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Unconditional factor demands and supply response for livestock products: A farm-level analysis of the Southern Rangelands of Kenya

John Kibara Manyeki*
Faculty of Economics and Business Administration, University of Szeged, Hungary. E-mail: manyeki.john@eco.u-szeged.hu

Balázs Kotosz
IESEG Management School, Paris, France. E-mail: b.kotosz@ieseg.fr

Izabella Szakálné Kanó
Faculty of Economics and Business Administration, University of Szeged, Hungary. E-mail: kano.izabella@eco.u-szeged.hu

* Corresponding author

Abstract

This paper evaluates output supply and input factor demands for livestock products in the Southern rangelands of Kenya. A flexible translog profit function that permits the application of the primal approach to the output supply and factor demand analysis was estimated using household-level data. The results indicate that the own-price elasticities of supply for cattle, sheep and goats were all positive. The own-price elasticities for the supply of sheep and goat products were elastic, while the own-price elasticities for the supply of cattle products was inelastic. Cross-price and scale elasticities were found to be within the inelastic range in all cases, with goat production complementing both cattle and sheep production. All factor input demand elasticities for cattle, sheep and goats had the expected negative sign and were inelastic. These results offer a valuable opportunity for the development of pro-pastoral price policies that reduce factor market imperfections and thus enhance livestock productivity in the rangelands of Kenya.

Key words: primal approach; own-price elasticity; cross-price elasticity; livestock products; Kenya

1. Introduction

In the ongoing debate on implicit taxation through changes in macroeconomic policies and movement quarantines in the Kenyan livestock trade (Ronge *et al*. 2005), the economic analysis of potential output, price and trade responses has played an important role in the negotiation process. The Kenyan livestock product markets are increasingly influenced by intense livestock inflow from neighbouring countries of up to 25% (Behnke & Muthami 2011), rapid technological improvement (Thornton 2010; Collier & Dercon 2014), shorter product production life cycles, and customers gradually unwilling at times to settle for mass livestock products with limited value. The “new types of customers” who demand greater attention, and a new competitive environment that exposes local livestock farmers to competition, form a new development that needs to be addressed (Robinson & Pozzi 2011; Kariuki *et al*. 2013; Yego & Siahi 2018). In this emerging scenario, product supply and factor market responsiveness may be among the most important options needed for livestock farmers to achieve a competitive advantage. The crucial element in this analysis is knowledge of the responsiveness of Kenyan livestock outputs (live cattle, sheep and goats) to price dynamics. The basic assumption is that the livestock farmers maximise profits and thus choose to produce an optimal amount of these outputs while utilising the minimum costs of production.

While the available livestock production studies in the literature give some insight into output-price responsiveness (e.g. Nyariki 2009; Kibara *et al*. 2016; Mathini *et al*. 2017), they have not portrayed fully our understanding of factor complementariness/competitiveness in the livestock industry. One of the shortcomings intrinsic in their approach, as mentioned by Debertin (2012), is that input demand and output supply (OS) are parts of a general system. Estimating the latter alone therefore provides inefficient results for the underlying supply relationship. It hence is desirable to estimate the interlinked livestock OS and factor input demand equations simultaneously. The efficacy of the use of these few research studies that directly address livestock production and marketing behaviour is low because, in most cases, they are restricted to only a few of the livestock products and target specific small regions of the country. Furthermore, most of them employ small estimation samples, while some fail to meet the behavioural (curvature) properties necessary for the approaches used. This is partially because many variables are aggregated that have been criticised for obscuring the behaviour of individual input variables (Nyariki 2009; Olwande *et al*. 2009; Zhou & Staatz 2016; Kibara *et al*. 2016; Tothmihaly 2018). To bridge the existing information gap, this paper employs the primal approach to profit maximisation to simultaneously investigate the output supply and factor input demand (FID) responsiveness using household farm-level data collected from 1 512 farmers in the southern rangelands counties of Kenya.

The remainder of this paper is structured as follows. Section 2 presents the methodology applied in this paper, comprising the theoretical framework, empirical data and data estimation procedures. This is followed by a presentation of the results in section 3 and their discussion in section 4. Finally, section 5 summarises the main finding and draws some policy implications.

