

African Agricultural Water Efficiency
A Technical Efficiency Analysis of African Agriculture

By

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Under the Supervision of Dr. Russell Kashian

I investigate the impact water resource management and use of water inputs have on the efficiency of agricultural processes in Africa. The data was collected from NASA's Global Precipitation Climatology Project (GPCP), the United Nations Food and Agriculture Organizations FAOSTAT/AQUASTAT databases. The main result of the Stochastic Frontier Analysis indicates there is inefficient use of all available water resources. Other results include increasing returns to scale for increases in a nation's agricultural labor force, an increase in efficiency for an increase in the amount of land irrigated in a nation, and an increase in efficiency for an increase in the amount of fertilizer consumed. There is also evidence that agricultural productivity of the sampled nations has increased on average by 3% year-over-year over the period examined.

1. Introduction

African nations employ approximately 60% of their work force in the agricultural sector and yet that sector only accounts for one-third of gross domestic product for the continent. African nations have the opportunity over the next 15 years to unlock a trillion dollar opportunity through the modernization of their agricultural sector (The World Bank, 2013). A key to unlocking this potential is eliminating inefficiency in agricultural production. Inefficiencies in agricultural production create barriers to profitability; it hinders the ability for African nations to compete on global export markets. Prior literature has explored the importance of improved labor quality, the deficiency of capital and credit markets, as well as the role of African governments in contributing to these inefficiencies (Yu and Nin-Pratt, 2011). This paper builds on the prior literature and identifies the impact of water (be it from freshwater sources, or rainfall) on agricultural efficiency.

While feeding Africa has been a priority of the world for decades; 1-in-4 individuals in Sub-Saharan Africa go hungry (WFP, 2014). According to the World Development Report published by the World Bank in 2008, investment in agriculture is two times more effective in reducing poverty and hunger than investment in any other sector. The National Geographic Society and Food and Agriculture Organization of the United Nations (FAO) estimate the average African farmer has roughly the same yield per acre as a Roman farmer during the Roman golden age of approximately half a ton; by comparison modernized nations' yields exceed three tons. For the African continent the

importance of an efficiency analysis of agricultural production and promoting efficient use of scarce water resources cannot be understated.

In addition to unique water data, I will also consider the availability of water delivery systems through data on the amount of agricultural area equipped for proper irrigation and how the availability of proper irrigation impacts production efficiency. I also consider the importance of access to proper irrigation in comparison to the access of higher rainfalls and a larger capability for water withdrawals. The results point to a lack of maturity in the agricultural sector of the nations observed and only an increase in the total area equipped for irrigation has a positive impact on agricultural efficiency while taking into concern nation-level fixed-effects, persistent inefficiency, and time varying inefficiency.

2. Literature Review

Africa produces a wide variety of crops including but not limited to coarse grains, wheat, and rice. As framed above, Africa's yields are one-sixth that of the world's leading producers. Nin-Pratt et al. (2009) identify the greatest opportunities in closing yield gaps utilizing spatial analysis and conclude that there is no one-size-fits-all solution. To this end it is important to identify the yield gaps of particular staple crops in each nation and match it with the largest growth market for those commodities within the region as the optimal approach to maximizing the outcome of any agricultural initiative. They implied that in order to make closing these yield gaps feasible for the average farmer, regional cooperation on technology adaptation is essential. Regional cooperation was a common theme over the course of their paper as they also focused on the need for

strengthening regional agricultural markets and enhancing the links between agricultural and nonagricultural markets in order to enhance productivity and innovation. One of the problems associated with Nin-Pratt et al. (2009) is that they don't identify the systemic problems associated with closing this yield gap. One explanation for this yield gap, offered by Bindraban, Loffler, and Rabbinge (2008), is the lack of technological adaptation. Technology has been used in the rest of the world to fuel productivity growth. It also highlights that modern farming systems are used in only 10% of Africa's agricultural sector. Lamb (2000) begins to truly dissect these problems with a look at total agricultural output, food crops, export crops, and how they are affected by exchange rates and food prices.

Lamb highlights the short run problems associated with exchange rate changes and food prices on total African agricultural output. He argues that it is necessary that the structure of African agricultural markets is considered. Lamb notes that the most advanced agricultural nations produce food crops at such efficient rates that exporting food crops from African nations is typically not a profitable endeavor; thus in order to expand export crop production African nations must focus on cash crops at the expense of food supply in these African nations. Lamb finds that the increase in export supply takes years to materialize indicating that in the short run, increasing export crop production has in fact a negative impact on the agricultural sector in that nation. He also notes that the exchange rate is a proxy for macro-economic variables that are not passed on through prices. Thus a change in global prices may not entirely explain total agricultural supply in Africa, but changes in the exchange rate help to fill in the holes.

Thiele (2003) provides evidence of how the macro-landscape impacts the agricultural sector of African nations through the actions of their governments. The literature behind the inadequacies and missteps of the governments on their agricultural sectors is substantial. The common theme behind much of the literature is that protectionist policies, high taxes, and low infrastructure and service spending by these governments have hamstrung the growth of their nations as well as the sophistication of their agricultural sectors leading to wide spread poverty and famine. Thiele highlights that while the discrimination against Sub-Saharan African agriculture has waned since its peak prior to the 1980s that there has been only slight progress in eliminating heavy taxation and that policies that favor publicly managed agricultural sectors vary widely from nation to nation. In essence, he finds that you can find some positive undertones in the overall health of the agricultural sector of African nations but reform as a whole is lacking.

Badiane and Makombe (2014) support Thiele by highlighting the government interventions of the 1960s and 1970s as African nations attempted to industrialize their nations. These attempts at industrialization resulted in hampered agricultural growth as investment in rural services were abandoned in favor of urbanization. African nation's continued that centralization and heavy handed public sector management restricting growth in the agricultural sector and delaying structural reforms necessary to keep pace with the modern world. Badiane and Makombe insist that agricultural development is dependent on strong government approaches empowering the private sector and investing in services and infrastructure within the sector. They suggest that the East Asian

agricultural revolution of the last 20 years is a model for Africa's future. The East Asian agricultural revolution transformed Eastern Asia from a net food importer to a net food exporter in the span of approximately a quarter century.

While the prior literature offers insight to the overall structure and status of African agriculture over the last 50 years, it doesn't address the micro-economic issues that surround the sector. Binswanger and Townsend (2000) point to three major reasons for slow growth in the agricultural sector. These include adverse resource endowments, adverse policies, conflict and political instability. The adverse resource endowment argument supports an earlier paper by Hayami and Platteau (1997) who argue that adverse resource endowments have led to slower growth through a cyclical process. They frame this cyclical process as an overabundance of land and low population density leading to slow growth within the sector. They claim that low population density leads to greater transportation and transaction costs in delivering goods to market, discouraging production and trade. This makes it unprofitable for a sufficient number of traders to enter the market and leads to a lack of a competition in the market.

The adverse resource endowment theory also argues that due to low output volumes there is too little demand for credit to develop a sufficient credit system. The supply of credit is further constrained by the lack of suitable collateral due to low land values (because of the abundance of land). As a result of the lack of well-developed of the market, and the lack of credit supply, technology adoption is difficult due to the high transaction costs. Thus the common theme for improving African agriculture is to give

these nations the technology or the money to buy the technology. These nations are inhibited by the lack of infrastructure to support these markets and the landlocked nations are further burdened by increased transportation costs to get their goods to regional and global markets.

