Profit inefficiency of goat farming in Malawi: A Bayesian approach

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ABSTRACT

Goat farms located in villages constitute an important sub-sector to buffer household livelihoods against climate shocks in absence of insurance markets, and thus the need to intensify production to meet the growing goat meat demand. There has been little attempt to quantify the efficiency of goat farms and the associated drivers. Potential initiatives to bolster goat farm incomes have not gone beyond production. Using the Bayesian Stochastic Frontier Approach and Malawi’s national Integrated Household Panel Survey data from 2010 to 2019, we analyze the profit efficiency of goat farming and the priority drivers that influence inefficiencies across production plants. The findings reveal that farmers are operating below the profit frontier and 71% of the profit-loss is influenced by farm characteristics. The results further suggest that policies involving stir-frying commercializing and specialization are key to closing the efficiency gap. Finally, the study proposes new policy directions, namely, government provision of livestock extension services to farmers, incorporating goat farming into women’s empowerment programs, and provision of access to tailor-made livestock microfinance loans.

1. Introduction

Goat farming plays a key role in all Sustainable Development Goals (SDGs), most of which are positive and a few negatives and diverse trade-offs. Particularly related to SDGs 2 and 3, goat farming has an important role in food and nutrition security. It provides about 18% of the calories (kcal) and protein of consumers globally, essential micronutrients including vitamin A, vitamin B-12, riboflavin, calcium, iron, and zinc which are insufficient from plant-based sources (FAO, 2010; Mumba et al., 2003; Du-Pont et al., 2020).

Corresponding directly with SDGs 2 and 3, the livestock sector has critical roles to play in food and nutrition security. Beyond providing 18% of the total calories (kcal) and 40% of the protein in people’s diets at a global level, livestock-derived foods provide critical micronutrients such as vitamin A, vitamin B-12, riboflavin, calcium, iron, and zinc, which are difficult to obtain in adequate quantities from plant sources alone, especially for the world’s most vulnerable groups, such as children, pregnant women, and the elderly. Milk, meat, and eggs can help combat (FAO, 2010; Du-Pont et al., 2020).

Global production has risen dramatically compared to other livestock in the last 60 years due to changes in household income and food preferences (Miller and Lu, 2019). Asia holds the first position by having over 3 billion goats, which is 71.4% of the current total world goat production. The rest of the continents lag behind Asia and Africa takes second place with a contribution of 23.6%, having a total number of about 1.2 billion goats produced in the last 10 years (FAOSTAT, 2020). The production of goats in the regions of Africa has marginally increased over the past decade, with Nigeria and Ethiopia having the most significant collective production of over 341 million. On the other hand, the sub-Saharan region has produced about 914 million goats which is 75.2% of the total production in Africa (FAOSTAT, 2020).

In Malawi, goats rank first among the ruminants’ livestock (Maganga et al., 2015), however, in the past ten years, Malawi produced only about 10.7 million goats and more than 90% of the production is indigenous goats kept by smallholder farmers who practice tethering and/or herding production systems in herds of an average of 6 goats (Chintzanya et al., 2004). The total national meat production was 3,415,790 tonnes (Table 1), which was dominated by chicken and pork with a contribution of 29.4% and 45.2% to the production, respectively, and chevon contributed 416,659 tonnes, which constituted 12.2% of the total national meat production (FAOSTAT, 2020).

The demand for goats and other goods obtained from animals for human use is on the rise each year in the country (Msalya et al., 2020),

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and despite the efforts by the government of Malawi and development partner's to allocate resources to increase livestock production through these policies; the National Livestock Development Policy and the National Agricultural Policy (NAP) the current rate of production is still failing to meet the growing domestic and export demand.

Low goat production has remained persistent over the years and remains a challenge despite the country’s potential. Low levels of productivity, poor technical and managerial skills, lack of appropriate and timely implementation strategies, insufficient funding to buy agricultural inputs, low bargaining power, and ignorant regulatory framework for goats can all be blamed for the subpar performance of the goat industry (Banda et al., 2011; Ketto et al., 2020; Mulwafu and Krishnankutty, 2012). Nandolo et al. (2016) further observed that most Malawian farmers’ are more interested in the processes of improving traits, higher growth rates, and higher mature weights other than increasing production. These factors have made it more challenging to scale up and improve production and therefore negatively affect the farmers’ profit and consequently affect the sector’s viability and competitiveness.

