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MICROECONOMETRIC MODELS OF THE LIVESTOCK SECTOR: A FARM-LEVEL ANALYSIS OF SOUTHERN RANGELANDS OF KENYA

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Table of Contents

1. Actuality and Justification of the Research Topic (Research Problem)

The livestock sector globally is highly dynamic. While many livestock production systems in developed countries are increasing their efficiency and environmental sustainability, demand for livestock products is growing only slowly or stagnating, although at high levels (Thornton 2010). In contrast, in developing countries, livestock production is evolving in response to rapidly increasing demand for livestock products. However, the production and consumption gap for the significant livestock products has been widening across the of sub-Saharan Africa – SSA (Otte–Chilonda 2002). This global mismatch between production and consumption of livestock products presents a significant opportunity for the expansion of livestock production, particularly in any of SSA country where the most demand is met by local production while moderating its impact on the environment.

Sub-Saharan Africa countries present the fastest growing human populations growth rate of 2.6% per annum in the world, yet they also have the world's lowest per capita consumption levels for livestock products[1] (Otte–Chilonda 2002). This situation is aggravated in that growth in the production of livestock products in SSA countries is not keeping pace with the growth in human population, resulting in declining per capita production in the case of beef (-2.2%), milk (-1.5%), sheep meat (-0.9%) and goat meat (-0.4%) per annum (Appendix 1). In Kenya, as is elsewhere in SSA countries, one of the significant challenges over the last few decades has been to maintain the increase in livestock production needed to satisfy rapidly increasing demand for meat requirements and the export needs of the country (Vivien 2004, Behnke–Muthami 2011) while attempting to make land available to more farmers through subdivision of the old settler farms (GoK 2009). In the context of effective demand, the country is currently not self-sufficient in most of the animal products. The insufficient demand is verified by the tremendous increase in the annual deficit of the major livestock products, beef and mutton, of about 38,323 MT and 12,879 MT, respectively, in 2005 to 49,835 MT and 18,885 MT, respectively, in 2014 (GoK 2011)[2]. In the same spirit, Kenya has also not been able to supply its quota of 142 MT annually of beef awarded by European Union under the Lome and Cotonou Agreements and the European Beef and Veal Protocol since the year 2000. Thus, there is an

[1] Per capita consumption was estimated at 11.0 kg of meat and 27.2 kg of milk (compared with the developing world average of 26.4 kg for meat and 48.6 kg for milk), which are approximately one seventh and one quarter of those in the developed world (Otte–Chilonda 2002).

[2] This demand was expected to grow at the same rate with the human population, which is 3.2 percent (GoK 2010).

urgent need to find ways to increase livestock productivity and output, so that it not only keeps pace with the rising population[3] but also creates surpluses for market disposal.

While the expansion of the livestock population can contribute to the necessary increase in output, increases in animal productivity are also necessary. Opportunities for substantial livestock production progress exist: in the efficiency in the use of resources at farmers' disposal, livestock marketing strategies, better animal management practices, institutional infrastructure, and focusing on smallholder pastoral farmers since livestock is estimated to be present on more than 75% of the smallholdings in Kenya (Edwards–Jones 2006, Salami et al. 2010) – pastoralists dominate with 80%, accounting for over 67% of meat supplies (KEPZA 2005). This study concerns on production efficiency and marketing since they are an essential issue in economics. For these reasons, first, it is paramount to measure and understand the causes underlying efficiency in the use of resources at pastoral farm level because a measure of producer's performance is often useful for policy purposes (Kolawole et al. 2006, Delgado et al. 2008, Nganga et al. 2010, Otieno et al. 2014). In productive efficiency measurements, we are familiar with three types of efficiency: technical, allocative and economic efficiency.[4] In this study, we consider technical efficiency (TE) because it is one of the crucial interventions proposed by modern economic theorists that could enhance producer productivity by ensuring TE of the factors of production that are at the producers' disposal (Farrell 1957). Additionally, data limitation necessitated this thesis focuses on estimating technical efficiency other than the other two.

So, what is farms' TE, and how can it be measured? Various options are suggested in the literature, but of particular importance is Lovell's (1993) definition of efficiency of a production unit in terms of *a comparison between observed and optimal values of its output and input*[5]. The comparison can take the form of the ratio of observed to optimal potential output obtainable from the given input or the ratio of minimum potential to observed input

[3] Recent statistics shows the population of the country will reach about 96 million by 2050, an increase from 46 million todays; 41 million people will live in urban areas compared with 12 million todays, and they are expected to consume more high-value food products, particularly animal-sourced foods, such as meat, milk and eggs (UN-DESA 2017). The consumption is approximated as 15-16 kg of red meat (meat and offal from cattle, sheep, goats and camels) per capita annually (Behnke et al. 2011) and based on the current population, red-meat demand is approximated to be 600,000 MT (GoK 2010).

[4] TE reflects the effectiveness with which a given set of inputs are used to produce output, while allocative efficiency reflects how different resource inputs are combined to produce a mix of different outputs, given their respective prices. Economic efficiency comprises both and refers to producing the 'right' amount of allocative efficiency in the 'right' way of TE.

[5] TE is also defined by Galanopoulos et al. (2006) as *a measure of the ability of a firm or a decision making unit to produce maximum output from a given level of inputs and technology (output-oriented) or achieve a certain output threshold using a minimum quantity of inputs under a given technology (input-oriented).*

required to produce the given output. In these two comparisons, the optimum can be defined in terms of production possibilities. Much of the empirical evidence suggests that although producers may indeed attempt to optimize, from the theoretical point of view, they do not always succeed to maximize their production functions and fall short of the optimal level boundary (Simon 1957). In light of the evident failure of at least some producers to maximize, it is desirable to recast the analysis of production away from the traditional production function approach toward a frontier-based approach.