Binswanger and Townsend's second reason for slow growth was adverse government policies as they relate to each nation's agricultural sector. Protectionist policies in the mid-20th century limited the sector to foreign investment and a lack of incentive for producers to adopt efficiency advancing technologies. This was a product of government's efforts to encourage industrialization at the expense of the agriculture sector (Badiane and Makombe, 2014). Their third reason is highlighted as the lack of commitment from African nations to their agricultural sectors. Often times they found that initiatives in development were short lived and often time suffered from public sector bias and over centralization. Finally they took time to highlight the impact of conflict and political instability that has hampered the growth of Africa. They pointed to internal conflict and strife causing displacement and instability amongst the populace as well as the markets and that the benefits of turning away from conflict are blatantly obvious. They used Mozambique's relative peace as an example of the growth in agriculture once a nation begins to find stability.

Binswanger and Townsend (2014) commend the gains that have been seen in Africa over the last 20 years. They found evidence of the easing of anti-export bias. In addition the general African macroeconomic stability has improved. They find that the

international community and African nations themselves have been more serious about their investment in agricultural services and infrastructure, but that after nearly a century of poor policies and neglect there are huge unrealized opportunities for future growth in the sector. They highlight this neglect by stating that public expenditure and commitment to rural areas remains woefully inadequate and that decentralization of public agricultural and rural development services is painfully slow and that fiscal decentralization is non-existent. To Binswanger and Townsend (2014) this becomes a question of empowering not simply those that are in need but those that know what they need. Binswanger and Townsend (2014) go into great detail on the policy suggestions to improve and hasten growth within the sector through macroeconomic policies, trade policies, as well as market access.

There is an understanding that there are inefficiencies in Africa's agricultural sectors but there is little research that goes directly into quantifying the efficiency of these nations. There is a hesitance in the applied community to approach African topics due to the lack of accurate data. Yu and Nin-Pratt (2011) tackled this lack of literature with their Stochastic Frontier Analysis of Sub-Saharan Africa's agricultural sector. They note as shown above that the last 50 years has led to the deterioration in the competitiveness of African agriculture. Yu and Nin-Pratt highlight potentially "dubious" data techniques of the FAO which led them to use estimations and causal generation of some missing data points. Their approach is to consider the productivity of a nation's agricultural sector to constitute changes in output for given levels of inputs. Their output is agricultural production in millions of United States dollar's (USD's). Their inputs are

agricultural land, agricultural labor, the amount of livestock a nation has, the number of tractors in a nation, and the quantity of fertilizer consumed by a nation. Agricultural land is the sum of arable land, permanent crops, and permanent pastures. Agricultural labor is measured as the number of people economically active and actively engaged in the agriculture sector.

Yu and Nin-Pratt (2011) also use efficiency changing variables that impact inputs or output as a whole. Examples of these are education level, conflict status, and anything else that affects labor productivity. These variables are based on research suggests causal relationships between these variables and productivity. Hayami and Ruttan (1985) find agricultural labor productivity to be increased by investments in education and research. Fulginiti and Perrin (1997) suggest a positive productivity effect of public research, land quality, and improved human capital (i.e. education). Finally, J.M. Antle (1983) determines that agricultural policy can have an impact on aggregate agricultural productivity.

The productivity effect is finicky though; Antle (1983) found that the effect is only significant for nations that tax or subsidize agriculture moderately. This effect is insignificant where nations' tax or subsidize the sector. A marginal reduction of taxation or subsidization is not shown to be significant in Antle (1983). This presumes that high levels of taxation or subsidization distort the farmers' incentives to a degree that marginal changes do not affect the farmers' behavior. As a result a decisive change and commitment from African nations is necessary foster structural changes to the sector.

Yu and Nin-Pratt (2011) and Schuh and Norton (1991) further support Fulginiti and Perrin (1997), as well as Hayami and Ruttan (1985), in finding that education has a significant influence on agricultural output. Yu and Nin-Pratt (2011) controls for labor quality by considering the adult literacy rate and life expectancy of each nation. In addition land quality is modeled using a quality index provided by the FAO and the percentage of irrigated land used in agriculture, and dummies for the institutional and political environment. They control for which European nation colonized them, and whether or not the nation is independent at the time of the observation. They also used a dummy for whether or not there was armed conflict in the nation for that observation's year as well as dummies for a political rights and civil liberties indexes. Yu and Nin-Pratt (2011) determined that average productivity for all nations declined by approximately 0.57% per year over the last 40 years. This is consistent with prior studies but does conflict with a recent FAO study that productivity has increased by half a percent a year over the same period.

For such an important sector of one of the poorest continents on the planet, the literature has gaps due to the lack of reliable data. What this review has shown is that the problems plaguing Africa are both endemic and systematic. Africa suffers from a lack of cohesive planning from governments and regions to develop their agricultural markets and return to being the net exporter of food that they were in the 60s. There are many common themes within the research such as educating rural populations to enhance productivity, directing foreign aid into the agricultural sectors, and national governments investing in agricultural services and infrastructure especially in rural areas. There is a

consensus that the problems plaguing the agricultural sectors of African nations are multi-headed and no quick fixes exist. Improvements to the sector will take comprehensive planning, commitment, and stability from the respective nations. One of the few conflicts in the literature is that the United Nation's Food and Agriculture Organization (UNFAO) is more positive and optimistic than other sources. While other researchers have found that African agricultural productivity has fallen over the last 50 years, the FAO has found a slight increase, stating that it is about hastening growth. Further research must pin down an appropriate evaluation of productivity over the last 50 years to help determine a comprehensive plan for each nation. My research will introduce new variables to the analysis, specifically the inclusion of water efficiency to consider the impact proper irrigation of crops can have on overall productivity in the sector.

3. Data

A panel of primarily West African nations is examined. This panel covers 20 years, from 1985-2005. The nations observed are presented via political map in Figure 4. Four nations (Kenya, Morocco, Niger, and Tunisia) lacked observations for agricultural water withdrawals for the first five years of the range but the analysis accounts for unbalanced panel data. (Kumbhakar, Wang & Horncastle, 2015)

Agricultural water withdrawal data was provided by the United Nation's Food and Agricultural Organization (U.N.F.A.O.) through their AQUASTAT database. AQUASTAT is a global water information system developed by the U.N.F.A.O.'s Land

and Water Division. Agricultural water withdrawal is the annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture purposes from primary renewable and secondary freshwater sources. This measure is not limited to freshwater and does include treated wastewater and desalinated water. Water withdrawal data from AQUASTAT was chosen over irrigation water use available within the same database. The irrigation water use data closely mirrored that of the agricultural water withdrawals (and in any case of their being a difference in total water withdrawal the increase was minor). In many cases the agricultural water withdrawal numbers are estimates by the Land and Water Division of the U.N.F.A.O. and there are gaps in the data. In order to compensate, I adopt a strategy similar to other researchers on African topics; I interpolate from the data available. One of the key assumptions that must be made in this analysis is that agricultural water withdrawals increase or decrease in a relatively linear manner from year to year. While weather and need are attributable to the fluctuation in water withdrawals, it is reasonable to suspect that water withdrawals do not fluctuate unreasonably year to year and as time moves forward the capability of each nation to withdraw and utilize water resources moves along a relatively linear trend. Water withdrawals are provided as cubic kilometers and for my purposes was transformed into cubic millimeters to be directly comparable to rainfall measurements.

