Efficiency differentials and technological gaps in beef cattle production systems in Nigeria

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Abstract

The present study analysed the technical efficiency and technological gaps (TGR/MTR) in three major beef cattle production systems in Nigeria, using the stochastic metafrontier approach. The usual methods of dealing with technological differences makes it difficult to separate "technology gaps" from technical inefficiency within a given system, hence the need for an analytical framework such as metafrontier which allows us to distinguish between the two. Results show that technical inefficiency exists in the three production systems but the ranching system is more efficient, in that it has a higher MTR. The average pooled technical efficiency TE with respect to the metafrontier was estimated to be 0.56; this suggests that there is scope to improve beef output in Nigeria by up to 44% of the total potential, giving existing technologies and inputs.

Key words: Beef cattle; production systems; technical efficiency; technological gap ratios; Nigeria

JEL: C1, C8, C42, 50

1. Introduction

Crop and livestock enterprises in Nigera are generally characterized by stagnating or declining productivity, partly due to high unit cost of production and inability of farmers to afford high-yielding farm technologies (Omonona *et al.,* 2010). Beef cattle are mainly produced in Nigeria under a pastoralist type of management where cattle are held in the vicinity of the village or urban areas during the wet season and then taken to lower pastures during the hot months in search of better grazing (Blench, 1999). In some cases, especially in the ranching system, natural pasture are supplemented with improved pasture and purchased feeds such as concentrates from cereals and legume fodder. However, pasture supply fluctuates due to seasonal rains, while the quality of commercial feeds is often compromised in the supply chain (FMARD, 2011). Cattle are produced and marketed in all parts of Nigeria but with the North-eastern and North-western parts predominating. Cattle are also exchanged not only between northern markets but also between the northern and southern parts of Nigeria (Inuwa, 1989; Fricker, 1993).

There is a documented report on a decline in beef cattle production especially, in developing countries (Scollan, 2010). Consequently, there is deficiency in the intake of beef, which is an important source of nutrients; such as proteins in human diet. For instance, in Nigeria, the intake of animal protein is 4.82g/caput (Tewe, 2010) as against a minimum requirement of 35g recommended by FAO (2009a). It is obvious that Nigeria, with a population of over 160 million people requires several heads of cattle to satisfy its demand for cattle and cattle products. Again, with a population growth rate nearing 2.8% per year, the country's own domestic production is by far from being able to meet demand (Grain de sel, 2010).

Since cattle are tradable commodity that can be exported, policy makers are currently debating options for beef cattle production systems that are economically efficient and sustainable. Also, considering the size of the human population that depends on beef cattle production in Nigeria, the development of domestic and export markets is critical to ensure food security, alleviating poverty, raising revenue and continuing the trend towards more market orientation (Haruna and Murtala, 2005). These issues suggest that it is important to improve the manner in which inputs and technologies are used in beef cattle production systems (TAA, 2010). Improving the production efficiency is considered as a possible strategy that could reduce the economic costs of production. This should entail producing optimal output per unit product, for instance, by use of better cattle breeds and enhancing other farm management practices, including feeding (Scollan *et al.,* 2010). Efficient production is important in order to improve supply for beef cattle domestic and export markets in Nigeria. These issues might have a considerable bearing on farmers' production decisions and efficiency. Against this backdrop, the present study investigates technical efficiency (TE) and technological gaps in Nigeria's main beef cattle production systems namely, nomadic pastoralism, agro-pastoralism and ranches.

Nomadic pastoralists (also referred to as nomads) typically have temporary abodes and migrate seasonally with cattle and other livestock in search for pasture and water. They are less commercialized, but derive a relatively large share of their livelihood from cattle and other livestock. In contrast, the agro-pastoralists are sedentary; within this system, livestock rearing and crop production are practiced interdependently, where livestock is grazed on harvested fields and animal manure is applied as crop fertilizer (NBS, 2007/2008). In comparison to the traditional pastoralist system where herders go in search of pasture and water during dry seasons, sedentary agro-pastoralists faced additional challenges from land pressure and limited pastures for their cattle. However, agro-pastoralist system is more commercialized than the nomadic system. Ranches are purely commercialized livestock enterprises and may also grow a few crops for use as on-farm fodder or for sale. They mainly use controlled grazing on their private land, and purchased supplementary feeds, in contrast to both the nomads and agro-pastoralists that generally depend on open grazing, with limited use of purchased feeds. Investigating the TE of various beef cattle production systems in Nigeria should provide insights on how to better integrate livestock development into the national and economic agenda, as well as guidance to farmers on resource allocation.

Past studies (Okoruwa and Ogundele, 2006; Omonona *et al.,* 2010) on efficiency estimation in Nigeria usually employs stochastic frontier models, which typically assumes that the underlying production technology is the same for all farms. Estimates of technical inefficiency under this assumption are therefore suspect so long as variations exist in production technology among farmers. For instance, in the case of Nigerian beef cattle production systems which we investigated, such variations are the norm rather than the exception, from subtle changes in ways of doing things, such as slight differences in input attributes, to major differences such as use of significantly different production technologies and differences in environmental conditions. The usual method of dealing with these technological differences makes it difficult to separate "technology gaps" from technical inefficiency within a given system. A recent methodological advance in estimating technical inefficiency that minimizes this difficulty by specifying a metafrontier for production (Battese and Rao, 2002; Battese *et al.*, 2004) allows technology gaps to be distinguished from technical inefficiency.

