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Abstract

Agricultural productivity in Africa from 1971 to 2000 is examined using the recently developed metafrontier function technique, for the purpose of studying differences in efficiency and technology gap across different regions of the continent. The results support the view that technology gap plays an important part in explaining the ability of agricultural sectors in one region to compete with agricultural sectors in different regions in Africa. The study has also evidenced that average technical efficiency score of the agricultural sector has been almost stable over time, while a marginal decrease of the productivity potential over the 30 years period was observed.

Keywords: Agricultural productivity, Data Envelopment Analysis, Metafrontier function, Efficiency, Technology gap, Africa.

JEL: N57; O47 ; O55 ; Q10

Introduction

Agricultural growth will prove essential for improving the welfare of the vast majority of Africa's poor. Roughly 80% of the continent's poor live in rural areas and even those who do not will depend heavily on increasing agricultural productivity to lift them out of poverty (Sahn et al,. 1997; World bank, 2000). As producers, 70% of all Africans and nearly 90% of their poor work primarily in agriculture (World Bank, 2000). As consumers, all African's poor, both rural and urban count heavily on the efficiency of the continent farmers, since farm productivity and production costs prove fundamental determinants of the prices of basic foodstuffs which account for 60% to 70% of total consumption expenditure by low-income groups (Sahn et al,. 1997). Consequently, significant reductions in poverty will hinge in large part on the collective ability of African farmers, governments, and agricultural specialists to stimulate and sustain broad-based agricultural growth. With its importance in overall GDP, export earnings and employment, as well as its forward and backward linkages to the non-farm sector, only growing in agriculture productivity can simultaneously reduce food prices, which govern real incomes and poverty in urban areas, and increase incomes of the 70% of Africans who work in agriculture. Agricultural growth provides a central thrust around which the battle against African poverty must be waged.

The agricultural sector can improve the level of total factor productivity either by improving technical efficiency and/or by improving technological level. A relevant question for agricultural policymakers is whether to pursue a strategy directed towards technological change or a strategy towards efficiency change (Nkamleu, 2004a). The presence of shortfalls in production efficiency means that output can be increased without requiring additional conventional inputs and without the need for new technology. If this is the case, then empirical measures of efficiency are necessary in order to determine the magnitude of the gain that could be obtained by improving performance with a given technology. In the presence of technological gap, technical progress is the rationale strategy to significantly increase agricultural production.

In this paper, we apply recently developed techniques; a metafrontier production function to investigate productivity potentials (technological gap) and efficiencies of agricultural sector in different regions of the African continent. This methodology has the advantage of permitting comparison of technical efficiency of agricultural sector in different regions that may not share the same technology. The study used country level panel data of 26 selected countries of the continent.

2. Data

The present study is the first major empirical analysis applying Meta frontier production function technique on African countries exclusively. The analysis is based on data drawn from FAOSTAT (http://faostat.fao.org) system of statistics used for dissemination of statistics compiled by the Food and Agricultural Organization. Panel data on 26 African countries, from 1971 to 2000 was used. The countries included in the data set are evenly distributed over all the regions of the continent and are grouped into five regions (table 1).

Data consisted of information on agricultural production and means of production in the study countries. Record of agricultural production, agricultural labor, number of tractors in use, quantity of fertilizer used, agricultural areas and livestock were obtained. Specification of output and inputs in our analysis was as follow (table 1):

Output

Agricultural production: To construct the output series, we followed the methodology suggested in Rao and Coelli, (1998). Output aggregated for the year 1990 was used to compute output series (Rao, 1993). These 1990 aggregated outputs were computed using international average prices (expressed in US dollars) derived using a Geary-Khamis method (see Rao 1993). The aggregates are based on the sum of price-weighted quantities of different agricultural commodities produced after deduction of quantities used as seed and feed weighted in a similar manner. The resulting aggregates represent, therefore, disposable production for any use, except as seed and feed. The 1990 output series were then extended to cover the study period, 1971-2000, using the FAO production index number series.