The measure for rainfall was retrieved from NASA's Global Precipitation Climatology Project (GPCP). NASA's Mesoscale Atmospheric Process Laboratory produces monthly precipitation estimates combining observations on the ground with satellite precipitation data into 2.5° by 2.5° global grids. These grids were mapped via

ArcGIS and summed into annual totals for each nation observed. There was minor overlapping when constructing the maps so all rainfall measures are slightly inflated due to the inaccuracy of the maps. The minor inflation of all nations is unlikely to cause instability in the consistency of my results as no nation is without this inaccuracy and the inflation cannot be quantified as more than half a percent of the total rainfall number.

The remaining variables were drawn from the U.N.F.A.O.'s FAOSTAT database. The FAOSTAT database is managed by the Statistics Division of the U.N.F.A.O. All currency related variables are in constant 2005 international dollars¹. This choice was made as to relate directly to the purchasing power derived from, for example, agricultural output. The first output variable I use in my model is net agricultural production value² which includes aquaculture, livestock, and crop value. This value is derived by the U.N.F.A.O.'s Statistics Division multiplying gross physical production by farm gate level pricing³ (in international dollars). Choosing total agricultural output was directly related to the use of agricultural water withdrawals and the choice of a monetary value over that of production quantities.

Additional input controls include agricultural land and labor. Agricultural land is retrieved by the U.N.F.A.O. by surveying each nation's agricultural bureau and is defined as land typically devoted to agriculture particularly the rearing of livestock and the production of crops. As a control for the application of water resources to farm land, I

¹ The World Bank definition for an international dollar is the amount of goods a dollar would purchase in a certain nation comparable to the amount of goods and services a U.S. dollar would buy in the United States.

² The value of production after seed and feed has been subtracted from gross production.

³ Farm gate pricing is the net value of the product when it leaves the farm after subtracting marketing costs.

also use the total agricultural area equipped for irrigation. All land related variables in this analysis are in hectares, a metric unit of square measure equivalent to 100 acres. Equally as important to water application and the availability of the land is the condition of the land. Land equipped for irrigation was defined as land under full and partial control irrigation, lowland areas equipped to control water flow, and areas equipped for spate irrigation. Spate irrigation catches flood water to be applied to fields. As a measure of quality and the adoption of modern farming techniques, I use the consumption of fertilizers in metric tons. Total agricultural employment is also measured by the number of full-time equivalent persons economically active within the agricultural sector. This data was obtained through the International Labor Organization as estimated by the United Nations (United Nations, Dept. of Economic and Social Affairs, Population Division, 2009).

Table 1 provides the descriptive statistics for the aforementioned variables. Comparing the sample of nations to that of continent-wide figures indicates approximately 57% of the labor force is employed in the agricultural sector, which roughly mirrors the 60% of the labor force for the entire continent estimated by the World Bank. On average 42% of a nation's land has been set aside for agricultural production in the sample, which again matches up to the continent's averages. When comparing net agricultural production and net crop production, crop production tends to make up approximately 85% of net agricultural production. While the premise of this paper tends to lean heavily on crop production and efficient use of water on crop

production, the construction of the agricultural water withdrawals makes it important to consider the entirety of agricultural production and not simply crop production.

This analysis uses the logarithm of every variable (aside from the count variable for year) listed above to accommodate the linearized version of the Cobb-Douglas production function used in the analysis. One metric ton was added to fertilizer consumption to accommodate taking the logarithm of the variable.

4. Methodology

An industry or firm is technically inefficient if a higher level of output is technically attainable for the given inputs or that the observed output level can be produced using fewer inputs (Kumbhakar et al., 2015). In order to examine the effects of efficiency changing variables on agricultural productivity, I chose to estimate an output-oriented technical inefficiency measure. By choosing an output oriented technical inefficiency measure, an assumption is made that given the current level of inputs the firm or nation is not on the production frontier and more output can be produced. Moving forward, I begin with a basic presentation of a Stochastic Frontier Analysis with time-invariant fixed-effects model established by Schmidt and Sickles (1984) and build toward a model that separates firm effects, persistent inefficiency and time-varying inefficiency (Kumbhakar, Lien, and Hardaker 2014).

The primary equation of interest is the following Cobb-Douglas production function:

$$Output_{it} = AK_{it}^{\alpha}L_{it}^{\beta} \quad (1)$$

where i indexes the nation and t indexes the year, $Output_{it}$ is the net production value of all agricultural products, A is a constant, K is the net value of all agriculture related capital expenditures (excluding live-stock related expenditures), L is the total number of people employed within the agriculture sector in full time positions, and α and β are constants between 0 and 1. The output oriented technical inefficiency is then modeled by taking the log of this production function resulting in the following model

$$\ln Output_{it} = \ln A + \alpha * \ln K_{it} + \beta * \ln L_{it} + \varepsilon_{it} \quad (2)$$

where ε_{it} is a composed error term equal to the difference of v_i , the random error, and u_i , the technical inefficiency. This is represented as

$$\ln Output_{it} = \ln A + \alpha * \ln K_{it} + \beta * \ln L_{it} + v_i - u_i. \quad (2.2)$$

$$\text{where } u_{it} = \boldsymbol{\delta} \mathbf{z}_{it} + W_{it}. \quad (2.3)$$

The technical efficiency is comprised of a \mathbf{z}_{it} , a vector of explanatory variables associated with technical inefficiency. These explanatory variables include agricultural land measured in hectares, yearly rainfall totals for a nation measured in cubic millimeters, agricultural water withdrawals measured in cubic millimeters, the land area equipped for irrigation measured in hectares, and the amount of fertilizer consumed by a nation in metric tons. W_{it} is a random variable defined by the truncation of the normal distribution with a zero mean and variance, and $\boldsymbol{\delta}$ a vector of unknown estimable coefficients.

At this point Schmidt and Sickles' (1984) within estimator is applied to the equation as shown below:

$$\ln Output_{it} = \beta_0 + \mathbf{x}'_{it}\boldsymbol{\beta} + v_{it} - \mu_i \quad (3)$$

$$= (\beta_0 - \mu_i) + \mathbf{x}'_{it}\boldsymbol{\beta} + v_{it} \quad (3.1)$$

$$= \alpha_i + \mathbf{x}'_{it}\boldsymbol{\beta} + v_{it}. \quad (3.2)$$

In the interest of readability, A (technology), K (capital), and L (labor) were replaced by the vector $\mathbf{x}'_{it}\boldsymbol{\beta}$ and the within estimator (α_i) is defined as the difference between the constant (β_0) and technical inefficiency (μ_i). By using fixed-effects, all time-invariant unobserved heterogeneity is controlled for within a nation and by making this assumption it is implied that μ_i is fixed and allowed to be freely correlated with \mathbf{x}_{it} (Kumbhakar et al., 2015).

At this point the model defines efficiency as time-invariant. Since it is likely there is an element of agricultural output efficiency that is related to time, I utilize Cornwell, Schmidt, and Sickles (1990) random trend model to adjust. As shown above, α_i is replaced with α_{it} presenting the model as

$$\ln Output_{it} = \alpha_{0i} + \mathbf{x}'_{it}\boldsymbol{\beta} + v'_{it}, \quad (4)$$

$$\text{where } v'_{it} \equiv v_{it} + \alpha_{1i} t + \alpha_{2i} t^2. \quad (4.1)$$

The maximum likelihood estimation method is used to obtain consistent estimates of $\boldsymbol{\beta}$ these methods result in estimates of a nation's efficiency and allow comparison against the most efficient nation in that year (instead of comparing one nation against the most

efficient nation over the entire analysis) (Kumbhakar, 2015). The most efficient nation on average may not be the most efficient year-over-year.

