Total Factor Productivity of Agricultural Commodities in the Economic Community of West African States: 1961-2005

By

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AERC Research Paper 253
African Economic Research Consortium, Nairobi
December 2012

1. Introduction

In the Economic Community of West Africa States (ECOWAS), which comprises Benin, Burkina Faso, Cape Verde, Côte d'Ivoire, the Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Sierra Leone, Senegal and Togo, the agricultural sector is still a major driver of food security, economic growth and development. In economic terms, this sector contributes about 35% of the region's gross domestic product. Agricultural exports constitute an important element of the region's foreign trade, generating about US$6 billion, which accounts for about 16.3% of all the products and services exported from the region. In terms of employment, the sector is still the biggest employer in ECOWAS. Over 60% of the active population in the region is engaged in agriculture, even though it pays less than other economic sectors. Agriculture is also a vital sector in efforts to combat poverty and food insecurity in ECOWAS. The sector is characterized by millions of small family-run farms that derive their income and livelihood from producing primary agricultural products. At present, almost 80% of the regional population's food needs depend on regional produce. Moreover, in the next few years, West African agriculture will have to meet a huge increase in demand generated by demographic growth. At the moment, the population of the region stands at 290 million, and is set to exceed 400 million by 2020, and 500 million by 2030. Despite the importance of agriculture in ECOWAS, the region is characterized by low productivity. Per-hectare yields for most crops are among the lowest in the world, only increasing by an average of 42% between 1980 and 2005, and accounting for just 30% of the increase in agricultural and food production. The use of productivity increasing inputs such as improved seed, fertilizer and agricultural machinery barely feature in most producers' farming activities. Over the past 20 years, increases in production have generally been obtained by putting more land under cultivation, with a 229% increase in farmland accounting for 70% of the growth in regional production.

Given the importance of this sector in the national economy, and the constraints to production, an important policy option of ECOWAS from its establishment has been to make the agricultural sector more competitive by furthering production growth and increasing intra-regional trade. The main thrust of the ECOWAS reforms as it affects agriculture is on the free movement of unprocessed goods and traditional handicraft products, which should be exempt from import duties and taxes. The list of unprocessed goods and traditional handicraft products, as well as the nomenclature of non-tariff barriers to be lifted, were approved as far back as 1979, which means that trade in these products has, to all intent and purposes, been liberalized. Generally, the issue of how agricultural markets respond to price liberalization is a central issue in development policy, and one that has been surrounded by much controversy. One view is that subsidy may reduce farmers' performance due to lack of adequate incentives. Another view maintains that the subsidy system may stimulate small scale farmers to perform better in spite of their disadvantages in respect of economies of scale. One question has been how large any response in agricultural output to liberalization should be. A second concern has been the effect of removing subsidies on inputs, which are often an important policy intervention by governments. A third has been whether innovation, in the sense of adopting new techniques leading to a rise in total factor productivity, is possible by means of liberalization. The agricultural sector of ECOWAS offers an opportunity to explore these questions. The liberalization policy involving substantial devaluation of the nominal exchange rate largely eliminated the black market premium, increased real producer prices, and eliminated subsidies so that the real prices of inputs rose far faster than the consumer price index. The basic research question is whether liberalization among ECOWAS countries has led to improved productivity of crops relevant to food security in the region. If liberalization can lead to improved productivity, there seems to be plenty of scope with known technologies. Given the importance of productivity in understanding the outlook for the ECOWAS agricultural market, assessing the unexplored productivity potential is expedient to evaluating the future path of productivity.

Prior to market liberalization, considerable government intervention helped marginal farmers remain in business in the region. A more open market would be expected to induce some marginal farmers to retire from farming, which means that average current productivity would be misleading as an assessment of the productivity potential. This underscores the relevance of the frontier method adopted in this study to measure productivity. The underlying economic reason of the liberalization policy was the low productivity in the pre-liberalization period, and expectation that productivity would improve after transition to market economy. While much evidence has been provided attesting the productive performance of the agricultural sector in Africa and factors influencing it (Thirtle, Hadley and Townsend, 1995; Coelli and Rao, 2001; Nkamleu, 2004; Nkamleu, Kalilou and Abdoulaye, 2008), there is little evidence on crop-specific and sub–regional productive performance. An assessment of crop-specific efficiency and productivity analysis should be of more interest to policy makers implementing liberalization policy than overall aggregate, for two reasons. Firstly, a better understanding can be provided on the potential for resource savings and productivity growth of individual crops. Secondly, the producers can learn from the front runners the best approach for resource use efficiency. Therefore, the main research questions in this study are:

a) Is there any potential for improving the efficiency of rice, cotton and millet producers in ECOWAS? If so, what are the magnitudes?
b) Has there been any productivity progress in ECOWAS rice, cotton and millet production since 1979? (The choice of 1979 as reference point is to account for periods before ECOWAS policies became effective in member states.
c) Are the results of (a) and (b) irrespective of the methodology applied? (The third question is also of considerable interest for policy. If methods do not give results that are similar or highly correlated to each other, the policy may be fragile depending on which frontier approach is employed.)

The objective of this study, therefore, is to determine how market liberalization policies affect productivity of ECOWAS agricultural commodities. The specific objectives are to:

- Measure the level and growth of total factor productivity (TFP) in the selected crop-producing countries in both pre-ECOWAS and ECOWAS periods; and,
- Explain the sources of inefficiencies among the producers.

2. Importance of rice, cotton and millet in ECOWAS

This section gives some background information about the importance of the selected crops to food security in ECOWAS, and provides the basis for their selection. A summary of the production and trade statistics for the selected commodities for all ECOWAS member nations are presented in Table 1.

Table 1: Production and trade statistics on ECOWAS rice, cotton and millet for 2005

Country	Rice import (tonnes)	Rice export (tonnes)	Rice production (tonnes)	Rice area (Hectares)
Benin	376,185	0	70,972	28,904
Burkina Faso	100,000	77	113,700	52,563
Côte d'Ivoire	691,092	10,854	715,898	353,169
Gambia	50,466	0	31,024	17,873
Ghana	47,894	0	250,000	120,000
Guinea	155,390	9	1,340,313	723,973
Guinea Bissau	49,673	0	106,000	65,000
Mali	132,263	0	1,053,236	414,023
Niger	289,857	984	78,377	15,110
Nigeria	1,040,322	4,367	4,042,000	2,494,000
Senegal	1,109	0	190,493	97,779
Sierra Leone	71,410	709	1,062,320	730,000
Togo	23,846	35	76,284	32,983
Country	**Cotton import**	**Cotton export**	**Cotton production**	**Cotton area**
Benin	0	161,271	250,000	310,000
Burkina Faso	1	194,600	759,858	621,748
Côte d'Ivoire	90	129,304	267,844	285,714
Gambia	0	0	500	1,300
Ghana	8	572	18,988	25,000
Guinea	250	529	41,000	35,000
Guinea-Bissau	0	176	4,500	3,500
Mali	481	258,830	432,466	3,000
Niger	18	695	10,700	38,254
Nigeria	1,586	22,124	563,000	130,000
Senegal	0	15,307	52,027	11,000
Sierra Leone	0	0	0	11,462
Togo	0	24,406	39990	11,245

continued next page

Table 1 Continued

Country	Millet import	Millet export	Millet production	Millet area
Benin	0	0	32,842	45,517
Burkina Faso	0	7,121	1,175,040	130,9710
Côte d’Ivoire	0	62	38,308	43,478
Gambia	43	0	125,680	127,321
Ghana	0	27	165,000	185,000
Guinea	0	0	290,000	320,000
Guinea Bissau	0	0	49,569	25,000
Mali	50	6,780	1,128,773	5,000
Niger	6,145	60	3,008,584	5,893,900
Nigeria	0	504	7,705,000	4,685,000
Senegal	0	6	494,345	800,763
Sierra Leone	0	0	25,000	20,000
Togo	0	0	43,747	51,358

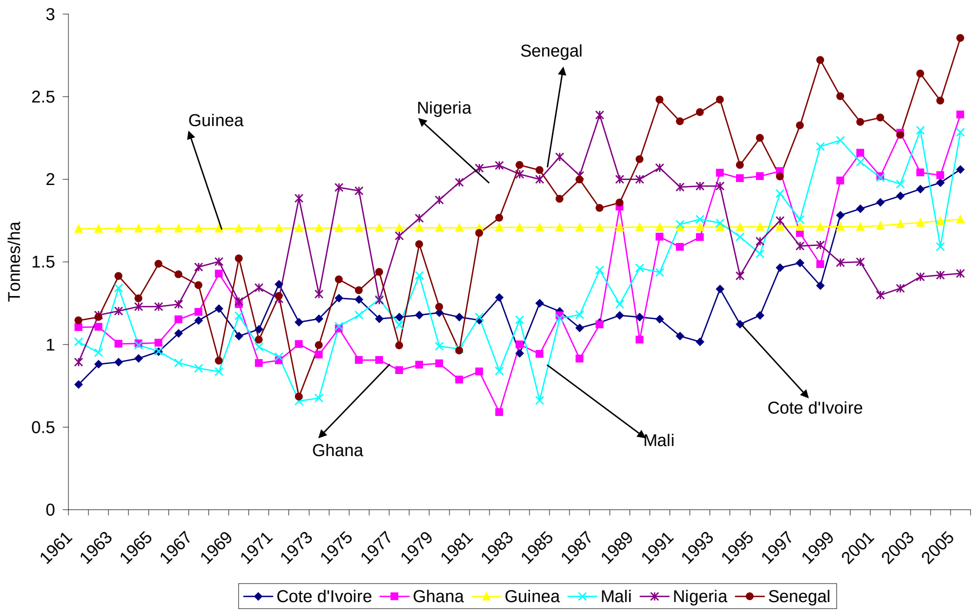
Source: FAOSTAT database

Rice

Rice production in West Africa represents about 50% of consumers’ needs in the sub-region. In terms of per capita consumption, rice is the core staple in Senegal (93kg per head per year) while it is only one staple in a more diversified diet in Ghana and Nigeria with, respectively, 25kg and 29kg of rice consumed yearly per capita. The shift to rice consumption in Senegal started as early as the colonial period. Production efforts were then driven towards production of groundnuts, to the detriment of millet, and broken rice was imported from Indo-China as cheap staple food. Nigeria has experienced its rice diet transition in the 1970s (with a rice per capita consumption annual growth rate of 11%) induced by income growth triggered by the oil boom. Ghanaian consumers started to shift to rice only recently, compared with the two other countries, and experienced a faster growth of rice per capita since 2000 (Lancon and Benz, 2007). Most of these countries have adopted enhanced food security as a common policy goal. Dramatic changes in consumption patterns during the past two decades have led to a large increase in the demand for rice from African consumers. Growth in consumption has been most substantial in Africa’s rapidly growing cities, where rice is increasingly becoming the staple diet of the poorest urban households. Rice has therefore become a staple of considerable strategic importance. At present, rice imports are still substantial perhaps because the region is not self-sufficient in rice production. The way imports have been managed means that there has not yet been any measurable impact of market opening on the domestic market. But, it is obvious to rice producing countries in ECOWAS that the changing domestic and world policy environment requires them to pay increasing attention to productivity issues.

To provide a historical perspective on ECOWAS rice production, Figure 1 shows land productivity over the past four-and-a-half decades (1961-2005) using the production-land ratio. Before inception of ECOWAS, rice productivity had been sluggish, with year-to-year fluctuations. Since the 1979/1980 production season, there is some improvement in the productivity of rice in all the major producing countries, apart from Guinea. The largest improvement can be observed in Senegal. It has the highest rate of per capita consumption in the region.