2. Methodology

2.1 Theoretical framework

This paper applies the primal approach to profit maximisation (Shephard 1970; Debertin 2012) and uses it to analyse the supply and factor input demand responses for livestock products. In the primal approach to profit maximisation, the basic behavioural assumption is that economic agents optimise an objective function subject to a constraint (e.g. Kumbhakar 2013; Tocco *et al*. 2013; Vrankić & Krpan 2017). Two approaches have been applied widely in the literature. In the first approach, the technology in the short run is proxied by the short-run production function, and a normalised profit function is estimated in the short run (Vrankić & Krpan 2017). In this approach, the input demand identifier variable is the labour cost. Alternatively, technology is represented by the real variable cost function, where costs are expressed in the labour units and the normalised profit function is derived, this time expressing profit in the labour units (Tocco *et al*. 2013; Vrankić & Krpan 2017). The identifier variable in this approach is the quantity of production. The emphasis in these two viewpoints of the primal approach is on the first-order necessary conditions of both models. In this paper, we apply the latter, and the primal profit-maximisation model is represented by the short-run production function and the normalised profit function from an input perspective.

While the goal of the study was to obtain a system of OS and FID equations, the possible estimation problems are connected with the production function (Chambers 1988; Sadoulet & De Janvry 1995). The reason for adopting a profit-maximisation method (maximum profit attainable given the inputs, outputs and prices of the inputs) over the cost-minimisation approach is that the latter, as observed by Olwande *et al*. (2009) and Debertin (2012), assumes that output levels are not affected by factor price changes, and thus the indirect effect of factor price changes (via output levels) on FIDs are ignored. In addition, the inclusion of output levels as explanatory variables in the cost-minimisation function might lead to simultaneous equation biases if output levels are not indeed exogenous. The profit-maximisation function approach overcomes most of these problems, although it requires a stronger behavioural assumption. However, profit maximisation suffers from problems associated with infeasibility, corner-point solutions, and a lack of unique solutions. To overcome these problems, we assumed an unconditional profit-maximisation function and restricted our analysis to a non-negative input price vector (w > 0), product output (y > 0), and output prices (p > 0). These conditions guarantee a solution to the profit-maximisation problem and, as such, the optimal solution to this problem will always generate a profit that is larger than zero.

The FIDs estimated using a profit function framework allow one to measure the input substitution and output scale effects of factor price changes. In addition, one can measure the cross effects of output price changes on FIDs, and vice versa, as well as OS responses and their cross-price effects. Finally, the profit function framework allows the estimation of multi-output technologies in a much simpler way than a cost function or a transformation function.

The emerging econometric application of the variable profit function epitomises a major step forward towards producing an appropriate system of agricultural OS and FID functions, which are critical for the application of economic theory in agricultural development policy (Lau & Yotopoulos 1972; Yotopoulos *et al*. 1976; Sidhu & Baanante 1981). Our interest was to examine the behavioural decisions of pastoral livestock farmers on output and input use and, more specifically, on their responsiveness. To do so, farmers were assumed to maximise restricted profit conditional on a convex production possibility set or technology, signified as T. Following Vrankić and Krpan (2017), we started by defining the production technology in the short run, which is described by $Q = f(X, \overline{Z})$, where Q is the output quantity, and X and $\overline{Z}$ are the variable labour quantity and fixed inputs (e.g. size of pasture land) in the short run respectively. In this functional form, the choice variable is the profit-maximising labour and output quantities. Since the optimal variable input and output quantities are not influenced by the quantity of the fixed input (in this case pasture land), following Lau (1976) and Maligaya and White (1989) we can specify the short-run profit-maximisation problem as the excess of the total value of output over the costs of variable inputs, expressed as

$$\pi\left(P, W, \overline{Z}\right) = \underset{Q,X}{Max}\{pQ - wX | F(Q, X; Z) \in T\}, \tag{1}$$

subject to the constraint that $\pi = R - C \geq \pi^{*}$,

and where $R = pQ$ represents the gross receipts and $C = w(.)$ is the cost functional structure. Term Q and X are vectors of quantities of outputs and variable inputs, and P and W are the corresponding vectors of output and input prices respectively. Here, $\overline{Z}$ denotes the quantity of fixed factor inputs (e.g. land pasture). Note that the profit function, $\pi(.)$, is assumed to be non-decreasing in *p*, non-increasing in *w*, linearly homogeneous, and convex in *p* and *w*. The function $\pi = R - C \geq \pi^{*}$ shows the livestock farmer-specific minimum acceptable levels of profit, with π^{*} referred to as the lower bound and representing the satisficing behaviour assumption due to information asymmetry in the market.