To curb the challenge, many non-state actors have implemented goat pass-on schemes that enable farmers to have access to goat starter packs for their private production with an increasing number of farmers benefitting from the starter pack in each successive generation of goats. Unfortunately, these schemes also faced some challenges, Kenamu and Maguza-tembo (2016), and Monau et al. (2020) suggested the use of close monitoring during the goat distribution and pass-on process, inclusiveness of livestock farming in agricultural extension messages, and development of one-stop input supply centers.

It is therefore unsurprising to see that incentives to increase goat production haven’t looked beyond the production aspect and it can also be seen that not many non-state actors if not none have had initiatives to stir up the markets for goats among the smallholder farmers to increase farmers’ production and income. Furthermore, there is limited research that has focused on the marketing side of goat production in Malawi (Maganga et al., 2015). The marketing system as reported by Kaumbata et al. (2020) and Banda et al. (2011) does not favour smallholder farmers as they obtain varying and dismal profits from their enterprises even though there is potential to generate more income.

Despite the current level of goat production, the goat industry has managed to create a source of income for rural farmers, this displays how significant it is to increase profit margins. Thus, benchmarking potential initiatives to bolster goat incomes requires baseline knowledge of the current level of profit efficiency among the farmers so that progress on the same can be objectively evaluated over time. However, to the best our knowledge no study has established the current levels of profit efficiency in goat enterprises and let alone provide necessary information about the key drivers of profit efficiency on which the development players can concentrate their efforts to increase farmers’ returns in the goat sector as most of the studies have put much emphasis on the efficiency of crop agriculture, consequently devising strategies to improve goat production through marketing has to be done without evidence. Therefore, this study unpacks the current levels of profit efficiency and associated drivers in small-scale goat farming.

Our study provides information for fine-tuning livestock policy and tailoring investments, and interventions for the livestock subsector’s improvement. As the government is trying different initiatives to increase farmers’ income, this study will enlighten on how much gap there is in the profitability of goat enterprises and the key drivers to closing the profit gap. Second, the study contributes to the current debate on the link between profit efficiency and the major determinants in the tropical context using the Bayesian approach. This approach has recently gained superiority over the frequentist approach because of its ability to supplement sample information with prior knowledge. Third, while most of the previous studies used cross-section data, this study uses nationally representative panel data which is reached in generating reliable estimates in terms both in space and time.

2. Methodology

2.1. Study area and data

The study used nationally representative Integrated Household Panel Survey (IHPS) data from National Statistical Office. The panel data was collected during distinct periods of 2010, 2013, 2016, and 2019. The IHPS sample was selected to be a representative of the national, regional, and urban/rural levels for each of the following 5 strata: (i) Northern Region – Rural, (ii) Northern Region – Urban, (iii) Central Region – Rural, (iv) Central Region – Urban, (v) Southern Region – Rural, and (vi) Southern Region – Urban.

The use of stratified sampling is a common practice in national household surveys where each stratum is homogenous internally and heterogenous with other strata, and have assigned sampling weights to each observation when there is large variability between strata. This sampling method is beneficial to this study because ignoring the concept of homogeneity and heterogeneity can lead to overestimation and misleading results. Even though these surveys covered several household modules, the household questionnaire included a module on household livestock dynamics which was used in the study, and the combined total observations used for this study are 1,447 farmers who engaged in goat farming.

2.2. Theoretical framework

Goat farmers are rational agents and their objective is to operate at the most highest possible level of profit. Profit is defined as revenue minus the cost of acquiring the necessary inputs for production. Given a competitive goat market, a farmer can sell each unit of output at the market price, p. The total revenue will therefore be the product of output and market price, R(y) = p.y.

Assuming that the farmer is considering a designated output y0. If x1 is a feasible vector of inputs to produce y0, and if w is the vector of input prices, the cost of using x1 to produce y is simple w.x1. This production plan would yield profits of psy0 – w.x1. There are two things worth considering. First, output y0 may not be the best level of output, input level x1 may not be the minimum possible input combination to produce y0. The farmer must therefore take some decisions. The farmer must decide both what level of output to produce and how much of which inputs to use to produce it.