Figure 1: Rice yields in tonnes per hectare



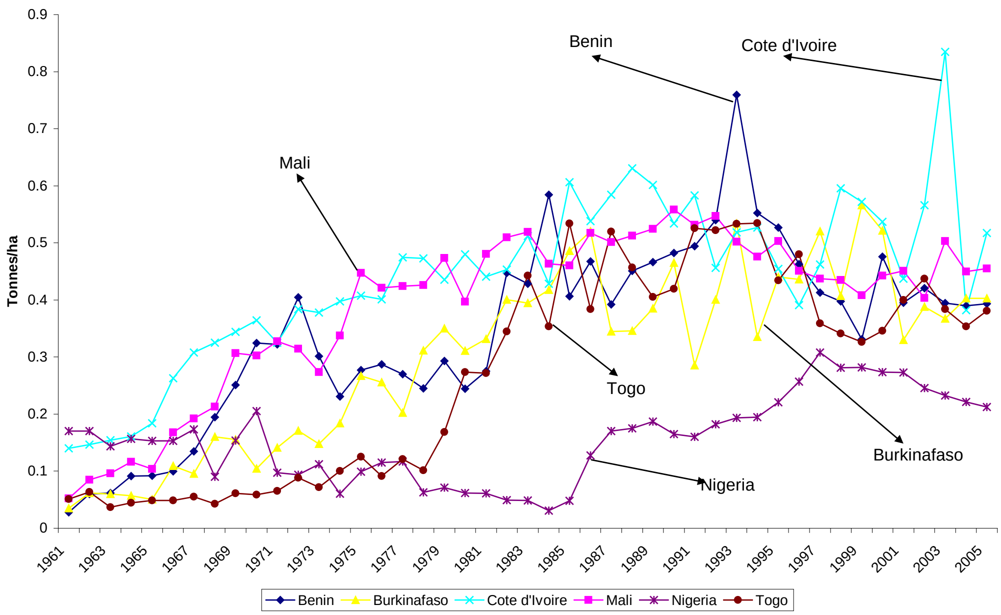
Cotton

Cotton plays an important part in ECOWAS development. At present, between one million and two million households produce cotton in ECOWAS. Generally, up to 16 million people are involved in cotton production in some way, and West and Central Africa taken together are the world's second largest exporters of cotton after the United States. In the ECOWAS region, cotton plays a critical role in the national economy with a share of total GDP accounting for about 3.5% in Benin and up to 8.8% in Togo. It also forms a significant share of total exports and contributes substantially to employment, providing a direct source of living for two million people in Burkina Faso (16 % of total population) and Mali (18 % of total population) (Fortucci, 2002).

While the region produces about 5% of the total world cotton, it exports about 15% of world cotton trade, with most cotton produced (95%) exported. This makes the region vulnerable to world cotton price fluctuations and to global factors that depress export prices. Consequently, the long-run economic performance of the cotton sector critically depends on improving the sector's efficiency through sectoral reforms, and sustained productivity through adoption of cost-effective and yield-enhancing technologies. A number of incentives exist for farmers to produce cotton as a key route to access cash income, particularly in the Sahelian zone of West Africa. These include a crop suited to climate (limited rain); natural comparative advantage given the low production cost and high quality of West African cotton fibre; existence of international demand; availability of a support infrastructure, agricultural and social services (e.g. extension, pharmacies, schools, etc) and established marketing channels; perhaps most importantly – there are limited alternative cash crops suited to these zones for which there is sufficient market demand. On the other hand, the traditional textiles industry has a long history in certain countries (e.g. Mali, Ghana, and Nigeria) and may present development opportunities. Ghana and Nigeria, in particular, seem to have developed an efficient local cotton processing industry that uses the majority of cotton produced in these countries. Employment related to the production of traditional cloth and clothing (spinning, dying, cloth making, sale, etc.) is, according to the Sahel and West Africa Club, the second largest employer in West Africa after agriculture. The study states that some 65%-70% of artisans in Mali, 50% in Burkina Faso and 30%-40% in Ghana are employed in the traditional textiles industry. Indeed, high regional demand continues to exist for the elegant traditional robes ("boubous") worn formally and for special occasions. However, this market remains more regional than international and, while of high quality, the products are more expensive than many clothing imports from Asia.

Figure 2 shows the productivity of cotton over the analysis period. Almost equal amounts produced are exported while imports are negligible. As in many other cotton producing countries in the world, ECOWAS countries experienced expanded cotton production and rising yields during the 1970s and 1980s, largely due to the expansion of insecticide use. However, towards the end of the 1980s, yields reached a plateau and began a downward trend, affecting many of the ECOWAS countries. Several factors account for yield decline, including rising insect resistance and less effective chemical control methods. Also, expanding cotton production into marginal lands with poor soil quality and reduced fertility-recovering fallow period have also contributed to lower yields (Levin, 2000). Another contributing factor to lower yields is the increased labour shortage resulting from cotton area expansion, as cotton is more labour-intensive than alternative cropping (Tefft et al., 1998).

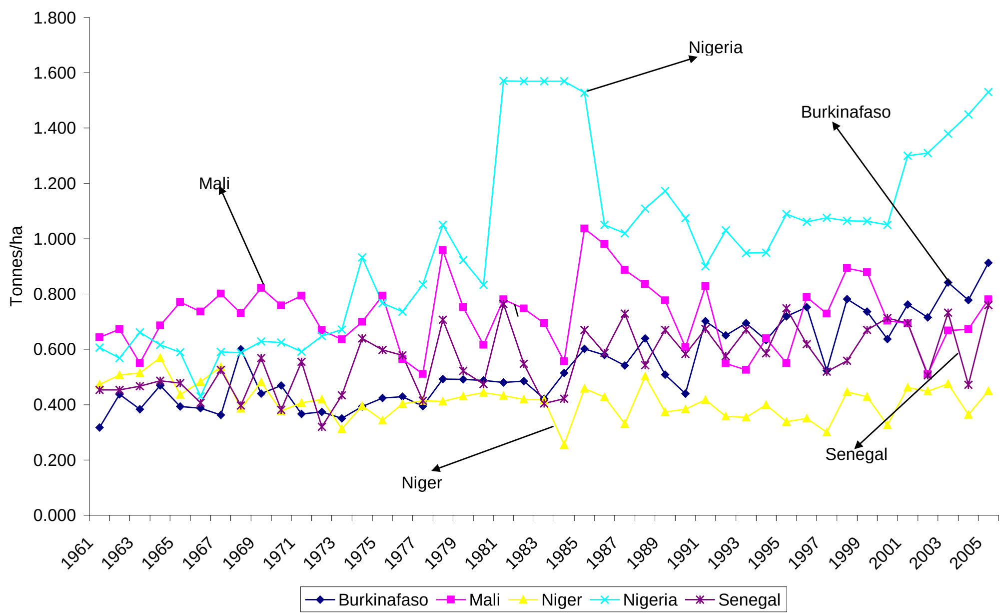
Figure 2: Cotton yields in tonnes per hectare



Millet

Millets [*Pennisetum glaucum* (L.) R. Br.] are essential to diets of people in the semi-arid tropics, where droughts often cause frequent failures of other crops. They are most important in West Africa, especially in the Sahelian part of ECOWAS sub-region, where they take about 70% of total cereal production. Generally, pearl millet is planted on about 28 million hectares, mainly in Africa and India, to produce 10 million tonnes of grain per year for about 70 million people. Pearl millet is particularly adapted to Sahelian West Africa where landraces have evolved in different ecological niches. In five major producing countries in ECOWAS region, namely Burkina Faso, Mali, Niger, Nigeria and Senegal, more than half of their population depends on pearl millet for over 1,000 calories per person per day. The yields of millet may be low under the area's environmental conditions, but they are relatively the most dependable staple crop. Gradually, Africa is becoming the world's leading producer of millet. In the quarter century since the early 1970s, African millet harvests increased 22%, whereas other regions registered substantial production declines.

Figure 3: Millet yields in tonnes per hectare



The percentage of millet used for domestic food consumption is rising steadily in Africa, but the vast and still expanding millet areas continue to produce low but steady yields with very few fertilizer inputs. Soon, Africa is likely to have the largest millet acreage of all developing regions, with yields only slightly below the developing country average. At present, Africans eat about four times as much millet per capita as the second largest consumers, Asians. Figure 3 indicates that the productivity of millet has increased steadily, particularly following the establishment of ECOWAS in 1975.

3. Methodology

This section outlines the concepts and methods applied in this study.

Measurements of total factor productivity

Productivity is defined as the ratio between output(s) and input(s). The basic (or partial) productivity measures used in the study of agriculture are labour and land productivity. *Labour productivity* is measured as output per person employed in agriculture; *land productivity* is measured as output per hectare or some other measures of land input. These measures are essentially partial productivity measures and when considered in isolation, they may provide a misleading indication of overall productivity. For example, it is possible to achieve increased land productivity by utilization of extra labour (or fertilizer, etc), which may result in improved overall productivity (Coelli and Rao, 2001). Since the pioneering work by Farrell (1957), which drew upon the works of Debreu (1951), a considerable effort has been directed at refining the measurement of productivity. An improvement over common partial productivity measures such as land productivity (yield) and/or labour productivity is the concept of overall or total factor productivity (TFP) and its components such as technical efficiency and technical change.

TFP measures aggregate output per aggregate input used in production. The technical efficiency of a country is defined as the degree to which it is able to convert its agricultural inputs efficiently into outputs – relative to best practice, where best practice is defined by the production frontier. The true production frontier is rarely known in practice. It is generally estimated using sample data on a number of farms or countries. When one considers productivity comparisons over time (productivity growth), an additional source of possible productivity improvements is technical change. It measures the extent to which the production frontier, representing the state of the technology in a particular time period, shifts upwards over time. Such shifts represent technological progress.

Broadly based empirical analyses have focused on global (Rao and Coelli, 1998), regional (Fulginiti, Perin and Yu, 2004; Coelli and Rao, 2001) and country level performance (Alabi, 2005). With regard to international comparison of TFP, there are five different approaches, namely: (i) time series growth accounting; (ii) cross section growth accounting; (iii) panel regression; (iv) non-parametric or parametric frontier; and (v) partial productivity approach. By time series approach, we refer to that growth accounting tradition in which analysis is focused on the time series dimension of data either in absolute or relative form. In the absolute form, time series data of individual countries are analysed without relating these to time series of other countries. In this form, researchers obtain TFP growth rates within individual countries. This approach does not require time series data of different countries to be brought to a common currency. This limitation is overcome by time series approach in the relative form, which brings data for different countries to a common currency, using either official exchange rates or exchange rates based on purchasing power parity. The use of the absolute form is as old as the study of TFP itself. This includes Timbergen (1959), who used the framework to conduct a comparison of TFP growth in France, Germany, the UK and the US for the period 1870-1910. Other works include Solow (1957) and Barger (1969). An excellent survey of previous works of absolute form can be found in Christensen, Cummings and Jorgenson (1981). More recent use of the approach includes Elias (1992), Chete and Adenikinju (1994), and Onjala (2002).

Jorgenson and Nishimizu (1978) initiated the relative form of time series approach to international TFP comparison. The authors conducted growth accounting for the US and Japan by considering their data in relative form. Christensen, Cummings and Jorgenson (1981) extended the method to the sample of nine countries. Recent users of the approach include Wolff (1991). The cross section growth accounting approach to TFP has been suggested recently by Hall and Jones (1999). The methodology is similar to that of time series growth accounting, but it is now applied along the cross section dimension. The panel approach to international TFP comparison arose directly from recent attempts at better explanation of cross country growth irregularities. Many researchers have used the method to investigate the determinants of growth (Hall and Jones, 1999; Makiw, Romer and Weil, 1992; and Islam, 1999).

