ICAE 2024

32nd International Conference of Agricultural Economists
2-7 August 2024 | New Delhi | India

Economics of Small Ruminant Production under Different Healthcare System: A Stochastic Meta-frontier Approach

Luke .O. Adebisi[1], Abayomi .O. Omotesho[2], and Oluwaremilekun .A. Adebisi[3]

1: Agricultural and Rural Management Training Institute (ARMTI) Ilorin, Kwara State, Nigeria. 2: Department of Agricultural Economics and Farm Management, University of Ilorin, Ilorin, Nigeria 3: Centre for Economic Policy and Development Research (CEPDeR), Covenant University, Ota, Ogun State, Nigeria

Corresponding author email: tobadebisi@gmail.com

Abstract

Prior use of the stochastic frontier model and subsequent measurement of performance of the agricultural produce sector, which relies on the presumption that the underlying technology is the same for all the different agricultural systems is not adequate as heterogeneity does exist in most agricultural production environments and failure to account for this, is likely to result in biased production frontier and efficiency. This study contributed to the existing knowledge, estimating technical efficiency and the technological gap in Nigerian Small Ruminant farms using the stochastic meta-frontier approach. For this study, we classified the farms based on the different production technologies adopted. The result of the analysis shows that farms differ in performance and technology use with the farms engaging both orthodox and traditional animal healthcare technologies having the highest efficiency. Furthermore, the results prove support for specific agricultural policies targeted at increasing the performance of indigenous technology in the livestock industry for better productivity and the prosperity of Nigeria.

JEL Codes: Q100, Q010, C010

IAAE

INTRODUCTION

Historically, agricultural productivity growth has been recognized as the key to economic development and poverty reduction in parts of the world, including Africa (Alene 2010; Alem, Lien, Hardaker and Guttormsen 2019). Improving agricultural productivity has therefore become a common strategy for improving the poverty status of rural households in Africa. Despite its poor outcomes, lots of investments are still being made in African agriculture to improve agricultural productivity. It is therefore important to examine productivity and its drivers to inform evidence-based policies in African countries. Productivity measurement has long been of interest to economists, as two main approaches have been explored for measuring farm performance; which are, a parametric approach such as the stochastic frontier approach, and a non-parametric approach, such as data envelopment analysis. In both methods, the basis for performance measurement is the radial contraction or expansion, connecting inefficient observed points with the reference points on the production frontier. For a sample of producers, both approaches involve estimating the best-practice frontier for a specific group of farms. If the actual production point of a farm lies on the frontier, the farm is considered as performing to its best and using resources efficiently; if it lies below the frontier, then it is inefficient. The choice of estimation method has been an issue of debate, and each approach has its advantages and disadvantages (Alem 2018; Kumbhakar et al. 2015).

Most efficiency analyses, assume homogeneity of technologies and all observations are evaluated against a common frontier. However, heterogeneity does exist in most production environments and failures to account for it, are likely to result in biased production frontier and efficiency (Owusu et. al., 2016). Thus, comparing the performance of farms on different technologies using technical efficiency scores, obtained from single estimates across the farms is likely to produce misleading results (Owusu et al., 2016).

Hence, production economics literature has identified this limitation and proposed various measures to address heterogeneity in efficiency studies. One of the approaches is the meta-frontier approach (Battese et al. 2004; O'Donnell et al. 2008). Meta-frontier method is preferred to, use a one-step stochastic frontier approach (SFA) because, it accounts for technology gaps and it also allows comparison of technical efficiencies, across heterogeneous groups, such as; production systems (Villano et al., 2010).

The meta-frontier concept is based on defining the boundary of the overarching technology set, that envelops the group frontiers and it allows one to decompose efficiency into group-level technical efficiency (within group inefficiencies) and technology gaps (group inefficiencies relative to a meta-frontier). The meta-frontier can be modelled, using parametric, semi-parametric framework. The approach was initially formulated, within the stochastic framework (Battese et al. 2004) and later extended to non-parametric methods (O'Donnell et al. 2008). Since the meta-frontier was introduced, there had been several empirical applications. The meta-frontier proposed by Battese et al. (2004) and O'Donnell et al. (2008) is defined as, an envelopment of the average production functions, where this envelopment is achieved using linear programming (LP) methods, for estimating the coefficient values of a meta-frontier function subject to constraints that ensure the fitted meta-frontier envelops lies above all the group frontier.

