International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Stochastic Frontier Approach to Total Factor Productivity Measurement in Nigeria Crop Agriculture, 1961 – 2020

Ajiboye Abiodun

Department of Agricultural Economics and Extension Services Ekiti State University
PMB 5363, Ado Ekiti. Ekiti State, Nigeria
Email: abiodun.ajiboye@eksu.edu.ng, Telephone: +2348030452320

ABSTRACT:

This paper applies a stochastic production frontier model to measure total factor productivity growth, technical efficiency change and technological change in Nigerian crop agriculture for the 60 observations from 1961 to 2020, using a national data collected from the various sources for the 36 states in the country. The results revealed that technical change increased at the wake of the years for just three years after which it suffered a back and forth trends till the end of the period with an average of 1.25. Technical efficiency experienced the same zigzag progression throughout the period and the mean value is 1.00. TFP growth was observed to be more downward trending as the year grew by and the mean TFP was 1.25.

Key word: *stochastic, technical change, technical efficiency, productivity*

1.0 Introduction

Globally, agriculture is one of the most powerful tools to end extreme poverty, boost shared prosperity, and feed a projected 9.7 billion people by 2050. Growth in the agriculture sector is two to four times more effective in raising incomes among the poorest compared to other sectors. Agriculture that is supposed to be a vital engine of economic growth is accounting for only 4% of global gross domestic product (GDP) and in some least developing countries, it can account for about 25% of GDP. (World Bank 2022) Agriculture remains an indispensable sector in most developing countries, where it is a major factor in the provision of food and a means of livelihood for the people .Agriculture remains the largest sector in Nigeria contributing an average of 24% to the nation's GDP over the past seven years (2013 – 2019). In addition, the sector employs more than 36% of the country's labour force, a feat which ranks the sector as the largest employer of labour in the country. AfCFTA **(2020).** Ever since independence, the nation has been embattled with diverse economic hardships coupled with myriads of bottlenecks, nevertheless, agriculture has maintained its stand as the shock absorber of economic instabilities and sustainer of the people at various times (World Bank, 2024). The survival of some people is solely dependent on agriculture and its allies alone (Mojeed and Mukta 2021). Going by projection therefore, the world's population is expected to grow to nearly 10 billion by 2050 and according to the UN Food and Agriculture Organization (FAO) 70 percent more food will be needed in 2050 than was produced in 2009, the year FAO made its calculation. Experts have identified four main developments that are putting pressure on agriculture to meet the demands of the future: demographics, scarcity of natural resources, climate change and food waste. To this end, a very big responsibility lies ahead for all the stakeholders in the sector if success will be achieved. There is no gainsaying that agriculture remains an effective poverty reduction strategy especially in the rural sector (World Bank, 2024). Production from agriculture must intensify greatly if the projected bridging of the supply-demand gap will be attained at the set time.

Agricultural productivity, at least, at the micro level translates to an increase in farm income, food security, poverty reduction, and improved rural household welfare, while leading to inclusive industrial development and economic growth on the aggregate (Awotide et al, 2015). The importance of Agricultural Productivity growth cannot be over-discussed in a world of rapidly increasing food demand and raw material needs to catch up with an exploding population. The country has an agricultural land area of about 84 million hectares, of which 33 million hectares is currently under cultivation. About 3 million hectares of the agricultural land is irrigable but only about 220,000 hectares is actually irrigated. Nigerian agriculture is inefficient and poor-performing because a unit of input employed in the production process does not yield its highest possible level of output. This is as a result of poor past policies, civil and social unrest, burgeoning population, resource mis-management and failure to build capital and strengthen local industries. Adedeji et al 2014. .Agricultural Productivity growth is important in the face of rapid increase in the demand for food and raw materials to meet steady population growth. Since 1980s a number of studies has been conducted to clarify agricultural productivity in Nigeria (Amire, 2016;Awoyemi et. al 2017; Adeleke, O. A.2020; Coker et al 2019, Orisaremi et.al 2023) all these Studies, however, cannot really and totally explore the issues about the Nigerian agricultural productivity growth. This paper therefore employed the stochastic frontier approach to measure the productivity performance of the Nigerian arable crop subsector spanning from 1961 through 2020.

