - level of efficiency of resource use has important implication on mining in Nigeria, since efficient quarry firms make better use of existing and available resources, producing maximum output at lowest possible cost (Melodi, 2019). However, the importance of analyzing the technical efficiency of an industry cannot be over emphasized because it plays a significant role in the economic growth of the firm. Thus, it is important to not only focus on how government must improve the business environment, studies have to be done to shed light on how to improve the efficiency of firms by analyzing their technical efficiency. The problem of measuring the technical efficiency of an industry is hence important to both the economic theorist and the policy maker and as a result of these factors, new technical and organizational solutions in mining have to be implemented.

2. Literature Review

Quarrying of granite consists of removing blocks or fragmented rock from an identified and unearthed geologic deposit. Differences in the particular quarrying technique used often stems from variations in the physical properties of the granite deposit such as density, fracturing/bedding planes, and depth, financial considerations, and the site owner’s preference (Anaekwe, 2010). The operation process involves removal of overburden using heavy equipment (including transport to waste dump), drilling, cutting, splitting, and use of explosive charges, on-site transport of fragmented granite (run-off mine) using heavy equipment, crushing of run-off-mine to different aggregates sizes (Alaba and Agbalajobi 2017).

Productivity is a crucial factor in production performance of firms and nations, it is expressed as the ratio of output to inputs used in a production process, (Courbois and Temple, 1975). Efficiency is concerned with the relative performance of the processes used in transforming given inputs into outputs (Arene, 2008). Efficiency improvement is an important source of production growth in any economy. Productivity and efficiency studies have taken the attention of most mine economists and policy makers in recent years, since no meaningful economic development can take place in the absence of productivity growth (Sawaneh *et al.,* 2013).

Technical efficiency measures the ability of a firm to obtain the maximum output from given inputs. Technical efficiency is the success with which an organization uses its resources to produce outputs, that is the ability to produce a given level of output with a minimum quantity of inputs under certain technology. Technical efficiency is a principal element in economic productivity and profitability

The concept of efficiency measurement begins with Farrell (1957) who define a simple measure of firm efficiency which could account for multiple inputs. The estimation of production frontier with the stochastic frontier approach is used in this study. This method appears to be superior because it incorporates the traditional random error of regression. In this case the random error, besides capturing the effect of unimportant left out variables and errors of measurement in the dependent variable, would also capture the effect of random breakdown on input supply channels not correlated with error of the regression. An appropriate formulation of stochastic frontier model (Battese, and Coelli, 1995) in terms of a general production function from t^{th} production unit is

$$(Y_i = f(X_{ij}\beta) + V_i - U_i), \qquad (1)$$

where

Y_i = Output of ith quarry,

X_{ij}= the actual j^{th} input used by i^{th} quarry,

β= the regression coefficient to be estimated,

V_i= random variables outside the control of the quarry, and

U_i= error term under the control of the quarry.

3. Materials and Method

The study covered a total of twenty quarries from the four states (Ogun, Ondo, Oyo and Osun state).

Table 1

Quarry coordinates

S/N	Quarry Name	Coordinate
1	OGUN1	6º 45′ 31″ N, 3º 21′ 08″ E
2	OGUN2	6º 52′ 10″ N, 3º 16′ 23″ E
3	OGUN3	6º 38′ 21″ N, 3º 36′ 48″ E
4	OGUN4	6º 44′ 49″ N, 3º 47′ 06″ E
5	OGUN5	6º 54′ 53″ N, 3º 33′ 16″ E
6	ONDO1	7º 09′ 23″ N, 5º 42′ 06″ E