According to Huang et al. (2014), this approach has two key limitations. Firstly, the application of the average group production functions to provide support for the meta-frontier is inconsistent with the idea of stochastic frontier analysis (SFA), where the focus is on estimating not the average production function (hereafter APF), but the frontier to the technology, which is unknown. Therefore, it is likely that the frontier is higher than the APF. Secondly, the meta-frontier approach fails to generate a distribution for the meta-frontier or related statistics or efficiency measures (Huang et al. 2014)

Huang et al. (2014) suggested a new meta-frontier approach, which addresses the second limitation. The model adopts a stochastic regression approach, in the estimation of the meta-frontier using a predicted pooled group frontier, an approach that generates statistical properties of the meta-frontier parameters. However, the model was estimated using maximum likelihood estimates (Huang et al. 2014).

Thus, with this method of estimating meta-frontier, a comparison of efficiency is possible between farmers that come from different technologies. The stochastic meta-frontier model enables the computation of comparable technical efficiencies for farms operating under different technologies (Ali and Samad, 2013). It is easy, with this estimation method to know if technologies influence the efficiency of producers. A good example of this is comparing ethnoveterinary which is an indigenous technology and modern veterinary treatment of livestock. This comparison plays a good role in contributing to the future of the livestock industry in the country.

This study investigated technical efficiency in different small ruminant farm types in Niger State, by classifying them according to the farm types and healthcare technologies. Small ruminant farms were categorized into four farm types, namely; farms rearing with only modern animal healthcare services, farms combining rearing with fattening and making use of only modern animal healthcare services, farms that only rear using a combination of modern and traditional animal healthcare system, farms that, combine rearing and fattening using both modern and traditional animal healthcare system. Such classification is intended to examine the effect on technological gaps and technical efficiency of apparent differences in technology.

This study therefore, fills the gap by utilizing the stochastic meta-frontier function approach for the analysis of the efficiency in different small ruminant farm types, in Niger State, Nigeria by examining the technical efficiency across the different farm types and animal healthcare technology usage among farmers. The objectives of the study are to estimate the technical efficiency of the small ruminant farms relative to the meta-frontier and determine the technology gap ratio.

METHODOLOGY

Study Area

Niger State is located between latitudes 8^{o} 11' N to 11^{o} 20' N of the equator and between longitudes 4^{o} 30' E and 7^{o} 15' E of the Greenwich Meridian. It covers an estimated area of 84, 000 square kilometers with an estimated population of 3.2 million people with 80 percent living in the rural area (Wada et al., 2013). The mean annual rainfall ranges between 800 to 1000mm, and the average temperature ranges between 26^{o}C and 36^{o}C. Rains start in late April and end in October, with its peak being in July. The dry season lasts for about six months of the year from November to April (Rahji, 2005). The state has an estimated cattle population of 2.4 million cattle, 7 million sheep, and 2.3 million goats. (Ministry of Livestock and Fisheries Development, 2013). The State is divided into three zones by the Niger State Agricultural Development Project in consonance with ecological characteristics, cultural practices, and the project's administrative convenience.

Sampling Technique

The population for the study comprised small ruminant farmers in the study area. A three-stage sampling procedure was employed in this study. The first was a random sampling of two agroecological zones, from the three zones in the State. Zone A (Bida) and Zone C (Kontagora) were randomly selected. In the second stage, the Yamane (1967) formula (using a 90% confidence level and 45% estimated proportion of the unit population), was used to determine the number of Extension Blocks that were selected per Agroecological zone. Following this, 6 and 7 Extension Blocks were selected from Bida ADP (EBs = 15) and Kotangora ADP Zone (EBs =17), respectively. The Yamane formula is given as:

$$n_o = \frac{N}{1+N(e^2)},$$

Where, represents the number of Extension Blocks per ADP zone, *e* is the level of precision (at 10%). Using a 90a % confidence level and 45% estimated proportion of the unit population.

The third stage was the selection of representative farming households, from the sampled Extension Blocks using the list of farming households, which also keep small ruminants generated through the subject matter specialist on animal production and health from the two ADP zones based on, the households they cover, in each Extension Block.

The number of farmers per Extension Block (EB) was determined, using the probability proportionate to size (PPS) technique, which entails the selection of 45% of farming households in each Extension Block. A total of 240 farmers were selected and interviewed, across the Extension Blocks in the two ADP zones. Within the sampled population of 240 farmers selected for the study, a total of 69 farmers were found to have used, a combination of the ethno-veterinary practice and conventional veterinary treatment, during the study, while the remaining 171 farmers used only the conventional veterinary treatment.