The methodology employed by Kumbhakar, et al. (2015) will be applied here to separate persistent and time-varying inefficiency within the inefficiency term. My model will be represented as

$$\ln Output_{it} = \alpha_{0i} + \mathbf{x}'_{it}\boldsymbol{\beta} + \omega_{it}, \quad (5)$$

$$\text{where } \alpha_i = \beta_0 - \mu_i + E(\tau_{it}) \text{ and } \omega_{it} = v_{it} - (\tau_{it} - E(\tau_{it})). \quad (5.1)$$

As defined above the error component is ω_{it} and τ_{it} is the time-varying component discussed previously. This addition to the model is the persistent component of inefficiency which is unlikely to change over-time without major overhauls to the sector. By doing this, it can be determined which portions of inefficiency are impacted by to policy and which portions of inefficiency are only impacted by industry-wide changes (Kumbhakar et al., 2015).

Finally, with firm related technical inefficiency is introduced by Kumbhakar, et al. (2014) and Colombi, Martini, and Vittadini (2014). This model is represented as

$$\ln Output_{it} = \alpha_i + f(\mathbf{x}'_{it}; \boldsymbol{\beta}) + \mu_i + v_{it} - \eta_i - u_{it} \quad (6)$$

where η_i represents the persistent technical inefficiency controlling for nation effects. By separating nation effects from persistent inefficiency, a potential source of bias is eliminated from the estimates and generally the overall efficiency calculations converge,

inflating their scores against previously mentioned models but decreasing them against the original fixed-effects model.

5. Estimation Results

Prior to reporting the final results, it is always important to provide evidence of consistent estimates through validity tests available for stochastic frontier analysis. The first problems confronted prior to the analysis were serial correlation and heteroskedasticity. These problems were tested utilizing Wooldridge's (2002) derivation of tests for heteroskedasticity and serial correlation and Drukker's (2003) implementation. While there was no evidence of heteroskedasticity, the serial correlation found within the base model was accounted for by lagging the dependent variable.

Secondly, Schmidt and Lin (1984) recommend an OLS residual test to check for validity of the estimated model. The premise of this test is to prove that the composed error $v_i - u_i$, $u_i \geq 0$ and v_i is distributed symmetrically around zero; thus, regardless of the distribution the OLS estimation should be negatively skewed (i.e., left skewed). For the purpose of the analysis, Coelli's (1995) test for skewness was performed; the null hypothesis being that there is no skewness. The test returned a statistic of 1.54, the critical value is 1.96, thus the null hypothesis of no skewness is rejected and there is support for the stochastic frontier specification of this model (Kumbhakar et al., 2015). An additional skewness test is performed after the estimation of the initial fixed-effects model confirming the above tests.

The final test performed was a likelihood ratio test to confirm that the difference between the null specification of persistent efficiency and the modeled specification of persistent efficiency are statistically significant. The likelihood ratio test confirms that the difference between the null model and the specification chosen is statistically significant (Kodde and Palm, 1986).

The stochastic frontier results are presented across Table 4, Table 5, and Table 8. The results in Table 4 present the estimations for the fixed effects model. These results include the estimation of the production frontier variables (agricultural labor and agricultural capital expenditure). As reported above Agricultural Output_{*t-1*} was included as a frontier variable to account for serial correlation within the model. The results from the fixed-effects estimation indicate that for a one percent increase in agricultural labor, on average, you would expect a 1.26 percent increase in net agricultural productive value with 95% significance. This coefficient suggests increasing returns to scale for an increase in labor. The analysis could find no evidence that a shift in capital is associated with a change in agricultural output. This may be due to the fact that African nations' have been slow to adopt technology and capital investment in their respective agricultural sectors is often unreliable at the national level.

Table 5 reports, equation 4.1 providing the analysis with the Residual Technical Efficiency or time-varying efficiency. The analysis of residual technical efficiency reports a decrease in technical inefficiency (or an increase in technical efficiency) over time similar to that of the reported productivity coefficient in Table 3. There is less than

a 0.10 probability of a type one error. The analysis could find no evidence of joint significance in terms of efficiency. As such there is no ability to predict further gains in efficiency or a maximum point in time-varying efficiency. What this tells us is generally African nations have become more efficient over time. This may be directly attributable to trickle down effects of education and access to information. It could also be land becoming more fertile over time or due to the improvement of efficiency affecting variables not controlled within the scope of the analysis.

Figure 2 provides a look at how residual efficiency acts over time and Table 13 provides a look at the average residual efficiency for each nation. The results in Figure 2 visually confirm an increase in efficiency on average over the last 20 years for the African nations sampled. Table 7 reports the time average residual technical efficiency by nation, what can be gleaned this table is evidence of major changes and higher volatility in efficiency over time for nations like Nigeria, Tunisia, and the Central African Republic.

As defined in Equation 5.1, persistent efficiency is estimated and reported in Table 8. When interpreting Table 8, like Table 5, it is important to remember that the estimation is on the inefficiency term prior to its transformation to the efficiency term. Interpretations of these coefficients are limited to the sign. In the case of agricultural water withdrawals, it is important to note that at the 90% level of significance there is a positive coefficient. This coefficient reflects that for a one percent increase in agricultural water withdrawals there is an increase in persistent technical inefficiency.

This provides some evidence to suggest that farmers are not adequately utilizing agricultural water withdrawals. It is important to note that at the 95% level of significance, or the 95% confidence interval, the coefficient ranges over both positive and negative numbers.

The same speculation can be said for the positive coefficient on rainfall. This positive coefficient suggests that for a one percent increase in rainfall we would expect an increase in persistent technical inefficiency (or a decrease in efficiency). There is between a 0.05 and 0.01 probability of a type one error. This may suggest again farmers' within these nations are not adequately utilizing rainfall or, as one would suspect, more arid nations are favored within this specification as more efficient producers of agricultural products. To elaborate what this analysis may be picking up is that some of the more arid nations produce far more agricultural goods than some of the more moist nations. As such an increase in rainfall doesn't cause additional inefficiency it tells us that nations within the data set that receive more rainfall are less efficient. This points to nation's not taking advantage of additional water resources and that more arid nations have more efficient operations out of necessity.

Also reported in Table 8 is that a one percent increase in the fertilizer consumed leads to a decrease in persistent technical inefficiency, a one percent increase in the land area equipped for irrigation leads to a decrease in persistent technical inefficiency, and an increase in agricultural land area leads to an increase in persistent technical inefficiency. There is between a 0.05 and 0.01 probability of a type one error in each of these

estimates. Figure 2 provides a look at how persistent efficiency evolves over time, revealing an increase in efficiency from 1985-1990 but relatively no change in persistent efficiency over the last 15 years for the nations presented. Table 13 reveals the average persistent technical efficiency over the last 20 years for each nation in the panel, ranked from most efficient to least efficient. In terms of persistent inefficiency I find Tunisia, Morocco, and Mauritania to be the most efficient. This further supports earlier claims that more arid environments may be favored by this specification.

Finally overall technical efficiency of the panel is calculated by taking the product of residual efficiency and persistent efficiency, presented in Table 12, Table 13, Figure 1, Figure 2, and Figure 3. Table 13 provides a look at the rankings for nations over time ranked from most to least efficient. The *kdensity* plot in Figure 1 provides a look at the probability density function of overall technical efficiency, in other words the distribution of efficiency ratings for these nations. Figure 2 provides a look at the interaction of residual, persistent, and overall efficiency as well as a look at how overall efficiency has trended over the last 20 years. In order to provide a concise picture of the results, Figure 3 was limited to seven observations. In order; the top three nations by efficiency, average efficiency, and bottom three nations by efficiency are provided to examine the progress made by the panel and individual nations over the last 20 years.