In this short-run profit-maximisation function, the major obstructions are the cost structure of the variable inputs, $w(.)$, assuming the independence of the production possibility sets. Normalisation itself is a database design technique and, in this article, it is applied to remove any money illusion. Consequently, livestock producers are assumed to respond to relative price changes, and this reduces the demand on degrees of freedom by successfully reducing the number of equations and parameters to be estimated. In the case of a single output, a normalised unconditional profit function (defined as the ratio of the unconditional profit function to the price of the output), π^*, can be formulated. Following Färe and Primont (2012), and assuming a multi-output normalised profit function, where numéraire is the output price of the nth commodity, the unconditional profit function was specified as:

$$\pi_i^* = \pi_i^*(P^*, W^*; Z), \tag{2}$$

where $\pi_i^* = {}^{\pi}/_{p}$ is the normalised profit; $P_i^* = {}^{P_i}/_{P}$ are the output prices; and $W_i^* = {}^{W_i}/_{P}$ are the input prices. Here, *P* is the minimum acceptable price for either cattle, sheep or goat outputs (shoats hereafter) for a satisficing livestock producer's *i* – referred to as the farm-gate price. The solution of the above optimisation problems would yield the output supply function, the variable input demand functions or the labour demand function, and the maximum short-run normalised profit function. Furthermore, differentiating equation (2) in real wages $\left({}^{W_i}/_{P}\right)^0$ would yield the marginal productivity of labour, $\left({}^{W_i}/_{P}\right)^0 = \frac{f(X,\bar{Z})}{\partial X}$, and the second-order sufficient conditions that represent the decreasing marginal products of labour – the well-known result in the microeconomic theory based on a concave analysis framework.

2.2 The empirical model

Our interest is to analyse the output supply and factor input responsiveness focusing on the pastoral livestock farmers who would give insight into the policy recommendations. To do so, it was necessary to first specify a short-run profit functional form in a primal approach. Several flexible functional forms that give a second-order Taylor approximation to an arbitrary (true) functional form are proposed in the literature. These include functions such as the translog functional form (by Christensen *et al*. 1973); the generalised Leontief (by Diewert 1973); the symmetric generalised McFadden (by Diewert & Wales 1987); and the normalised quadratic (by Lau 1976). The normalised translog version of the profit function was considered for approximation of the production function and simultaneously for the estimation of OS and FID responsiveness, since they are closely linked to each other. Therefore, following Christensen *et al*. (1973), the logarithmic Taylor series expansion of the normalised profit function (equation (2)) was specified as

$$\begin{aligned} Ln\pi_i^*\left(P_i^*, W_j^*; Z_k^*\right) &= \alpha_0 + \textstyle\sum_{i=1}^{N} \beta_i LnP_i^* + \sum_{j=1}^{M} \gamma_j LnW_j^* + \sum_{k=1}^{K} \delta_k LnZ_k^* + \\ &\textstyle\sum_{i=1}^{N}\sum_{j=1}^{M} \vartheta_{ij} LnP_i^*\, LnW_j^* + \sum_{i=1}^{N}\sum_{k=1}^{K} \theta_{ik} LnP_i^*\, LnZ_k^* + \sum_{j=1}^{M}\sum_{k=1}^{K} \xi_{jk} LnW_j^*\, LnZ_k^* + \\ &\tfrac{1}{2}\left(\textstyle\sum_{i=1}^{N}\sum_{h=1}^{N} \tau_{ih} LnP_i^* LnP_h^* + \sum_{j=1}^{M}\sum_{l=1}^{M} \phi_{il} LnW_j^*\, LnW_l^* + \sum_{k=1}^{K}\sum_{u=1}^{K} \psi_{iu} LnZ_k^*\, LnZ_u^*\right), \end{aligned} \tag{3}$$

where subscripts *i* denote the output prices and run from 1 to *N*[1]; subscripts *j* and *l* denote variable input prices and run from 1 to *M*[2]; and subscripts *k* and *u* stay for fixed inputs and run from 1 to *K*[3]. Terms P_i and W_j are output and input prices respectively, while Z_k represent the quantity of factor *k* that is assumed to be fixed in the short run (e.g. area of land pasture in acres). Term π_i^* is the restricted profit of the *i*-th product normalised by the product average price, P_i; P_j^* is the normalised price of multi-output technologies, normalised by the output price P_i (that is, $P_j^* = P_j/P_i$ where *i, j* = cattle, sheep and goat prices). The terms $\boldsymbol{P}^*; \boldsymbol{W}^*; \bar{\boldsymbol{Z}}$ are vectors of these variables, and coefficients α_{i0}, β_{ij}, γ_{ik}, δ_{ih}, ϑ_{ijk}, θ_{ijh}, ξ_{ikh}, τ_{ijl}, ϕ_{ikm} and ψ_{ihn} are parameters to be estimated. *Log* denotes the logarithm of the variables.