Input

- Labor refers to economically active population in agriculture for each year, in each country. Economically active population in agriculture is defined as all persons engaged or seeking employment in agriculture, forestry, hunting or fishing sector, whether as employers, own-account workers, salaried employees or unpaid workers. Since it is not possible to have information on differentials in skill levels and the number of hours worked on the farm, the economically active population in agriculture is the best proxy of labor input into the agricultural sector.

- Agricultural land: the sum of area under *Arable land* (land under temporary crops, temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow), *Permanent crops* (land cultivated with crops that occupy the land for long periods and need not be replanted after each harvest, such as cocoa, coffee and rubber), and *Permanent pastures* (land used permanently for herbaceous forage crops, either cultivated or growing wild).

- Fertilizer: Fertilizer consumption is often view as a proxy for the whole range of chemical inputs and more (Mundlak et al., 2003). Fertilizers used in different countries involve different amounts and different types of fertilizers. Following other studies (Hayami and Ruttan, 1970; Rao et al., 2003), the sum of nitrogen (N), potassium (P_2O_2) and phosphate (K_2O) expressed in thousands of tons, that is contained in the commercial fertilizers consumed is used as measure of fertilizer input. There were four observations with fertilizer input equal to zero. These observations were replaced by the means of adjacent years.

- Tractors: We used data on number of tractors, which refer to total wheel, and crawler tractors (excluding garden tractors) used for agricultural production.

- Livestock: Following Hayami and Ruttan (1970), the livestock input variable used in this study is the sheep-equivalent of five categories of animals. The categories of animals considered are buffaloes, cattle, pigs, sheep and goats. Data on number of these animals are converted into sheep equivalents using the following conversion factors as suggested by Hayami and Ruttan: 8 for buffalo and cattle; and 1 for sheep coats and pigs.

3. Theoretical framework: DEA approach to metafrontier

DEA approach to metafrontier

The use of a common production frontier to assess the level of efficiency of agricultural sector of countries is now a common practice (Fulginiti and Perrin, 1998; Rao and Coelli, 1998; Nkamleu 2004). While technical efficiencies of countries measured with respect to a given frontier are comparable, this is not normally the case among countries that operate under different technologies. Such problem arise when comparison of countries from different regions are involved. Battese and Rao (2002) suggest an approach to investigate efficiency of firms in different regions that may not have the same technology. With that approach, the productivity of the agricultural sector in a given region, and their technical gap, may be estimated relative to a metaproduction frontier. In this paper, this method was employed. Given that countries are within regions, it is possible to identify a ‘‘regional frontier’’ on the data for countries from the given region. The metafrontier (Hayami and Ruttan, 1971) is then constructed by using the data set obtained by pooling all the observations for countries of all the regions. In this paper, we use DEA to construct different production frontiers. Simply defined, DEA is a linear programming methodology that uses data on output and inputs of countries, to construct a piece-wise linear surface over the data point. This frontier surface is constructed by the solution of a sequence of linear programming problem.

The procedure is easily introduced via the ratio form (Coelli *et al*., 1998; Nkamleu, 2004b). For each country we would like to obtain a measure of the ratio of all outputs over all inputs, such as $u'y_i/v'x_i$, where ‘u’ is an m x 1 vector of output weights and ‘v’ is a k x 1 vector of input weights. Under constant return to scale assumption, the optimal weights are obtained by solving the mathematical programming problem:

$$\begin{aligned} & Max_{u,v}\left(u'y_i / v'x_i\right), \\ & \text{subject to} \quad u'y_j / v'x_j \leq 1, \quad j = 1,2,\ldots\ldots, N \qquad (1) \\ & \qquad u,v \geq 0 \end{aligned}$$