Apart from the above three approaches, some research considered the use of Data Envelopment Analysis (DEA) and/or its parametric equivalent, Stochastic Frontier Approach (SFA) in computing productivity growth using the Malmquist productivity index, and provide a decomposition of this index into efficiency and technical change components. A detailed review of both approaches is provided through the collective works of Lovell and Schmidt (1988); Schmidt (1986); Bauer (1990); Seiford and Thrall (1990); and Greene (1993). The most commonly cited models using DEA are those developed by Malmquist (1953); Charnes, Cooper and Rhodes (1978); and Banker, Charnes, and Cooper (1984). In DEA, the performance of a farm or country is evaluated in terms of its ability to either shrink usage of an input, or expand the output level subject to the restrictions imposed by the best-observed practices. This measure of performance is relative, in the sense that the efficiency of each decision making unit (DMU) is evaluated against the most efficient DMU, and it is measured by the ratio of actual output to maximum potential output. In Stochastic Frontier Approach (SFA), there are two error terms. One accounts for the existence of technical inefficiency, and the other accounts for random disturbances arising out of measurement error, luck, bad weather, etc. In the past, common criticisms of DEA related to its inability to account for the measurement error and to test for significance of the efficiency measures. Fare, Grosskopf and Lovell (1995) proposed several statistical tests that have subsequently made DEA a powerful tool for efficiency analysis. One of the major limitations of the SFA is the restrictive assumption on the functional form of the production function and the distribution of the one-sided error term (Caves, Christensen and Diewert, 1982; Førsund, Lovell and Schmidt, 1980). In the agricultural economics literature, stochastic frontier estimation is generally the preferred procedure because of the inherent nature of uncertainty associated with agricultural production. Uncertainty in production can arise due to bad weather, fires, pests, and diseases.

However, because of limitations associated with both stochastic and non-stochastic frontier approaches, we use both techniques in the current study to compute productivity growth in rice, cotton and millet in ECOWAS. The non-stochastic method is, however, used as a confirmatory method. The Malmquist index has the advantage of computational ease and does not require information on cost or revenue shares to aggregate inputs or outputs (Hjalmarsson and Veiderpass, 1992). Consequently, it is less data demanding and it allows decomposition into changes in efficiency, technology and multilateral comparison. Several studies have investigated the sensitivity of efficiency estimates to estimation methods (Ferrier and Lovell, 1990; and Ruggiero and Vitaliano, 1999). This study seeks to make an important contribution to such knowledge related to the comparative analysis of alternative methods of measuring productivity growth and its decomposition. Details about the DEA and SFA framework are presented in the Appendix.

Empirical specification

In estimating both DEA and SFA models, this study utilized data on output and inputs of rice, cotton and millet from major producers of the crops to construct their indexes of TFP using the two methods described by Equations 1-17 in the Appendix. The sample data comprise annual measures of the output of each crop and six direct inputs (land area, seed, fertilizer, labour, capital and irrigation) for rice. The major countries producing rice are Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria, and Senegal. The major producers of cotton are Benin, Burkina Faso, Côte d'Ivoire, Mali, Nigeria, and Togo while the main producers of millet are Burkina Faso, Mali, Niger, Nigeria, and Senegal. In estimating the SFA model for each crop, several functional forms were fitted, beginning with Cobb-Douglas technology. The underlying stochastic production frontier function upon which the results and discussion of this study are based is approximated by the generalized Cobb-Douglas form (Fan, 1991). The function may also be viewed as a translog specification without cross terms, i.e. a strongly separable-inputs translog production frontier function. For rice, the specification is:

$$\ln y_{it} = \alpha_0 + \alpha_h \ln H_{it} + \alpha_s \ln S_{it} + \alpha_f \ln F_{it} + \alpha_l \ln L_{it} + \ln K_{it} + \ln I_{it} + \alpha_t t + \alpha_{tt} t^2 + \alpha_{ht} (\ln H_{it})\, t + \alpha_{st} (\ln S_{it})\, t + \alpha_{ft} (\ln F_{it})\, \mathrm{t} + \alpha_{lt} (\ln L_{it})\, t + \alpha_{kt} (\ln K_{it})\, \mathrm{t} + \alpha_{lt} (\ln I_{it})\, t + v_{it} - u_{it} \quad (18)$$

For cotton, fertilizer and irrigation are eventually omitted from the model because they remain insignificant, and empirical evidence alludes to their less importance in cotton production in the study area. The time trend variable was still included in the regression runs to account for general long-term time trends, which may have been influenced by a number of other factors. Examples of such influences are technological change and innovations (e.g. improvements in agricultural inputs and/or practices, and/or changes in production patterns), and increased productivity due to pesticide effects. The specification, therefore, is:

$$\ln y_{it} = \alpha_0 + \alpha_h \ln H_{it} + \alpha_s \ln \mathrm{Sit} + \alpha_l \ln L_{it} + \ln K_{it} + \alpha_t t + \alpha_{tt} t^2 + \alpha_{ht} (\ln H_{it})\, t + \alpha_{st} (\ln S_{it})\, t + \alpha_{lt} (\ln L_{it})\, t + \alpha_{kt} (\ln K_{it})\, t + v_{it} - u_{it} \quad (19)$$

For millet, the specification is also without irrigation, but fertilizer is an essential input for millet production, i.e.:

$$\ln y_{it} = \alpha_0 + \alpha_h \ln H_{it} + \alpha_s \ln S_{it} + \alpha_f \ln F_{it} + \alpha_l \ln L_{it} + \alpha_k \ln K_{it} + \alpha_t t + \alpha_{tt} t^2 + \alpha_{ht} (\ln H_{it})\, \mathrm{t} + \alpha st (\ln S_{it})\, t + \alpha_{ft} (\ln F_{it})\, t + \alpha_{lt} (\ln L_{it})\, t + \alpha_{kt} (\ln K_{it})\, t + v_{it} - u_{it} \quad (20)$$

The symbols are defined as follows:
y_{it} is the output of crop i in the tth year
H_{it} is the hectares of land cultivated to each crop
S_{it} is the quantity of seed planted in '000 tonnes
F_{it} is the quantity of fertilizer used in '000 tonnes
L_{it} is the amount of labour used in man-days
K_{it} is the amount of capital used
I_{it} is the proportion of each crop land area under irrigation
ln is the natural log
$\alpha_i s$ are unknown parameters to be estimated
$v_{it}s$ are $iidN(0,\sigma_v{}^2)$ random errors and are assumed to be independently distributed of the $u_{it}s$ which are non-negative random variables associated with TE inefficiency.

The distribution of the $u_{it}s$ are obtained by truncation at zero. The mean is defined as:

$$u_{it} = \beta_0 + \beta_1 \frac{K_{it}}{L_{it}} + \beta_{dj} \sum_{j=1}^{n} D_{tj} + \beta_{tj} \sum_{j=1}^{n} D_{tj} t \quad (21)$$

for cotton and millet.

where,

$\frac{K_{it}}{L_{it}}$ is capital-labour ratio for crop i in the t^{th} year

D_j is the dummy variable, which takes the value of 1 for the j^{th} state producing the selected crops.

βs are unknown parameters to be estimated.

For rice, rice import in tonnes is included to account for its influence on the inefficiency of rice producers in the region. The specification, therefore, is:

$$u_{it} = \beta_0 + \beta_1 \frac{K_{it}}{L_{it}} + \beta_2 M_{it} + \beta_{dj} \sum_{j=1}^{n} D_{tj} + \beta_{tj} \sum_{j=1}^{n} D_{tj} t \qquad (22)$$

where M indicates import of rice milled measured in tonnes.

In order to account for factors influencing the technical efficiency using DEA, the modification of the model by Ray (1991) and McCarty and Yaisawarng (1993) was used. In the modification, a two-stage approach is used to include the inefficiency factors. In the first stage, only the discretionary inputs are used in the DEA model. In the second stage, the efficiency index (E) obtained from the first stage is regressed upon the exogenous factors to disentangle inefficiency from production. The appropriate methodology for the regression is the Tobit model, since efficiency index (E), which is the dependent variable, lies between 0 and 1. The residual variance derived from the Tobit model captures the inefficiency unexplained by the production factors. This procedure has previously been documented and applied, among others, by Ruggiero and Vitaliano (1999). The regressor variables used in the Tobit model are the same as those that were used to explain technical efficiency in the SFA case for each crop.

Data and definition of inputs and outputs

Data for inputs and outputs are collected principally from FAOSTAT 2007. This is supplemented with International Rice Research Institute (IRRI) world rice statistics, and International Cotton Advisory Committee's (ICAC) cotton statistics. The data covered a period of 45 years from 1961 to 2005. Rice data are from six countries producing more than 80% of rice paddy in ECOWAS. They are Côte d'Ivoire, Ghana, Guinea, Mali, Nigeria and Senegal. Similarly, cotton data come from Benin, Burkina Faso, Côte d'Ivoire, Mali, Nigeria and Togo, while millet data are obtained from Burkina Faso, Mali, Niger, Nigeria and Senegal. The selected countries accounted for more than 90% production of cotton and millet in ECOWAS. The Malmquist indexes are calculated separately for each crop because of differences in the producing countries. The data set for each crop contains six inputs, namely: land area, seed, fertilizer, labour, tractor, irrigation and country dummies. The descriptions of the input-output data used in this study are:

Outputs

The quantity of each crop production is tonnes. This is taken from FAOSTAT database.

Inputs

Fertilizer: Fertilizer use is proxyed as the total fertilizer use in metric tonnes times the share of each crop harvested fields over arable land (UN, FAO).

Labour: This is measured as the amount of labour in each crop production proxied as the economically active agricultural labour force per unit of agricultural land times each crop harvested area (FAO). Some studies have used active workers in rural areas (World Bank, 2001). This was also tried but the results were not as good as when the former was used.

Capital: Capital as used in this study refers to the amount of capital used in each crop production. It is proxied as tractors used per unit of agricultural land times rice-harvested area (UN, FAO).

Land: Expressed in 1,000 hectares, it is measured as individual land area under each crop. Land data is also drawn from FAOSTAT data base.

Seed: Drawn from FAOSTAT data base and expressed in '000 metric tonnes, it covers quantity of each crop seed planted.

Irrigation: This is the proportion of rice land area that is irrigated. The proportion of rice land area irrigated is taken from IRRI world rice statistics.

Import: Import is included only in rice inefficiency model. It is measured as the metric tonnes of rice milled imported by the major producers considered in this study.

The descriptive statistics for the inputs and outputs are summarized in Tables 2 to 4. The tables contain the mean value and standard deviation of each crop producing nation by year as well as by reform period. In terms of the means across the reform periods, it is clear from the tables that there is a variation in both inputs and outputs among the countries. Cotton output from Mali, for instance, is up to three times as high as that achieved by Togo. The input usage follows the same trend. For example, Nigeria is using up to four times the amount of labour used by Mali. Rice output obtained by Nigeria in the sample is up to eight times as high as that achieved by Senegal, and the input usage also follows the same trend. In terms of standard deviation, large values are observed with respect to both output and inputs for all the crops. The figures show that both output and input values are generally higher in ECOWAS era than pre-ECOWAS.