7	ONDO2	7º 01′ 08″ N, 5º 24 ′11″ E
8	ONDO3	7º 10′43″ N, 5º 12′ 43″ E
9	ONDO4	7º 06′ 03″ N, 5º 31′ 00″ E
10	ONDO5	7º 07′ 23″ N, 5º 19′ 14″ E
11	OYO1	8º 30′ 02″ N, 4º 35′ 26″ E
12	OYO2	8º 22′ 35″ N, 4º 28′ 45″ E
13	OYO3	8º 17′ 44″ N, 4º 24′ 39″ E
14	OYO4	8º 26′ 15″ N, 4º 33′ 20″ E
15	OYO5	8º 32′ 09″ N, 4º 20′ 00″ E
16	OSUN1	7º 51′ 46″ N, 4º 37′ 23″ E
17	OSUN2	7º 44′ 21″ N, 4º 55′ 00″ E
18	OSUN3	7º 32′ 48″ N, 4º 47′ 01″ E
19	OSUN4	7º 39′ 12″ N, 4º 30′ 43″ E
20	OSUN5	7º 41′ 01″ N, 4º 49′ 14″ E

Data Collection and Analysis

A well-structured questionnaire was used to collect the data of the quantity of granite aggregate produced per month and other production variables which includes; Number of equipment, Hours of daily use of equipment, Mean days of weekly use of equipment, Number of skilled staff, Number of unskilled staff, Quantity of fuel use per month, Age of quarry, age of the equipment, Availability of engineer for repairs, Total number of downtime, Number of working days per week, Number of working hours per day, Number of monitoring per month, Year of experience of quarry manager. Statistical Package for Social Sciences (SPSS) and Software for Statistics and Data Science (STATA) were used to analysis the data for the various objectives by using the appropriate models.

Productivity Estimation

In other to estimate the level of productivity of granite aggregates production in the study area, the productivity of each of the quarries was determined using the formula below;

$$\mathrm{Pr}\,oductiviti = Output(y)/Input(x) \tag{2}$$

The factors influencing the productivity of granite aggregates production in the selected quarries was also determined using multiple regression analysis. The principal components technique that was used maximized the sum of squared granite aggregates extracted.

Estimation of Production function:

A two stage stochastic frontier approach was used. In the first stage, stochastic production function and the technical efficiencies was estimated using the Maximum Likelihood Estimation technique. The stochastic frontier production function model is specified as

$$\mathrm{Ln}Y_i=\ln\beta_0+\beta_1\ln X_1+\beta_2\ln X_2+\beta_3\ln X_3+\beta_4\ln X_4+\beta_5\ln X_5+\beta_6\ln X_6+V_i-U_i \quad (3)$$

Where Ln is Natural logarithm, Y_i is the Output of granite aggregates (tonnes), β_1, β_2, β_3, β_4, β_5, β_6 are unknown parameters to be estimated, $Z_1$is Total number of equipment, $Z_2$is Hours of daily use of equipment, $Z_3$is Mean days of weekly use of equipment, $Z_4$is Number of skilled staff, $Z_5$is Number of unskilled staff, $Z_6$is Quantity of fuel used per month, β_0 is a Constant term, V_i is random error component which is due to factors beyond the control of the quarry, U_i is the nonnegative technical inefficiency component of the error term.

According to Coeli *et al*. (2005), output oriented technical efficiency can be represented by

$$TE=\frac{Y_i}{Y_{\max}}=\frac{\exp\left(X_i\beta\right)v_i-u_i}{\exp\left(X_i\beta+v_i\right)}=\exp^{(-ui)} \quad (4)$$

TE = Technical Efficiency

In the second stage, the research used Censored Maximum Likelihood Estimation technique to investigate the causes of inefficiency. In this estimation technique the specific technical efficiency estimates were used as the dependent variable. The inefficiency of production U_i is modeled in terms of the factors that are assumed to affect the efficiency of the processor as follows

$$U_i=\delta_0+\sum_{n=1}^{8}\delta_n Z_n \quad (5)$$

$$U_\mathrm{i}=\delta_0+\delta_1\mathrm{Z}_1+\delta_2\mathrm{Z}_2+\delta_3\mathrm{Z}_3+\delta_4\mathrm{Z}_4+\delta_5\mathrm{Z}_5+\delta_6\mathrm{Z}_6+\delta_7\mathrm{Z}_7+\delta_8\mathrm{Z}_8 \ (6) \quad (6)$$