As mentioned in the residual technical efficiency section above, productivity is reported via the Year coefficient in Table 3. The literature distinguishes a change in productivity over the last 40 years of somewhere between a -0.5 percent and a +0.5

percent acknowledging a peak of African agriculture in the mid-1980s. The literature also concludes that Africa as a continent was a net food exporter up until the 1960s. What the coefficient of 0.0298, rounded to 0.03 in Table 3, indicates is that for each additional year we'd expect agricultural output to increase by 2.98%. There is less than a 0.01 probability of a type one error. To speculate about the increase in productivity year-over-year, it is important to consider that prior studies are looking at 40 years, including the assumed decline of African agriculture from its position as a net food exporter and that the last 20 years have been the beginning of the resurgence of these nations' agricultural sectors.

6. Discussion

The Green Revolution found its roots in a U.S. agronomist and Nobel laureate named Norman Borlaug. Borlaug ran a wheat-research program under the direction of the Rockefeller Foundation and the government of Mexico. Through the implementation of high-yielding cereal grains, increased chemical fertilizer use, and better irrigation, Mexican wheat yields quadrupled making Mexico a self-sufficient cereal-grain producer by the mid-1950s.

This success was largely ignored by developing nations until Borlaug himself petitioned the governments of India and Pakistan. India and Pakistan in the mid-1960s were threatened by destabilizing famine, forcing Indian and Pakistani governments to relent and allow the introduction of high yield crops and new production technologies into their respective agricultural sectors (Borlaug, 1970). With the support of their

respective governments, farmers were provided loans to help encourage new production styles and were rewarded with nearly a doubling of wheat production in 5 years, and in a little less than 10 years both nations were self-sufficient in terms of wheat production.

In a similar, case the Ford and Rockefeller Foundations, funded the Philippines in concert with the International Rice Research Institute and the U.S. Agency for International Development to produce hardier rice crops. This crop was often dubbed “miracle rice” and was used to increase rice production in a variety of nations, including but not limited to most of East Asia (Jain, 2010).

The improvement of these nations’ fortunes did have unintended consequences. Critics are quick to point out that programs in India were often reserved for areas, primarily the north and northwestern portions of the nation, with assured supplies of water and the irrigation practices to control it, access to large amounts of fertilizer, and access to credit markets. This incongruent application of practices led to disparities across the nation and many researchers argue led to the displacement of poor farmers, driving them into urban slums. These are valuable lessons to be learned and applied to African nations where a large proportion of their labor forces is associated with the agricultural sector (Lobb, 2013).

The key many researchers believe to these “Green Revolutions” were strong central governments and the willingness of these governments to improve the infrastructure that facilitates the production of agricultural products. Many of these programs have been attempted in African nations and their success is often short-lived or

impact too small to improve the fortunes of entire nations due to instability. The results can lead one to speculate that these practices have caused some changes to these agricultural sectors but the implementation is far from complete. An example of this can be seen in that the analysis found no evidence of capital having a significant impact on productivity. While no one will argue that capital has an obvious impact on productivity, this result indicates that labor for these nations has a linear relationship with agricultural output to the point where increasing returns to scale exist; for a one percent increase in labor equates an increase in agricultural output greater than one percent is estimated (Table 4).

These results may lead one to speculate that agricultural sectors in question are still labor intensive and there is greater value in increasing the workforce than there is to increasing capital expenditures. This result stands more as a warning of the lessons India has illustrated. The implementation of these policies can lead poor farmers to cities in search of work that which has led to the slums, that are so prevalent in everyone's mind when you think, of India.

7. Conclusion

Before making policy changes that impact the food supply of some of the poorest and most unstable nations in the world, it is important to consider the impact of practices on nations that have recently adopted similar changes, as well as how the implementation of policies in the past have positively changed (and failed the nations involved). There is no disagreement that these nations have been trying to improve their situations for the better half of 50 years. Yet, there is a disconnect in what is happening on the ground and

how policy change has been attempted to improve outcomes at the policy level. This analysis adds to the literature by providing a better picture of the agricultural sectors in question.

Over the course of this analysis, I have modelled efficiency in the agricultural sector for African nations. With the inclusion of more recent data and water metrics, I have found that since the mid-1980s the nations examined have seen an increase in agricultural productivity by approximately 3% year-over-year. The panel analysis conducted indicates the structure of the agricultural sector is primarily labor intensive and that at this point there are still increasing returns to scale with regards to the agricultural labor force. I find that there is some evidence in the nations sampled that Green Revolution principles have started to take hold, but for reasons outside of the scope of the model presented, significant barriers still exist to improved productivity.

In addition to overall productivity there were various efficiency effecting variables investigated. There is evidence to suggest that fertilizer use and increased properly irrigated land area both increase efficiency, while at this scale of irrigation there seems to be evidence that water is not being efficiently used. As found in the prior literature, an increase in agricultural land overall is shown to decrease efficiency. This result lends itself to the literature presented by Hayami and Platteau (1997) and reports by the World Bank (2013) that it is not for the lack of land that African agriculture is struggling, but its access to inputs. The contributions outlined here should give future researchers an additional view on how to conduct agricultural efficiency analyses for both individual nations and subsets of the continent.

7.1 Extensions

Both on the micro- and macro-economic levels, the availability of data is problematic in studies such-as-this-one. When studying a continent undergoing as many changes as Africa, it is important to understand and model these changes in order to make appropriate policy decisions. This decision making process is compromised because of lack of information for many African nations. The analysis presented lacks many control variables that could bias the results, inclusion of which could turn an analysis like this one into a viable tool for making policy decisions. As the United Nations Food and Agriculture Organization continues to collect more promising agriculture and water data, it is reasonable to believe that in the next five to ten years that a more comprehensive study can be conducted which includes all continental African nations.

The same is true for the availability of many national level control variables. The accuracy of the model can be further improved with the inclusion of nation stability variables including but not limited to conflict status, national corruption and stability indices. The structure of each nation's tax structure and agricultural sector, land and labor quality controls, a control for agricultural research and development in the nation, trade information, taxation, land values, and the ease of access to credit markets could provide further insight. With better national level survey systems for African nations in place, much like those used in developed nations, the true impact of policy initiatives on the structure of African nation's agricultural sectors can be found.

References

Africa's Agriculture and Agribusiness Markets Set to Top US\$ One Trillion in 2030.

(2013, March 4). Retrieved August 4, 2015.

Aigner, D., and S. Chu (1968), "On Estimating the Industry Production Function,"

American Economic Review, 58, pp. 826–839.

Antle, J. M. (1983), "Infrastructure and Aggregated Agricultural Productivity:

International Evidence." The Pakistan Development Review 21: 609-19.

Badiane, Ousmane, and Tsitsi Makombe (2014), "The Theory And Practice Of

Agriculture, Growth, And Development In Africa."

Binswanger, Hans P., and Robert F. Townsend (2000), "The Growth Performance Of

Agriculture In Sub-Saharan Africa." American Journal Of Agricultural

Economics 82.5: 1075-1086.

Bourne, Joel K. (2014), "The Next Breadbasket" <http://www.nationalgeographic.com/>

National Geographic Magazine & U.N. F.A.O.