Table 2: Rice descriptive statistics

	1961-1978		1979-2005		1961-2005	
Variable	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
COTE D'IVOIRE						
Output	338,288.89	101,551.01	605,203.93	103,788.77	498,437.91	166,843.72
Land (Ha)	304,183.33	61,612.88	454,897.70	107,777.87	394,611.96	117,924.51
Fert (Kg)	4,126.88	3,014.73	10,609.76	4,551.62	8,016.61	5,105.82
Labour (kg)	16,682.56	5,658.03	41,891.51	11,739.63	31,807.93	15,804.79
Tractor (no)	19.39	12.79	63.93	10.97	46.11	24.92
Irrigated(Ha)	27.45	20.64	85.21	21.15	62.11	35.32
Seed (kg)	34,939.06	7,174.80	54,432.41	9,283.20	46,635.07	12,809.49
GHANA						
Output	58,496.00	23,518.76	151,103.81	79,855.99	114,060.69	78,019.19
Land (Ha)	58,904.72	29,482.52	92,599.67	26,837.41	79,121.69	32,250.76
Fert (Kg)	373.22	603.62	554.07	370.16	481.73	479.34
Labour (kg)	7,211.02	4,410.94	19,594.61	8,629.50	14,641.17	9,442.59
Tractor (no)	16.06	1.83	27.30	4.56	22.80	6.68
Irrigated(Ha)	14.13	9.97	26.37	5.57	21.48	9.67
Seed (kg)	3,476.61	1,665.15	5,121.26	1,496.63	4,463.40	1,748.94
GUINEA						
Output	312,480.28	71,831.28	825,516.52	248,431.94	620,302.02	321,043.09
Land (Ha)	183,334.72	41,962.61	480,444.04	141,754.58	361,600.31	184,990.58
Fert (Kg)	562.51	201.09	1,215.00	930.96	954.00	795.15
Labour (kg)	15,261.69	4,442.64	6,1525.39	27,218.03	43,019.91	31,156.66
Tractor (no)	37.22	19.94	92.19	2.39	70.20	29.98
Irrigated Ha)	0.93	0.80	16.74	10.26	10.42	11.12
Seed (kg)	19,187.83	3,645.02	23,448.22	3,638.77	21,744.07	4,172.83
MALI						
Land (Ha)	171,248.61	27,257.81	271,072.85	96,945.76	231,143.16	91,030.96
Fert (Kg)	442.53	408.59	2,380.25	1,112.37	1,605.16	1,310.46
Labour (kg)	3,747.42	733.80	9,197.97	4,452.41	7,017.75	4,383.41
Tractor (no)	60.06	0.24	115.04	72.49	93.04	62.03
Irrigated Ha)	2.68	1.47	16.45	8.44	10.94	9.46
Seed (kg)	17,461.17	3,198.54	27,669.41	9,955.38	23,586.11	9,385.94
NIGERIA						
Land (Ha)	234,444.44	58,719.90	1,461,340.74	687,282.14	951,058.70	808,096.18
Fert (Kg)	201.21	238.59	11,817.31	6,414.13	7,020.18	7,564.42
Labour (kg)	39,000.22	11,052.65	248,153.22	116,384.56	161,035.62	137,552.54
Tractor (no)	200.00	0.00	227.67	28.09	213.41	33.27
Irrigated Ha)	14.13	12.51	533.81	344.06	318.89	368.18
Seed (kg)	12,419.44	3,326.02	88,355.93	51,958.95	56,821.30	54,862.09
SENEGAL						
Output	101,833.22	32,619.45	163,352.96	46,149.35	140,009.73	50,846.35
Land (Ha)	79,665.94	13,420.75	75,517.33	11,050.88	77,283.07	12,200.52
Fert (Kg)	724.47	506.18	780.53	326.27	769.90	400.06
Labour (kg)	7,363.56	1,514.44	11,294.92	3,209.28	9,818.39	3,254.49
Tractor (no)	77.61	7.94	87.22	19.36	83.68	16.45
Irrigated(Ha)	2.89	0.90	5.19	1.45	4.33	1.66
Seed (kg)	5,600.78	931.35	5,276.78	740.27	5,424.25	828.21

Table 3: Cotton descriptive statistics

	1961-1978		1979-2005		1961-2005	
Variable	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
BENIN						
Output (MT)	7,533.33	5,772.21	84,148.81	59,005.28	54,343.76	59,299.53
Land (Ha)	33,140.67	11,326.99	190,741.96	143,240.10	130,351.62	135,874.20
Seed (kg)	13,444.44	9,370.87	120,919.54	86,151.27	79,464.62	85,599.38
Tractor (no)	77.67	11.02	153.81	28.63	124.04	44.73
Labour(pop)	1,163.61	43.12	1,542.27	223.90	1,399.18	264.85
BURKINA FASO						
Output MT)	9,697.94	6,386.52	87,537.26	58,363.13	56,401.53	59,293.72
Land (Ha)	62,357.50	16,175.11	214,848.67	145,602.37	153,852.20	135,410.78
Seed (kg)	16,697.33	10,771.88	125,132.11	87,294.44	81,758.20	86,219.64
Tractor (no)	59.78	23.59	1,119.41	830.16	695.56	826.47
Labour (pop)	2930.28	207.55	4,336.04	742.31	3,773.73	909.57
COTE D'VOIRE						
Output (MT)	15,039.83	11,284.98	105,829.85	38,429.99	69,513.84	54,269.11
Land (Ha)	41,471.11	21,206.86	201,527.67	60,945.88	137,505.04	93,041.45
Seed (kg)	22,350.44	15,294.49	128,912.81	39,411.65	86,287.87	61,607.58
Tractor (no)	1,357.06	819.91	3,548.15	278.90	2,671.71	1,218.24
Labour (pop)	1703.50	237.28	2919.67	370.21	2,433.20	682.48
MALI						
Output (MT)	20,125.78	14,799.32	132,138.04	72,510.17	87,333.13	79,190.37
Land (Ha)	70,491.83	20,274.04	28,2713.00	166,679.15	197,824.53	166,223.19
Seed (kg)	31,100.00	21,771.16	166,832.26	76,261.93	112,539.36	90,232.24
Tractor (no)	495.72	252.46	2,012.04	638.16	1,405.51	910.84
Labour (pop)	2,668.89	270.81	3,965.63	545.17	3,446.93	785.30
NIGERIA						
Output (MT)	49,966.17	15,911.35	86,313.19	49,649.11	71,774.38	43,343.96
Land (Ha)	406,388.89	124,988.06	472,258.26	118,265.72	445,910.51	123,958.32
Seed (kg)	96,544.56	31,869.63	150,727.30	83,852.38	129,054.20	72,579.82
Tractor (no)	3,822.22	3,090.75	22,992.59	7,471.33	15,324.44	1,1264.15
Labour (pop)	15,027.89	753.83	15,464.07	108.01	15,289.60	522.64
TOGO						
Output (MT)	2,531.94	561.34	39,611.00	22,111.22	24,779.38	25,029.69
Land (Ha)	40,322.06	15,558.98	98,135.70	59,662.05	75,010.24	54,930.13
Seed (kg)	4,863.44	1,253.11	52,203.56	27,859.68	33,267.51	31,769.99
Tractor (no)	56.83	15.44	87.04	7.48	74.96	18.69
Labour (pop)	677.61	78.03	1,124.89	211.44	945.98	279.06

Table 4: Millet descriptive statistics

	1961-1978		1979-2005		1961-2005	
Variable	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
BURKINA FASO						
Output	321,857.28	57,921.23	728,363.26	248,118.27	565,760.87	279,704.84
Land (Ha)	775,176.00	96,236.80	1,127,030.70	198,295.56	986,288.82	239,167.78
Seed (kg)	11,754.81	1,314.94	17,090.59	2,740.99	14,956.28	3,477.90
Fert (kg)	507.59	848.12	5,719.71	4,272.60	3,634.86	4,211.06
Tractor (no)	5.64	2.46	136.30	101.93	84.04	101.65
Labour(pop)	273,748.19	41,744.85	510,544.92	127,842.76	415,826.23	155,223.29

continued next page

Table 4 Continued

	1961-1978		1979-2005		1961-2005	
Variable	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
MALI						
Output	449,777.78	52,013.07	761,070.15	199,948.36	636,553.20	220,124.24
Land (Ha)	643,833.33	108,189.51	1,067,938.15	310,579.72	898,296.22	325,069.20
Seed (kg)	19,031.67	3,201.32	32,201.32	7,655.28	26,933.46	9,008.91
Fert (kg)	1,708.56	1,775.55	9,399.13	4,377.47	6,322.90	5,201.78
Tractor(no)	9.98	5.74	64.04	29.38	42.42	35.22
Labour(pop	54,087.30	11,112.45	123,219.99	41,810.12	95,566.91	47,473.98
NIGER						
Output	903,622.22	157,912.30	1,735,260.48	509,129.02	1,402,605.18	576,686.42
Land (Ha)	2,083,455.56	346,545.15	4,335,816.15	1,056,529.45	3,434,871.91	1,396,863.30
Seed (kg)	32,320.15	5,702.57	64,443.80	13,697.93	5,1594.34	19,409.54
Fert (kg)	109.93	165.78	1,258.07	871.17	798.81	884.67
Tractor (no)	2.80	2.45	17.23	3.99	11.46	7.93
Labour op)	145,879.21	45,649.69	509,127.14	185,451.00	363,827.97	231,333.58
NIGERIA						
Output	2,841,944.44	606,745.27	4,678,962.96	1,399,677.20	3,944,155.56	1,458,836.40
Land (Ha)	4,289,555.56	753,003.88	4,056,777.78	1,289,582.29	4,149,888.89	1,102,301.73
Seed (kg)	67,037.33	13,681.08	71,582.81	24,203.24	6,9764.62	20,580.10
Fert (kg)	3,105.18	3,386.32	33,705.71	17,460.77	21,465.50	20,357.50
Tractor (no)	225.65	182.33	1,420.12	745.39	942.33	831.48
Labour op)	926,414.45	174,561.11	878,043.17	281,723.27	897,391.68	243,406.44
SENEGAL						
Output	434,266.67	108,419.60	539,558.19	129,216.81	497,441.58	130,878.63
Land (Ha)	877,150.00	78,430.05	880,236.26	100,802.90	879,001.76	91,560.51
Seed (kg)	26,437.83	2,172.66	26,394.46	3,033.65	26,411.81	2,694.89
Fert (kg)	8,005.67	5,388.36	8,837.18	2,699.27	8,504.57	3,961.43
Tractor (no)	31.99	9.15	59.39	9.13	48.43	16.31
Labour (pop)	194,280.41	30,365.46	308,595.94	50,034.64	262,869.73	7,1015.36

4. Empirical results

The results of the stochastic frontier and inefficiency models

The parameter of the stochastic quasi translog production frontier function is estimated using FRONTIER 4.1 software (Coelli, 1996). The parameter estimates of the model for the whole period (1961-2005), pre-ECOWAS period (1961-1978) and ECOWAS period (1979-2005) are presented in tables 5, 6 and 7 for rice, cotton and millet, respectively. The variance parameters σ^2 and γ are significantly different from zero. This provides statistical confirmation of the presumption that there are differences in technical efficiency among the countries. The mode of the truncated normal distribution μ, is significantly different from zero, providing statistical evidence that the distribution of the random variable μ, has a non-zero mean and is truncated below zero. The ratio of the country specific variability to total variability measured by γ is positive and significant at 1% significance level for all the crops. This implies that country-specific technical efficiency is important in explaining the total variability of each crop output produced in ECOWAS. Thus, the stochastic frontier production function is empirically justified. Further, the statistical significance of modelling country effects is further examined using likelihood ratio tests. The logarithm of the likelihood function indicates a satisfactory fit for the generalized Cobb-Douglas specification for all the crops. The statistical significance of all of the parameters: σ^2, γ, and L, reinforces the view that technical efficiency affects productivity. The results of the maximum likelihood estimate of the stochastic frontier model for individual crops are reported below.

Table 5: MLE estimates of the stochastic frontier model for ECOWAS rice

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
α_0	-1.44	-3.42	2.00	5.54	1.10	5.44
α_h	0.61	6.81	0.73	4.96	0.56	16.13
α_f	-0.052	-3.67	0.056	2.86	-0.0097	-0.74
α_l	0.41	9.94	-0.020	-0.28	0.26	8.49
α_s	0.33	6.25	0.098	1.71	0.021	0.76
α_i	0.029	1.28	0.13	1.39	0.43	12.75
α_k	0.012	0.85	-0.12	-7.36	0.058	4.91

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Table 5 Continued

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
α_t	0.12	9.81	-0.066	-0.92	0.082	6.20
$0.5\alpha_{tt}$	0.0011	5.64	-0.0067	-6.74	0.0011	5.12
α_{ht}	0.0044	1.39	0.025	9.09	0.012	4.59
α_{ft}	0.0020	3.02	-0.0053	-2.06	0.00032	0.34
α_{lt}	-0.012	-7.36	-0.00064	-0.11	-0.015	-7.66
α_{st}	-0.013	-6.31	-0.013	-1.11	-0.0053	-2.23
α_{it}	0.0065	5.79	0.00042	0.23	-0.013	-6.76
α_{kt}	0.0020	3.28	0.0051	6.84	0.00088	0.90

*, +, ^ indicate significant at 1, 5, and 10%, respectively.