Where $U_i$is the nonnegative technical inefficiency component of the error term, δ_0 is constant term, $\delta_1,\delta_2,\delta_3,\delta_4,\delta_5,\delta_6,\delta_7,\delta_8$ are unknown parameters to be estimated, $Z_1$is Age of equipment, $Z_2$is Availability of engineers for repair, $Z_3$is Total number of down time, $Z_4$is Age of quarry, $Z_5$is Number of working days per week, $Z_6$is Number of working hours per day, $Z_7$is Number of monitoring visits per month, $Z_8$is Year of experience of quarry manager.

4. Result and Discussion   Productivity Analysis

The productivity was estimated and the productivity statistics is shown in table 2, the major leading production variables are identified to be monthly granite production with a mean of 17,854.23 tonnes, monthly productivity per worker with a mean of 706.04 tonnes and monthly productivity per hour with a mean of 41.74 tonnes. From figure 1, the quarry with the highest productivity is identified to be OGUN1 (1,726.14) while the quarry with the lowest productivity is OGUN5 (256.83) indicting that among all the measured quarries, OGUN5 has the poorest combination of basic factors of production such as the ratio of the number of skilled staffs to that of unskilled staffs, number of workings days per week and the number of working hours pay day.

Table 2

Quarry production and Productivity statistics

Production variables	min.	max.	Mean	Std. Dev
Hours of daily equipment use	7.00	11.00	9.34	1.5312
Days of Weekly equipment use	5.00	7.00	5.82	0.9869
Skilled Staff (persons)	4.00	30.00	18.57	20.4936
Unskilled Staff (persons)	10.00	50.00	26.31	14.8210
Working Days per week	5.00	7.00	5.86	0.7422
Working Hours per Day	8.00	11.00	9.53	1.1034
Granite Production (tonnes/mth)	4,000	40,000	17,854.23	9534.6603
Productivity per worker (tonnes/pers/mth)	256.83	1,726.14	706.04	526.0782
Productivity per hour (tonnes/hr/mth)	485.17	3,636.40	41.74	729.5108

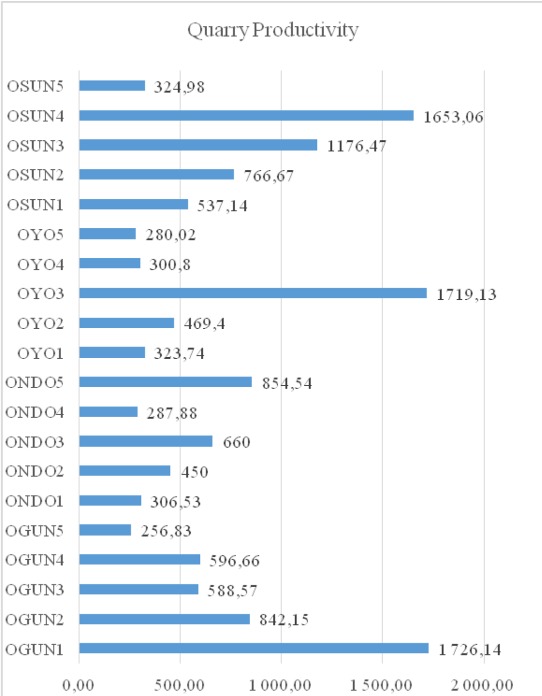

Fig. 1. Comparison of quarry productivity

Factors Affecting Productivity:

Multiple regression analysis was carried out to determine the factors influencing productivity in the selected quarries and the result is presented in Tables 3, 4 and 5.

The correlation coefficient (R) is calculated as 0.927, i.e. the correlation between the dependent (Mean Production of the quarries) and the independent variables (Mean age of equipment, Number of working days per week, Number of working hours per day, Age of the quarry, Number of skilled staff, Number of unskilled staff, Total repairs). The value of 0.927 implies a high and positive correlation between the dependent and the independent variables, the value also indicates a good level of prediction. The coefficient of determination (R-square) is estimated to be 0.859, which implies that about 86% of Mean production are accounted for by the included independent variables. The remaining 14% is attributed to extraneous others factors that are not included in the model.