Table 1: Names of sampled Extension Blocks (EBs) and number of farmers

ADP Zone	Extension Block	Numbers of Farmer	Number of Ethno-veterinary Practice Users

Bida	Donko	16	6
	Kutigi	18	5
	Badegi	14	4
	Katcha	24	7
	Agaie North	19	3
	Again East	14	4
	Kaboji	19	8
	Ibbi	13	3
	Banji	20	7
Kontagora	Mariga	22	6
	Kontagora	26	7
	Kawo	17	5
	Duku	18	4
Total	13	240	69

Analytical Techniques

Stochastic Meta-Frontier

The data were analyzed using the R statistical package. The first stage of this analysis was the estimation of technical efficiency for each homogenous group frontiers (i.e. Rearing and Fattening using Veterinary and Ethno-veterinary (RFVE); Rearing using Veterinary and Ethno-veterinary (RVE); Rearing and Fattening using Veterinary (RFV); Rearing using only Veterinary (RV)) was done, using stochastic production frontier.

The stochastic frontier model is defined by:

$$Y_{ij} = f(X_{ij}, \beta) e^{V_{ij} - U_{ij}}, \qquad i = 1, 2, \ldots, N_j$$

Where:

Y_{ij}= Output (kg) for the i^{th} farm in the j^{th} group

X_{ij} = vector of functions of the inputs used by the i^{th} farm in the j^{th} group

Where

X_1: Cost of feed (Naira/month)

X_2: Cost of treatment (Naira/month)

X_3: Labour (naira/month)

X_4: Starting flock/cost of purchasing animals (Naira/Animal Unit)

V_{ij} = statistical noise assumed to be independently and identically distributed as N (0, sV_j) as random variables

U_{ij} = non-negative random variables assumed to account for technical inefficiency in production. This is assumed to be independently distributed as truncations at zero of the N (μ_j, σU_j) distribution. The second stage is the estimation of the meta-frontier

$$TGRk = \frac{TE}{TEk}$$

Where: TE for the frontier production function for each group (RFVE + RFV+RVE+RV)

TE^k is the potential output that is defined by the meta-frontier function

TGR^k is the technology gap ratio

The technical efficiency relative to the stochastic frontier for each group, the technology gap ratio (TGR) and the TE of the i[th] farm relative to the meta-frontier (TE_i^*) were then estimated as:

$$TE_i = TE_0 \text{ x } TGR_i$$

Where TE_i is the technical efficiency of the Meta frontier

TE is the technical efficiency relative to the stochastic frontier for each group

TGR is the technical gap ratio

RESULTS AND DISCUSSION

Technical Efficiency of Different Small Ruminant Farm Types

This section presents the results obtained from the technical efficiency of small ruminant production using a stochastic meta-frontier as shown in Table 2.

Table 2 shows the result of the stochastic production model estimation for the four small ruminant production systems. The stochastic production frontier models were estimated both with the Cobb-Douglas and the Translog functional form. For all of the four groups (RFVE – Rearing and Fattening using Veterinary and Ethno-veterinary, RVE – Rearing using Veterinary and Ethno-veterinary, RFV – Rearing and Fattening using only Veterinary and RV– Rearing using only Veterinary) a likelihood ratio (LR) test revealed that the fit of the Translog functional form was significantly better than the fit of the Cobb-Douglas functional form. Hence, the Translog functional form was used in the analysis. The dispersion parameter of the inefficiency term (σu)

for the group (Rearing and Fattening using Veterinary and Ethno-veterinary –RFVE) is much smaller when compared with the other groups, this shows that the RFVE group is not as affected by inefficiency when compared with the other three groups (RVE – Rearing using Veterinary and Ethno-veterinary, RFV – Rearing and Fattening using Veterinary and RV– Rearing using Veterinary).

Table 2: Estimates for Parameters of the Cobb Douglas and Translog Stochastic Frontier Model for the various Groups