Table 6: MLE estimates of the stochastic frontier model for ECOWAS cotton

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
α_0	-1.92	-6.35	-0.37	-0.99	-0.32	-0.63
α_h	0.14	2.91	0.057	0.90	-0.063	-0.78
α_s	1.03	28.49	1.00	2.34	1.07	2.03
α_l	-0.051	-2.44	0.096	-2.87	-0.010	-0.27
α_k	0.036	2.01	-0.057	-1.51	0.036	1.68
α_{ht}	-0.013	-0.58	-0.0043	-0.80	0.015	2.60
α_{st}	-0.0020	-1.12	-0.0030	0.93	-0.024	-5.07
α_{kt}	-0.0028	-3.52	-0.0022	-0.68	-0.0028	-1.03
α_{lt}	-0.00070	-1.00	0.0036	2.00	0.0045	2.24
α_t	0.063	4.46	0.067	1.84	0.16	4.01
$0.5\alpha_{tt}$	0.00058	2.98	-0.0019	-2.06	-0.00076	-1.51

*, +, ^ indicate significant at 1, 5, and 10% respectively.

Table 7: MLE estimates of the stochastic frontier model for ECOWAS millet

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
α_0	6.08	5.61	-0.65	-0.86	12.07	10.88
α_h	0.47	2.55	1.00	3.83	0.38	1.16
α_s	0.14	0.87	0.25	0.91	0.19	0.58
α_f	0.027	0.81	0.17	0.32	0.15	1.81
α_k	-0.05	-0.80	0.045	0.72	0.34	4.54
α_l	-0.012	-0.13	-0.21	-1.89	-0.66	-3.09
α_t	0.0088	0.30	0.22	2.23	-0.042	-0.67
$0.5\alpha_{tt}$	-0.00013	-0.49	0.00022	0.098	0.0013	2.09
α_{ht}	0.0077	1.16	-0.0087	-0.39	0.014	1.32
α_{st}	-0.012	-1.83	-0.015	-0.68	-0.0073	-0.65
α_{ft}	-0.0010	-0.93	0.0011	0.25	-0.0036	-1.59
α_{kt}	0.0041	2.83	0.0073	1.35	-0.0016	-0.73
α_{lt}	0.0013	0.38	0.0029	0.25	-0.0057	-0.82

*, +, ^ indicate significant at 1, 5, and 10% , respectively.

The results of the inefficiency models for both DEA and SFA are reported in tables 8, 9 and 10. The results show that the included variables impact efficiency in the two models more or less differently. Several variables that are significant for the SFA are not significant for the DEA model. They also differ significantly in respect of signs and magnitudes across the whole period, as well as the reform periods under consideration. In terms of robustness and reliability of estimated parameters, the results for SFA are preferred, and hence discussed.

Table 8: MLE estimates of the efficiency model for ECOWAS rice

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
Stochastic Frontier approach						
β_0	0.37	0.93	-0.21	-0.51	0.88	1.93
β_1	-0.97	-3.52	0.79	2.37	-0.017	-4.43
β_2	-0.00060	-3.55	-0.55	-1.31	0.59	0.84
β_3	0.56	1.47	-0.56	-1.52	-0.83	-1.76
β_4	0.51	1.32	0.15	0.37	-0.039	-0.096
β_5	-1.64	-3.95	-0.83	-2.26	-1.36	-3.55
β_6	0.30	0.77	0.40	1.03	0.61	1.55
β_7	0.45	1.18	0.15	0.40	0.85	2.02
β_8	0.18	0.48	0.50	1.37	1.65	3.21
σ^2	0.054	8.54	0.048	6.31	0.041	10.86
γ	0.99	3.04	1.00	56642	1.00	6124100
L	173.33		78.51		183.79	
Data Envelopment Analysis approach						
β_0	1.02	76.66	0.98	66.66	0.98	53.69
β_1	-0.08	-2.33	1.00	0.65	3.33	1.50
β_2	-0.0003	-1.34	0.0004	0.69	-0.0004	-1.57
β_3	0.02	1.29	0.006	0.36	0.012	0.66
β_4	0.004	-0.31	-0.01	-0.84	-0.003	-0.16
β_5	-0.002	-2.05	-0.003	-0.17	-0.03	-1.39
β_6	-0,006	-0.45	-0.01	-0.64	-0.06	-2.38
β_7	0.14	2.04	-0.34	-1.28	0.26	2.79
β_8	-1.72	-8.06	-1.17	-3.46	-2.28	-8.06
σ^2	0.06	23.39	0.04	8.89	0.07	15.53
γ						
L	441.47		213.11		254.15	

*, +, ^ indicate significant at 1, 5, and 10%, respectively.

Table 9: MLE estimates of the inefficiency model for ECOWAS cotton

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
Stochastic Frontier approach						
β_0	-0.014	-0.037	-0.14	-0.36	-0.73	-1.70
β_1	-0.030	-0.25	-1.05	-3.71	2.88	3.59

continued next page

Table 9 continued

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
Stochastic Frontier approach						
β_2	-0.066	-0.17	0.15	0.38	-0.17	-0.39
β_3	-0.50	-1.32	-0.89	-1.64	-0.035	-0.092
β_4	0.0016	0.0042	0.28	0.72	-0.29	-0.74
β_5	0.12	0.32	0.20	0.52	-0.51	-1.17
β_6	0.36	0.97	-0.12	-0.29	0.054	0.13
β_7	-0.063	0.16	0.23	0.58	0.22	0.57
σ^2	-0.014	10.87	-0.018	3.98	0.021	7.30
γ	0.29	6.21	0.83	135.95	0.64	6.24
L	214.25		113.94		135.95	
Data Envelopment Analysis approach						
β_0	0.98	87.59	0.98	51.29	0.97	69.70
β_1	0.02	1.33	-0.007	-0.15	0.04	1.52
β_2	-0.04	-2.25	-0.05	-1.76	-0.03	-1.45
β_3	-0.04	-2.18	-0.03	-1.10	-0.04	-2.10
β_4	-0.04	-2.19	-0.04	-0.95	-0.06	-1.75
β_5	-0.02	-1.48	-0.03	-0.98	-0.03	-1.31
β_6	-0.04	-2.05	-0.03	-0.90	-0.08	-1.91
β_7	-0.79	-7.60	-0.40	-1.65	1.06	-4.72
σ^2	0.08	23.92	0.08	10.88	0.08	18.13
L	334.05		125.89		215.47	

*, +, ^ indicate significant at 1, 5, and 10%, respectively.

Table 10: MLE estimates of the inefficiency model for ECOWAS millet

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
Stochastic Frontier approach						
β_0	0.51	1.15	-0.57	-1.23	0.12	0.27
β_1	0.013	0.024	3.33	2.82	1.26	1.61
β_2	0.65	1.54	0.34	0.79	0.017	0.042
β_3	0.25	0.62	-0.053	-0.13	0.99	2.32
β_4	0.22	0.53	0.39	0.87	-0.16	-0.37
β_5	-1.15	-2.74	-1.26	-2.54	-1.16	-2.53
β_6	0.54	1.30	0.11	0.26	0.44	1.05
σ^2	0.028	11.20	0.029	4.06	-0.040	6.39
γ	0.21	4.25	0.60	4.75	0.99	181.15
L	97.06		48.77		66.55	
Data Envelopment Analysis approach						
β_0	0.93	61.01	0.97	32.77	0.94	40.85
β_1	-14.58	-0.87	-399.43	-3.55	-17.85	-0.87

continued next page

Table 10 continued

	1961-2005		1961-1978		1979-2005	
Coefficient	**estimate**	**t-ratio**	**estimate**	**t-ratio**	**estimate**	**t-ratio**
Data Envelopment Analysis approach						
β_2	0.04	1.79	-0.01	0.14	0.02	0.78
β_3	-0.03	-1.41	-0.02	-0.66	-0.03	-1.04
β_4	-0.03	0.11	-0.02	-0.55	-0.02	-0.67
β_5	0.14	1.01	-0.04	1.08	0.15	0.69
β_6	0.04	0.23	0.32	0.97	-0.15	-0.63
σ^2	0.10	13.23	0.09	11.24	0.11	9.01
γ						
L	183.11		84.65		107.94	

*, +, ^ indicate significant at 1, 5, and 10%, respectively.

Rice

The results indicate that 14 out of 22 variables are found to be statistically significant. Apart from fertilizer, the coefficients of all the variables have the expected positive signs over the entire analysis period. However, in pre-ECOWAS era, the coefficient of fertilizer follows a priori expectation of positive and significant sign, while in ECOWAS it is insignificant. The result is a reflection of the political economy of fertilizer in the region. The removal of fertilizer subsidies appears to have drastically limited or delayed the availability of fertilizer to the rice farmers when needed and/or at affordable price in the region. The negative coefficient of fertilizer over the entire analysis period suggests operation in stage III of the production function, where there is considerable congestion in the use of fertilizer. Such congestion might be due to late availability of fertilizer to farmers in the region. Over the analysis period, the coefficient of both labour and capital are positive and significant. The capital-labour ratio, however, has a negative impact on the rice technical efficiency. The coefficient on the time trend indicates positive technological progress in rice production between 1961 and 2005. The frontier is shifting upwards at an annual rate of 12%. The technological progress actually takes place in the ECOWAS era, as the results indicate technological decline during the pre-reform period.

Cotton

The Maximum Likelihood Estimates for cotton is not as robust as that of rice. The number of statistically significant variables is seven. The coefficients of the variables, except labour, conform to a priori expectation of positive sign. This indicates over-utilization of labour input. However, a lot of the surplus labour seems to have been shed in the pre-reforms era, as the results of the reform period indicate insignificance of labour use in cotton production. The coefficient of capital is positive and significant over the entire analysis period, as well as in the reform period. Capital-labour ratio is positive and significant in the reform period. A 1% increase in capital-labour ratio will cause about 2.88% increase in cotton technical efficiency in the reform era. The correlation in pre-reform era is negative. Like rice, the coefficient on the time trend indicates positive technological progress in cotton production in all the time period considered for analysis. Between 1961 and 2005, the frontier shifted upwards at an annual rate of 6.3%. The rates of increase in pre-reform and reform periods are 6.7% and 16%, respectively. Various cotton support systems and growing textile industries in the region might be the reason for this phenomenal technological progress.

Millet

The Maximum Likelihood Estimates for millet is somehow similar to that of cotton. The number of statistically significant variables is seven and the coefficients of the variables, except labour, conform to a priori expectation of positive sign. This indicates over-utilization of labour input. Unlike cotton, however, overutilization of labour continues in the reform period. The coefficient of capital is positive in both reform periods. It is, however, significant only in the reform period. Capital-labour ratio has positive but insignificant impact on millet technical efficiency over the entire analysis period, as well as in the reform period. However, a 1% increase in capital-labour ratio will cause about 3.3% and 1.26% increase in millet technical efficiency in pre-reform and reform era, respectively. Like rice and cotton, the coefficient on the time trend indicates positive technological progress in millet production over the entire analysis period (1961-2005), the frontier shifting upwards at an annual rate of about 0.9%. The technological progress actually takes place in the pre-ECOWAS era as the results indicate technological decline in the reform period.

Technical efficiency scores

Solving the linear programme (13) yields Farrell's technical efficiency scores, a component of the productivity index calculation. The equivalent parametric scores are obtained by estimating exp(–*u*). The estimates of the parametric efficiency scores are obtained using Battese and Coelli's (1992) formula for deriving the expected value of the efficiency scores. The average efficiency scores for major countries producing the selected crops are shown in Table 11. The results can be interpreted as the average performance of each country relative to the regional frontier in a given period. Compared with the SFA approach, the DEA estimation tends to produce higher efficiency scores for all the selected crops. They, however, show fewer systematic patterns over the years than SFA scores as expected. These results mean that the underlying technology and the length of time for which it constraints output/input decisions make a difference to the efficiency results. The non-parametric method attributes any deviation from the frontier to inefficiency, whereas the parametric method recognizes the stochastic component in constructing the frontier. This tendency is more pronounced in the result for Senegal among rice producing countries, and Benin and Burkina Faso among cotton producing countries in ECOWAS. Among the millet producing countries, the tendency is more pronounced for Niger and Togo than others. Even though the efficiency scores fluctuate using both methods, the overall means for each state as shown in Table 11 indicate that Guinea, Nigeria and Mali are the least efficient rice, cotton and millet producing countries, respectively.