There is an extensive literature on TE analysis on crop, dairy and mixed crop-livestock enterprises. However, published research on TE of beef cattle is very limited; exceptions include (Featherstone *et al.,* (1997); Rakipova *et al.,* (2003); Iraizoz *et al.*, (2005); Hadley (2006); Barnes, (2008); Flemming *et al.,* (2010); Otieno *et al.,* (2011). In Nigeria, where the livestock sector contributes about 31% of agricultural output (ABS, 2010), there are few studies on TE of livestock technology including beef cattle (Okoruwa *et al., (*1996); Mamza *et al.,* (2014) but none of the studies applied metafrontier analysis. The studies undertaken on TE in Nigeria mainly focused on crops (Okoruwa and Ogundele, 2006; Gani *et al.*, (2007); Jabber and Akter (2008); Oluwatayo *et al.,* (2008); Omonona *et al.*, (2010), to mention a few.

Empirical applications of the stochastic metafrontiers are still few, but include estimation of TE and technology gaps for different agricultural enterprises (Boshrabadi *et al.,* (2008); Chen and Song (2008); O'Donnell *et al.,* (2008); Villano *et al.,* (2010); Wang and Rungsuriyawiboon (2010). Otieno *et al.,* (2011) specifically applied stochastic metafrontier to study the TEs and technology gaps in the various beef cattle production systems in Kenya. This method has also been used to assess efficiency differences in other sectors, for instance garment firms (Battese *et al.*, (2004), electronic firms (Yang and Chen, 2009), and electricity distribution firms (Huang *et al.,* (2010). Following Otieno *et al.,* (2011), the present study applied the stochastic metafrontier to investigate TEs and technology gaps in the various beef cattle production systems in Nigeria.

The rest of the paper is organized as follows: conceptual framework and empirical model in section 2, while section 3 described the data and empirical estimation. Results were presented and discussed in section 4; finally, some discussions were highlighted in section 5.

2. **Conceptual framework and empirical model**

2.1. Conceptual framework

Technical efficiency (TE) is defined as the ability of a firm to produce a maximum output from a given level of inputs, or achieve a certain output threshold using a minimum quantity of inputs, under a given technology (Farrell, 1957). In other words, a measure of technical efficiency indicates the extent to which a farm could produce additional output without changing the levels of inputs used if it were to operate on the production frontier, which is determined by the best-practice farms. For example, a technical efficiency index for a farm of 64 percent means that, for given levels of input use, it is operating at 64 percent of its potential output. That is, the farm could produce an additional 36 percent of output without changing the levels of inputs used if it were to improve its efficiency and produce on the production frontier.

Measurement of TE therefore provides useful insights that may enhance decision-making on optimal use of resources and effective capacity utilization. As noted by Abdulai and Tietje (2007), analysis of TE can also deliver important information on competitiveness of farms and their potential for increasing productivity. However, the limitation of TE is that it cannot measure the technological gaps between different groups or systems; thus while technical efficiencies of the production systems that were measured with respect to the given frontier were comparable, the estimates from the comparison may not be trusted since the production systems operate under different technologies. In order to capture variations in technology within and between production systems, (Battese and Rao (2002); Battese and Rao (2004) and O'Donnell *et al.*, (2007) proposed the use of a metafrontier production function to measure technical efficiencies and technology gaps of firms producing in different technological environments. The framework for the metafrontier approach follows Aigner et al., (1997), Meeusen and van den Broeck (1997) and Battese and Rao (2002) and is presented thus:

Suppose we have k groups or production systems in the cattle industry, the function can be represented by:

$$Q_{nk} = f(X_{nk},\ \beta_k)\ exp\ (V_{nk} - U_{nk}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where Q_{nk} is the of the n^{th} farm in the k^{th} production system; X denotes a vector of inputs used by the farm; β is a vector of parameters to be estimated; v represents statistical noise assumed to be independently and identically distributed (IDD) as a normal random variable with zero mean and variance given by $\sigma^2 v,$ i.e., ~ $N\,(0, \sigma^2 v)$; while u is a non-negative random variable assumed to capture technical inefficiency in production. The u is assumed to be IDD half-normal, i.e., u ~ /N (0, $\sigma^2 u)1$. Following Battese and Corra (1977), the variation of output from the output due to technical inefficiency is defined by a parameter (γ) given by:

$$\gamma = \frac{\sigma_u^2}{\sigma^2} \text{ such that } 0 \leq \gamma \leq 1 \ldots\ldots (2)$$

Where $\sigma^2 = \sigma_u^2 + \sigma_v^2$

Although u can assume exponential or other distributions, the half-normal distribution is preferred for parsimony because it entails less computational complexity (Coelli *et al.*, 2005). Equation (1) can be estimated through maximum likelihood. The TE of the n^{th} farm with respect to the k^{th} production system frontier is obtained as:

$$TE_{nk} = \frac{Q_{nk}}{f(X_{nk}, \beta_k)\exp(v_{nk})} = \exp(-u_{nk}) \ldots\ldots (3)$$