2.0 Material and Method

2.1 Data

The variables used for the analysis are agricultural output defined as the gross production value (constant 2014-2016 in thousand USD) and it was sourced from the FAO statistical data base. The value was obtained by aggregating detailed output quantity data on 173 agricultural commodities which include crops and livestock. Agricultural labour was defined by the economically active population in agriculture (mainly rural population), sourced from the World Development Indicator (WDI) of the world bank . The next is agricultural land, defined as the land used in crop production including land under permanent crops as well as the area under permanent meadows and pastures and was collected from the FAO. The area is given in 1000 Ha and agricultural tractor was defined as the Units of agricultural tractors in use and it was sourced from the AFDB Socio-economic database. The fifth variable is fertilizer which was also collected from AFDB Socio-economic database and defined as Quantity of NPK Fertilizer expressed in metric tonnes

2.2 The model

Stochastic frontier analysis (SFA) is a method of economic modeling. It has its starting point in the stochastic production frontier models simultaneously introduced by Aigner, Lovell and Schmidt (1977) and Meeusen and Van den Broeck (1977). The *production frontier model* without random component can be written as:

The model $y_i = f(x_i \mid \beta).TE_i$ 1

where y_i is the observed scalar output of the producer *i*; $i=1,..I$, x_i is a vector of *N* inputs used by the producer *I*, β ; is a vector of technology parameters to be estimated; and $f(x_i, \beta)$ is the production frontier function. TE_i denotes the technical efficiency defined as the ratio of observed output to maximum feasible output. $TE_i = 1$ shows that the *i-th* firm obtains the maximum feasible output, while $TE_i < 1$ provides a measure of the shortfall of the observed output from maximum feasible output. A stochastic component that describes random shocks affecting the production process is added. These shocks are not directly attributable to the producer or the underlying technology. These shocks may come from weather changes, economic adversities or plain luck. We denote these effects with $\exp\{v_i\}$. Each producer is facing a different shock, but we assume the shocks are random and they are described by a common distribution. The stochastic production frontier will become:

$$y_i = f(x_i \beta).TE_i \exp\{v_i\} \quad 2$$

We assume that TE_i is also a stochastic variable, with a specific distribution function, common to all producers. We can also write it as an exponential ,TEi = $\exp\{v_i\}$ where $u_i \geq 0$, since we required $TE_i \leq 1$. Thus, we obtain the following equation:

$$y_i = f(x_i, \beta).\exp\{-u_i\}.\exp\{v_i\} \quad 3$$

Now, if we also assume that $f(x_i, \beta)$ takes the log-linear Cobb–Douglas form, the model can be written as:

$$\ln y_i = \beta_0 + \sum_n \beta_n \ln x_{ni} + v_i - u_i \quad 4$$

where v_i is the "noise" component, which we will almost always consider as a two-sided normally distributed variable, and u_i is the non-negative technical inefficiency component. Together they constitute a compound error term, with a specific distribution to be determined, hence the name of "composed error model" as is often referred

$$TE_t = E\left[\exp(-\mu_t) \mid (v_t - \mu_t)\right] \quad 5$$

The technical efficiency change index (EFFCH) from period t to period s (s =t-1) is given by

$$EFFCH = \frac{TE_t}{TE_s} \quad 6$$

The TE scores were computed from the estimated parameters of the stochastic frontier model

The technological change between the period t and the period s is given by

$$TECH = \left\{\left[1 + \frac{\delta f(x_s, s)}{\delta_s}\right] * \left[1 + \frac{\delta f(x_t, t)}{\delta_t}\right]\right\}^{0.5} \quad 7$$

TFP = EFFCH + TECH 8

Results

Table 1: definitions of the variables used in the analysis and the sources.