This involves finding values for u and v such that the efficiency measure of the i-th farmer is maximized, subject to the constraint that efficiency measures must be less than or equal to one. To avoid having an infinite number of solutions, one imposes the constraint v'x = 1, which provides,

$$\begin{aligned} & Max_{\mu,v}\left(\mu' y_i\right), \\ & subject\ to \quad v' x_i = 1 \\ & \qquad \mu' y_j - v' x_j \le 0, \quad j = 1,2,\ldots\ldots, N \\ & \qquad u, v \ge 0 \end{aligned} \qquad (2)$$

where the notation changes from 'u' and 'v' to 'μ' and 'ν' reflect the transformation. This form is known as the multiplier form of the linear programming problem (Coelli, 1996). Using the duality in linear programming, one can derive an equivalent envelopment form of this problem:

$$\begin{aligned} & Max_{\theta,\lambda}\theta, \\ & subject\ to \quad -y_i + Y\lambda \ge 0 \\ & \qquad \theta x_i - X\lambda \ge 0 \\ & \qquad \lambda \ge 0 \end{aligned} \qquad (3)$$

where θ is a scalar and λ is a Nx1 vector of constants. θ measures the ratio of the observed vector of outputs to the maximum vector that could be achieved, given the input vector. The value of θ obtained will be the efficiency scores for the i^{th} country.

The constant returns to scale (CRS) assumption is appropriate when all firms are operating at an optimal scale. The use of the variable returns to scale (VRS) specification will permit the calculation of efficiency scores devoid of scale efficiency effects. According to Coelli (1996), the VRS specification has been the most commonly used specification in the 1990's. We also opted for the VRS specification. The linear programming problem under CRS (eq.

3), can be easily modified to account for VRS by adding the convexity constraint: N1'λ=1 to equation (3) to give:

$$
\begin{aligned}
& Max_{\theta,\lambda}\theta, \\
& subject\ to \quad -y_i + Y\lambda \geq 0 \\
& \qquad \theta x_i - X\lambda \geq 0 \\
& \qquad N1'\lambda = 1 \\
& \qquad \lambda \geq 0
\end{aligned} \tag{4}
$$

where $N1$ is an Nx1 vector of one. If we have data on L_k countries, the above linear program is solved L_k times for each year. The metafrontier is constructed using a DEA model based on the pooled data for all the countries in all the regions. Since we have a total of $L = \sum_k L_k$ countries, we re-run the above linear program model with the inputs and output matrices with data for all countries. We used Data Envelopment Analysis computer Program, - DEAP2.1 – and a multi-stage DEA procedure (Coelli, 1996) to run the models.

Productivity Potential and Efficiency Levels

The regional frontier is a representation of the state of knowledge/technology pertaining to the transformation of agricultural inputs into output in the region, while the metafrontier represents the state of the knowledge/technology at the continental level. The ratio of the frontier score of region 'r' and the metafrontier, represents the technology gap ratio (TGR) of the region 'r' (Nyemeck and Nkamleu, 2006).

Alternatively, if we denote the technical efficiency of region 'r' relative to its technology (frontier) by TE_r^r, and the technical efficiency of the same region evaluated at the metatechnology (meta-frontier) by TE_r^*, the productivity potential or technology gap ratio (TGR) of the region can be defined as (Battese *et al*., 2004):

$$TGR_r^* = \frac{TE_r^*}{TE_r^r} \quad (5)$$

Thus, the technical efficiency relative to the metafrontier function is the product of the technical efficiency relative to the frontier for a given region and the TGR. This shows that technical efficiency measured with reference to the metatechnology can be decomposed into the product of the technical efficiency measured with reference to the region 'r' technology, and technology gap ratio between the region technology and the metatechnology. Because the technical efficiency relative to the metafrontier is always less than the technical efficiency relative to the regional frontier, TGR is bound between zero and one.

4. Results

African countries in the sample are grouped into five regions using standard geographical classification; Northern, Western, Central, Eastern and Southern Africa. The mean technical efficiencies obtained from the regional DEA frontiers and the metaproduction frontier are presented in table 2 for the 30 years period 1971-2000.