[1] In our case $N = 3$, because we have three outputs: cattle, goats and sheep.
[2] In our case $M = 1$, because we have only one variable input: labour.
[3] In our case $K = 1$, because we have only one fixed input: pasture land area.

Using Hotelling's lemma, the first-order derivatives of equation (3) for normalised livestock product prices of i yield a system of the OS equations, *(Y)*:

$$Y\left(P_i^*, W_j^*; Z_k^*\right) = \frac{\partial Ln\pi_i^*\left(P_i^*, W_j^*; Z_k^*\right)}{\partial LnP_i^*} = \beta_i + \sum_{j=1}^{M} \vartheta_{ij} LnW_j^* + \sum_{k=1}^{K} \theta_{ik} LnZ_k^* + \sum_{h=1}^{N} LnP_h^* + \varepsilon \qquad (4)$$

From equation (3), a system of inverse variable input demand equations that represent technological change is computed by differentiating for normalised variable input prices, W_i^*, yielding FID equations X, which are expressed as:

$$X\left(Y: P_i^*, W_j^*, Z_k^*\right) = -\frac{\partial Ln\pi_i^*\left(P_i^*, W_j^*; Z_k^*\right)}{\partial LnW_i^*} = \gamma_j + \sum_{i=1}^{N} \vartheta_{ij} LnP_i^* + \sum_{k=1}^{K} \xi_{jk} LnZ_k^* + \sum_{l=1}^{M} \phi_{il} LnW_l^* + e \qquad (5)$$

This system of supply and demand response (equations (4) and (5)) shows the relationship of OS and FID to the output prices, input prices, and the quantities of fixed factors. To exhibit the properties of a well-behaved profit function, equation (3) must be non-decreasing in output price ($\beta_i \geq 0$, for i = cattle, sheep and goat outputs), non-increasing in input prices ($\delta_k \leq 0$, for k = pasture land, and $\gamma_j \leq 0$ for labour price), and symmetry constraints are imposed by ensuring equality of the cross derivatives (e.g. $\vartheta_{ij} = \vartheta_{ji}$ for all i, j; $i \neq j$, $\theta_{ik} = \theta_{ki}$ for all i, k; $i \neq k$ and $\xi_{jk} = \xi_{kj}$ for all j, k; $j \neq k$). This implies that all own-price elasticities are expected to be positive for OS and negative for input variable costs, and less than unity. However, the cross-price elasticities are expected to assume any sign, such that a negative sign implies a degree of complementarity while a positive sign indicates competing products. The homogeneity and adding-up are automatically maintained by constructing a normalised translog profit function. Similarly, the OS equation (4) and FID equation (5) exhibit theoretical restrictions reflecting the properties of the profit functions.

In this paper, the empirical model consists of equations (4) and (5), with symmetry imposed and truncated normal distribution imposed (with mean μ and standard deviation σ, and appended *iid* error terms $\{\varepsilon, e, \eta\}$). In total, systems of three equations were derived from the normalised profit function and the variables were converted to logarithms before being subjected to analysis. Variable inputs include labour (a composite of family and hired labour) expressed in market value. With regard to the fixed input demand response, the size of the improved land pastures demand equation is regarded as important in production decisions, and improvement is an extra production cost in the short run, but, in the long run, it helps reduce production costs and increase profit, thus stimulating a higher supply. However, in the short-run primal profit-maximisation model, pasture land is assumed fixed. When it comes to the variable input-demand equation, we only included labour cost, since data on other variables, such as costs of livestock supplies (e.g. drugs, vaccines) and veterinary services/ consultancies were not available. This is because farmers in the study areas do not keep proper records and it proved very difficult for a farmer to recall these for the previous year. The labour variable was computed in man-days and included both hired and family labour, and the prevailing government wage rates were used to estimate the cost of labour. As such, holding the marginal product of labour constant, the more the man-days the more the production costs and, therefore, the less the expected profit, and vice versa.