Beyond the TE measurement, the other aspect of ensuring livestock productivity is enhancing markets and improved market access. Despite the well-known potential benefits of engaging in markets, very low levels of market participation are observed among household farmers throughout most of SSA (Coulter–Onumah 2002, Poulton et al. 2006, Barrett 2008). However, despite a low level of markets participation, there is overwhelming evidence that practically all rural farmers depend on trading for some household needs and hence seek income-generating activities (Siziba et al. 2013). This increased dependence on markets puts a premium on understanding household market participation behaviour as the foundation for development strategies. The increased market dependency also justifies the need for livestock product and factor markets and marketing analyses as it represents an essential guide for the formulation of sectoral and microeconomic policies that aim to improve the welfare of agricultural households. This is because market-based development strategies may fail to facilitate wealth creation and poverty reduction if many households do not participate actively in markets or do not respond to market signals.

So, what would motivate smallholder agricultural pastoral households to produce and participate in the livestock markets efficiently? Indeed, this provides an empirical basis for identifying farm-level factors that influence production and market participation. Such analysis would offer information for policy alternatives that could promote and enhance better commercial-orientation, and thus lead to improved rural household incomes. Most of the available literature on agricultural household production and marketing behaviour is on crop industry for high potential agricultural areas (e.g. Obare 2003, Omamo 2007, Nyagaka et al. 2010), while those addressing livestock industry are limited (e.g. Kavoi et al. 2010 in dairy, Otieno et al. 2014 in beef cattle). Additionally, a shared limitation among the researches mentioned above is that they assumed homogeneous production technologies overlooking the possible presence of heterogeneous, particularly in the production decision process. In Kenya, as is elsewhere in SSA, livestock is reared in different production systems, which face varying constraints, possess different potentials for growth and have different resource endowments. In

other part of the world, many case studies have shown resource and production conditions in livestock producing societies to be highly heterogeneous (e.g. Alvarez et al. 2012, Sauer–Morrison 2013) and the use of a single characteristic to cluster sample, as was the case with study by Otieno et al. (2014), might be challenging when heterogeneity is likely to arise from more than one factor, leading to incomplete division of the sample. Therefore, differentiation by production or farming system is a powerful tool for communicating conclusions to policymakers in SSA livestock studies.

Under the maintained hypothesis that production and marketing behaviour is driven by a household's objective of maximizing profit it enjoys, one can usefully focus attention on the choice problem that relates optimal levels to household attributes and other environmental factors that condition production and market behaviour while accounting for unobserved farms heterogeneity. The recognition that agricultural pastoral farm households typically face natural, market and social uncertainties that influence their decision behaviour, then optimal (rational) level became unattainable, and therefore they are forced to 'satisfice' (Simon 1957). For this reason, structural micro-econometric models are applied, since they explicitly model the behaviour of individual farmers and are capable of accounting for deviation from the optimal outcome. Thus, the contribution of this study is threefold: first, to develop micro-econometric models of the critical structural relationships, which will provide insight into the key factors that influences the following endogenous variables: production, product supply and factor demand and market participation for cattle, sheep and goat component for the smallholder pastoral farmer leaving in the southern rangelands of Kenya; second, to estimate the parameters and obtain impact multiplier, technical inefficiency and elasticities; and three, deduce their policy implication. The results of this study provide some guidance for livestock sectoral policy development not only in the Kenyan economy but also in other SSA countries considering that the study takes the premise that livestock is kept in a different livestock production system with different potential for expansion.

2. Purpose of the Research

The study focuses on two main research topics namely 1) the livestock production behaviour, and 2) the livestock marketing behaviour in products supply and factors demand and market participation specifically for the smallholder pastoral farm household. The two topics are assumed to be independent but sequential, and this assists in developing a more comprehensive model conforming to current multivariate economic behaviour in the context of ongoing drastic change in the social-cultural, religion, economic, political and environment condition under

which livestock sector in Kenya is being undertaken. The overall goal is to determine the key factors that contribute to decision making of smallholder pastoral farmer in production, supply and factor input demand and market participation behaviour for the beef cattle, sheep and goat meat component of the livestock sector. The specific objectives are:

1. To develop micro-econometric models of the critical structural relationships, which will provide insight into the factors that influences the following endogenous variables:
   1.1. Production efficiency of smallholder farm households leaving in the southern rangelands of Kenya while considering farm uses a different technological scope.
   1.2. Supply and factor demand responsiveness of livestock products for the smallholder pastoral livestock farmer leaving in the southern rangelands of Kenya; and
   1.3. Market participation and intensity of participation for the smallholder pastoral livestock farmer leaving in the southern rangelands of Kenya.
2. To use the model in making recommendations to support policy formation associated with estimated parameters.

To address the above objectives, key research questions considered for this study fall along with categories of exploring the livestock ***production, output supply and input demand, and market participation*** in southern rangeland of Kenya. Aligned with this context, the research questions posed for this assessment are the following:

1. Can livestock farmers in southern rangelands of Kenya increase livestock production substantially by an efficient allocation of agricultural factors of production presently at their disposal?

Here, we not only intend to identify whether the factors of production currently at the farm-household level are efficiently utilized in livestock production, but also how far from the optimal levels are the smallholder pastoral farmers' operation, and what causes the deviation.