Equation (3) allows comparison of farms operating with similar technologies. However, farms in different environments (e.g. production systems) do not always have access to the same technology. Assuming similar technologies when they actually differ across farms might result in erroneous measurement of efficiency by mixing technological differences with technology-specific inefficiency (Tsionas, 2002). Technologies in this study comprise of type of cattle breed, breeding method and feeding methods. Variations in output between production systems due to technology differences can be captured by using the metafrontier, which is considered to be a smooth common technology frontier that envelops the deterministic components of the group stochastic frontiers (Battese and Rao (2002); Battese *et al.*, (2004). The metafrontier explains deviations between observed outputs and the maximum possible explained output levels in the group frontiers. Following O'Donnell *et al.*, (2008), the stochastic metafrontier equation can be expressed as:

$Q_n^* = f(X_n, \beta^*)$ $n = 1,2 \ldots$N……………………..……………………………………….…… (4)

Where $(f(.)$ is a specified functional form; Q_n^* is the metafrontier output; and β^* denotes the vector of metafrontier parameters that satisfy the constraints.

$f(X_n, \beta^*) \geq f(X_n, \beta_k)$ for all k = 1, 2,…K…………………….……………………………..…(5)

According to (5), the metafrontier function dominates all the group frontiers. In order to satisfy this condition, an optimization problem is solved, where the sum of absolute deviations or sum of squared deviations of the metafrontier values from the group frontiers is minimized. The optimization problem is usually expressed as (Battese *et al.,* (2004) :

$\mathrm{Min} = \sum_{n=1}^{N} 1 Inf(X_n, \beta*) - Inf(X_n, \beta_k)$ I…………………………………………………….. (6)

s.t $\inf(X_n, \beta^*) \geq \inf(X_n, \beta_k)$

The standard errors of the estimated metafrontier parameters can be obtained through bootstrapping or simulation methods.

In terms of the metafrontier, the observed output for the n^{th}farm in the k^{th} production system measured by the absolute frontier in (1) can be expressed as:

$Q_{nk}^* = \exp(-u_{nk}) . \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} . f(X_n, \beta^*) \exp(v_{nk})$ ………………………………………. (7)

where (recall from (3) that $\exp(-u_{nk}) = TE_{nk}$ the middle term in (7) represents the technology gap ratio (TGR), whose value is bounded between zero and one:

$$TGR_n = \frac{f(X_n, \beta_k)}{f(X_n, \beta^*)} \qquad (8)$$

The TGR measures the ratio of the output for the frontier production function for the k^{th} group or production system relative to the potential output defined by the metafrontier, given the observed inputs (Battese and Rao (2002); Battese *et al.*, (2004). Values of TGR closer to 1 imply that a farm in a given production system is producing nearer to the maximum potential output given the technology available for the whole industry. For instance, a value of 0.85 suggests that the farm produces on average 85% of the potential output, assuming all farmers use a common technology.

The notion of TGR defined in (8) depicts the gap between the production frontier for a particular production system or group frontier and the metafrontier (Battese *et al.*, (2004). However, a confusion of terminology arises because an increase in the (technology gap) ratio implies a decrease in the gap between the group frontier and the metafrontier. Further, it is important to expand the definition of TGR to account for constraints placed on the potential output by the environment, and the interactions between the production technology and the environment. Accordingly, recent literature uses meta-technology ratio (MTR) or environment-technology gap ratio (ETGR), rather than TGR (Boshrabadi *et al.*, (2008); O'Donnell *et al.*, (2008). Subsequently, the TGR is referred to as MTR in this study. The MTR considers environmental limitations on the production technology. Generally, the potential for productivity gains from use of a given technology (e.g. cattle breed and breeding method) varies across production systems, depending on natural environmental constraints such as rainfall distribution (which determine feed quality and availability). Further, human influences on the production environment, for example, skewed distribution of extension services, and veterinary drugs and advisory services, might affect the ability of farmers to achieve the highest production potential of a given technology.

The TE of the n^{th} farm relative to the metafrontier (TE_n^*) is the ratio of the observed output for the n^{th} farm relative to the metafrontier output, adjusted for the corresponding random error such that:

$$TE_n^* = \frac{Q_{nk}}{f(X_n, \beta^*)\exp(v_{nk})} \quad \ldots\ldots (9)$$

Following (3), (7) and (8), the TE_n^* can be expressed as the product of the TE relative to the stochastic frontier of a given production system and the MTR:

$$TE_n^* = TE_{nk}.MTR_n \quad \ldots\ldots (10)$$

2.2. Empirical model

The parameters of the stochastic frontiers for the production systems were estimated using the Cobb-Douglas production function given by:

$$lnQ_{n(k)} = \beta_{o(k)} + \sum_{i=1}^{4} \beta_{i(k)} lnX_{ni(k)} + v_{n(k)} - u_{n(k)} \quad \ldots\ldots (11)$$

where $Q_{n(k)}$ is the annual of beef cattle output; X_{ni} represents a vector of inputs where X_{n1} is the beef herd size, X_{n2} is feed equivalent and X_{n3} is the cost of veterinary services, while X_{n4} is a Divisia index which is calculated following (Boshrabadi *et al.*, (2008) which is expressed as follows:

$$X_{n4(k)} = \prod_{i=1}^{3} C_{ni(k)}^{\propto_{nt}} \quad \ldots\ldots 12$$

Where $\propto_{ni(k)}$ represents the share of the i^{th} input in the total cost for the n^{th} farm in the k^{th} production system; these shares included:

$Cn_{1(k)}$= depreciation costs, insurance and taxes on farm buildings, machinery and equipment (Naira);

$Cn_{2(k)}$= cost of labour (Naira);

$Cn_{3(k)}$ = other costs, e.g. fuel, electricity, hire/maintenance of machinery, market services, Purchase of ropes, branding etc (Naira);

u denotes inefficiency, while v represents statistical noise

The log likelihood for the half-normal model is expressed as (Greene, 2003):

$$LogL = nlog\theta - \frac{n}{2}\log\frac{2}{\pi} - \frac{1}{2}\sum_{n=1}^{N}(\theta Q_n - \xi' X_n)^2 + \sum_{n=1}^{N} log\phi[-\lambda(\theta Q_n - \xi' X_n)] \ldots\ldots\ldots\ldots (13)$$

where:

$\theta = \frac{1}{\sigma}$, $\xi = \theta\beta, \lambda = \frac{\sigma u}{\sigma v}$, $\sigma = \sqrt{\sigma_u^2 + \sigma_v^2}$ $and\ \phi(.)$ is the probability density function of the standard normal distribution.

Following O'Donnell *et al.*, (2008), the stochastic metafrontier equation can be expressed as:

$$Q_n^* = f(X_n, \beta^*) \quad n = 1,2,3 \ldots N \ldots\ldots\ldots\ldots (14)$$

where $f(.)$ is a specified functional form; Q_n^* is the metafrontier output; n represents the beef cattle production systems and β^* denotes the vector of metafrontier parameters that satisfy the constraints:

$$f(X_n, \beta^*) \geq f(X_n, \beta_k), \text{ for all n = 1, 2, 3 ...n} \ldots\ldots\ldots\ldots (15)$$

According to equation (15) the values of the metafrontier are no less than the deterministic functions associated with the stochastic frontier models for the different production systems in the analysis (i.e. the metafrontier dominates all the individual frontiers when considered as a group of frontiers). Thus, the metaffrontier is related to the metaproduction function concept defined by Hayami and Ruttan (1971). In the present study, the frontiers were estimated using cross-sectional data from the three major beef cattle production systems in Nigeria. The parameters of the stochastic frontiers of three production systems were obtained by maximizing the log likelihood function (15) using FRONTIER version 4.1c software in Coelli

(1996) while the metafrontier was estimated in SHAZAM version 10 software (Whistler, *et al.*, (2007) following codes adapted from O'Donnell *et al.*, (2008).

3. **Data source and variable measurement**

3.1. Data and characteristics of beef cattle producers

The study used survey data from six states (Oyo, Ebonyi, Delta, Adamawa, Sokoto and Niger) that are representative of the three beef cattle production systems in Nigeria namely nomadic pastoralism, agro-pastoralism and ranches. Nigeria is found in the tropics, where the climate is seasonally damp and very humid. The natural vegetative zones that exist in the country are governed by the combined effects of temperature, humidity, rainfall and particularly, the variations that occur in the rainfall. The humid tropical forest zone of the south that has longer rains is capable of supporting crop production while the northern part of the country representing about 80% of the vegetative zones experience lower rainfall and shorter rainy season and they make up the savannah land. The savannah land forms an excellent natural habitat for a large numbers of grazing livestock such as cattle. Nigeria's agro-ecological zones can be classified into: mangrove forest and coastal vegetation; freshwater swamp forest; tropical high forest zone; derived guinea savannah; guinea savannah zone; sudan savannah (short grass savannah); sahel savannah (marginal savannah) and montane savannah). The areas sampled in the study represent different agro-ecological zones, but are contiguous, hence logistically more accessible.

A multi-stage cluster (area) sampling approach (Horpilla and Peltonen, 1992) was used. In each of the six states, 2 Local Government Areas (LGAs) were selected. Within the 2 LGAs, 4 smaller units (villages) were randomly selected from the list of all the villages in the LGAs, taking into account the general distribution of cattle in the study area. Subsequent stages involved a random selection of a sample of 5 locations. The primary sampling units for the survey were therefore 20 locations in each state. In each of the locations, a random sample of respondents was drawn from the available list of farmers; in total, 360 farmers including 55 ranchers, 97 nomads and 208 agro-pastoralists were interviewed. A structured questionnaire was used to collect data on: relative importance of cattle and other enterprises to household income; cattle inventory in the past twelve months; production inputs such as feeds, labour, veterinary supplies and advisory services, fixed inputs; cattle breeding methods, access to extension and market services; and beef cattle producers' socio-demographic characteristics. With the assistance of well experienced extension officers, who were trained prior to the survey, the questionnaire was piloted, revised and then administered through face-to-face interviews of farmers between October 2012 and March, 2013. Due to incompleteness of some of the questionnaire, a total of 339 respondents were finally used for the analysis (39 ranchers, 92 nomads and 208 agro-pastoralists).