2.3 Data and estimation procedure

The dataset used was the Household Survey, which was a nationwide survey of rural households that was undertaken in September and October 2013. The survey was undertaken in the 47 counties across the country, from which 12 651 agricultural households were randomly selected from a total sampling frame of 6 324 819 (Government of Kenya [GoK] 2010). The systematic probability proportional to size sampling technique was applied by considering the prominent production systems (agro-ecological zones) found in Kenya. This study is restricted to the counties that lie in the southern rangelands of Kenya, which include Garissa, Kajiado, Kilifi, Kitui, Kwale, Lamu, Makueni, Narok, Taita-Taveta and Tana River, therefore the unit of analysis comprises 1 512 pastoral households. These counties were deemed representative of many livestock production systems and zones in the country. Output and input variable data were extrapolated based on the prevailing market values in 2013.

The approach used in this paper to estimate the derived OS and FID functions is the maximum likelihood estimation (MLE) technique. The approach involves a two-stage method. In the first step, a stochastic structure was assumed, which indicated that any deviations of the observed profit, OS and FID from their profit-maximising levels were due to random errors in optimisation. It also showed that the disturbances were additive and followed a multivariate normal distribution, with a zero mean (μ) and a constant contemporaneous covariance matrix (Σ), expressed in shorthand notation as $X \sim N(\mu, \Sigma)$. Then, once the random errors were fixed, the first-order derivative using Hotelling's lemma was computed, deriving a system of four equations from the normalised profit function.

The second step involved the estimation of derived systems of OS and FID equations, for which a truncated regression approach was adopted. Following Wooldridge (2010), the MLE technique involved assuming a truncated (at zero) normal distribution, which is the probability distribution of a normally distributed random variable with a mean μ and standard deviation σ. To simplify the mathematical expression of the functional notation, both output and variable input quantities were included in the vector y_i. Thus, y_i is a 'netput' vector, for which positive values are outputs and negative values are variable inputs. Also, both output and input prices, and both fixed inputs, are included in the vector x_i. To avoid bias in estimation, sample selection for this study was determined solely by the value of the x variable, and the density of the left-truncated (at zero) normal distribution of the i-th observation was expressed by

$$L_i = \frac{\frac{1}{\sigma}\phi\left(\frac{y_i - x_i'\beta}{\sigma}\right)}{\Phi\left(\frac{x_i'\beta}{\sigma}\right)}, \tag{7}$$

where ϕ and Φ are the density and distribution functions of the standard normal distribution. A major concern of truncating is that farmers are required to have a minimum achievement output of more than zero to be considered having participated in the livestock market. Thus, the sample is truncated at an output score of zero, which would reduce the variance in the outcome variable.

The log-likelihood function is given by

$$LogL(\beta,\sigma) = \sum_{i=1}^{N} LogL_i = -\frac{N}{2}[Log(2\pi)] + Log(\sigma^2) - \frac{1}{2\sigma^2}\sum_{i=1}^{N}\varepsilon_i^2 - \sum_{i=1}^{N} Log\left[\Phi\left(\frac{x_i'\beta}{\sigma}\right)\right], \tag{8}$$

where the values of (β,σ) that maximise LogL are the maximum likelihood estimators of the truncated regression. Since the product output and input prices were transformed into logarithmic form before estimation, their coefficients represent their respective elasticities. Following Färe *et al*. (1986), the scale elasticity was calculated by summing up the partial differentiation for each of the inputs. Here, own-price elasticities were defined as the percent change in quantity demanded (supplied) of input (output) of type i in response to a 1% change in the prices of input (output) of type i. Likewise, the cross-price elasticities were defined as the percentage change in quantity demanded (supplied) of input (output) of type i in response to a 1% change in prices of input (output) type j, holding all prices other than of the j-th input (output) constant. The positive (negative) value of cross-price elasticities indicated that i and j were complementing (or competing) products.

3. Results

The system of OS and factor demand equations was estimated with the parametric imposition of symmetry and homogeneity and used to compute the elasticities (Table 1). All own-price factor-demand elasticities were negative, while the output price elasticities were positive, which would suggest that the demand functions are downward sloping while the supply functions are upward slopping. They hence satisfy the laws of demand and supply respectively. The estimates of sigma square (goodness of fit) are significantly different from zero at a 1% level of significance, implying a good fit and correctness of the specified distribution assumptions of the composite error term. The Wald chi-square value (Wald $chi^2(6)$) showed that statistical tests are highly significant (P < 0.000), suggesting that the model had strong explanatory power.