2. How does the law of supply and demand affect the output and factor input market?

In this research question, we intend to determine the factors substantially influences smallholder pastoral and agro-pastoral farms' household livestock products supply and input factor demand responsiveness.

3. What is the extent of participation in livestock markets by the smallholder's pastoral livestock farmers? For ones that do, what are the key factors that would significantly

promote the decision of the farmers to participate in livestock marketing, and are the factors the same?

In this research question, our aim is to investigate the degree of smallholder livestock market participation and the key factors that would greatly influence the two decisions – probability and the level of participating in livestock marketing by the pastoral farmers.

3. Justification of the Study

The rationale for selecting the micro-econometric models as a tool for analysing the farm-specific smallholder pastoral farming behaviours is because they explicitly model the behaviour of individual smallholders' farmers. Micro-econometric models are the set of behavioural relationships that are based on microeconomic theory and estimated on farm-level data using econometric techniques (Cameron–Trivedi 2005). In the economics literature, micro-econometric models have been developed for explaining input demand and output supply behaviour (profit functions) in combination with explaining household decisions (household models), income risk (risk models) and investments in fixed assets (investment models. For this study, in order to understand the underlying causes of the production and marketing fluctuation and uncertainty, a micro-econometric analysis comprising of three hurdles that includes, first, the household production decision model, second, the product supply and factor demand decision model, and third market participation decision model was adopted and fitted to cross-sectional data analysis (objective 1).

The perceptions of the behaviour of smallholders have implications in the development of interventions and policy prescriptions as they are based on their predicted responses or lack thereof. A thorough understanding of smallholder farmers' production and marketing behaviour is, therefore, a prerequisite. Micro-econometric models are often used in such analysis of economic issues that affect the agricultural industries because of their rigour in modelling the behavioural nature of the relationships between the significant economic variables in the industries of interest. And since smallholders' pastoral farmers are also interested in the impact of changes in explanatory variables such as on their production, marketing and market participation, the coefficients of elasticity need to be estimated in order to determine the effect of changes in the explanatory variable on the quantity produced and marketed (objective 1).

Lastly, the study also seeks to provide participants and policymakers with the tools which will enable them to deal with variations in exogenous variables and the quantity produced and marketed. With adequate information, producers may be able to revise their expectations, and this could enhance the economic benefits that accrue to both producers and

society in general. Since fluctuations quantities produced and marketed are also caused by exogenous variables, such as the supply of livestock inputs, it is essential to determine the policy implication of the significant exogenous variables on livestock production and market participation. Estimated elasticities and production, inefficiency and market participation parameters could provide policy insights; thus, enabling policymakers to better evaluate the effects of proposed policies (objective 2) and their implications on the livestock production and markets. Such insights are essential in formulating policies directed toward stabilizing producer incomes.

4. Thesis structure

The thesis from which this thesis booklet is derived is organized into six chapters. The introduction chapter layout the research issues and rationale for the study – research problem. Chapter two discuss the status of the livestock industry that includes the economic importance of the livestock industry in Kenyan, the geographical distribution, and the livestock production system spotlight. Chapter three, four and five are organized in topical form and discuss the relevant theoretical framework and econometric models for (1) analysing smallholder pastoral farm households livestock production and marketing behaviour as well as (2) parts of the enormous literature in the field of productivity and efficiency analysis, product supply and factor input demand responsiveness, and market participation, (3) the specific research methodologies applied in the study and (4) conclude with the presentation and discussion of the results on the key factors that influence livestock production, product and factor market and market participation behaviours. Finally, some important conclusions, policy implication and suggestions for future research are offered in chapter six.

5. The methodology of the research and its sources

In all aspects of the thesis, analysis involves the use of a cross-sectional database which was derived from responses from agricultural pastoral farm household residing in the southern rangelands of Kenya. To investigate Hypothesis H_1 and H_2, the frontier-based approach was adopted in order to investigate the key determinants of livestock production under homogenous technology, and when unobserved heterogeneous technologies are assumed. Since the seminal paper of Farrell (1957), TE has typically been analyzed using two principal analytical frameworks. These are the non-parametric but deterministic data envelopment approach and the parametric stochastic frontier approach (SFA). SFA approach is preferred because of stochastic treatment of deviations from the frontier, which are decomposed into a non-negative

inefficiency term and a random disturbance term that accounts for measurement errors and other random noise so that the measure is more consistent with the potential production under 'normal' working conditions. In the first instance of homogeneity in technology among sampled farmer, since based on the reviewed literature it is not clear a priori the distribution to choose for the inefficiency error term, all the widely applied distributions, that is, half-normal (Aigner et al. 1977), the exponential (Meeusen–Van der Broeck 1977), the truncated normal (Stevenson 1980) and gamma distributions (Greene 2003) were considered in order to illuminate the role of distribution in efficiency measurement. Under homogenous technology, the output-oriented TE was calculated as a ratio of the observed output to the corresponding frontier output, given the available technology,

When we assumed the presence of heterogeneous technologies, a latent class stochastic production frontier (LCSFA) model was specified. We adopted this framework because, in agricultural efficiency literature, this method has increasingly been recognized as a suitable model where different production systems are utilized among farms (e.g. Alvarez et al. 2012, Sauer–Morrison 2013, Baráth–Fertő 2015 etc.). Although inefficiency error term can take many distribution forms, we restricted our analysis to the widely used and supported latent class estimator by LIMDEP Version 11 Econometric Software - the normal half-normal and normal exponential-normal distributions (Greene 2016). In the LCSFA model, the calculation of TE is tedious because each farm can be assigned to several frontiers, each one with an associated probability. Then, based on Orea–Kumbhakar (2004), TE can be measured with respect to the most likely frontier (the one with the highest posterior probability) or using a weighted average of the TE for all frontiers with the posterior probabilities as weights. This scheme of random weighting and random selection of the so-called reference technology was avoided by using the following expression:

$$TE_i = \sum_{J=1}^{J} P_{ij}(j|i) * TE_i(j),$$

where $P_{ij}(j|i)$ are posterior class probabilities of being in the *j*-th class for given farm *i*, $0 < P_{ij}(j|i) < 1$ and $\sum_{J=1}^{J} P_{ij}\,(j|i) = 1$, while $TE_i(j)$ is its efficiency using the technology of class *j* as the reference technology.