Table 3

Regression Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.927[a]	.859	.777	.51942

a. Predictors: (constant), Mean age of equipment, Number of working days per week, Number of working hours per day, Age of the quarry, Number of skilled staff, Number of unskilled staff, Total repairs he F-ratio in the ANOVA (Table 7) tests whether the overall regression model is a good fit for the data.

The table shows that the independent variables statistically significantly predict the dependent variable, F (7, 12)=10.438, p=0.000, significant at 5% level.

Table 4

Analysis of Variance Anova[a]

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	19.712	7	2.816.	10.4	000[b]
Residual	3.238	12	270	38	
Total	22.950	19			

a. Dependent Variable: Mean Production

b. Predictors: (Constant), Mean age of equipment, Number of working days per week, Number of working hours per day, Age of the quarry, Number of skilled staff, Number of unskilled staff, Total repairs.

The estimates of regression coefficients as presented in table 8, reveals that Number of working days per week, Number of working hours per day, Age of the quarry, Number of unskilled staff, Total repairs have direct relationship with the Mean production but only the estimated coefficients of Total repair is significant at 5% level i.e. Total repair p(0.001)<0.05 . On the other hand, the estimated coefficient Mean age of equipment and Number of skilled staff have inverse relationship with the Mean production. Furthermore, the estimated coefficients reveals that a unit increase in number of working days per week results in 0.041 units increase in the mean production, also a unit increase in Number of working hours per day, Age of the quarry, Number of unskilled staff and Total repairs results in 0.241, 0.462, 0.408 and 0.768 units increase in the mean production respectively. However, a unit increase in the Mean age of equipment and

Number of skilled staff results in 0.154 and 0.160 units decrease in the mean production respectively.

Table 5

Regression Coefficients Coefficients[a]

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error			
(Constant)	-782	1.261.	-	-.620	.547
Mean age of equipment	-154	222	1.111	-.696	500
Number of working days per week	041	377	023	109	915
Number of working hours per day	241	410	097	587	568
Age of the quarry	462	218	410	2.121	055
Number of skilled staff	-160	133	-.214	-1.206	251
Number of unskilled staff	408	237	339	1.723	111
Total Repairs	768	179	702	4.301	001

Technical Efficiency Assessment

The statistics summary for the production variables used in the analysis are given in Table 2. The study shows that the mean granite stone production is 17,854.23 tonnes per month. The mean number of skilled and unskilled staff are 18.57 and 26.31 respectively which implies that there is dominant number of unskilled workers involved in granite production though the technical knowledge of the operation is required for efficient and effective production. Also the table reveals the mean hours of daily use and the mean days of weekly use of the equipment to be 9.34 hours and 5.78 hours. The mean age of equipment is 6.54 years, mean number of downtimes is 3.61 and mean availability of engineers for repair is 1.48.

Table 6

Statistics of the production variables used

Variables	min.	max.	Mean	Std. Dev.
Granite stone production (tonnes/mth)	4,000	40,000	17,854.23	9534.6603
Total number of equipment	5.00	15	7.15	3.9807
Hours of daily equipment use	7.00	11.00	9.34	1.5312
Number of skilled staff (persons)	4.00	30.00	18.57	20.4936
Number of unskilled staff (persons)	10.00	50.00	26.31	14.8210
Quantity of fuel used per month (litres)	3,500.00	101,760.00	39,374.63	38,944.16

Age of equipment (years)	2.00	12.00	6.54	1.0962
Mean days of weekly use of equipment	5.00	7.00	5.83	0.9869
Total number of downtime	1.00	8.00	3.61	1.6606
Availability of engineer for repairs	1.00	2.00	1.48	0.4743
Number of working days per week (days)	5.00	7.00	5.86	0.7442
Number of working hours per day (hours)	8.00	11.00	9.53	1.1034
Number of monitoring visit per month	1.00	4.00	2.66	2.7408
Year of experience of quarry manager	5.00	20.00	9.11	6.2795
Age of Quarry (years)	3.00	15.00	8.51	7.7872