Suppose that the farmer’s objective is to maximize profits. The farm will choose that level of output and that combination of inputs that solves the following problem (equation (1)):  

$$\max_{(x,y)\in \mathbb{R}^+^2} \quad f(x) \geq y$$  

(1)

Where f(x) is a production function. The solution to this problem will indicate both the level of output and inputs combination that the farmer will use. Since the production function is monotonic, we may replace the inequality in the constraint with equality. Thus, the maximization problem becomes (equation (2)):  

$$\max_{x \in \mathbb{R}^+} \quad psy - w.x$$  

(2)
Now we assume that this profit-maximization problem has an interior solution at the input vector \( x^* \geq 0 \). Hence the profit-maximizing amount of output produced is \( y^* = f(x^*) \). Then the first-order conditions require that the gradient of the maximand be zero because there are no constraints (Nicholas and Snyder, 2008). This is written as equation (3):

\[
\frac{\partial f(x^*)}{\partial x_i} = w_i, \forall i = 1, \ldots, n
\]  

(3)

The product of the output price with the marginal product of input \( i \), is the marginal revenue product of input \( i \). It gives the rate at which the revenue increases per additional unit of production. At the profit frontier, this must equal the cost per unit of input \( i \), which is \( w_i \), for a farmer to be categorized as fully efficient. The distance between where the farmer is operating and the profit frontier is the level of inefficiency (Abbas and Siddiqui, 2020; Rasmussen, 2011).

Kumbhakar and Lovell (2000) elaborated that the profit frontier assumes that producers face strictly positive output and input prices and seek to maximize the profit they obtain from using inputs to produce an output. According to Arbelo et al. (2018) the profit function takes the output quantities as given and allows the output prices to vary freely. In this manner, it takes into account differences in the quality of outputs and the possible existence of firms that have certain market power for setting the prices of the outputs. Thus, following Arbelo et al. (2018) the stochastic profit function specified for a farmer in a given season is expressed as equation (4):

\[
\pi_i = f(y; \theta)\cdot(y_i - u_i)
\]  

(4)

where \( \pi_i \) is the profit of the farmer \( i \) during the period \( t \), \( y \) is the vector of explicative variables (input prices and output quantities), \( \theta \) represents the vector of parameters to be estimated, \( y_i \) is the identical and independent random error distributed as \( u_i \sim N(0, \sigma_e^2) \) and independent of \( u_i \) and \( u_j \) represents the positive-definite error component defining the farmer’s profit inefficiency, which is considered to be independently and identically distributed, with a mean of zero and constant variance. This component is hypothesized to be affected by several socio-economic and institutional factors. This is expressed as equation (5):

\[
u_i = f(z; \delta) + \epsilon_i
\]  

(5)

where \( u_i \) is the inefficiency component, \( z \) is a vector of factors that affect the profit efficiency of goat enterprise, \( \delta \) is a vector of parameters to be estimated.

Following Jabbar et al. (2005) the profit efficiency of the i-th farmer is given as a ratio of the observed profit to frontier profit or the most possible efficient profit for the given farmer. For a fully efficient farmer, who is operating on the profit frontier, the non-negative error component, or the inefficient component collapses to zero. Mathematically, profit efficiency can be represented as equation (6):

\[
\hat{\theta} = \frac{f(y; \theta) \cdot \exp(y_i - u_i)}{f(y^*; \theta) \cdot \exp(u_i)} = \exp(-u_i)
\]  

(6)

Where, \( \hat{\theta} \) is the level of profit efficiency, \( f(y; \theta) \) is the observed profit function, \( f(y^*; \theta) \) is the frontier profit function. The inefficiency component in the denominator collapses to zero to show that the farmer is operating on the profit frontier and any deviations from the frontier are random as a result of the traditional error component beyond the control of the farm decision-maker.

### 2.3. Specification of the empirical model

This study adopts the Bayesian approach to modeling profit efficiency. Bayesian estimation of frontier models was spearheaded by Van den Broeck et al. (1994). The Bayesian approach is more suitable for stochastic frontier modeling than the frequentist approach because of several advantages. The use of the Bayesian approach is gaining prominence due to its greater flexibility and benefits concerning the maximum likelihood method. The approach allows for a more precise estimation of efficiency scores and associated inference (Tonini, 2012) even with small sample sizes.

The main advantage of the Bayesian approach compared with the frequentist approach is that it allows the inclusion of prior information on the vector of random parameters \( \theta \) to be estimated through a probability density function \( f(\theta) \), which represents the researcher’s subjective beliefs about the parameters of interest before gaining any information from the current data set \((\pi, \gamma)\), hence, the previous knowledge can be introduced in the research model (Arbelo et al., 2018; Dorfman, 1998). It also allows the researcher to incorporate prior beliefs and regularity conditions through the kernel density.