The summary of some of the farmers' characteristics in Table 1 shows that on average, the farm size and herd size were significantly different among the three production systems, with ranchers having the largest. Majority of the farmers in all the production types were males but ranchers had the least proportion of males. There was no significant difference in the average age of agro-pastoralists and nomads, but generally farmers in both categories were slightly older than the ranchers. On average, the household sizes across the three groups earned income from other sources apart from cattle rearing. This showed a high dependence of the farmers' households' on cattle as the main source of income. On the other hand, a higher proportion of ranchers used controlled cattle breeding, which involves use of artificial insemination (AI) or planned and monitored natural breeding rather than random natural breeding. This was consistent with the observation that the more commercially-oriented farmers (i.e., ranchers and agro-pastoralists) preferred cattle breeding strategies that target market and/or profitability requirements, e.g. faster growth and higher gains in live weight, while the relatively less-commercialized nomads mainly focused on cattle survival traits such as drought resistance, hardiness and disease tolerance (Gamba, 2006; Otieno *et al.*, 2011).

Furthermore, about 45 percent of ranchers had formal education at secondary school level above while nomads had the least. This was not consistent with the result of the study carried out by Otieno *et al.*, (2011), where only a quarter of farmers had access to credit, but agro-pastoralists had the least. Also, on the average, access to veterinary advisory services across the production types was poor (43.64%), though ranchers had better access followed by nomads. Finally, there were no significant difference in the length of farmers' experience in cattle production between nomads and agro-pastoralists, but ranchers were less experienced.

3.2. Variable measurement

In studies adopting the metafrontier approach, beef output was considered as the dependent variable, while a number of inputs (e.g. herd size, feeds, veterinary costs, fixed costs, etc) were included as regressors in the model. Due to measurement difficulties, previous studies have used proxy variables such as physical weights of cattle (Rakipova *et al.*, 2003; Featherstone *et al.*, 1997); however, such data were not available in the present study. This study therefore followed the revenue approach employed by Hadley (2006); Abdulai and Tietje (2007); Gasper *et al.*, (2009) and Otieno *et al.*, (2011). The model is hereby expressed as:

$$Q_{n(k)} = \frac{\sum_r^R yp}{t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

where $Q_{n(k)}$ is the annual value of beef cattle output of the n^{th} farm in the k^{th} production system (measured in Nigerian Naira; N); r denotes any of the three forms of cattle output considered (e.g. current stock, sales or uses for other purposes in the past twelve-month period); y is the number of beef cattle equivalents[1] (conversion factor); p is the current price of existing stock or average price for beef cattle sold/used during the past twelve months; and t is the average maturity period for beef cattle in Nigeria, which is four years (FDLPCS, 2010). The output prices used were average market prices; this possibly controls for differences associated with various market types and ensures that TE measures are attributable to farmers' managerial abilities.

The main inputs used for the study included herd size (proxy for capital in the classical production), feeds, veterinary services, depreciation, labour, land and other inputs. The cattle herd size was computed as the average number of cattle kept in the past twelve months, adjusted with the relevant conversion factors. In order to capture the approximate share of feeds from different sources in each production system, the quantities of forage (or on-farm) feeds were first

[1]Beef cattle equivalents were computed by multiplying the number of cattle of various types by conversion factors (Hayami and Ruttan, 1970; O'Donnell *et al.*, 2008; Otieno *et al.*, 2011). Following insights from focused group discussions with key informants in the livestock sector in Nigeria, the conversion factors were calculated as the ratio of average slaughter weight of different cattle types to the average slaughter weight of a mature bull. The average slaughter weight of a mature bull, considered to be suitable for beef in Nigeria is 159 kg (FAO, 2005). The estimated conversion factors were: 0.2, 0.6, 0.75, 0.8 and 1, for calves, heifers, cows, steers and bulls, respectively.

adjusted with the average annual number of dry and wet months, respectively, in each state following Okoruwa *et al.*, (1996) and (ABS, 2010). Assuming one price in a given locality (Chavas and Aliber, 1993), average feed/supplement prices were computed using prices from recent surveys (ABS, 2010). Both purchased and non-purchased feeds were then converted to improved feed equivalents by multiplying the respective feed quantities by the ratio of their prices (or opportunity costs) due to the average per unit price of improved fodder. Thus, the total annual improved feed equivalent was computed as:

$$\{\varphi(p_f * d) + s(n_p * w)\}\ldots\ldots (17)$$

where; φ and s denote, respectively, the ratio of prices of purchased and non-purchased feed to that of improved fodder; p_f and n_p represent the average quantities of purchased and non-purchased feed, respectively, in kilograms per month; d is the approximate number of dry months (when purchased feeds were mainly used), while w is the length of the wet season (when farmers mostly use on-farm or non-purchased feeds) in a particular area. Medicines/drugs were measured in vials. Due to measurement difficulties, the local herbs used especially by the Fulani in the treatment of their cattle were not considered.

Depreciation costs on fixed inputs were based on the straight line method, assuming a 10 percent salvage value following discussions with relevant officials in the Ministry of Livestock Development. Also, following key informant discussions, the useful economic life for small farm equipment (e.g. wheel barrow) and large machinery (e.g. vehicles and tractors) were set at 5 years and 10 years respectively. The depreciable value of an asset was based on the proportion of time that it was used in the cattle enterprise. Labour costs comprised both paid and unpaid labour; the latter valued using the average minimum farm wage in a particular agro-ecological zone. The labour costs were adjusted with the share of cattle income in household income. Similar adjustments were applied to other incidental variable costs, such as fuel and electricity bills.[2]

[2] In addition, land was measured as farm size (adjusted with the share of cattle income in household income). However, it was found to be highly correlated with feeds in agro-pastoralism. Further, it was difficult to establish owner-occupancy on land with respect to cattle production for nomads. Consequently, the use of imputed land rent as input) see for example, Hadley (2006) was not suitable for this study.