Table 1: Elasticity estimates of livestock factor demands and output supply in the rangelands of Kenya

Parameter	Cattle (N = 221)	Goats (N = 231)	Sheep (N = 231)
_cons	-3.546* (2.057)	-7.285*** (1.691)	-5.436*** (1.838)
Cattle prices	0.889*** (0.241)	-0.014 (0.112)	-0.065 (0.127)
Goat prices	-0.536** (0.232)	1.494*** (0.199)	-0.686*** (0.211)
Sheep prices	0.294* (0.154)	0.265** (0.137)	1.263*** (0.219)
Labour cost	-0.592*** (0.067)	-0.507*** (0.058)	-0.412*** (0.061)
Scale elasticities	0.055 (0.173)	1.238 (0.127)	0.1000 (0.154)
Sigma	0.899*** (0.044)	0.804*** (0.038)	0.752*** (0.039)
Wald chi2(4)	108.76***	140.80***	208.06***
Log-likelihood	-286.417	-276.181	-210.193
Breusch-Pagan / Cook-Weisberg	3.14[1]	12.62[2]	0.02[3]

Notes: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.001$; Standard errors are in parentheses; [1] Prob > chi^2 = 0.0764; [2] Prob > chi^2 = 0.0004; [3] Prob > chi^2 = 0.8981

The result indicates that the own-prices elasticities for goats and sheep are positive and elastic, while that for cattle was positive and inelastic (Table 1). The own-price supply elasticities of cattle, goats and sheep were estimated at 0.89, 1.49 and 1.26 respectively. However, it is worth noting that sheep and goats are more responsive to own prices than cattle, which can be associated with a longer production cycle that tends to make producers less responsive to changes in cattle prices. The output response to variable input was measured by the cost of labour, normalised by output price of type *i*. Overall, as shown in Table 1 in which this variable was tried, its estimated elasticity had a negative sign and was significant at the 1% level, implying strong explanatory power for the supply of livestock products. Logically, based on this result, one would expect that, with an increase in real wages for a given technology and a fixed factor of production, the active livestock producer of three products will adjust to the new changes in real wages and hire less labour. This will lead to a decrease in production by a magnitude of 0.59, 0.51 and 0.41 for cattle, sheep and goats respectively. However, an important implication of this result is that sheep production is less responsive to labour than cattle and goats.

In all cases, cross-price elasticities were found to be differentiated and in the inelastic range, which indicates that a price change will result in a relatively small uptick in the supply of livestock products. Generally, these elasticities are not or only weakly significant, except for the response to goat prices. Irrespective of the signs, cattle output appears to be more price responsive to goat and sheep prices than goat and sheep output is to cattle prices. A cross-examination of the cross-price elasticities indicates that sheep can be a complement for cattle and goats while, on the other hand, goats can be a competing product for sheep and cattle. A more likely explanation for the negative elasticity between cattle and sheep output to goat prices is that, in Kenya, goat meat prices at the consumption level are high. A slight increase in the price of goat therefore would reduce the demand compressing the producer prices and that would result in a reduction in the supply. Moreover, the high goat meat prices would make the consumer shift to cattle or sheep meat, thereby increasing the demand for cattle and sheep and, subsequently, the prices of live cattle and sheep will increase, which will increase the supply. In addition, the livestock market is not perfect (Maina 2013; Tully & Shapiro 2014). Tully and Shapiro (2014) observe that access by livestock producers to inputs and information is not equal, as producers are heterogeneous. Mostly, their decisions are largely based on traditions and beliefs instead of on economic rationality; and the actors in the retail chain also distort the market, hence the observed asymmetry in the results is well founded.

The elements in the row labelled 'scale elasticities' in Table 1 reflect the output supply response to a change when all exogenous variables are combined. Generally, the scale elasticities reflect the return to scale and, for the three livestock products, they were not less than zero. The decreasing returns to scale for cattle and sheep indicate the possibility of free disposal. However, goat output seems to be more responsive to factor inputs than cattle and sheep outputs are. As observed by Degen (2007), goats are becoming attractive in pastoralist areas, where frequent droughts and diseases are experienced, since they are less prone to these and can easily be de-stocked during drought and re-stocked thereafter, hence reducing any losses due to starvation.