The major challenge efficiency measurement analysts face often relates to skewness and multicollinearity. This problem was address by considering the third moment proposed by Greene's (1990) and following the step-by-step excluding the input whose correlation with other inputs is quite high or by eliminating an apparently insignificant variable, which can produce significant changes in estimates (Filippini et al. 2008).

The other technological characteristic analyzed is the scale elasticity. For latent class model, the elasticities are computed for each variable with respect to their individual frontier as indicated by the *J* subscript, and these reflect the importance of each of the inputs in output production, while the sum of all input elasticities gives a measure of returns to scale for each farm i in each class j.

Hypothesis H_3 and H_4 were investigated concurrently. In these two hypotheses, we intend to determine the factors that would substantially influence smallholder pastoral farms' household livestock products supply and input factor demand responsiveness. The issue of supply and factor demands response is ultimately an empirical question. In order to derive factor demand equation, the common practice has been to formulate a transformation function and then empirically derive factor demand equations from the first-order conditions of cost minimization or an output supply equation from the first-order conditions from the profit maximization. In our case, producer response is determined by two elements which include the technological relationship between combinations of inputs and the resulting level of output, and producers' behaviour in choosing inputs (given market prices and fixed factor availability). Integration of these two features leads to (a) definition of the output supply and factor demand that can be determined from profit-maximizing or cost-minimizing functions and (b) to a direct method by which optimal decisions on output supply and factor demand can be determined. The latest development that is based on duality theory provides such a simple approach and ensures researcher that it is in fact theoretically sound since it reduces the problems of solving first order conditions by directly specifying suitable minimum cost functions or maximum profit functions rather than production or transformation functions and therefore was found to be ideal for this study (Sadoulet–de Janvry, 1995).

In this study, the dual framework was assumed to be output-oriented and, therefore, to examine the behavioural decisions of smallholder pastoral livestock producers on output and input use, specifically on their responsiveness, farmers were assumed to maximize restricted profit function conditional on a convex production possibility set or technology. A normalized Translog profit function (as was the case in Christensen et al. 1973 study) specified using logarithmic Taylor series expansion, from which the supply and factor demand functions were analytically derived using Hotelling's Lemma procedure. In the case of the multi-output normalized profit function, the numéraire is the output price of the nth commodity. A system of three output supply and six input factors demand response equations that show the relation between output supply and input demand to the output prices, input prices and the quantities of fixed factors were estimated using the truncated regression model. The own-price, cross-

price and scale elasticities were then analyzed from the estimation. All own price responsiveness (elasticities) are expected to be positive for output supply and negative for input variable costs, and less than unity. However, the cross-price elasticities are expected to be indeterministic such that a negative sign implies a degree of substitutability with a positive sign indicate a degree of complementarity.

Hypotheses H_5, H_6 and H_7 aim at investigating the degree of smallholder livestock market participation and the key factors that would greatly influence the two decisions; that is, the probability and the level of participating in livestock marketing by the pastoral farmers. Markets and improved market access are critical for improving rural incomes and lifting rural households out of poverty trap, particularly in developing countries. However, agricultural households often face imperfect or incomplete markets for some goods and factors, which are then non-tradable. In the literature, theories that address market participation include asset-based approach (ABA), transaction cost approach (TCA) and agricultural developmental approach (ADA). Among the three, TCA was found to be ideal because it postulates that economic activity does not occur in a frictionless environment, but rather are always accompanied by the transaction costs of carrying out the exchange which is directly influenced by the efficiencies of the institutions (Key et al. 2000). In other words, some of the assumptions of neo-classical economics (such as perfect information, zero transaction costs, full rationality) are relaxed, but the assumption of self-seeking individuals attempting to maximize an objective function which is subject to the constraint(s) still holds.

Therefore, hypotheses H_5-H_7 were investigated using the theoretical background of TCA under the new institutional economics framework. The transaction cost theory theorizes that the household pastoral farmers always tend to avoid participation in the market if transaction costs are high. In specifying empirical model to be applied in the analysis of smallholder livestock market participation, 'bounded rationality' is expressed by extending the neo-classical theory that provides a useful standard for profit maximization analysis to include transaction costs. As was observed by Simon (1957), the major impediment in solving the first-order condition of profit maximization function is that economic agents do not always possess perfect knowledge on the transaction costs contained in the cost function constraints in this theory and were forced to satisfice rather than optimize. This information asymmetry forces the farmer to have only two decisions; first, the decision whether or not to participate in the livestock market and second, the number of livestock to supply in order to maximize household welfare given the fixed and variable transaction costs faced by the household. The two decisions to participate in the livestock market and supply are assumed sequential; thus, the

Double-hurdle (DH) approach that was proposed by Cragg (1971) was adopted. The DH model applied in this research is a parametric generalization of the Tobit model, in which two separate stochastic processes determine the decision to participate and the level of participation. The DH comprises of a Probit model which was fitted in the first stage and a Truncated model in the second stage.