	Mean	Std.Dev	Min	Median	Max
Capital	4545108.55	8600148.03	4267.00	274178.00	44187032.00
Log labor	11.09	0.29	10.57	11.12	11.50
Log fertilizer	11.53	1.69	7.24	12.20	13.51
Log land	10.43	0.22	9.89	10.45	10.68
Log capital	12.95	2.73	8.36	12.52	17.60
Log tractor	9.88	1.73	6.21	10.06	12.73
Log output	16.87	0.60	16.09	16.85	17.78

Table 1 summary statistics of the log forms of the variables

Table 2. Stochastic production frontier estimation of the Nigerian crop agriculture

Translog model		
Production function	**Coefficient**	**z-value**
Constant	2.37×10^{3}	2373.63^{***}
Log land	-1.22×10^{2}	-124.54^{***}
Log fertilizer	-2.29×10^{-2}	-0.02
Log labor	-2.46×10^{2}	-256.30^{***}
Log tractor	8.33	8.26^{***}
Log capital	-96.71	-102.80^{***}
Trend	18.43	61.45^{***}
Log land* Log land	0.68	1.52
Log land* Log fertilizer	-8.98×10^{-2}	-0.97
Log land* Log labor	11.18	22.35^{***}
Log land* Log tractor	-0.51	-1.93
Log land* Log capital	7.68×10^{-2}	0.65
Log land * trend	-0.02	-4.69^{***}
Log fertilizer * Log fert	1.53×10^{-2}	0.44
Log fertilizer * Log lab	-4.22×10^{-2}	-0.27
Log fertilizer *Log tractor	8.97×10^{-2}	1.94
Log fertilizer * log capital	5.92×10^{-2}	1.19
Log fertilizer * trend	-1.37×10^{-2}	-1.69
Log labor* Log labor	5.46	8.02^{***}
Log labor* Log tractor	-0.68	-2.04^{*}
Log labor*Log capital	8.42	45.03^{***}
Log labor* trend	-1.38	-30.87^{***}
Log tractor* Log tractor	-0.48	-6.22^{***}

Log tractor*log capital	0.80	6.01***
Log tractor* trend	-7.32 x 10^{-2}	-3.48***
log capital* log capital	-6.88x 10^{-2}	-0.88
log capital* trend log	-0.19	-13.54***
Trend* Trend	5.3 x 10^{-2}	14.93***
Diagnostic statistics		
Sigma Squared	3.30 10^{-3}	6.15***
Gamma	1.00	2429.09***
MU	-4.26$10^{-2}$	-2.56*
Log-likelihood	142.38	

Note. *** =significant at 1 percent level (P<0.01)

* =significant at 5 percent level (P<0.01)

** = significant at 10 percent level (P<0.01)

The parameter estimates for the translog stochastic frontier production function are reported in Table 2. A total of 18 coefficients out of 28 were significantly different from zero at the 10 percent level, indicating the importance of some of the interactions and non-linearities among variables. All direct effects, (apart from fertilizer) three squared terms and eight interaction terms coefficients were significantly different from zero. This indicates that rejection of the Cobb-Douglas model as an adequate representation of Nigerian crop agriculture is justified; because of the non-linearity of the function in some dimensions and that there are important interactions among the variables. Although for the Cobb Douglas the coefficients in the table represents the output elasticities (except for the time variable), but for the translog model, the elasticities are the functions of the estimated coefficients and the values of the input variables inclusive. Four, of all the five inputs, land, rural population , tractor and capital , were the major determinants of agricultural growth in the period from the results presented in the table, tractor remains the single most important input with an output elasticity of 8.33 followed by capital with elasticity of -96.7 and land with - 122 , then rural population with -246 , respectively. Reasonably enough, for a labour surplus economy like Nigeria, labour which is proxied by rural population has the lowest output elasticity of only -246.