	RFVE (N = 30)		RVE (N = 39)		RFV(N = 138)		RV (N = 33)	
	Cobb-Douglas	Translog	Cobb-Douglas	Translog	Cobb-Douglas	Translog	Cobb-Douglas	Translog
Intercept	5.83886** (2.5408)	-1.25+03*** (1.00e+00)	2.52e+00 (2.76e+00)	-239.724*** (1.0000)	6.44705*** (2.0066)	-291.3219*** (1.0246)	8.74938*** (1.3436)	90.68324 (53.4969)
A (Medication cost)	-0.32439 (0.1823)	1.76e+02*** (1.00e+00)	2.56e-01 (1.57e-01)	-4.70249*** (1.0000)	0.11033 (0.0787)	3.40559 (4.5296)	-0.0218 (0.0599)	-3.42918 (4.2819)
B (Labour)	0.12309 (0.1623)	-2.23e+01*** (1.00e+00)	-1.92e-01 (1.86e-01)	39.42635*** (1.0000)	-0.36005 (0.2104)	46.86258*** (9.1721)	-0.03602 (0.0892)	-11.35836* (5.3037)
C (Cost of starting flock)	0.11331 (0.1301)	7.61e+01*** (1.00e+00)	-6.77e-02 (2.45e-01)	29.20579*** (1.0000)	-0.01547 (0.1051)	7.29600 (6.3911)	0.03998 (0.0538)	-7.44072 (4.1067)
D(Feeding cost)	0.09539 (0.0820)	3.21e+01*** (1.00e+00)	2.69e-01** (1.33e-01)	2.51522*** (1.0000)	0.16874*** (0.0569)	10.82113 (5.7197)	-0.2583*** (0.0714)	0.94919 (4.5638)
0.5*A*A		-2.87e+00*** (1.00e+00)		1.42648 1.0000)		-0.18019 (0.3127)		-0.04246 (0.2587)
0.5*A*B		-4.92e+00*** (1.00e+00)		-0.88856 (1.0000)		-0.99092 (0.8382)		0.55739 (0.3944)
0.5*A*C		-1.88e+01*** (1.00e+00)		-1.48422 (1.0000)		0.84930 (0.7598)		0.43393 (0.2654)
0.5*A*D		-7.69e+00*** (1.00e+00)		1.01079 (1.0000)		0.104419 (0.3646)		-0.04502 (0.3947)
0.5*B*B		2.20e+00** (1.00e+00)		-0.51363 (1.0000)		-2.32175 (1.7039)		-0.00765 (0.4262)
0.5*B*C		3.71e+00*** (1.00e+00)		-7.06379 (1.0000)		-4.60360*** (1.3263)		0.62719 (0.4418)
0.5*B*D		2.33e+00** (1.00e+00)		1.13197 (1.0000)		-1.83491 (1.1003)		1.01236** (0.4265)
0.5*C*C		-3.67e-01 (1.00e+00)		-0.20732 (1.0000)		1.44137** (0.6239)		0.30875 (0.2676)
0.5*C*D		-7.43e-02 (1.00e+00)		-0.97917 (1.0000)		0.07862 (0.3191)		0.08041 (0.2923)
0.5*D*D		-4.35e-01 (1.00e+00)		-0.42482 (1.0000)		-0.31004 (0.2474)		-0.40376 (0.2841)
SigmaSq	4.0007*** (6.32e-05)	4.24e-02 (1.00e+00)	1.19e-01 (2.97e-02)	0.09454 (1.0000)	0.15903*** (0.0478)	0.13269*** (0.0412)	0.1887*** (0.0411)	0.17124*** (0.0393)
Gamma	0.0013 (0.9989)	5.00e-02 (1.00e+00)	3.88e-05 (3.47e-02)	0.05000 (1.0000)	0.76069*** (0.1509)	0.76432*** (0.1608)	0.7243*** (0.1304)	0.71213*** (0.1452)
Log-likelihood	6.8832-	2.1913	-11.8063	-7.3717	-9.2043	-3.6799	-39.0822	-33.0818

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.10

Source: Data Analysis, 2021

N.B: Medication cost (A), Labour (B), Cost of starting stock (C), Feeding cost (D); RFVE – Rearing and Fattening using Veterinary and Ethno-veterinary; RVE – Rearing using Veterinary and Ethno-veterinary; RFV – Rearing and Fattening using Veterinary; RV– Rearing using Veterinary

Table 3: Estimates for Parameters of the Cobb Douglas and Translog Stochastic Frontier Model for the Pooled Data Model and the Metafrontier