6. Scientific results of the PhD dissertation

The overall objective of this study was to investigate the key factors that contribute to decision making of smallholder pastoral farmer in production, supply and factor input demand and market participation behaviour for the beef cattle, sheep and goat meat component of the livestock sector. This has generally been addressed by the findings from the analysis through the various hypotheses. Important conclusions based on the findings are presented in this section following the hypothesis of the study.

6.1. On Technical Efficiency Analysis in Smallholder Livestock Production

Under this topic, two hypotheses were tested. The first one (**H_1**) states, '*the size and access to agricultural factors of production (land, labour and livestock production supplies) positively influences livestock production of the smallholder pastoral farming and their impact is not homogenous in the farmer population*'. This was done by estimating a single stochastic and latent class frontier models in the SFA framework using a cross-sectional firm-level dataset collected from pastoral farm households residing in the ten counties that are found in the southern rangelands of Kenya. In the first instance, we applied a single stochastic frontier analysis to evaluate the role of distributions in estimating the technical efficiency in smallholder livestock production in the southern rangelands of Kenya. Stochastic production frontiers were parametrically estimated for both CD and Translog model types while also considering the widely applied distributions for the composite error term. The model performs well in estimating TE and inefficiency, and in explaining it in terms of farm-specific variables as identified in similar studies in other countries. We find significant variability in TEs, particularly among the different distributions with the normal-gamma CD and Translog functional forms resulting in higher overall efficiencies levels which means that normal-gamma generally "fits" the data better. Between the two functional forms, Translog seems to generally 'fit' the data better, allowing more observations to lie near the frontier. We also find that the mean TEs in most models were reasonably high in most models and are sensitive to the model choice. The estimated technical inefficiency ranges from 20-49%, suggesting that there is still

room for improving livestock by ensuring efficiency in the use of the technologies available at farmer disposal.

The parametric estimates are found to be robust and of very close magnitudes for the majority of model, distributions considered. The results from CD and Translog production Frontier are different with elasticities estimate from CD generally being small, while those from the Translog model are larger mainly due to interaction effects of the variables. For the CD models, we verify that the greatest and statistically significant elasticity observed was that of labour input, followed by pasture land size and capital input in that order, confirming the importance of classical production factors (labour, capital and the size of agriculture pasture land) in executing livestock-related investments and thus accepting the hypothesis. Similarly, as expected, feed and minerals assumed a positive, although inferior elasticity in relation to the livestock production. When it comes to Translog technological form, the empirical results obtained in the estimation of livestock production frontier functions for the southern pastoral rangelands of Kenya indicate that the variance of asymmetric error in the model is a moderately highly significant component. Additionally, the most significant inputs that contributed for livestock productivity were labour factor, as well as the feed and mineral supplement and veterinary drugs. The interactions between labour and pastureland size and land and capital were positive and statistically significant at different levels indicating a compliment for one another in livestock production, thus accept the hypothesis. Based on the single stochastic frontier model that assume same production technologies for all farm; and considering the various distributions of inefficiency error terms, we can, therefore, conclude by **accepting the claim that the size and access to agricultural factors of production (land, labour and livestock production supplies) influences livestock production of the smallholder pastoral farming**.

With regards to the second part of this hypothesis, we targeted to explore the possibility of incorporation of unobserved heterogeneity that exists among pastoral livestock producer in the southern rangelands of Kenya, and also assess the implications of such heterogeneity for the estimation of inefficiency and the technical parameters. Again, our recent study (Manyeki–Kotosz 2019) where both functional forms were tested, the flexible Translog functional forms were found to be an adequate representation of the dataset and, therefore, we only estimated the same. Although inefficiency term can take many other forms of distributions, in the latent class stochastic frontier model, we restricted our analysis to half-normal and exponential since they are supported by latent class estimator in most of the statistical software. Apparent differences in the estimated TE, AIC and log-likelihood statistics tests were observed among

the single frontier and latent class model. Applying both AIC and Likelihood Ratio test statistics leads to the conclusion that a model with 3 class stochastic frontier with inefficiency component of the composite error through a half-normal random variable is the preferred model for this data. Significant differences in TE estimates obtained in implementing both a single frontier and a three-class latent class model were observed, with TE scores being higher when farms are compared to their own frontier as the latent class model does, indicating that unless livestock farmers' heterogeneity is appropriately taken into account, estimated inefficiency is likely to be biased upward. This result implies that, if single production frontier function is used, technical inefficiency estimates tend to be overestimated if technology heterogeneity is present in the sample but not accounted for in the estimation process. Overall, the results point out the significance of correctly addressing technology heterogeneity in order to make correct policy recommendations regarding the improvement of farm economic performance, and also take into account farm differences in the design of the farm-level and other policy measures in Kenya. The results also suggest that, under the current state of environment, livestock producing can be said to be constrained by a variety of challenges ranging from low livestock production caused by low input use (e.g. lower TLUs per land area and differentiated capital per TLU), unsustainable and diminishing size of average landholding and low livestock supplies inputs, as such, the technologies smallholders use are challenging to depict only with data. This is because the coefficient of the stocking rate, capital unit per TLU and labour units per TLU affects prior probability, which proves our hypothesis that farm size, labour and capital assets play an essential role in the establishment of the three classes. Therefore, assuming heterogeneous technologies, again, we can **accept the hypothesis that the size and access to agricultural factors of production (land, labour and livestock production supplies) influence livestock production of the smallholder pastoral farming and their impact is not homogenous in the farmer population**.