The coefficient on the time-trend variable indicates that there is a positive technological improvement. and the effect is non-linear, as can be seen by the significant coefficients on the squared terms

Total Factor Productivity and its Decomposition

Table 3

Year	Efficiency Change	Technical Change	Total Factor Productivity	Year	Efficiency Change	Technical Change	Total Factor Productivity
1961	1.000	1.000	1.000	1991	1.075	1.267	1.361
1962	1.009	1.629	1.644	1992	1.012	1.247	1.262
1963	0.988	1.613	1.593	1993	0.979	1.204	1.178
1964	1.000	1.595	1.594	1994	0.999	1.170	1.169
1965	0.981	1.567	1.536	1995	0.953	1.131	1.078
1966	1.024	1.530	1.567	1996	1.018	1.092	1.111
1967	0.982	1.507	1.480	1997	1.040	1.085	1.129
1968	1.000	1.492	1.492	1998	1.000	1.088	1.088
1969	1.019	1.471	1.498	1999	0.983	1.093	1.075
1970	1.012	1.458	1.475	2000	0.984	1.099	1.081
1971	0.915	1.449	1.326	2001	1.026	1.115	1.144
1972	1.036	1.422	1.473	2002	0.999	1.131	1.130

1973	0.993	1.404	1.395	2003	0.989	1.121	1.110
1974	1.045	1.399	1.462	2004	1.031	1.090	1.124
1975	1.016	1.351	1.373	2005	0.970	1.057	1.025
1976	0.958	1.263	1.210	2006	0.957	1.024	0.980
1977	1.019	1.217	1.240	2007	1.004	1.043	1.047
1978	1.003	1.224	1.229	2008	1.075	1.091	1.173
1979	1.020	1.244	1.269	2009	0.943	1.101	1.038
1980	0.976	1.239	1.210	2010	1.060	1.109	1.176
1981	1.022	1.222	1.249	2011	0.906	1.130	1.024
1982	0.957	1.225	1.172	2012	1.052	1.155	1.214
1983	0.962	1.249	1.202	2013	0.936	1.169	1.095
1984	1.017	1.295	1.316	2014	1.118	1.175	1.314
1985	1.073	1.344	1.442	2015	0.979	1.190	1.165
1986	0.988	1.349	1.332	2016	1.023	1.213	1.241
1987	0.920	1.336	1.229	2017	0.961	1.219	1.171
1988	1.078	1.341	1.445	2018	0.998	1.197	1.194
1989	0.975	1.306	1.274	2019	1.041	1.153	1.201
1990	0.963	1.269	1.222	2020	0.987	1.130	1.116

Mean: EFFCH = 1.001, TECH = 1.252, TFP = 1.253

The indices for changes in total factor productivity, technical efficiency and technological change for the period from 1961 to 2020 are presented in Table 2. Technological change was positive during the two-year periods from 1961-1963 and then declined to become negative in 1978 when there was a little revival in 1979 probably due to the green revolution policy of the then government . A switch from positive to negative continued at intervals of some four or five years until 1989 when the decline stretched year-ward until 2000 till 2003 after which the struggles between technical progress and technical decline continued till date. Thus the improvement of TFP over the year suffered a back and forth trend up to the year end of the analysis. The indices presented in the table were calculated from econometric approximations so they tend to show the theoretical proofs rather than the true state of things. There is the possibility that the model itself might have suffered some failures in accurately decomposing the effects of technological progress and efficiency change. Undeniably, there were pockets of policies formulated during this years some of which favour the agricultural sector and some of which farmers were inadvertently ill-treated. Programmes such as green revolution, operation feed the nation, operation back to land, e-wallets and so on and so forth were directly targeted towards farmers welfare while policies like the structural adjustment program, good policy somersaults by a new regime and even sanctions from the Nigerian higher diplomatic partners during the military eras were responsible for the unsteadiness of the TFP growth. The highest TFP was recorded in the year 1962 and the lowest was in 1976 with the vaues os 1.62 and 0.98 respectively but the trend in TFP was observed to be more negative as the year grew by. The mean TFP was 1.253

Conclusion and Policy Implications

This paper used a time series data for a 60-year period to study technical efficiency, technical progress and TFP growth in Nigerian crop agriculture using a stochastic frontier approach. In this approach, TFP indices are constructed without price data, which are difficult to obtain and often not too reliable in a developing country like Nigeria. Over all TFP did not grow appreciably as expected with modernization and supposed access to better production methods. This TFP raises serious concerns about food security and the sustainability of the crop subsector . However, the value of the mean technical efficiency raises some hopes about future improvements of productivity by improving efficiency alone.

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