	Pooled data		**Meta-frontier**	
	Cobb-Douglas	Translog	Cobb-Douglas	Translog
Intercept	1.82712*** (0.6361)	-0.94238 (15.9427)	4.50251 (1.31808)	100.52486 (72.0956)
A (Medication cost)	0.14328** (0.0556)	1.81268 (1.6900)	-0.03440 (0.0713)	-3.89080 (4.9686)
B (Labour)	0.07561 (0.0671)	0.52932 (1.9483)	0.04033 (0.0779)	-5.07000 (7.0329)
C (Cost of starting flock)	0.11415*** (0.0419)	-4.13408 (2.2086)	0.03268 (0.0905)	-7.35393 (5.5312)
D(Feeding cost)	0.13327*** (0.0386)	3.99752 (1.1454)	0.15020 (0.0499)	-5.62912 (4.0211)
0.5*A*A		-0.25234 (0.2098)		-0.37843 (0.3022)
0.5*A*B		-0.23934 (0.3263)		0.87511 (0.6554)
0.5*A*C		0.31777 (0.2093)		0.98293 (0.5748)
0.5*A*D		-0.14764 (0.1898)		0.22949 (0.2787)
0.5*B*B		0.06889 (0.3262)		-0.19552 (0.3607)
0.5*B*C		-0.20570 (0.2436)		-0.08263 (0.5409)
0.5*B*D		0.24708 (0.2349)		0.41459 (0.3637)
0.5*C*C		0.35550*** (0.1781)		0.55824 (0.5935)
0.5*C*D		-0.10388 (0.1735)		-0.09662 (0.3398)
0.5*D*D		-0.34049*** (0.0874)		0.26999 (0.2378)
SigmaSq	0.26541*** (0.05097)	0.21182*** (0.0409)	0.34043*** (0.0646)	0.28602*** (0.0695)
Gamma	0.77358*** (0.1130)	0.73814*** (0.12026)	0.92943*** (0.0512)	0.9039*** (0.0862)
Log-likelihood	-96.6792	-75.5249	-50.8126	-43.4131

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.10

Source: Data Analysis, 2021

N.B: Medication cost (A), Labour (B), Cost of starting stock (C), Feeding cost (D); RFVE – Rearing and Fattening using Veterinary and Ethno-veterinary; RVE – Rearing using Veterinary and Ethno-veterinary; RFV – Rearing and Fattening using Veterinary; RV– Rearing using Veterinary

Table 3 shows the result of stochastic production frontier models estimation for the pooled data and the Meta-frontier. The stochastic production frontier models were also estimated both with the Cobb-Douglas and the Translog functional form. For the pooled data and meta-frontier, a likelihood ratio (LR) test shows that the fit of the Translog functional form was much better than the fit of the Cobb-Douglas functional form. Thus, the Translog functional form was further used in the analysis. The dispersion parameter of the inefficiency term (σu) for the pooled data was greater than that of the meta-frontier, this implies that inefficiency is much when all the groups of small ruminant farming households are pooled together than in the meta-frontier.

Technical Efficiency and Technology Gap Ratio

The result of the technical efficiency scores and technology gap ratios (TGRs) are presented in this section.

Table 4: Technical Efficiencies and Technology Gap Ratios Estimate for Small Ruminant Farms in the Four Groups

		RFVE	**RVE**	**RFV**	**RV**	
TE (Technical Efficiency)						**Pooled**
	Mean	0.96	0.94	0.77	0.75	0.75
	Std. Dev	0.003	0.01	0.16	0.10	0.13
	Min	0.78	0.53	0.31	0.42	0.37
	Max	0.97	0.95	0.94	0.93	0.92
TGR (Technology Gap Ratio)						
	Mean	0.98	0.96	0.88	0.85	
	Std. Dev	0.01	0.04	0.18	0.11	
	Min	0.89	0.87	0.86	0.75	
	Max	0.99	0.97	0.94	0.91	
MTE (TEs to the meta-frontier)						**Meta**
	Mean	0.94	0.93	0.76	0.73	0.72
	Std. Dev	0.02	0.05	0.15	0.15	0.03
	Min	0.75	0.50	0.29	0.40	0.35
	Max	0.96	0.93	0.92	0.91	0.91

Source: Data Analysis, 2021

N.B: RFVE – Rearing and Fattening using Veterinary and Ethno-veterinary; RVE – Rearing using Veterinary and Ethno-veterinary; RFV – Rearing and Fattening using Veterinary; RV– Rearing using Veterinary

The result of the estimated technical efficiency scores and technology gap ratios (TGRs) are presented in Table 4. From the result, all four groups' mean TE are 0.96, 0.94, 0.77 and 0.75 respectively with the mean pooled technical efficiency the same as the Rearing using Veterinary (RV) group. The average TE score of 0.96 in the RFVE group implies that the small ruminant farms are producing only 96% of the maximum possible (frontier) output, given the inputs used. That is, an average small ruminant farm could increase its output by around 4% if it became technically efficient. This result is in line with the study carried out by Jiang and Sharp (2015) where they reported a mean ranging between 0.82 and 0.92.