The second hypothesis (**H_2**) stated that *'Human related attributes (e.g. gender, age, education level), access to socioeconomics factors (e.g. land ownership, off-farm income etc.), service providers (extension, agricultural institution etc.), market factors (e.g. input markets, market information etc.) and financial institutions (e.g. credit facilities etc.) influence efficiency in the livestock production for smallholder pastoral farmers'*. This hypothesis was tested based on the single and latent class stochastic frontier model. Based on single stochastic frontier model, the factor that significantly reduces technical inefficiency in livestock production were related to gender and high-level education of household head, number of technologies adopted, access to livestock market information, off-farm income and land

ownership while at lower level of education, old age of household head in years and market access portray an opposite effect on technical inefficiency. Based on a single frontier, our suspicion is that the less efficient farms are those who are being maintained by families more reliant on off-farm income (which probably correlates with market access and high education), and which are being held for their asset and family security reasons rather than as income generators.

When we adopt a latent class stochastic frontier model, the determinants of inefficiency were found to be specific to the class structure of the livestock sector when we account for technological differences. This implies different policy measures needs to be formulated for different productive units based on the class structure in order to ensure efficiency. For instance, access to veterinary services and input markets seems to significantly reduce inefficiencies for capital-intensive farms than in the labour-intensive farms. Gender of household head, ownership for the land and access to input markets has the opposite effect on inefficiency, which implies that they would increase inefficiency; hence, their effects should be reduced to the bare minimum. The results allow us to conclude **that human-related attributes, access to socioeconomic factors, service providers and market factors influence the efficiency in livestock production differently for smallholder pastoral farmers** and, therefore, based on these mixed results **we can only partially accept the research hypothesis H_2.**

6.2. On Products supply and Factor Inputs Demand Responsiveness

The objective of products and input market responsiveness analysis was to investigate the hypothesis (**H_3**) that *'The supply of livestock products is not affected by price and non-price input incentives (e.g. such as size of pasture land, income and labour inventory)'* and (**H_4**) that *'factor demand for livestock production is not affected by price factors and non-price input incentives (e.g. such as size of pasture land, income and labour inventory)*'**.** A dual framework was adopted, and a profit maximization framework was selected given the multi-inputs, multi-outputs, and prices of the inputs. The livestock products supply and factor demand functions were derived analytically from a normalized profit maximization function from which output supply and input demand responsiveness were estimated. The results of the study show that all own-price elasticities of output supply for the three livestock product had the correct signs, which was positive. The own-price elasticity was elastic for cattle while for goat and sheep supply were inelastic with the most inelastic being sheep followed by the goat enterprise. The relatively elastic own-price elasticity cattle product concurred with the finding of Nyariki

(2009) and Manyeki et al. (2016) in Kajiado District in Kenya. The possible explanation to this finding is perhaps producers respond to an increase in prices accompanied by diverting resources into increasing cattle herds in anticipation for a better price in future.

Cross-price elasticities were found to be in the inelastic range in all cases which indicate that a price change will result in a relatively small uptick in supply of livestock products. The cross-price elasticities result also shows that cattle can be a substitute for sheep and goat while there are some complement possibilities between sheep and goat for cattle. The possible explanation of this scenario can be associated by the observation made by Farmer–Mbwika, (2016) that goat meat prices at the consumption level are high and a slight increase in the price of goat prices would reduce the demand compressing the producer prices, and this would result into reduction in the supply. The high price would make the consumer shift to cattle meat, thereby increasing the demand for the cattle meat. Subsequently, the prices of cattle meat will increase, and that would result in an increase in the supply. The sheep quantity is more than thirteen-time as sensitive to the goat output prices than goat quantity is to sheep output prices. This finding, therefore, suggests that, in order to understand economic substitutability (or complementability) and the potential economic impacts of introducing livestock type-specific programs policy, it is informative to understand the relationships among the existing livestock product types. Outputs supply responsiveness was further measured to variable input such as cost of labour, the individual household income and the size of improved pastureland in hectares. Based on the magnitude of the elasticities, a slight change in labour price would have a more significant effect on output level than pastureland improvement price in all the livestock type. The unexpected negative elasticity with respect to household income can be associated with the data type, which was from survey sources and, thus, only the short-run response can be captured. However, in long-run, a sign switch is expected, and a policy incentive that would increase capital investment to the bottom of the income pyramid such as the poor farmers who, in the absence of formal insurance markets, tend to diversify including keeping livestock to achieve a balance between potential returns and the risks associated with climatic variability and market and institutional imperfections would improve livestock off-take. With regards to the livestock supply response to the fixed inputs, size of pastureland was found to be the most significant and positive as expected, which is consistent with theory. In relative terms for the three type of enterprises, cattle output supply is almost twice as sensitive to the size of the improved pastureland. The high magnitude on the pastureland variable for cattle output supply possibly may be associated with the fact that cattle being the primary beef producer in Kenya is pasture-based and hence dependent on land availability. Other factor inputs such as labour

cost and household income were significant but had the unexpected sign. Overall, based on the above evaluation on the factors that influence livestock product supply responsiveness behaviour, there is sufficient evidence **to reject the hypothesis H_3 that the supply of livestock products is not affected by price and non-price input incentives (e.g. such as the size of pasture land, income and labour inventory).**