From the stochastic frontier regression model that was carried out and presented in Table 10, the sigma-square σ^2 has an estimate of approximately 0.03 which attests to the good fit and correctness of the model. Also, the gamma γ estimate of approximately 1.00, this means that 100% of the variation in quarries' output was due to inefficiencies on the part of the production processes rather than random variability. The total number of equipment has a positive sign (0.0588), this indicates that a percentage increase in the total number of equipment available for use would result in 0.0588% increase in granite production. The estimated coefficient of mean days of weekly use of equipment is 5.4, which is significant at 1%, this means that an increase in days of weekly use equipment will equally lead to increase in the quantity of output of granite aggregates produced by the quarries. Number of skilled staff is positively correlated and insignificant with an estimate of 0.32 while quantity of fuel used per month (liters) also has positive estimated of 0.21 implying that increase in the use of these variables will also lead to increase in the output of the quarries if properly managed. The variable with negative coefficients such as hours of daily use of equipment which is significant at 5% and number of unskilled staff. This implies that as the hours of daily use of the equipment (-2.1) and the number of unskilled staff (-0.21) increases there is a negative effect on production efficiency.

Table 7

Maximum likelihood estimates of stochastic frontier for granite aggregate production

Variables	Parameters	Estimate	Std. error	t-value
Constant	β_0	6.2130	1.3754	5.9928
Total number of equipment	β_1	0.0588	1.2033	0.0521
Hours of daily use of equipment	β_2	-2.1572	1.1164	-1.9074
Mean days of weekly use of equipment	β_3	5.3921	0.9438	5.9882
Number of skilled staff (persons)	β_4	0.3160	0.2203	0.8469
Number of unskilled staff (persons)	β_5	-0.2075	0.4133	-0.4635
Quantity of fuel used per month (litres)	β_6	0.2109	0.2855	0.9257
Variance Parameters				
Sigma-squared	σ^2	0.0295	0.0324	0.8651
gamma	r	0.9863	0.0205	59.3
Log likelihood function		1.7812		
LR test of one-sided error		9.6035		

Technical Efficiency Estimates of the quarries

The estimated value of the technical efficiencies of each quarry is shown in Table 4, it can be deduced that the quarry with the highest technical efficiency is identified to be ONDO2 (0.9937) while the quarry with the least technical efficiency is OGUN5 (0.4352). This means that ONDO2 makes the highest output with its average given input while OGUN5 makes the lowest output with its average given input based on the variables considered. The mean technical efficiency is 0.6843.

Table 8

Technical Efficiency Estimates of the selected Quarries

Quarries	Efficiency Estimate
OGUN1	0.9554
OGUN2	0.8761
OGUN3	0.4728
OGUN4	0.9795
OGUN5	0.4352
ONDO1	0.6495

ONDO2	0.9937
ONDO3	0.8737
ONDO4	0.7840
ONDO5	0.8245
OYO1	0.5129
OYO2	0.4536
OYO3	0.5242
OYO4	0.6379
OYO5	0.4581
OSUN1	0.7735
OSUN2	0.4965
OSUN3	0.7329
OSUN4	0.6915
OSUN5	0.5607