For the sampled countries, the technical efficiency score ranged from 0.25 to 1.00, with an average of about 0.74, indicating that the agricultural sector produce on average only 74% of the potential output given the technology available in African agricultural sector as a whole. This is greater than 68% found by Rao et al., (2003) in their study where they compared African agricultural sector with world agricultural sector using 1986-1990 panel data. It also appeared that average technical efficiency score of the agricultural sector has been globally stable over time. The more interesting feature is the difference between the average technical efficiency scores from the regional and the metafrontier models. For example, the average technical efficiency for the southern region relative to the metatechnology is only 57%, while its mean efficiency is quite large with respect to its own regional frontier (96%). The differences between the two efficiency scores indicate the order of bias of the technical efficiencies obtained by using the regional frontiers, relative to the technology available for the agricultural sector in Africa. Generally, the technical efficiencies from the regional frontiers should be greater than those obtained from the metaproduction frontier, because the constraints in the regional linear programming problem are a subset of the constraints in the metafrontier linear programming problem.

The agricultural sector in the Central Africa region achieved the highest mean technical efficiencies relative to the metafrontier. Countries from Southern Africa had the highest mean technical efficiency relative to their regional frontier, but they tended to be furthest from the potential outputs defined by the metafrontier function. East Africa seems to be the least performing region in term of production efficiency.

Estimates for the technology gap ratios (TGR) are presented in table 3. The five African regions have productivity potential ratio ranging between 0.59 and 0.99. These values can be interpreted as the technological gap faced by the agricultural sector in those regions when their performances are compared with the continental level.

Not surprisingly, the Southern region has the lowest productivity potential ratio. This suggest that even if all countries from southern region achieved best practice with respect to the technology observed in the region, they will still be lagging behind because Southern Africa technology lags behind African global technology with a technology gap ratio of 0.59.

Figure 1 illustrates results presented above. In the same graphic are presented regional frontier curves of the five regions and the metafrontier curve. The inefficiency levels are indicated by the distance between the production point and the frontier curve, while the technology gap ratios are represented by the distance between the regional and the metafrontier curve.

From a policy point of view, these regional differences show the type of interventions needed to be putted in place in each region for enhancing the productivity of African agriculture. In some regions, like in Southern Africa region, the first target should be on raising technology while in other region like in Eastern Africa it will be more urgent to first deal with the improvement of the know-how. Another important feature to observe is the apparent decreasing of the technical gap ratio over the 30 years period. This tendency is disquieting with regard to the millennium development goal of an annual growth rate above 7 percent a year required to achieve economic convergence with other developing countries and to maintain similar quality of life.

5. Conclusion

In this paper, we apply a recently developed metafrontier function technique to investigate productivity potentials and efficiencies of the agricultural sector in different regions of the African continent. Since technology is a representation of the state of knowledge pertaining to the transformation of agricultural inputs into output, we conceptualized the existence of an over-arching technology, referred to as the metatechnology, which is represented by the metafrontier production function. The methodology enables the estimation of regional technology gap ratios (TGRs) by using a decomposition result involving both the regional production frontiers and the metaproduction frontier. Empirical results are derived using cross-country agricultural sector panel data for 30 years, 1971-2000.

The results of this study show a large productivity potential ratio gaps between regions of the continent, ranging between 0.59 and 0.99. These values can be interpreted as the technological gap faced by the agricultural sector in those regions when their performances are compared with the continental level. Agricultural sector in Central Africa region had the lowest technology gap while those from Southern Africa region had the highest. It is also shown that, although the agricultural sector, globally, has a good efficiency score (74%), large differences exist between regions.