Table 2 summarized the main production variables for the different cattle production systems. Compared with agro-pastoralists and ranchers, nomads used less improved feeds (2183.86 kg). This could be attributed to their nomadic nature, which made natural pasture more available to them. Similarly, the nomads expended less in professional veterinary services as compared to ranchers and agro-pastoralists. Ranchers significantly used more inputs (i.e., herd size, equipment, labour, feeds and other inputs) than the nomads and agro-pastoralists. Depreciation and cost of other inputs (e.g. market services) per unit of output were highest in ranches. The ranchers had the lowest per unit cost of labour and they used relatively less feeds per unit output.

Partial input shares were also computed to provide a priori indication of differences in production technologies across the three production systems (Table 3). Ranchers incurred more depreciation and labour costs than the other production systems. This could be attributed to larger farm size and intensive production system employed by the ranchers; cost of other inputs (e.g., market services) per unit of output was also highest in ranches. Agro-pastoralists incurred more veterinary cost, followed by the nomads. This could be due to the fact that agro-pastoralist farms are usually located in the interior, which made them to have relatively less access to subsidized veterinary services than the nomads and ranchers. Finally, the ranchers used relatively less feeds per unit of output which was an indication that they keep better cattle breeds. Considering these differences, farmers across the three production systems might be expected to have different levels of efficiency.

4. **Results and discussion**

Various hypotheses were tested to establish the model fit. For example, the null hypothesis on poolability of the group frontiers was rejected, suggesting that there are significant differences in the input parameters, TE scores and random variations across the three production systems. This implies that differences exist in the production technology and environment, which justifies estimation of a metafrontier (Battese and Rao, 2002; Battese *et al.*, 2004). The gamma (γ) test (0.79***) significant at 1% level showed that there was technical inefficiency in the pooled frontier and group frontier for nomads and agro-pastoralists, but less for ranchers.

The pooled sample results showed that an increase in the application of any of the inputs would significantly increase output. Herd size is significant across the three production systems; feed equivalents (improved feeds) were only significant in the ranching system. Only the ranchers derived significant returns from investment in professional veterinary management. Increased expenditure on other inputs (captured by the Divisia index) would lead to significantly higher output in both nomadic and ranching systems. As expected for a “smooth envelop” curve, (Battese and Rao, 2002), the metafrontier parameters were generally similar to average values of the group frontier parameters. The significance of σ^2 and the gamma (γ) parameter (Table 4) indicated, respectively, that the models were stochastic (rather than deterministic) and exhibited technical inefficiency. Furthermore, as shown in Table (5), the shortfall of all mean TE scores from one (1) confirms the presence of technical inefficiency. This implies that there is scope to improve efficiency in the utilization of resources.

With respect to the estimated pooled frontier, nomads had the lowest mean TE (0.57), with the highest standard deviation (SD) of 0.24; while ranchers had the highest mean TE (0.69), with the lowest variation (SD = 0.13). The mean TE across all production systems was estimated to be 0.66. The scores were similar to that of the pooled frontier (0.66).

The mean MTR in the pooled sample was 0.85, implying that, on average, beef cattle farmers in Nigeria produced 85 percent of the maximum potential output achievable from the available technology. Further, 95 percent of farmers across the three production systems had MTR estimates below 1, indicating that they used the available technology sub-optimally. The average MTR was highest in ranches (0.95) and lowest in the agro-pastoralist system (0.70); nomads had a mean MTR of 0.71. The lower MTR for agro-pastoralists and nomads could be explained by their relatively higher use of unpaid labour (mostly family members, who might be lacking specific cattle management skills). Ranchers also invested relatively more in cattle equipment (see higher depreciation costs in Table 3), hence they had a higher average MTR.

The nomads’ relatively higher MTR compared to agro-pastoralists perhaps can be partly explained by the notion of catching-up or convergence to best practices (Rao and Coelli, 1998). This suggests that, on average, farmers who conventionally operate below the technology frontier might be expected to adopt technologies at a relatively faster rate than those who produce near the frontier. The maximum estimated estimated MTR was 1 or unity in all three production systems, which means that the group frontiers were tangent to the metafrontier (Battese *et al.,* 2004). As expected, the mean TE estimates relative to the metafrontier were consistently lower than production system frontier estimates. This further confirms that generally there is potential to improve production efficiency, given the existing technologies. Results further showed that the distribution of metafrontier TE scores followed the same pattern as in the pooled and production system frontiers; nomads had the lowest TE mean of 0.42 with largest variation (S.D = 0.16), while ranchers had the highest TE mean of 0.64 and smallest variation (S.D = 0.11). It is important to note that a relatively larger MTR does not necessarily imply higher TE, considering that other factors (besides technology) in different production systems might influence farmers' ability to achieve the maximum potential output of a given technology.