Estimates of the mean values of TGR across the four groups are close to 1 which varies between 0.85 and 0.98, with no large differences between the farm groups, this implies that a higher (lower) TGR value implies a smaller (larger) technology gap between the individual frontier and the Meta-frontier. A value of 1 is equivalent to a point where the individual farm group frontier corresponds with the meta-frontier. This result is similar to the result of the study carried out by Boshrabadi et al. (2008) where their TGR values ranged from maxima of 1.00 for all regions, implying that some farms were producing the maximum outputs as indicated by the meta-function, given the current technology in the dairy sector.

The average technical efficiency scores for the group's frontier model (TE) and meta-frontier model (MTE) are very close to each other, since the TGR values are close to 1, as also presented in Table 17. The average overall technical efficiency scores for the small ruminant farms against the meta-frontier (MTE) vary from 0.73 to 0.94. As the MTE is mathematically expressed as a product of the TGR and the group-level technical efficiency (TE).

CONCLUSION AND RECOMMENDATIONS

It is clear from the study that all the small ruminant farm types were technically efficient however, farms that rear, fatten combining both veterinary and ethno-veterinary pest and disease control methods had the highest technical efficiency, given the inputs used. This shows that the combination of both animal healthcare systems improved greatly improved the farmer's production. It is therefore recommended that ethno-veterinary medicine is used as complementary to the orthodox ones.

REFERENCE

Alene, A.D., 2010. Productivity growth and the effects of R&D in African agriculture. Agricultural Economics, 41(3-4), pp.223-238

Alem, H., Lien, G., Hardaker, J.B. and Guttormsen, A., 2019. Regional differences in technical efficiency and technological gap of Norwegian dairy farms: a stochastic meta-frontier model. Applied Economics, 51(4), pp.409-421.

Alem, Habtamu. 2018. Effects of model specification, short-run, and long-run inefficiency: An empirical analysis of stochastic frontier models. Agricultural Economics 64: 508–16. [CrossRef]

Ali K. M. E. & Samad Q. A. (2013). Meta frontier production function for estimation of technical Efficiencies of wheat farmers under different technologies, Journal of Asian Scientific Research, 3(9), 933-944

Battese, George E., Prasada Rao, and Christopher J. O'Donnell. 2004. A Meta frontier production function for estimation of technical efficiencies and technology gaps for firms operating under different technologies. Journal of Productivity Analysis 21: 91–103. [CrossRef]

Boshrabadi H, Villano R, & Fleming E (2008).Technical Efficiency and environmental Technological gaps in wheat Production in Kerman Province of Iran. Agric. Econ. 38(1): 67-76.

Jiang, N. & Sharp, B. 2015. "Technical efficiency and technological gap of New Zealand dairy Farms: a stochastic meta-frontier model". Journal of Productivity Analysis, 44(1), 39-49.

Kumbhakar, Subal C., Hongren Wang, and Alan P. Horncastle. 2015. A Practitioner's Guide to Stochastic Frontier Analysis Using Stata. New York: Cambridge University Press

Ministry of Livestock and Fisheries Development (2013). Estimated Livestock Population in Niger State. An Annual Livestock Report in Minna, Nigeria

O'Donnell, Christopher J., D. S. Prasada Rao, and George E. Battese. 2008. Metafrontier frameworks for the study of firm-level efficiencies and technology ratios. Empirical Economics 34: 231–55. [CrossRef]

Rahji, M.A.Y. (2005). Determinants of efficiency differentials in lowland rice production systems in Niger State, Nigeria. Ibadan Journal of Agricultural Research.1(1), 7-17.

Owusu R., Michael B., Fiona G., and Atakelty H. (2016). Understanding Small-scale rice farmers' choice for new production technologies: Application of a scale adjusted latent class model. (Prepared for submission to Food Policy)

Huang C.J., Huang T.H., Liu N.H. (2014). A new approach to estimating the Meta frontier

Production function based on a stochastic frontier framework. J Prod Anal 42(241–254)

Wada, A. C., Kehinde, J. K., Ukwungwu, M. N., Adagba, M. A., & Usman, A. (2013). Some Factors Influencing Arable Crop Production in Niger State, Nigeria. *Open Science Repository Agriculture*, Online (open-access), e23050458. doi:10.7392/openaccess.23050458

Yamane, T., (1967).Statistics, An IntroductoryAnalysis, 2nd Ed., New York: Harper and Row