Borlaug, Norman (1970), "The Green Revolution, Peace, and Humanity." Nobel Lecture.

Available at <http://www.nobel.se>.

Chambers, R.G. (1988), "Applied Production Analysis: A Dual Approach" Cambridge

University Press.

Coelli, T. (1995), "Estimators and Hypothesis Tests for Stochastic Frontier Function: A

Monte Carlo Analysis," Journal of Productivity Analysis, 6, 247-68.

- Colombi, R., Kumbhakar, S. C., Martini, G., and Vittadini, G. (2014), "Closed-Skew Normality in Stochastic Frontiers with Individual Effects and Long/Short-run Efficiency," *Journal of Productivity Analysis*, 42(2), 123-26.
- Drukker, D. M. (2003), "Testing for serial correlation in linear panel-data models," *Stata Journal* 3: 168-177.
- Førsund, F., and Jansen E., (1977) ,"On Estimating Average and Best Practice Homothetic Production Functions via Cost Functions," *International Economic Review*, 18, pp. 463–476.
- Fulginiti LE and RK Perrin (1997). "Ldc Agriculture: Nonparametric Malmquist Productivity Indexes." *J Development Economics* 53(2): 373-390.
- Greene, W. H. (2005a), "Fixed and Random Effects in Stochastic Frontier Models," *Journal of Productivity Analysis*, 23, 7-32.
- Greene, W.H. (2005b), "Reconsidering Heterogeneity in Panel Data Estimators of the Stochastic Frontier Model," *Journal of Econometrics*, 126, 269-303.
- Greene, W. (2008), "The Econometric Approach to Efficiency Analysis," *The Measurement of Efficiency*. Oxford University Press, 92-159.
- Hanson, Kobena T., and Frannie Leautier (2013), "Jobless Economic Growth in Africa: Is There A Role For Agriculture?" *Journal Of African Development* 15.2: 1-17.
- Hayami, Y., and J.P. Platteau (1997), "Resource Endowments and Agricultural Development: Africa vs. Asia." *Cahiers: Serie Recherche (Belgium) No. 192*.
- Hayami Y & Ruttan V W. *Agricultural development: an international perspective*. Baltimore, MD: Johns Hopkins Press, 1971. 367 p.

- Jain, H.K. (2010). "Green Revolution: History, Impact and Future," Houston: Studium Press.
- Johnson, Daniel K. N., and Robert E. Evenson (2000), "How Far Away Is Africa? Technological Spillovers To Agriculture And Productivity." *American Journal Of Agricultural Economics* 82.3: 743-749.
- Jondrow, J., Lovell, C. A. K., Materov, I. S., and Schmidt, P. (1982), "On the Estimation of Technical Inefficiency in the Stochastic Frontier Production Function Model," *Journal of Econometrics*, 19, 233-8.
- Kodde, D. A., and Palm, F. C. (1986), "Wald Criteria for Jointly Testing Equality and Inequality Restrictions," *Econometrica*, 54, 1243-8.
- Kumbhakar, S. C., and Hjalmarsson, L. (1993), "Technical Efficiency and Technical Progres in Swedish Dairy Farms," *The Measurement of Productive Efficiency: Techniques and Applications*. Oxford University Press.
- Kumbhakar, S. C., and Hjalmarsson, L. (1995), "Labor-Use Efficiency in Swedish Social Insurance Offices," *Journal of Applied Econometrics*, 10, 33-47.
- Kumbhakar, S. C., Lien, G., and Hardaker, J. B. (2014), "Technical Efficiency in Competing Panel Data Models: A Study of Norwegian Grain Farming," *Journal of Productivity Analysis*. Cambridge University Press.
- Kumbhakar, S., Wang, H., & Horncastle, A. (2015), *A practitioner's guide to stochastic frontier analysis using Stata*. Cambridge Univ. Press.
- Lamb, Russell L. (2000), "Food Crops, Exports, And The Short-Run Policy Response Of Agriculture In Africa." *Agricultural Economics* 22.3: 271-298.

- Lobb, Richard L. (2003), "Green Revolution." Encyclopedia of Food and Culture. 2003.
<http://www.encyclopedia.com/doc/1G2-3403400302.html>
- Moor, Graham M., and W. Lieb Nieuwoudt (1998), "Tenure Security And Productivity In Small-Scale Agriculture In Zimbabwe: Implications For South Africa." *Development Southern Africa* 15.4: 609-620.
- Nin-Pratt, Alejandro, et al. (2009), "Priorities for Realizing the Potential to Increase Agricultural Productivity and Growth in Western and Central Africa" International Food Policy Research Institute (IFPRI).
- Quartey, Peter (2014), "How Do We Increase The Share Of Aid To Agriculture In Africa?" (Working Paper 2014/022) Retrieved from UNU-WIDER website:
http://www.wider.unu.edu/publications/working-papers/2014/en_GB/wp2014-022/
- Schmidt, P., and Sickles, R. C. (1984), "Production Frontiers and Panel Data," *Journal of Business and Economic Statistics*, 2, 367-74.
- Schuh, S. G. and G. W. Norton, (1991), "Agricultural Research in an International Policy Context." In "Agricultural Research Policy: International Quantitative Perspectives." Published for the International Service for National Agricultural Research. Cambridge University Press.
- Umbadda, Siddig, and Ismail Elgizouli (2013), "Foreign Aid and Sustainable Agriculture In Africa." Retrieved from UNU-WIDER website:
http://www.wider.unu.edu/publications/working-papers/2013/en_GB/wp2013-081/

United Nations, Department of Economic and Social Affairs, Population Division. The
2009 Revision Of World Population Prospects. 2009. Print.

Wooldridge, J.M. (2010), *Econometric Analysis of Cross Section and Panel Data*. MIT
Press.

“World Development Report 2008: Agriculture for Development”

<http://www.worldbank.org/> The World Bank, 2008.

Yu, Bingxin & Nin-Pratt, Alejandro (2011), “Agricultural productivity and policies in
Sub-Saharan Africa” International Food Policy Research Institute (IFPRI).

Appendix

Table 1. Descriptive Statistics

Variable	# OBS.	MEAN	STD. DEV.	MINIMUM	MAXIMUM
Dependent variables					
Net Agricultural Production Value (constant 2005 IS)	273	\$3,749,802,577	\$5,508,334,727	\$287,808,790	\$31,839,300,970
Frontier variables					
Agricultural Labor (FTE)	273	4,036,828	3,516,524	442,000	12,478,000
Agricultural Capital Expenditures (2005 constant IS)	273	\$5,508,553	\$7,048,766	\$405,920	\$30,278,620
Year	273	11	6	1	21
Efficiency factors					
Agricultural Land (hectares)	273	30,453,559	18,655,854	4,983,000	72,700,000
Yearly Rainfall Totals (mm ³)	273	709	474	86	1,557
Agricultural Water Withdrawals (mm ³)	253	1,866,047	2,659,610	400	11,050,000
Area Equipped for Irrigation (hectares)	273	188,987	343,025	100	1,458,000
Fertilizer Consumption (metric tons)	273	68,392	100,887	0	500,843

Table 2. OLS Estimation

Dependent variable:	Agricultural Output (logged)
	Coefficient (Standard Errors)
Agricultural Land (logged)	-0.086 (0.07)
Agricultural Labor (logged)	0.169 (0.054) ***
Agricultural Capital Expenditure (logged)	0.108 (0.05) **
Rainfall (logged)	0.121 (0.08)
Agricultural Water Withdrawals (logged)	0.031 (0.035)
Area Equipped for Irrigation (logged)	0.054 (0.059)
Fertilizer Consumption (logged)	-0.016 (0.01)
Agricultural Output _{t-1} (logged)	0.702 (0.093) ***
Year	0.008 (0.003) ***
Constant	2.057 (1.249)
Number of observations	252
Number of groups	13
R ²	0.96

*** signifies the probability of a type one error as less than 0.01.

** signifies the probability of a type one error as between 0.01 and 0.05.

* signifies the probability of a type one error as between 0.05 and 0.1.