In term of production efficiency, countries from Southern Africa region have the highest mean technical efficiency relative to their regional frontier, but they tend to be furthest from the potential outputs defined by the metafrontier function. East Africa appears as the least performing region. It also appeared that the average technical efficiency score of the agricultural sector in Africa has been globally stable over time, while a marginal decrease of the productivity potential over the 30 years period was observed. The data used in this study support the view that the technology gap plays an important part in explaining the ability of agricultural sectors in one region to compete with agricultural sectors in others regions in Africa.

From a policy standpoint, the results of this study have important implications for policy targeting. The study clearly makes it possible to distinguish for every region of the continent, where the urgency should be on policies to help shift in technology and where the movement toward the best practice frontier is the most desirable. However, there exists potential to extend the current study to analyze the reasons of the wide difference in efficiencies and productivity potential in the different regions and countries.

References

Battese, G.E. and Rao, D.S.P., 2002. Technology gap, efficiency, and a stochastic Metafrontier function. *International Journal of Business and Economics* 1(2): 87-93.

Coelli, Tim, 1996. A guide to DEAP version 2.1: A data envelopment analysis (computer) program. CEPA Working paper 96/08.

Coelli, T.J., Prasada, R.D.S. and Battese, G., 1998. *Introduction to efficiency and productivity analysis*. Kluver Academic Publisher, Boston

Fulginiti, Lilyan and Richard Perrin, 1998. "Agricultural productivity in developing countries". Agricultural Economics 19 (1998) 45-51.

Hayami, Y. and Ruttan, V.W., 1970**.** Agricultural productivity differences among Countries. *American Economic Review* 60: 895-911.

Hayami, Y. and Ruttan, V.W., 1971. *Agricultural Development: International perspective.* Baltimore: John Hopkins University Press.

Interacademy council, 2004. Realizing the promise and potential of African agriculture: Science and technology strategies for improving agricultural productivity and food security in Africa. Amsterdam, the Netherlands.

Mundlak, Y. and Hellinghausen, R., 1982. The inter-county agricultural production function: Another view. *American Journal of Agricultural Economics* 64: 664-672.

Nkamleu, Guy Blaise, 2004a. Expliquer l'échec de la croissance de la productivité agricole en Afrique francophone: analyse non paramétrique de l'efficacité et du changement technologique du secteur agricole. *Economie Rurale* 279: 55-67.

Nkamleu, Guy .Blaise, 2004b. Productivity growth, technical progress and efficiency change in African agriculture. *African Development Review* No16, vol.1, pp. 203-222, Blackwell Publishing Ltd, Oxford, UK.

Nyemeck J. and G.B. Nkamleu (2006). Potentiel de Productivité et Efficacité Technique du Secteur Agricole en Afrique. Canadian Journal of Agricultural Economic 54 (2006) 361-377.

Rao, D.S.P., 1993. Inter-country comparisons of agricultural output and productivity. S*ocial and Economic Development Paper*, No. 156 FAO.

Rao D.S.P. and Coelli T.J., 1998. Catch-Up and Convergence in Global Agricultural Productivity 1980-1995. CEPA Working Paper No 4/98.

Rao, D.S.P., O'donnell, J. and Battese, G.E., 2003. Metafrontier functions for the study of inter-regional productivity differences. *Centre for Efficiency and Productivity Analysis Working Paper* 1.

Sahn, David E., Dorosh, Paul A. and Younger, Stephen D., 1997. Structural adjustment reconsidered-Economy policy and poverty in Africa. Cambridge, UK: Cambridge university Press.

World Bank, 2003. A multi-country agricultural productivity program (mapp) for Africa. World Bank. Washington, DC.

World Bank, 2000. Can African claim the 21st century? Washington, DC: World Bank.