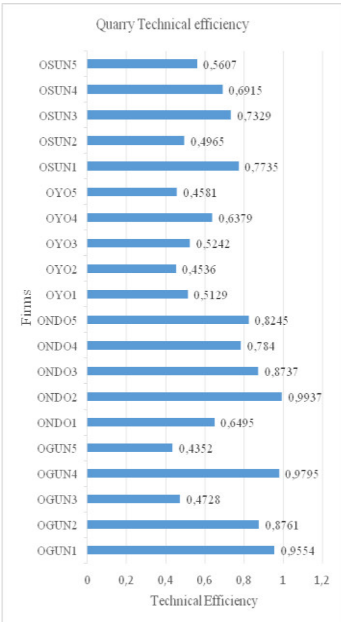

Fig. 2. Comparison of technical efficiencies

Technical Inefficiency

Table 5 describes the factors causing inefficiency in the study area. The coefficients for age of equipment (0.1653), availability of engineers for repair (0.5935) and number of working hours per day (0.1847) was estimated to be positive which indicates an increase in technical inefficiency and consequent decrease in technical efficiency, i.e. as the age of equipment increases productivity efficiency of the quarries drops, the availability of workers to implement preventive and corrective maintenance on quarry equipment would positively affect technical efficiency and reliability on the equipment for production, thereby decreasing technical inefficiency. Consequently, an increase in working hours per day would improve productivity and technical inefficiency decreases. Factors such as total number of downtime (-0.906), age of quarries (-0.1847), number of working days per week (-0.2490), number of monitoring visit (-0.0315) and years of experience of quarry manager (-0.0448) were estimated to be negative implying that these variables led to decrease in technical inefficiency or increase in technical efficiency. Therefore from the result, the major factors contributing to technical inefficiency in the quarries are; age of equipment, availability of engineers for repair and number of working hours per day.

Table 9

Technical inefficiency factors

Variables	Parameters	Estimate	Std. error	*t*-value
Inefficiency effect model				
Constant	δ_0	0.1654	0.9971	0.1743
Age of equipment (years)	δ_1	0.1653	0.1764	0.9532
Availability of engineers for repairs	δ_2	0.5935	0.7824	0.9675
Total number of downtime	δ_3	-0.0906	0.1825	-0.6041
Age of quarry (years)	δ_3	-0.1847	0.1373	-1.6202
Number of working days per week (days)	δ_5	-0.2490	0.7450	-0.4680
Number of working hours per day (hours)	δ_6	0.1857	0.3918	0.7063
Number of monitoring visits per month	δ_7	-0.0315	0.1594	-0.0951
Year of experience of quarry manager	δ_8	-0.0448	0.0658	0.7414
Variance parameters				
Sigma-squared	σ^2	0.0295	0.0324	0.8651
gamma	γ	0.9863	0.0205	59.3
Log likelihood function		1.7812		
LR test of the one-sided error		9.6035		

Conclusion and Recommendation

Based on the findings, the mean monthly granite production is 17,854.23 tonnes, monthly productivity per worker is 706.04 tonnes and monthly productivity per hours is 41.74 tonnes/hr. However, these outputs can increase with the right combination of production variables.

The study further shows that about 86% of Mean production was influenced by the factors of production used. Consequently, the number of working days per week, Number of working hours per day, Age of the quarry, Number of unskilled staff and Total repairs all have positive influence on the production. However, factors such as Mean age of equipment and Number of skilled staff have negative influence on the production.

Out of all the quarries used for the study, ONDO2 has the highest technical efficiency while the quarry with the least technical efficiency is OGUN5 quarry. This means that ONDO2 makes the highest output with its average given input while OGUN5 makes the lowest output with its average given input based on the variables considered. The mean technical efficiency is 0.6843 which indicates that production can still be increased by 31.6% using available technology. This means that substantial opportunities should be explored to increase productivity and income of quarries through availability and efficient utilization of productive resources. Factors such as age of equipment, availability of engineers for repair and number of working hours per day were found to be the sources of technical inefficiency.

The following recommendations are made based on the findings and conclusion of this study;

1. For an effective improvement in the level of efficiency among quarries, provision should be made by stakeholders investing in the quarries to provide access to affordable production inputs such as latest equipment, standby engineer for repair, etc., and the practice of two shift in a day should be encourage.

2. More studies should be done on technical efficiency as very few published works has been carried out on technical efficiency in the mining industry considering the fact that it plays a significant role in the economic growth of the firm.

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