Table 3. Fixed Effects with Yearly Productivity

Dependent variable:	Agricultural Output (logged)
	Coefficient (Standard Errors)
Agricultural Labor (logged)	0.183 (0.086) **
Agricultural Capital Expenditure (logged)	0.008 (0.011)
Agricultural Output _{t-1} (logged)	0.062 (0.017) ***
Year	0.03 (0.002) ***
Constant	16.957 (1.343) ***
μ	0.867
ε	0.1
ρ	0.987
Number of observations	272
Number of groups	13
R ²	0.8295
F(12, 252)	166.7 [0.00]

*** signifies the probability of a type one error as less than 0.01.

** signifies the probability of a type one error as between 0.01 and 0.05.

* signifies the probability of a type one error as between 0.05 and 0.1.

Table 4. Efficiency Model with Fixed Effects

Dependent variable:	Agricultural Output (logged)
	Coefficient (Standard Errors)
Agricultural Labor (logged)	1.255 (0.065) **
Agricultural Capital Expenditure (logged)	0.015 (0.014)
Agricultural Output _{t-1} (logged)	0.134 (0.023) ***
Constant	-0.251 (0.933) ***
μ	0.792
ε	0.136
ρ	0.971
Number of observations	272
Number of groups	13
R ²	0.68
F(12, 256)	79.63 [0.00]

*** signifies the probability of a type one error as less than 0.01.

** signifies the probability of a type one error as between 0.01 and 0.05.

* signifies the probability of a type one error as between 0.05 and 0.1.

Table 5. Residual Technical Efficiency

Dependent variable:	v_{it}
	Coefficient (Standard Errors)
Frontier	
Constant	0.062 (0.019) ***
usigmas	
Year	-0.301 (0.16) *
Year ²	0.003 (0.008)
Constant	-2.715 (0.433) ***
vsigmas	
Constant	-4.47 (0.124) ***
Number of observations	272
Number of groups	13
Wald chi ²	10.28 [0.00]
Log Likelihood	190.90

*** signifies the probability of a type one error as less than 0.01.

** signifies the probability of a type one error as between 0.01 and 0.05.

* signifies the probability of a type one error as between 0.05 and 0.1.

Table 6. Average Marginal Effect for Residual Technical Efficiency

Variable	Unconditional E(u)	Unconditional V(u)
Year	-0.01	-0.001
Year Count	8.50×10^{-5}	9.44×10^{-6}

Table 7. Time Averaged Residual Technical Efficiency by Nation

RANK	NATION	MEAN	STD. DEV.	MIN	MAX
1	Kenya	96%	0.01	93%	98%
2	Angola	95%	0.03	91%	99%
3	Burkina Faso	95%	0.04	82%	98%
4	Chad	95%	0.02	91%	98%
5	Mauritania	95%	0.04	77%	98%
6	Uganda	95%	0.02	92%	98%
7	Central African Republic	94%	0.06	73%	99%
8	Ivory Coast	94%	0.04	88%	99%
9	Mali	94%	0.06	71%	99%
10	Morocco	94%	0.05	82%	99%
11	Niger	94%	0.06	71%	99%
12	Tunisia	93%	0.08	66%	99%
13	Nigeria	91%	0.11	66%	99%

Table 8. Persistent Technical Efficiency

Dependent variable:	α_i
	Coefficient (Standard Errors)
Frontier	
Constant	0.336 (0.091) ***
usigmas	
Rainfall (logged)	1.457 (0.39) ***
Agricultural Water Withdrawals (logged)	0.424 (0.231) *
Fertilizer Consumption (logged)	-0.238 (0.102) **
Area Equipped for Irrigation (logged)	-0.746 (0.308) **
Agricultural Land (logged)	1.05 (0.435) **
Constant	-24.366 (7.475) ***
vsigmas	
Constant	-0.888 (0.11) ***
Number of observations	252
Number of groups	13
Wald chi ²	13.78 [0.00]
Log Likelihood	-259.61

*** signifies the probability of a type one error as less than 0.01.

** signifies the probability of a type one error as between 0.01 and 0.05.

* signifies the probability of a type one error as between 0.05 and 0.1.

Table 9. Average Marginal Effect for Persistent Technical Efficiency

Variable	Unconditional E(u)	Unconditional V(u)
Rainfall (logged)	0.259	0.145
Agricultural Water Withdrawals (logged)	0.075	0.042
Fertilizer Consumption (logged)	-0.042	-0.024
Area Equipped for Irrigation (logged)	-0.132	-0.074
Agricultural Land (logged)	0.187	0.105

Table 10. Time Averaged Persistent Technical Efficiency by Nation

RANK	NATION	MEAN	STD. DEV.	MIN	MAX
1	Tunisia	95%	0.01	93%	96%
2	Morocco	94%	0.02	91%	96%
3	Mauritania	87%	0.02	82%	91%
4	Mali	82%	0.03	76%	87%
5	Niger	82%	0.06	61%	88%
6	Ivory Coast	78%	0.01	76%	80%
7	Central African Republic	74%	0.06	65%	84%
8	Burkina Faso	70%	0.03	62%	77%
9	Kenya	68%	0.1	50%	78%
10	Nigeria	68%	0.02	66%	71%
11	Chad	65%	0.06	53%	71%
12	Uganda	52%	0.03	45%	57%
13	Angola	50%	0.02	46%	56%

Table 11. Time Averaged Overall Technical Efficiency by Nation

RANK	NATION	MEAN	STD. DEV.	MIN	MAX
1	Tunisia	91%	0.02	88%	94%
2	Morocco	90%	0.03	84%	94%
3	Mauritania	83%	0.04	69%	89%
4	Niger	79%	0.06	60%	83%
5	Mali	77%	0.06	59%	85%
6	Ivory Coast	74%	0.03	68%	78%
7	Central African Republic	70%	0.08	49%	82%
8	Burkina Faso	67%	0.04	56%	75%
9	Kenya	66%	0.09	47%	75%
10	Chad	62%	0.05	52%	69%
11	Nigeria	61%	0.06	46%	67%
12	Uganda	49%	0.04	42%	56%
13	Angola	48%	0.03	44%	55%

Table 12. Average Technical Efficiency Estimates

Type of Efficiency	# OBS.	MEAN	STD. DEV.	MIN	MAX
Residual Technical Efficiency	272	94%	0.054	66%	99%
Persistent Technical Efficiency	252	74%	0.139	45%	96%
Overall Technical Efficiency	252	70%	0.140	42%	94%