The nomads' low TE perhaps suggested that they were largely unable to adjust input levels optimally as a result of limited institutional capacity to provide them with requisite services such as appropriate training. Furthermore, the nomads might be expected to be less efficient because they were more likely to be prone to large losses (in stock numbers and quality) during severe droughts, due to their less-sedentary nature and low investment in pasture development. Agro-pastoralists depend more on crops and their residues as well as other enterprises, and thus invested relatively less in cattle production inputs; hence they might be expected to have low TE. In contrast, the ranchers' relatively high mean efficiency could be associated with generally high investment in cattle production services.

Across the three production systems, the mean TE relative to the metfarontier was estimated to be 0.56, suggesting that policies targeting optimal resource utilization could improve beef production in Nigeria by up to 44 percent of the total potential, given existing technologies and inputs. These results showed that, generally, Nigerian beef farmers were less efficient compared to their counterparts in developed economics and even some developing economies such as Kenya (albeit under different technologies, production environments and estimation approaches). For instance, the mean TE scores for beef cattle farmers were estimated to be 0.95 in Australia (Fleming *et al.*, 2010), 0.78 in Kansas, USA (Featherstone *et al.*, 1997), 0.92 in Louisiana, USA (Rakipova *et al.*, 2003), 0.84 in Spain (Iraizoz *et al.*, 2005), 0.82 in England and Wales (Hadley, 2006), 0.77 in Scotland (Barnes, 2008), 0.92 in the Amasya region of Turkey (Ceyhan and Hazneci, 2010), and 0.69 in Kenya (Otieno *et al.*, 2011).

5. **Conclusion**

The present study analyzed the technical efficiency and technology gaps in three major beef cattle production systems in Nigeria, using the stochastic metafrontier approach. The study also provides insight on whether a metfarontier analysis is needed to take specific account of the production technologies of the various beef cattle production systems, in estimating farm-level technical efficiencies. Our research thus contributes to empirical literature on the stochastic metafrontier method in general, and in the assessment of an important agricultural policy issues in a developing country in particular.

Results show that, on average, significant differences exists in technical efficiency between the three production systems; however the ranching system is more efficient, in that it has higher MTR. It also shows that the beef cattle producers differ in the use they make of inputs as measured by the TGR. Ignoring the limits placed on increasing technical efficiency because of constraints imposed by choice of production system could lead to incorrect conclusion about the scope for farmers to improve their technical efficiencies by adopting better production practices so as to improve the viability of the industry. The average pooled TE with respect to the metafrontier was estimated to be 0.56. This suggests that there is scope to improve beef output in Nigeria by up to 44% of the total potential, given existing technologies and inputs. Policies that promote efficient utilization of resources in Nigeria beef production are necessary in order to enhance supply for the domestic and export markets. Consequent upon efficient use of resources in the three production systems, improved technologies for beef cattle production (cattle breeds, feed/supplements etc.) should be made available to cattle producers (especially nomads and agro-pastoralists) so as to encourage production.

In line with the Agricultural Transformation Agenda (ATA) of the Federal Republic of Nigeria, there is need for the government to use its policy of Growth Enhancement Scheme (GES), to provide guaranteed minimum price support for beef cattle producers through timely, efficient and effective delivery of yield-increasing farm inputs so as to ensure incentives for accelerated production. Support for domestic cattle production should specifically include subsidies for veterinary drugs, feeds and supplements as results from the study show that access to professional veterinary services and availability of inputs in general, is a major issue in cattle production in Nigeria, especially amongst nomads and agro-pastoralists. Further research could investigate if efficiency in the beef cattle farms has bearing on their competitiveness in both domestic and export markets.

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Table 1: Sample Characteristics of the beef cattle producers in Nigeria

Variable	Nomads (n = 92)	Agro-pastoralists (n = 208)	Ranchers (n = 39)	Pooled sample (n = 339)
Average farm size (Ha)	1.64[c]	5.26[b]	14.89[a]	6.80
Average cattle herd size	42.00[c]	49.00[b]	53.00[a]	49.00
Average age of respondents (years)	47.04[a]	46.73[a]	43.56[b]	46.45
Access to veterinary advisory services in the past year (% of farmers)	27.3[b]	16.8[c]	55.9[a]	43.64
Average farm experience of respondents (years)	21.13[a]	19.78[a]	16.59[b]	19.78
Gender (% of male farmers)	89.5[a]	72.8[a]	70.4[a]	77.5
Average number of income earners in the respondents' household	3.09[b]	3.24[b]	3.44[b]	3.22
Average household size of respondents (Number)	11.34[b]	11.18[b]	11.92[b]	11.31
Access to credit in the past year (% of farmers)	12.2[c]	27.8[b]	60.0[a]	45.76
Use of controlled cattle breeding method (% of farmers)	15.9[c]	42.0[b]	42.0[b]	38.98
% of respondents who had formal education	13.3[c]	27.3[b]	59.4[a]	45.38
Main cattle breed is indigenous (% of farmers)	72.2[a]	19.4[b]	8.3[c]	48.78

a, b,c: Letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude. Note: N153 (Nigerian Naira) were equivalent to USD$1 at the time of survey.