Table 1: Summary statistics for the variables in the data set

Region		Mean (per country per year	Standard deviation	Minimum	Maximum
Region 1 : Northern Africa Algeria, Egypt Morocco, Tunisia)	Output (Thousands of 1989-91 international dollars	3173103	2501192	806706	11375264
	Land (1,000 ha)	20470	15444	2445	45433
	Tractor (Number in use)	44787	24389	11600	98157
	Fertilizer (Metric tons)	325589	323514	36000	1259731
	Labor (1,000 persons)	3703	2767	762	8481
	Livestock (Head)	32468169	14549275	9703200	63196427
Region 2 : Western Africa Burkina Faso, Côte d'Ivoire, Ghana, Guinea, Mali, Niger, Nigeria, Senegal	Output (Thousands of 1989-91 international dollars	2217974	3252889	306805	17204508
	Land (1,000 ha)	22,132	19,862	7,937	72,830
	Tractor (Number in use)	3,436	6,352	55	30,000
	Fertilizer (Metric tons)	40,952	77,818	157	461,000
	Labor (1,000 persons)	4,535	3,905	1,674	15,152
	Livestock (Head)	39269688	39720682	5265000	173494024
Region 3 : Central Africa Burundi, Cameroon, Chad, Congo, Dem Rep of Congo	Output (Thousands of 1989-91 international dollars	1203508	770225	444913	3212040
	Land (1,000 ha)	16,735	17,544	1,448	48,550
	Tractor (Number in use)	570	780	3	2,430
	Fertilizer (Metric tons)	9,610	12,626	100	49,800
	Labor (1,000 persons)	4,068	3,144	1,714	12,921
	Livestock (Head)	20807646	16151402	3418000	56565000
Region 4 : East Africa Kenya, Sudan, Tanzania, Uganda	Output (Thousands of 1989-91 international dollars	2896141	672147	1516585	4710737
	Land (1,000 ha)	48,698	41,954	10,030	133,898
	Tractor (Number in use)	7,850	3,314	1,400	16,898
	Fertilizer (Metric tons)	48,331	45,190	131	299,900
	Labor (1,000 persons)	7,675	2,443	4,348	14,244
	Livestock (Head)	121170820	74366644	36007600	381837000
Region 5 : Southern Africa Madagascar, Malawi, Mozambique, Zimbabwe, Angola	Output (Thousands of 1989-91 international dollars	1081526	419570	515588	2120643
	Land (1,000 ha)	31,128	19,332	3,160	57,500
	Tractor (Number in use)	7,504	6,086	880	24,000
	Fertilizer (Metric tons)	44,596	56,059	1,400	185,000
	Labor (1,000 persons)	3,862	1,337	1,858	7,591
	Livestock (Head)	35231601	27753103	4790769	86310000

Table 2: Mean technical efficiencies of the African agricultural sector by region and year, obtained from regional and meta-frontier.

		1971-1980	1981-1990	1991-2000	Overall: 1971-2000	Min	Max
Northern Africa	Meta	0.82	0.83	0.86	0.83	0.49	1
	Regional	0.93	0.93	0.99	0.95	0.58	1
Western Africa	Meta	0.72	0.69	0.73	0.72	0.35	1
	Regional	0.95	0.91	0.89	0.92	0.41	1
Eastern Africa	Meta	0.70	0.67	0.69	0.68	0.41	1
	Regional	0.79	0.89	0.86	0.85	0.45	1
Central Africa	Meta	0.94	0.93	0.96	0.94	0.64	1
	Regional	0.94	0.94	0.97	0.95	0.64	1
Southern Africa	Meta	0.61	0.54	0.56	0.57	0.25	1
	Regional	0.98	0.94	0.98	0.96	0.64	1
All Africa		0.75	0.73	0.76	0.74	0.25	1

Table 3: Technology gap ratio estimates.

	1971-1980	1981-1990	1991-2000	Overall: 1971-2000
Northern Africa	0.882	0.892	0.869	0.874
Western Africa	0.758	0.758	0.820	0.783
Eastern Africa	0.886	0.753	0.802	0.800
Central Africa	1	0.989	0.990	0.989
Southern Africa	0.622	0.574	0.571	0.594

Figure 1: Graphical representation of the performance of African agricultural sector