4. Discussion

The results of this study show that all own-price elasticities of the output supply equations for the three livestock products had the expected positive signs, with negative signs for variable labour input. The own-price elasticities for goat and sheep were elastic, while that for cattle supply was inelastic, with the most inelastic being cattle, followed by sheep. The relatively elastic own-price elasticity of goat products concurred with the findings of Nyariki (2009) and Kibara *et al*. (2016). The possible explanation for this finding is that producers respond to an increase in prices by diverting resources into increasing goat flocks in expectation of better prices in the future. Sheep and goats are more responsive to own-price elasticity than cattle, which can be associated with the longer production cycle of the latter. This tends to make producers more receptive to changes in cattle prices. In comparison, the supply elasticity of goat products was the highest amongst the three livestock products analysed. This coincides with Muigai *et al*.'s (2018) observation that goat and sheep prices are highly variable at the producer level, and are easily manipulated by other market actors, depending on the needs of the seller.

Output-supply responsiveness was further measured in relation to variable inputs such as labour costs. Traditionally, labour demand has been assumed to be inelastic, which was also found in this study. This result has important implications for the analysis of farm unionisation. The results appear to suggest that returns to hired labour for livestock production as a whole may decrease evenly as a consequence of the increase in effective wages associated with unionisation. Another interesting observation of the elasticities observed for labour input is that higher wages for hired labour will have different implications for the supply of animal outputs. A possible policy option that was observed is that the enhancement of the level of capital resources, either through injecting capital resources into the livestock industry or the provision of affordable microloans in remote rural areas, would caution farmers against the high cost of labour, thereby providing households with an incentive to invest in livestock production. This would also be encouraged by the wide spectrum of benefits provided by the livestock industry, such as cash income, food, manure, draft power and hauling services, savings, insurance, social status and social capital (Bebe *et al*. 2003).

The sign structure of the cross-elasticities of supply is of substantial interest. Cross-price elasticities were found to be inelastic in all cases considered, which indicates that a change in price will result in a relatively small uptick in the supply of livestock products. The result for the cross-price elasticities also shows that sheep appear to be a complement for cattle and goats. Conversely, based on farm goat prices, a goat appears to be a competing product for cattle and sheep. This is because a slight increase in farm sheep prices has an expansive effect on the supply of cattle and goats, while farm goat prices would negatively affect the supply of cattle and sheep.

The policy option to enhance livestock production and hence offtake in the country therefore should focus on improving the institutional and environmental conditions that support livestock output prices and input marketing, with an emphasis on specific livestock species. Priority areas for action to reduce the constraints to livestock production and incomes from livestock farmers, without causing damage to the rangeland, would include strengthening the capacity of investment among the farmers by improving their capital base; and accelerating livestock productivity through intentional pasture improvement to increase the carrying capacity of the land. Moreover, improving the factor market is expected to drive a wedge between efficient and observed factor price effects on livestock output supply. Other specific policies in factor markets that may have a non-trivial effect on the demand for farm labour also include the provision of minimum wage legislation in agriculture.

5. Conclusion

The study implemented a procedure for estimating the output supply of cattle, sheep and goats from a profit function perspective. The primal optimisation model was derived. In this model, the technology in the short run is represented by the short-run production function and the normalised profit function, which expresses profit in output units. Employing a truncated (at zero) regression technique, this study has shown that useful and statistically significant models of supply and input demand in the livestock sector can be derived from the basis of a single equation by applying very little knowledge about institutional factors in the sector. The effects of product output prices and labour costs were quantified successfully and individually. This information, which is vital for understanding the structure of production in the Kenyan livestock industry, is not directly available from the estimates of the profit function. However, due to a lack of data associated with variables of intermediate input, such as feed, technology (as a result of the use of cross-sectional data) and rainfall, among others, we recommend that forecasts that are made using the models presented here be contingent upon the continuance of model specification to include such variables. Finally, the empirical results are based on an unconditional profit function, and a promising suggestion for future research would be to use an integrative differential model that includes the risk aversion of livestock producers, since livestock producers' attitudes toward risk would affect the selection of livestock for sale. Even with such limitations, the results of this study are an important step in providing insight into the variable responsiveness of the livestock industry in Kenya.

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