Table 11: Average efficiency scores

Country	Average efficiency scores					
	SFA cotton	DEA cotton	SFA rice	DEA rice	SFA millet	DEA millet
Benin	0.972	0.945				
Burkina Faso	0.990	0.947			0.963	0.372
Côte d'Ivoire	0.958	0.953	0.996	0.984		
Ghana			0.980	0.975		
Guinea			0.961	0.964		
Mali	0.894	0.962	0.992	0.971	0.893	0.436
Niger					0.929	0.442
Nigeria	0.708	0.955	0.992	0.971	0.912	0.965
Senegal			0.993	0.997	0.925	0.373
Togo	0.930	0.980				

Malmquist productivity indexes: SFA

Malmquist productivity indexes and their efficiency change and technical change components were computed for each country in the sample. The year to year changes over the entire period for rice, cotton and millet are shown in tables 12, 13 and 14. The summary descriptions of annual changes over the entire period, pre-ECOWAS and ECOWAS era are shown in tables 15, 16 and 17. If the value of the Malmquist index or any of its components is less than one, it implies regress between two adjacent periods, whereas values greater than one imply progress or improvement. In order to obtain the magnitude of progress or regress, the values of Malmquist indexes or any of its components can be subtracted from one. The values of the indexes capture productivity relative to the best performers. Some salient features of the results are summarized for the selected crops as discussed in the next section.

Table 12: ECOWAS rice total factor productivity decomposition

	SFA Approach			DEA Approach		
Year	Efficiency change	Technical change	Total factor productivity	Efficiency change	Technical change	Total factor productivity
1961	1	1	1	1	1	1
1962	1.141	1.071	1.222	0.806	0.976	0.787
1963	1.055	1.072	1.131	0.888	1.017	0.902
1964	0.967	1.073	1.038	0.905	0.97	0.878
1965	1.043	1.075	1.121	1.097	1.039	1.14
1966	0.832	1.077	0.896	0.986	0.998	0.984
1967	1.063	1.078	1.146	0.954	1.002	0.956
1968	0.973	1.079	1.05	1.991	1.002	1.995
1969	1.094	1.08	1.181	0.826	0.949	0.784
1970	0.866	1.081	0.937	0.665	1.045	0.695
1971	1.094	1.083	1.185	0.797	1.014	0.808

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Table 12 continued

	SFA approach			DEA approach		
Year	**Efficiency change**	**Technical change**	**Total factor productivity**	**Efficiency change**	**Technical change**	**Total factor productivity**
1972	0.92	1.085	0.998	1.067	0.953	1.017
1973	1.032	1.085	1.12	1.544	0.983	1.517
1974	1.314	1.087	1.428	1.107	1.075	1.19
1975	0.962	1.088	1.046	1.12	0.977	1.095
1976	0.952	1.09	1.037	1.74	1.025	1.783
1977	0.988	1.09	1.078	0.733	1	0.733
1978	1.137	1.091	1.241	1.189	1	1.189
1979	0.914	1.092	0.997	1.095	1	1.095
1980	0.935	1.092	1.022	1.078	1	1.078
1981	1.174	1.094	1.284	0.909	1	0.909
1982	0.922	1.095	1.009	0.935	1	0.934
1983	1.123	1.096	1.231	2.292	1	2.292
1984	0.964	1.096	1.057	0.541	0.996	0.539
1985	1.138	1.097	1.249	0.834	0.918	0.765
1986	0.947	1.098	1.039	0.929	1.072	0.995
1987	1.073	1.099	1.179	0.816	1.008	0.822
1988	1.066	1.099	1.172	1.162	0.992	1.153
1989	0.964	1.1	1.061	1.192	1.013	1.207
1990	1.089	1.102	1.2	0.954	1.004	0.958
1991	1.019	1.102	1.123	2.653	1.018	2.701
1992	0.996	1.103	1.098	0.822	1.006	0.826
1993	1.075	1.104	1.186	0.761	0.933	0.71
1994	0.897	1.105	0.99	1.039	1.111	1.154
1995	1.023	1.105	1.131	1.045	0.978	1.021
1996	1.063	1.106	1.175	0.915	1.016	0.929
1997	0.948	1.107	1.05	0.964	1.001	0.965
1998	1.006	1.108	1.116	2.267	1.001	2.269
1999	1.062	1.109	1.178	0.676	0.941	0.636
2000	0.991	1.11	1.1	0.8	0.829	0.664
2001	0.946	1.111	1.051	1.014	1.055	1.069
2002	0.995	1.112	1.106	1.159	1.124	1.303
2003	1.045	1.113	1.163	1.217	1.005	1.223
2004	0.932	1.114	1.038	0.957	0.993	0.95
2005	1.122	1.115	1.251	0.987	0.934	0.922

Table 13: ECOWAS cotton total factor productivity decomposition

	SFA approach			DEA approach		
Year	Efficiency change	Technical change	Total factor productivity	Efficiency change	Technical change	Total factor productivity
1961	1	1	1	1	1	1
1962	1.047	1.007	1.222	0.976	1.45	1.416
1963	0.996	1.007	1.131	1.131	1.317	1.489
1964	1	1.007	1.038	0.995	1.22	1.213
1965	0.998	1.007	1.121	1.001	1.007	1.009
1966	1.009	1.007	0.896	0.953	1.034	0.986
1967	0.998	1.006	1.146	0.981	0.741	0.727
1968	0.989	1.006	1.05	1.137	1.558	1.772
1969	1.006	1.006	1.181	0.97	1.118	1.084
1970	1.002	1.007	0.937	1.024	0.689	0.705
1971	1.006	1.007	1.185	0.985	0.736	0.725
1972	0.994	1.007	0.998	0.999	1.071	1.07
1973	0.999	1.008	1.12	0.851	1.129	0.961
1974	1.006	1.008	1.428	1.155	0.818	0.944
1975	1.004	1.008	1.046	1.054	0.726	0.765
1976	0.986	1.008	1.037	0.912	0.363	0.33
1977	0.994	1.01	1.078	1.146	1.219	1.396
1978	1.01	1.01	1.241	1.002	0.887	0.888
1979	0.987	1.009	0.997	0.994	1.048	1.042
1980	1.011	1.01	1.022	1.016	1.349	1.37
1981	0.992	1.011	1.284	0.957	0.91	0.871
1982	1.011	1.011	1.009	0.99	0.979	0.969
1983	0.998	1.011	1.231	0.979	3.017	2.953
1984	0.999	1.011	1.057	1.125	1.085	1.22
1985	0.991	1.01	1.249	0.815	1.287	1.048
1986	1.012	1.009	1.039	1.26	0.825	1.04
1987	0.998	1.01	1.179	1.013	1.015	1.028
1988	1.003	1.009	1.172	1.007	1.032	1.039
1989	1.001	1.009	1.061	0.999	1.034	1.033
1990	0.994	1.009	1.2	0.956	0.991	0.947
1991	1.009	1.009	1.123	1.003	2.574	2.582
1992	1.002	1.01	1.098	0.972	0.757	0.736
1993	1.001	1.011	1.186	1.005	1.519	1.526
1994	1	1.01	0.99	1.003	0.572	0.573
1995	1.001	1.011	1.131	0.966	1.523	1.472
1996	1.002	1.01	1.175	0.977	1.249	1.22
1997	1.005	1.009	1.05	1.062	1.093	1.161
1998	1.002	1.009	1.116	1.021	2.841	2.9
1999	1.004	1.011	1.178	1.003	0.552	0.553
2000	0.991	1.012	1.1	0.996	0.7	0.697
2001	0.998	1.011	1.051	0.962	1.351	1.299
2002	0.993	1.011	1.106	1.034	1.442	1.49
2003	1.001	1.012	1.163	0.962	0.895	0.861
2004	0.97	1.012	1.038	1.054	0.917	0.966
2005	0.998	1.013	1.251	1.011	0.938	0.948

Table 14: ECOWAS millet total factor productivity decomposition

	SFA approach			DEA approach		
Year	**Efficiency change**	**Technical change**	**Total factor productivity**	**Efficiency change**	**Technical change**	**Total factor productivity**
1961	1	1	1	1	1	1
1962	1.007	1.121	1.128	1.046	0.834	0.872
1963	1.016	1.122	1.141	1.011	0.514	0.52
1964	1.006	1.122	1.129	0.991	0.609	0.604
1965	1.002	1.123	1.125	0.983	0.904	0.888
1966	0.976	1.122	1.096	0.954	0.98	0.935
1967	1.024	1.123	1.151	1.098	0.771	0.846
1968	0.986	1.123	1.107	0.921	0.921	0.848
1969	1.023	1.124	1.15	1.039	1.001	1.04
1970	0.967	1.125	1.088	1.088	1.647	1.792
1971	1.01	1.125	1.137	0.965	0.517	0.499
1972	0.969	1.124	1.09	0.94	0.796	0.748
1973	1.002	1.126	1.128	0.885	0.947	0.838
1974	1.036	1.126	1.167	1.083	0.873	0.946
1975	0.99	1.125	1.114	1.018	0.953	0.971
1976	0.995	1.125	1.119	0.961	0.76	0.73
1977	0.977	1.125	1.1	1.188	1.073	1.275
1978	1.054	1.123	1.184	0.811	0.854	0.693
1979	0.985	1.123	1.107	1.064	1.18	1.255
1980	0.991	1.125	1.115	0.917	0.744	0.683
1981	1.031	1.124	1.159	1.038	0.443	0.459
1982	0.98	1.125	1.102	1.105	0.527	0.583
1983	0.972	1.124	1.093	0.922	0.813	0.749
1984	0.983	1.125	1.106	0.935	1.036	0.968
1985	1.092	1.126	1.23	1.198	1.076	1.289
1986	0.981	1.127	1.106	0.892	1.177	1.05
1987	0.993	1.128	1.12	1.112	0.821	0.913
1988	1.018	1.129	1.149	1.047	1.824	1.909
1989	0.978	1.13	1.104	0.998	0.527	0.527
1990	0.973	1.131	1.1	0.98	0.817	0.801
1991	1.045	1.131	1.182	1.009	0.737	0.743
1992	0.973	1.13	1.1	1.052	1.068	1.123
1993	1.002	1.132	1.133	1.003	0.574	0.576
1994	1.006	1.132	1.138	0.958	0.9	0.862
1995	1.001	1.131	1.132	1.043	0.976	1.018
1996	0.998	1.131	1.129	0.915	1.296	1.186
1997	0.972	1.13	1.099	1.102	1.13	1.245
1998	1.045	1.131	1.182	0.835	1.02	0.851
1999	1	1.131	1.131	1.053	0.885	0.933
2000	0.98	1.131	1.108	1.051	0.888	0.933
2001	1.024	1.131	1.157	0.974	1.29	1.256
2002	0.965	1.132	1.092	1.13	1.075	1.215
2003	1.037	1.132	1.175	1.054	0.969	1.021
2004	0.96	1.131	1.086	1.021	0.835	0.853
2005	1.042	1.131	1.179	0.924	1.027	0.949

Table 15: Average annual changes for the selected producing countries by SFA and DEA: 1961-2005