Table 13. Time Averaged Technical Efficiency by Nation

Nation	Residual Technical Efficiency (Rank)	Persistent Technical Efficiency (Rank)	Overall Technical Efficiency (Rank)
Angola	95% (2)	50% (13)	48% (13)
Burkina Faso	95% (3)	70% (8)	67% (8)
Central African Republic	94% (7)	74% (7)	70% (7)
Chad	95% (4)	65% (11)	62% (10)
Ivory Coast	94% (8)	78% (6)	74% (6)
Kenya	96% (1)	68% (9)	66% (9)
Mali	94% (9)	82% (4)	77% (5)
Mauritania	95% (5)	87% (3)	83% (3)
Morocco	94% (10)	94% (2)	90% (2)
Niger	94% (11)	82% (5)	79% (4)
Nigeria	91% (13)	68% (10)	61% (11)
Tunisia	93% (12)	95% (1)	91% (1)
Uganda	95% (6)	52% (12)	49% (12)

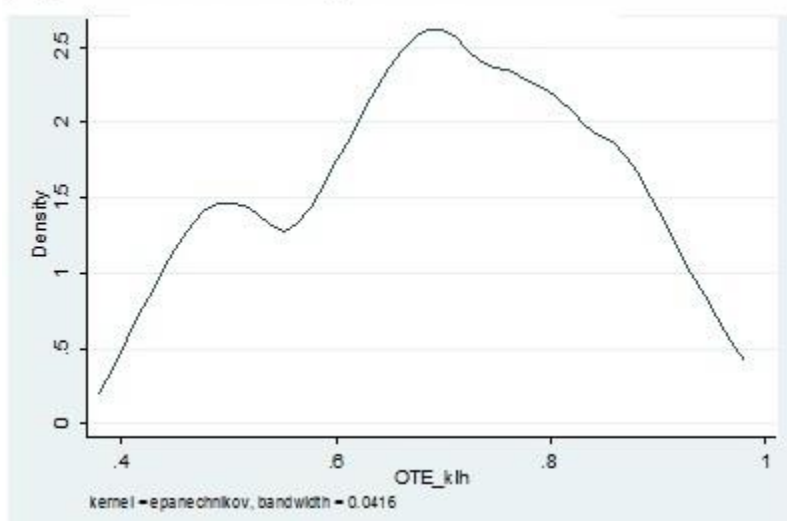
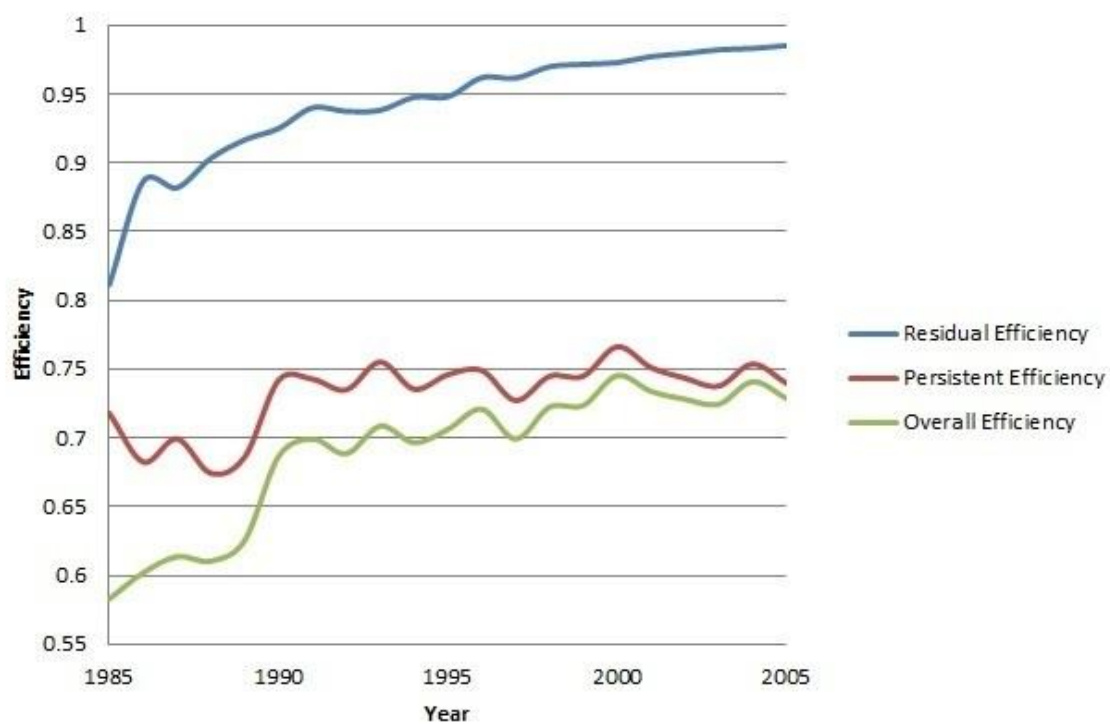
Figure 1. Kernel Density Estimate**Figure 2. Time Averaged Technical Efficiency**

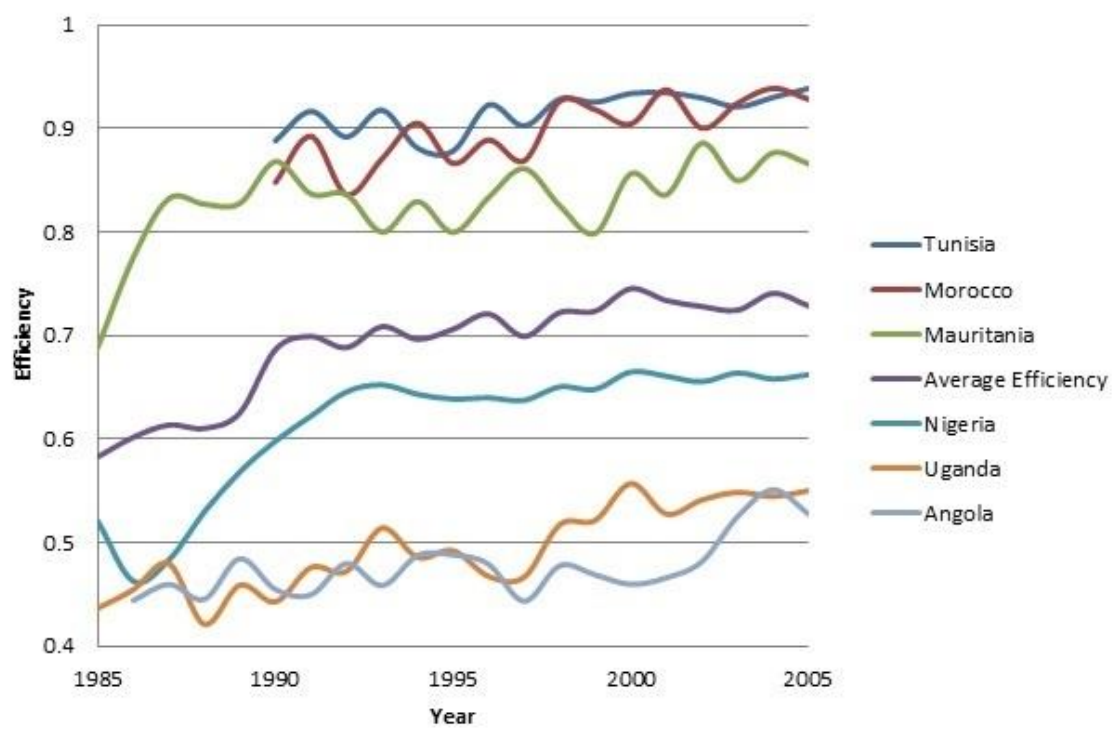
Figure 3. Top and Bottom 3 Nations

Figure 4. Map of Nations