Table 2: Average annual outputs and inputs of beef cattle production systems

Variable	Nomads (n = 92)	Agro-pastoralists (n = 208)	Ranchers (n = 39)	Pooled sample (n = 339)
Value of beef cattle output (Naira)	1519051.28[b]	1706312.98[b]	1747726.46[a]	1696008.66
Beef cattle equivalents (herd size)	42.34[b]	49.00[b]	52.00[a]	49.14
Depreciation costs (Naira)	28280.33[b]	17138.96[b]	64173.08[a]	25573.59
Veterinary costs (Naira)	31493.31[b]	85208.38[a]	89931.15[a]	80310.47
Paid labour costs (Naira)	57188.86[b]	56838.10[b]	67240.38[a]	61240.38
Unpaid (i.e., family) labour costs (Naira)	8346.47[a]	7692.31[a]	5188.16[b]	6333.37
Total labour costs (Naira)	63850.54[b]	62406.01[b]	69163.46[a]	63575.44
Improved feed equivalent of purchased feeds/supplements (kg)	1999.72[b]	2426.34[b]	2506.53[b]	2426.46
Improved feed equivalent of on-farm feeds (kg)	184.14[b]	194.73[b]	245.18[a]	201.93
Total improved feed equivalents (kg)	2183.86[b]	2621.07[a]	2751.71[a]	2518.88
Costs of other inputs, e.g., market services, branding etc. (Naira)	8939.38[b]	6652.80[b]	15275.52[a]	9255.95

a.b.c: Letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude. Note: N153 Nigerian (Naira) were equivalent to USD$1 at the time of the survey.

Table 3: Partial input shares in output

Input unit of output	Nomads (n = 92)	Agro-pastoralists (n = 208)	Ranchers (n = 39)	Pooled sample (n = 339)
Depreciation cost (Naira)	0.065[b]	0.075[a]	0.079[a]	0.075
Veterinary cost (Naira)	0.123[b]	0.169[a]	0.083[c]	0.146
Labour cost (Naira)	0.171[b]	0.188[b]	0.336[a]	0.274
Feeds	0.085[b]	0.253[a]	0.006[c]	0.186
Other costs	0.022[b]	0.011[b]	0.099[a]	0.068

a, b, c: Letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude. Note: N153 (Nigerian Naira) were equivalent to USD$1 at the time of the survey.

Table 4: Parameter estimates of stochastic and metafrontier models for the production systems

Variable	Nomads (n = 92)	Agro-pastoralists (n = 208)	Ranchers (n = 39)	Pooled frontier (n = 339)	Metafrontier (n = 339)
Constant (β_0)	5.57***	5.59***	5.25***	5.65***	5.66***
	(0.453)	(0.429)	(0.353)	(0.153)	(0.251)
Beef herd size (β_1)	3.89***	3.67***	6.35***	0.54**	0.65**
	(0.0212)	(0.0358)	(0.0298)	(0.0837)	(0.0234)
Feed equivalents (β_2)	0.035	0.17	0.03**	0.05**	0.03**
	(0.0139)	(0.105)	(0.143)	(0.277)	(0.253)
Veterinary cost (β_3)	0.09	0.10	0.03**	0.04**	0.09
	(0.0949)	(0.0515)	(0.0891)	(0.287)	(0.075)
Divisia index for other costs (β_4)	0.05**	0.07	0.01**	0.08**	0.02
	(0.0604)	(0.0376)	(0.0636)	(0.295)	(0.0136)
σ^2	0.33**	0.25**	0.18*	0.19*	
γ	0.79***	0.72***	0.76***	0.79***	
Log-likelihood	9.88*	18.80**	36.65***	33.18***	

Notes: Statistical significance levels: ***1%, **5%, *10%. Corresponding standard errors are shown in parentheses. Standard errors for metafrontier parameters were computed through bootstrapping (Freedman and Peters, 1984).

Table 5: Technical efficiency estimates and meta-technology ratios of the production systems

Model		Nomads	Agro-pastoralists	Ranchers	Total
TE w.r.t. the pooled frontier*					
	Mean	0.576985[b]	0.660557[a]	0.694128[a]	0.660053
	Min	0.08544	0.12729	0.15164	0.08544
	Max	0.81593	0.69021	0.88722	0.59020
	SD	0.244114	0.172212	0.137709	0.176296
TE w.r.t. production system frontiers*					
	Mean	0.599802[b]	0.678541[a]	0.707986[a]	0.6600
	Min	0.05626	0.17265	0.27741	0.0854
	Max	0.89576	0.90726	0.87586	0.9020
	SD	0.215038	0.158922	0.127269	0.1763
TE w.r.t. the metafrontier*					
	Mean	0.4200[a]	0.5059[b]	0.6445[a]	0.5647
	Min	0.0432	0.1629	0.1683	0.0636
	Max	0.8574	0.7715	0.8687	0.9502
	SD	0.1660	0.1534	0.1129	0.1801
Meta-technology ratio w.r.t. the metafrontier*					
	Mean	0.7125[b]	0.7021[b]	0.9501[a]	0.8573
	Min	0.5049	0.7490	0.5704	0.5338
	Max	1.000	1.000	1.000	1.000
	SD	0.1005	0.0393	0.0861	0.1470

Notes: these TE scores are only reported for the completeness of analysis. The caveat is that they are estimated relative to different technologies, hence non-comparable across the groups. Comparisons are based on the metafrontier and meta-technology estimates because these use a common industry-wide technology as the reference point.

a, b,c: Letters denote significant differences (at 10 percent level or better) in variables across the production systems in a descending order of magnitude.