	Efficiency change		Technical change		Malmquist index	
Country	**SFA**	**DEA**	**SFA**	**DEA**	**SFA**	**DEA**
RICE						
Côte d'Ivoire	1.025	0.998	1.097	0.846	1.125	0.844
Ghana	1.019	0.998	1.095	0.892	1.116	0.891
Guinea	1.179	0.996	1.087	0.941	1.281	0.938
Mali	1.026	0.999	1.107	1.162	1.136	1.161
Nigeria	1.038	0.997	1.084	1.199	1.125	1.195
Senegal	1.027	1.000	1.097	1.230	1.127	1.230
Mean	1.052	0.998	1.095	1.045	1.152	1.043
COTTON						
Benin	0.979	1.011	1.009	0.887	0.988	0.896
Burkina Faso	1.001	0.999	1.009	0.938	1.010	0.937
Côte d'Ivoire	1.000	1.000	1.011	0.965	1.011	0.965
Mali	0.996	1.000	1.011	1.118	1.010	1.118
Nigeria	0.998	1.000	1.001	1.207	1.000	1.207
Togo	1.008	1.000	1.015	1.225	1.023	1.254
Mean	0.997	1.002	1.095	1.057	1.007	1.063
MILLET						
Burkina Faso	1.002	1.000	1.124	0.909	1.002	0.909
Mali	1.002	0.993	1.119	0.959	1.002	0.952
Niger	1.002	1.002	1.126	0.968	1.001	0.970
Nigeria	1.000	0.990	1.144	1.026	1.000	1.015
Senegal	1.002	1.004	1.122	1.071	1.007	1.075
Mean	1.002	0.998	1.127	0.987	1.002	0.984

Table 16: Average annual changes for the selected producing countries by SFA and DEA: 1961-1978

	Efficiency change		Technical change		Malmquist index	
Country	**SFA**	**DEA**	**SFA**	**DEA**	**SFA**	**DEA**
RICE						
Côte d'Ivoire	0.965	0.997	1.138	0.964	1.098	0.962
Ghana	0.986	1.000	1.067	0.963	1.052	0.963
Guinea	1.029	0.996	1.033	1.001	1.063	0.997
Mali	1.027	0.999	1.144	1.093	1.175	1.093
Nigeria	1.030	0.975	1.166	1.193	1.201	1.163
Senegal	1.056	1.000	1.135	1.241	1.198	1.214
Mean	1.016	0.995	1.114	1.076	1.131	1.065
COTTON						
Benin	0.965	1.030	1.012	0.878	0.977	0.904
Burkina Faso	1.008	0.994	1.005	1.041	1.013	1.035
Cote d'Ivoire	1.003	1.000	1.018	1.082	1.021	1.082
Mali	1.015	0.992	1.012	1.126	1.027	1.117
Nigeria	0.980	1.000	1.012	1.216	0.993	1.216
Togo	1.040	1.000	1.008	1.249	1.047	1.249
Mean	1.002	1.003	1.011	1.099	1.013	1.140

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Table 16 continued

	Efficiency change		Technical change		Malmquist index	
Country	**SFA**	**DEA**	**SFA**	**DEA**	**SFA**	**DEA**
MILLET						
Burkina Faso	1.002	1.000	1.119	0.656	1.121	0.656
Mali	1.002	0.998	1.115	0.754	1.117	0.753
Niger	1.001	0.998	1.120	0.859	1.121	0.857
Nigeria	1.000	0.971	1.143	0.987	1.143	0.959
Togo	1.007	1.010	1.122	1.092	1.129	1.103
Mean	1.002	0.995	1.124	0.870	1.126	0.866

Table 17: Average annual changes for the selected producing countries by SFA and DEA: 1979-2005

	Efficiency change		Technical change		Malmquist index	
Country	**SFA**	**DEA**	**SFA**	**DEA**	**SFA**	**DEA**
RICE						
Côte d'Ivoire	0.970	0.997	0.989	0.907	0.960	0.905
Ghana	1.015	0.999	1.004	0.917	1.019	0.916
Guinea	1.009	0.997	1.002	0.952	1.011	0.949
Mali	1.023	0.999	1.003	1.123	1.026	1.122
Nigeria	1.009	1.006	0.960	1.179	0.969	1.186
Senegal	1.014	1.000	0.993	1.189	1.007	1.189
Mean	1.007	1.000	0.992	1.045	0.999	1.045
COTTON						
Benin	0.962	0.998	1.032	0.912	0.993	0.910
Burkina Faso	0.999	0.998	1.034	0.933	1.032	0.932
Cote d'Ivoire	1.010	1.007	1.038	0.950	1.048	0.957
Mali	1.000	1.000	1.032	1.036	1.032	1.036
Nigeria	0.977	1.001	1.054	1.050	1.030	1.051
Togo	1.041	1.000	1.038	1.095	1.081	1.094
Mean	0.998	1.001	1.038	0.996	1.036	0.997
MILLET						
Burkina Faso	1.002	1.000	1.127	0.793	1.129	0.793
Mali	1.001	0.987	1.121	0.864	1.123	0.852
Niger	1.002	1.001	1.131	0.991	1.133	0.992
Nigeria	1.000	0.983	1.144	1.089	1.144	1.071
Togo	1.000	1.000	1.121	1.207	1.121	1.254
Mean	1.001	0.994	1.129	0.989	1.130	0.992

Rice

Table 12 shows that the Malmquist indexes for both DEA and SFA models show a progress in rice productivity for most years in the entire analysis period despite differences in their values. The Malmquist index showing the TFP indicate an average productivity progress of about 15.2% and 4.3% as measured by SFA and DEA, respectively, as shown in Table 15. This implies that the two methods agree that over the entire analysis period, there has been a productivity improvement in the ECOWAS rice production sector. The mean technical change components for the two approaches indicate technological progress of about 9.5% and 4.5%, respectively. Both methods show, on average, that technical change components in ECOWAS rice agriculture are larger than efficiency change. The technical change and efficiency change components for the SFA approach are, however, higher in magnitude than those of the DEA approach. A breakdown of the results by different rice producing countries indicates productivity growth in all the major rice producing countries, on the average, irrespective of the method of analysis used. The means across the nations, however, indicate that the highest growth is recorded by Guinea for SFA model, but Senegal for the DEA model. The results further reveal that a major contributor to rice TFP growth in all the countries has been the technical change. All the countries have impressive technological progress, on the average. The TFP changes indicate more progress in ECOWAS than in pre-ECOWAS era for both SFA and DEA. Two things could be responsible for this phenomenon. First, is the impressive performance of West Africa Rice Development Association (WARDA) and International Institute for Tropical Agriculture (IITA), which led to adoption of over 20 improved varieties of rice in West Africa, including NERICA. The second is the ECOWAS liberalization schemes, which tend to boost farmers' income through increase in prices of agricultural export commodities. Quite similar conclusion was reached by Kwon and Lee (2004) when considering the TFP of Korean rice using both DEA and SFA methods. The finding is, however, contrary to Odeck (2007) who discovered that the DEA's efficiency scores and TFPs tend to be higher than SFA in Norwegian grain farming.

Cotton

The Malmquist indexes for cotton producing countries in ECOWAS in Table 15 indicate an average productivity progress of about 0.7% and 6.3% as measured by SFA and DEA, respectively. In similarity with the results for rice, the two methods agree that over the entire analysis period, there has been productivity improvement in the ECOWAS cotton production sector. However, in contrast to the results for rice, the Malmquist indexes computed with DEA method are greater than SFA's. On average, the results for the year to year technical change indicate technological progress over the entire period as shown in Table 13. The results indicate technological progress of 9.5% and 4.5% for SFA and DEA methods, respectively. Despite average technological and productivity progress across the analysis period, some of the cotton producing countries have not performed well. Their Malmquist indexes are less than one. The rows showing cotton producing countries in Table 15 indicate the countries to be Benin, Burkina Faso and Cote d'Ivoire. A breakdown of the results by reform era in tables 16 and 17 shows significant improvement of the reform period over that of the pre-reform era. This might be due to the success of the cotton support system in the major cotton producing nations in the region. Another factor could be the increased adoption of Bt cotton variety (a product of biotechnology) introduced to the region in early 2000s, which greatly limits the incidence of pests and disease, and hence reduced application of pesticides. The results corroborate the findings of Charkraborty, Mistra and Johnson (2002). The adoption of Bt cotton in West Africa as shown by Elbehri and MacDonald (2003) appear to be creating an improvement in its productivity, as the productivity growth from 1979 is a tremendous improvement compared with the situation in the pre-ECOWAS period.

Overall, Togo is the most impressive country for both SFA and DEA approaches. Incidentally, at the other end of the spectrum for both SFA and DEA, Benin has the lowest growth performance for most of the analysis period. The TFP growth in all the countries is more due to technical change than efficiency change. The impressive productivity growth in Togo is most likely a consequence of keen interest of the countries in export of cotton and development of indigenous industries using cotton as raw material. Another impetus to cotton productivity growth in Togo might be the remarkable investment and support programmes in the country. Such programmes include supply of credit, extension services, input supply and marketing through national companies. By and large, the growth rate recorded on the average for ECOWAS cotton sector can provide a basis for sustained growth in cotton in the region.

Millet

Contrary to the results for rice and cotton, the overall total factor productivity decreases at an annual rate of 0.2% for the DEA model but increases by almost the same proportion (0.2%) in case of the SFA model. However, in both models, the total factor productivity change in millet is driven mainly by technical change, just like cotton and rice. Another interesting feature of the millet results is that a higher technical change is observed with SFA approach when compared with DEA as is the case with rice. In spite of differences in total factor productivity components, the country by country comparison for both SFA and DEA models indicates that Senegal and Nigeria performed better overall than other producing countries. Except for these two ECOWAS millet producing countries, average productivity growth is less than 1% for other nations over the analysis period. Tables 16 and 17 indicate that there was an upsurge in productivity growth in pre-ECOWAS period across all the major rice producing countries in the region. Coincidentally, Senegal has the most impressive result, with total factor productivity growth rate of about 0.7% and 7.5% for SFA and DEA models, respectively. When the 45-year period is divided into the three sub-periods, the result of the empirical results of the total factor productivity calculations for millet shown in tables 16 and 17 give a clear evidence of the ECOWAS reforms enhancing millet productivity growth better than in pre-ECOWAS reform period. Similar to the case of rice, the main contributor to TFP growth has been technical change.

5. Conclusion and policy recommendations

This study applied non-parametric (DEA) and parametric (SFA) models to a sample of panel data of ECOWAS rice, cotton and millet production for the period 1961-2005. The productivity growth was estimated using the Malmquist index obtained through both SFA and DEA approaches. The productivity measures are decomposed into two sources of growth, namely efficiency change and technical change. The results for both SFA and DEA methods show evidence of phenomenal growth in total factor productivity for rice and cotton. Millet, however, has mixed results. The total factor productivity decreases at an annual rate of 0.2% for the DEA model but increases by almost the same proportion (0.2%) for the SFA model. A closer look at the total factor productivity differences in ECOWAS and pre-ECOWAS sub-periods shows larger total factor productivity in ECOWAS period (1979-2005) than in pre-ECOWAS period for cotton and millet for SFA model. In contrast, a larger TFP is obtained in pre-ECOWAS period than in ECOWAS period for rice with SFA model. The same inference can be drawn from DEA estimate of total factor productivity for rice and millet. However, the conclusion from DEA estimate of cotton total factor productivity is different from SFA's. The total factor productivity in pre-ECOWAS is significantly larger than in the ECOWAS period. Nevertheless, in both periods, productivity growths in all the crops are sustained through technological progress.