With respect to factor demand responsiveness, all variable considered were found to be in the inelastic range with exceptional to that of cattle output prices and labour cost which was elastic for land demand in cattle and goat production enterprises respectively. Of important was labour cost and its effect on labour demand was inelastic, having a positive own-price elasticity estimate that is not consistent with economic theory. The household income in both demand equations was positive in all cases with a relatively low negative effect on labour demand recorded in the cattle production enterprise. The household income effect can be observed under two scenarios: if a household aggregate level of income increases or if the relative cost of expanding pastureland or wage for labour decreases. Both situations increase the amount of discretionary income available, so does the quantity of pastureland and labour. Factor demands in sheep production enterprise were relatively more responsive to changes in household income. Generally, it is clear that most of the variables considered significantly affect factor inputs demand in all livestock enterprise considered and therefore we can conclude by **rejecting the hypothesis H_4 that factor demand for livestock production is not affected by price factors and non-price input incentives (e.g. such as size of pasture land, income and labour inventory).**

6.3. On Market Participation for Smallholder Livestock Farmers

This section provides empirical evidence of the significant transaction and non-transaction related factors influencing livestock market participation decision. Three hypotheses were tested. These were **H_5:** *Socioeconomic (e.g. household characteristics such as age, gender, education level, ownership of mobile phone, radio, television, vehicle etc.; endowments factors such as farm size and livestock numbers etc.) factors have promoted market participation of the smallholder pastoral farmers*, **H_6:** *Institutions (such as financial, markets, farmer groups, extension service providers, etc.) have promoted market participation of the smallholder pastoral farmers*, and **H_7:** *Factors affecting livestock farmers' decision to participate in the market are not different with those affecting the extent of participation*. To tests these three hypotheses, a Double-Hurdle estimation approach was applied since market participation comprises two distinct but sequential decision marking processes. Double-Hurdle estimation

approach involved parametric generalization of the Tobit model where Probit model is used in the first stage to investigate the factors that determine the decision to participate, and in the second stage, for those that participate, a truncated regression model is fitted to examine the factors that influence the level of participation.

With regard to hypothesis **H_5,** it should be acknowledged that transaction costs are not easy to measure; and thus, proxy variables were used. The empirical result shows that these high transaction costs emanate from, among other factors, access to off-farm income and availability of means of transport represented by ownership of motorcycle or a radio. The empirical analysis revealed that smallholder households with less access to off-farm income are less likely to decide to participate in livestock market while those who have extensive pasturelands and tropical livestock units, access to motorcycle or radio are more likely to participate in the livestock market. However, a finding worth noting is the effect of land size on household livestock market participation. The positive direction of the impact of land size is probably an indication that increased market participation is also a function of land productivity. It, therefore, implies that any initiative in the livestock industry to increase land size must be preceded with efforts to increase the productivity of the land currently at farmers' disposal. The other transaction costs issues that may hamper the effective market participation of producers relate to smallholder households limited education and gender orientation. However, high education levels seem to promote market participation as it may enhance better negotiation skills and better able to use available information. Thus, there is **sufficient evidence to accept the hypothesis H_5 that socioeconomic (e.g. household characteristics such as age, gender, education level, ownership of the mobile phone, radio, television, vehicle etc.; endowments factors such as farm size and livestock numbers etc.) factors have promoted market participation of the smallholder pastoral farmers.**

Regarding hypothesis **H_6**, market participation is said to depend on the status of institutions and institutions are transaction cost minimizing arrangements. Institutional assets were captured as dummy and constitute proxies to transaction costs. The type of transaction costs is hypothesized to impede market participation because they impose added cost burdens on the efficient conduct of market entry activities. The institutional factors that promote market participation include the ease in access to veterinary services, livestock products prices, access to credit facilities, livestock and market information. The other proxy to institution factors was associated with the long distances involved in trekking animals to the market. Greater distance to the livestock markets increases transaction costs which are associated with institutional failures. The sign of the coefficient for distance to the market is negative and in line with *a*

priori expectation. This implies that the farther away the smallholder household is from the livestock market, the more difficult and costly it would be to get involved, and therefore the less the probability of participant. Thus, there is **also sufficient evidence to accept the hypothesis H_6 that institutions (such as financial, markets, farmer groups, extension service providers, etc.) have promoted market participation of the smallholder pastoral farmers**.

With regard to H_7, the empirical evidence shows that market participation is governed by two independent decisions: the decision to participate in the market and the decision on the intensity of participation. The estimation results show that these two separate decisions are determined by different sets of factors with about eighteen factors influencing the decision to participate and thirteen affecting the decision on the level of participation. Of the eighteen factors included in market participation model, seventeen seem to influence the probability of market participation, while only ten in the intensity effect models were significant at either 1%, 5% and 10% levels. Thus, we **reject the hypothesis H_7 that factors affecting livestock farmers' decision to participate in the market are not different from those affecting the extent of participation**.