The following inferences can be drawn from the comparative analysis of DEA and SFA efficiency and productivity models examined. First, the DEA results tend to fluctuate more widely than SFA. This might be a direct consequence of the assumption on the stochastic component, something which may be intensified for agricultural data. The second is that inefficiency and productivity growth exists among rice, cotton and millet producing countries in ECOWAS. The magnitude of inefficiency and the extent of productivity growth that has taken place differ between the approaches applied. Third, examining the components relating to the shift in the frontier and efficiency change, technical change turned out to be a more important source of growth in both SFA and DEA models. A promising finding thereupon is that the two approaches applied are, on average, in conformity to each other although the magnitudes are different. In terms of efficiency measurements, the differences between the methodologies are very sensitive on levels of segmentations. In this respect, they somehow conform to previous findings in the literature, e.g. Wadud and White (2000). In terms of productivity measurement, even though both approaches track total productivity similarly, they do not map each well at the decomposition level. The deviations between DEA and SFA could have been anticipated because the SFA incorporates stochastic factor while DEA does not. A limitation of the study is that the data used as shown in the yield curves tend to fluctuate considerably. This means that the productivity measures are based on low productivity year. Also, a six-country panel data is relatively short to draw convincing results on variation in productivity among the producing country. It is unlikely that the differences in productivity among the countries can be sustained; rather it is confined to the specific data period and countries. Despite the caution in interpreting the results, the following policy recommendations are suggested from the findings.

A major cause of inefficiency for countries producing the selected crops is capital-labour ratio. It is advisable for the region to invest more in labour-saving technologies to enhance the efficiency of the member nations producing cotton. More farmers are, however, required in the region to ensure the producing countries' efficiency in rice and millet production.

Given differences in the contribution of efficiency change and technological progress to the TFP of the selected crops, ECOWAS agricultural policy (ECOWAP) should marry policy with specific crop need within the framework of their programmes for member nations.

The differences between the techniques applied here suggests that policy makers as well as researchers should not be indifferent as to the choice of technique for assessing efficiency and productivity, at least with respect to the magnitudes of potential for efficiency improvements and productivity growth.

Finally, studies are yet to detect why and how the different approaches are so different with respect to the decomposed productivity measures. Hence, necessary caution should be observed in interpretation of either SFA or DEA until such time that the field of efficiency and productivity measurement understand how and why these approaches portray efficiency and productivity the way they do. To this end, there is need for further research in understanding the observed differences.

Future works should also quantify parametrically, the determinants of the productivity growth in the crops.

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Appendix

DEA versus Stochastic Frontier measurement of TFP index

The Malmquist productivity index (MPI)

The distance function can be defined in terms of inputs and outputs. An input distance function considers a production technology by looking at a minimal proportional contraction of input vector, given an output vector while an output distance function characterized a maximal proportional expansion of the output vector, given an input vector.

In this study, output distance function is assumed. Assuming that for each time period t= 1, 2, …, T, $x_t \, E \, R_+^N$ and $y_t \, E \, R_+^M$ denote, respectively, an 1 × N input vector and an 1 × M output vector for period t. (t=1,2,…, T). The set of production possibilities is given by the closed set,

$$S_t = \{(x_t, y_t): x_t \text{ can produce } y_t\} \tag{1}$$

where technology is assumed to have the standard properties such as convexity and strong disposability, as described in Färe et al. (1994). The output sets are defined in terms of S_t as:

$$P_t(x_t) = \{y_t : (x_t, y_t) \, E \, S_t\} \tag{2}$$

According to Shephard (1970), the output distance function in t for any productivity unit would be:

$$d_o^t(x_t, y_t) = \inf \{\theta : (y_t / \theta) \, \mathrm{E} \, P_t(x_t)\} \tag{3}$$

where subscript "o" stands for "output oriented". The distance function was the Farrell's reciprocal measurement (Farrell, 1957). This distance function represents the smallest factor, θ by which an output vector y_t is deflated so that it can be produced with a given input vector x_t under period t's technology. That is to say $d_o^t(x_t, y_t)$ provides a standardized average of distance of a unit in the period t to frontier t of production set when inputs are constant. It will take the value of less than 1 if the output vector y is an element of the feasible production set. It will take the value of 1 if y is located on the outer boundary of the feasible set and value of greater than 1 if y is located outside the feasible production set. The productivity change using technology of period *t* as reference is as follows:

$$M_o^t(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)} \right] \quad (4)$$

Similarly, we can measure Malmquist productivity index with period t+1 as references as follows:

$$M_o^{t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)} \right] \quad (5)$$

In order to avoid choosing arbitrary period as reference, Fare et al. (1994) specifies the Malmquist productivity index as the geometric mean of the above two indexes:

$$M_o(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_o^t(x_{t+1}, y_{t+1})}{d_o^t(x_t, y_t)} * \frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)} \right]^{1/2} \quad (6)$$

Equation 13 can be decomposed into the following two components, namely efficiency change index, which measures the output-oriented shift in technology between two periods. When it is greater or less than one, there exists some improvements or deterioration in the relative efficiency of this unit. The second component is the geometric average of both components, and technical change between period t+1 and *t.* The first component in TECHCH measures the position of unit *t+1* with respect to the technologies in both periods. The second component also estimates this for unit *t*. If the TECHCH is greater (or less) than one, then technological progress (or regress) exists.

$$EFFCH = \left[\frac{d_o^{t+1}(x_{t+1}, y_{t+1})}{d_o^{t}(x_t, y_t)} \right] \tag{7}$$

and

$$TECHCH = \left[\frac{d_o^{t}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)} * \frac{d_o^{t}(x_{t+1}, y_{t+1})}{d_o^{t+1}(x_t, y_t)} \right]^{1/2} \tag{8}$$

In order to take cognizance of the return to scale properties of the technology, Grifell and Lovell (1995) use a one input, one output example to illustrate that Malmquist index may not correctly measure TFP changes when Variable Return to Scale (VRS) is assumed for the technology. Therefore, Constant Return to Scale is imposed upon the technology used to estimate the distance functions for the calculation of the Malmquist index for this study.

The envelopment of decision making units (DMU) can be estimated through LP methods to identify the best practice for each DMU. Assuming CRS technology in their analysis, the required LPs are:

$$\left[d_o^{t}(x_t, y_t) \right]^{-1} = Max_{\phi,\lambda}\phi. \tag{9}$$

$$s.t - \phi y_{it} + Y_t \lambda \geq 0$$
$$x_{i,t} - X_t \lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[d_o^{t+1}(x_{t+1} + y_{t+1}) \right]^{-1} = \mathrm{Max}_{\phi,\lambda}\phi.$$
$$st - \phi y_{i,t+1} + Y_{t+1} \lambda \geq 0 \tag{10}$$
$$x_{i,t+1} - X_{t+1} \lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[d_o^{t}(x_{t+1}, y_{t+1}) \right]^{-1} = \mathrm{Max}_{\phi,\lambda}\phi \tag{11}$$

$$st$$
$$-\phi y_{i,t+1} + Y_t \lambda \geq 0$$
$$x_{i,t+1} - X_t \lambda \geq 0$$
$$\lambda \geq 0$$

$$\left[d_o^{t+1}(x_t, y_t)\right]^{-1} = Max_{\phi\lambda}\phi.$$
$$st \ -\phi y_{i,t} + Y_{t+1} \lambda \geq 0 \qquad (12)$$
$$x_{i,t} - X_{t+1} \lambda \geq 0$$
$$\lambda \geq 0$$

Where λ is a N x 1 vector of a constant and θ is a scalar with θ greater than 1

Stochastic frontier method

The distance measures required for the Malmquist TFP index calculations can also be measured relative to a parametric technology using stochastic production function. The stochastic production function for panel data can be written as:

$$\ln (y_{it} = f(x_{it}, t, \alpha, v_{it} - u_{it}) \qquad (13)$$

i = 1,2, …………..N and t = 1,2,…………………T (Battese and Coelli, 1992)

Where y_{it} is production of the ith firm in year t, α is the vector of parameters to be estimated. The v_{it} are the error component and are assumed to follow a normal distribution N(0, σ^2_{it}), u_{it} are non negative random variables associated with technical inefficiency in production, which are assumed to arise from a normal distribution with mean μ and variance σ^2_{it}, which is truncated at zero. f(.) is a suitable functional form (e.g translog), t is a time trend representing the technical change.

In this parametric case, the measures of technical efficiency and technical change can be used to get the Malmquist TFP via (6), (7) and (8). The technical efficiency of production for the ith region at the tth year can be predicted using Coelli, Rao and Battese (1998). The technical efficiency is obtained as:

$$TE_{it} = E(\exp)(-u_{it}) / v_{it} - u_{it}) \qquad (14)$$

This can be used to compute the efficiency change component by observing that $TE_{it} = d_o^t(x_{it}, y_{it})$ and $TE_{i,t+1} = d_o^{i,t+1}(x_{i,t+1}, y_{i,t+1})$ the efficiency change (EC) is

$$EC = TE_{it} / TE_{i,t+1} \tag{15}$$

This measure can be compared directly with (7). An index of technological change between the two adjacent periods *t* and *t* + 1 for the i[th] region can be directly calculated from the estimated parameters of the stochastic production frontier. This is done by simply evaluating the partial derivatives of the production function with respect to time at x_{it} and $x_{i,t+1}$. If technical change is non-neutral, the technical change may vary for the different input vectors. Following Coelli, Rao and Batesse (1998), the technical change (*TC*) index is

$$TC_{it} = \left\{ \left[1 + \frac{\delta f\left(x_{it}, t+1, \alpha\right)}{\delta t+1} \right] X \left[1 + \frac{\delta f\left(x_{it}, t, \alpha\right)}{\delta t} \right] \right\}^{1/2} \tag{16}$$

This measure may be compared directly with (8). The TFP index can be obtained by simply multiplying the technical change and the technological change, i.e.:

$$TFP_{it} = EC_{it} * TC_{it} \tag{17}$$

This is equivalent to the decomposition of the Malmquist index suggested by Fare et al. (1994).

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THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are those of the author, however, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 – City Square
Nairobi 00200, Kenya

Printed by: Modern Lithographic (K) Ltd
P.O. Box 52810 – City Square
Nairobi 00200, Kenya

ISBN 978-9966-023-30-8

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Abstract

This study examines total factor productivity growth and its decomposition for rice, cotton and millet producing countries in ECOWAS. The productivity measures were estimated using Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA). The data cover a 45-year period (1961-2005) separated into pre-ECOWAS (1961-1978) and ECOWAS (1979-2005) periods in order to study the effects of ECOWAS reforms on productivity growth of the selected crops. Calculations are based on data collected from FAOSTAT database, International Rice Research Institute (IRRI) world rice statistics, and International Cotton Advisory Committee database. The data include output of each crop (rice, cotton and millet) and seven input variables comprising land area, labour, seed, fertilizer, tractor use, irrigation and country dummies. The results for both SFA and DEA show that: (i) there are inefficiencies but productivity progress among ECOWAS member nations producing rice, cotton and millet; (ii) though magnitudes of the inefficiencies and productivity progress vary across models applied and by segmentation of the data set, there is little or no conflict in the overall results; (iii) technical change has had the greatest impact on productivity, indicating that producers have a tendency to catch up with the front runners; and (iv) the total factor productivity in ECOWAS and pre-ECOWAS sub-period differ across crops depending on the models applied. In general, policy makers should try not to be indifferent with respect to the approach used for efficiency and productivity measurement, as these may give different results.

Key words: *Efficiency change, technological progress, productivity growth, ECOWAS*

Acknowledgements

I am grateful for financial, material and technical assistance from the African Economic Research Consortium (AERC), without whose support this study may not have been a success. I appreciate useful suggestions and comments of group D resource persons: Professors Ademola Oyejide, Francis Mwega, Andy Mckay, Oliver Morrisey, Dominique Njinkeu, Nehemiah Ng'eno, John Page, Ann Veiderpass, Olawale Ogunkola, and a host of others. I am also grateful to the researchers and PhD scholars in the same group for their contribution to the improvement of this paper. Any surviving errors are, however, mine.

Acronyms and abbreviations

AERC	African Economic Research Consortium
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
ECOWAS	Economic Community of West African States
FAO	Food and Agricultural Organization
ICAC	International Cotton Advisory Committee
IITA	International Institute for Tropical Agriculture
IRRI	International Rice Research Institute
MLE	Maximum Likelihood Estimate
NERICA	New Rice for Africa
SFA	Stochastic Frontier Approach
TFP	Total Factor Productivity
WARDA	West Africa Rice Development Association