6.4. Policy recommendation on livestock production and marketing

Several interesting policy implications can be drawn from our empirical analysis of smallholder pastoral household. First of all, with reference to stochastic frontier analysis, from a methodological point of view in the, we have shown that the pooled model estimates a general technology which misrepresents the technology of different production systems. In particular, the study has demonstrated that there are clear differences in the production technologies, returns to scale and efficiency amongst the smallholder livestock farmers in the southern rangeland of Kenya. The differentiated livestock production technologies amongst the smallholder livestock farmers in southern rangeland of Kenya lends support to the importance of correctly accounting for heterogeneity in order to make correct policy recommendations regarding the livestock production and performance. The results of the study indicate that livestock production is positively related to the availability of labour, feed and mineral supplement, the size of pastureland, and capital. This, therefore, calls for policies that promote ownership of pastureland in which farmers can plant fodder and or crops residues to feed their livestock. More importantly, intentional adjudicate of economical land property rights, and exploration of other tenure reform arrangements would play a vital role in enhancing productivity in the livestock sector, hence increasing markable surplus. There is also a need for

encouraging the farmers to consider livestock production as a promising business and liberal provision of better wages to attract and retain some young category of labour who are attracted to formal employment. Policies that would guarantee adequate access to credit facilities by the livestock farmers would ensure that the farmers have enough capital resources for expansion.

In addition, inefficiency in livestock production in Kenya could be reduced not only by better use of available resources, given the current state of technology, but also through policies that would encourage the livestock farmers to access to market information, off-farm income and ease in the adoption of technology. This can be achieved through formulation and judicious enforcement of policies on relevant aspects of enhance market information flow, injecting capital resources into the industry that can be used to strengthening linkages between the livestock farmers and the extension service provider or through innovative technology delivery approaches, such as mobile phone systems and radio-based training, coupled with tested approaches (pro-pastoral field schools), represent a significant opportunity for improving efficiency in both livestock production and extension. Finally, enhance support to institutions that can accelerate livestock productivity through research on new technologies so as to reduce the land area per unit livestock output.

Since livestock production, product supply and factor input demand are closely interlinked, policy option on livestock production and hence off-take are closely related. However, to enhance livestock off-take, policy geared towards improving the institutional and environmental conditions that support livestock output prices and input marketing with an emphasis on specific livestock species seems to be a promising option. Priority areas of action appear to be an adequate and attractive option in order to increase aggregate output supply of livestock in Kenya without damage to the rangeland environment would, therefore, be a pro-pastoral support price policy. Equally, another appropriate option may be to encourage more intensive use of productivity-enhancing inputs such as land through investing on pasture improvement perhaps this way may increase its effect on the supply, encouraging investment among livestock farmers by improving their capital base through improved access to grant or loan.

With regards to market participation for smallholders farmers, the policy and programmatic implication of these results is not that, the ongoing public investments effort in market access in Kenya have no role to play in increasing market participation, but that, with current levels of production technology, increased private asset endowments (such as herd size and quality of land) appear necessary for households to be able to take advantage of the reasonably open access to livestock markets in Kenya and any associated public investments

in improving market information flow or physical access to markets. Other transaction costs issues that hamper the effective participation of producers relate to limited education, gender orientation and ease in access to veterinary services. In the spirit of promoting literacy among smallholder, a properly targeted adult training program needs to be instituted. With gender variable, in Kenya pastoral setup, men generally have greater and easier access to property ownership (such as land, livestock, etc.) than women and youth, thus explaining why gender variable had a high partial effect. Prevailing gender inequalities may, therefore, constrain the net benefit for many women and policy that ensure intentional adjudication of land property rights to all gender would play a vital role in enhancing livestock market participation. Additionally, an innovative veterinary service delivery approaches, such as radio-based training represents a significant opportunity for improved market participation by smallholder pastoralists. In conclusion, to minimise remoteness of the smallholder farmers, building physical infrastructures such as roads, information and communications channels connecting small farms to markets, and institutions that reduce transaction costs and minimise risks, are essential to enhance the livestock farmer's access to the market.

7. Future research possibilities

In investigating the possibility of incorporating the effect of heterogeneity in measuring efficiency for the livestock sector, our analysis was based on the frequently used exponential and half-normal distributions. A promising avenue for further research would be to incorporate other types of distributions such as gamma and truncated-normal. It is also essential to conduct a more detailed analysis of the sources of decreasing returns to some classical factors of production on livestock productivity in order to help semi-subsistence small-scale livestock households escape from poverty traps. Since livestock farming in Kenya is also carried in, diverge agroecological zones, overlooking the influence of agroecological conditions on productivity and efficiency may be biased. Therefore, the other possible research is to incorporate differences in agro-ecological zones which was not captured by the current modelling approach due to data limitation. Study such as Alvarez–del Corral 2010 controlled for different agro-climatic conditions, using sets of dummy variables and found that efficiency estimates to be sensitive to agro-climatic condition. The knowledge of how production efficiency varies across different agro-ecologies can assist policy in choosing technologies that are more adaptable to specific agro-ecologies and enhance sustainable development of the livestock sector in the face of climate change.

Another promising avenue for further research on efficiency estimation would be to look at the possibility of incorporating corruption cost in this type of model framework since according to the study by Anik et al. (2011), corruption costs might be efficiency-enhancing or reducing, depending on the specific situation and context. This is in line with the World Bank concession that in some cases, corruption might increase economic efficiency for individuals or groups if they enable firms to escape overly restrictive regulations or confiscatory tax rates, especially in the short run. Much of the current debate rages over the effects of current rampant corruption cost on the efficiency of economic agent and such research is lacking in Kenya livestock production literature.

On livestock product supply and input demands responsiveness, a promising suggestion for future research would be to use an integrative differential model that includes risk aversion of livestock producers since livestock producers' attitudes toward risk would affect the selection of livestock for sale. Regarding smallholder market participation, future research can also investigate whether there is a possibility that farmers' decisions to participate and the extent of participation are made simultaneously. Finally, it is, however, essential to note that the study uses cross-sectional data that do not capture changes over time. A longitudinal study is needed to capture changes over time regarding smallholder pastoral livestock farming.

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