Once the data have been observed, the information is summarized in the known likelihood function, \( f(\pi \mid \theta, \gamma) \), which is the conditional density of the vector of random observations \( \pi \) given a particular set of values for the random parameters \( \theta \) and predetermined variables that are used to explain the variations within random observations \( \pi \). Then the Bayes’ theorem combines the two sources of information (the prior and the data) (equation (7)):

\[
f(\theta \mid \pi) \propto f(\pi \mid \theta) f(\theta)
\]  

(7)

where \( f(\theta \mid \pi) \) is the posterior density function which is proportional to the product of the likelihood function and the prior density, that is, the posterior distribution includes all the information about the vector of parameters \( \theta \) contained in the prior and the data (Arbelo et al., 2018; Van den Broeck et al., 1994). In this way, the results are presented in terms of probability density functions, which allow probability statements to be made about hypotheses, models, and parameters, (Coelli et al., 2005). The \( \theta \) is a composite vector of parameters \( a, b, c^2, \) and \( \lambda \).

Due to the complexity of estimation of a Bayesian stochastic frontier model, a numerical integration procedure is employed. The most widely used procedure in the literature is the Markov Chain Monte Carlo (MCMC) which was pioneered by Koop et al. (1995) and since then special routines such as MCMC Gibbs Sampler have been used (Griffin and Steel, 2007). This study adopts a likelihood frontier model which assumes independence between the inefficiency error component \( u_i \) and the random error term, \( \epsilon_i \). The quantity \( u_i \) follows a one-sided distribution and the distributions mostly used in the literature are truncated normal, exponential, and gamma (Kumbhakar and Lovell, 2000).

We use a Bayesian stochastic frontier model that uses a three-level hierarchical modeling approach. In the first level, the normalized profit function is estimated. Normalized translog stochastic profit frontier is the most popular flexible functional form often interpreted as a second-order approximation to a profit function form (Berndt and Christensen, 1973). Applying it to this study, the normalized profit function is specified as equation (8):

\[
\ln E = \beta_0 + \exp(-\eta(t - T))u_t + \sum \beta_k \ln P_i + \frac{1}{2} \sum \beta_k \ln P_i \ln P_i + v_i - u_t
\]  

(8)

Where: \( k, l = \text{input } 1, \ldots, m; v_t \) denotes the traditional error component and \( \eta \) the non-negative inefficiency component. \( v_t \) is assumed to be independently and identically distributed (iid), symmetric, and distributed independently of \( u_t \). Thus the composite error term for the model, \( e_t = v_t - u_t \) is asymmetric, since \( u_t = 0 \), and \( \eta \) is a time-varying component. NPI (Negative Profit Indicator) was included as an independent variable because the logarithm of negative numbers is undefined, thus making it impossible to generate profit inefficiency estimates of farms with losses. According to Arbelo et al. (2018) the NPI takes value 1 for those farms with positive profits and the absolute value for farms with negative profits. Simultaneously, the profit variable takes value 1 for those farms with negative profits and the corresponding value for farms with positive profits.

In the second level, the profit inefficiency component is modeled following an exponential distribution specified as \( u_t \sim (\lambda) \), conditioning
Table 2. Descriptions of variables used, their measurements, and expected signs.

| Variable       | Description                                                                 | Expected sign | References |
|----------------|-----------------------------------------------------------------------------|---------------|------------|
| Dependent variable | Profit Normalized profit of the ith farm is defined as gross income less variable cost divided by farm output price. |               |            |
| Independent variables | Labour cost Expenditure per year (MWK)                                      | -             |            |
|                  | Feed cost Expenditure per year (MWK)                                         | -             |            |
|                  | Veterinary cost Expenditure per year (MWK)                                   | -             |            |
|                  | Other inputs cost Expenditure per year (MWK)                                 | -             |            |
|                  | Sex Female = 1, Male = 0                                                      | /+            |            |
|                  | Land Hectares                                                                | -             |            |
|                  | Household size Number of people                                              | -             |            |
|                  | Education Primary, secondary, tertiary level                                  | -             |            |
|                  | Age Years                                                                    | -             |            |
|                  | Credit Access (Yes = 1, No = 0)                                              | -             |            |
|                  | Extension Access (Yes = 1, No = 0)                                           | -             |            |
|                  | Herd size Number of goats (<10,11-20,-20)                                    | -             |            |
|                  | Commercialization Produced for sale (Yes=1, No=0)                            | -             |            |
|                  | Specialization Number of types of livestock produced                          | -             |            |

Table 2 shows a list of variables included for modeling.

2.4. Data analysis

Descriptive statistics were analyzed in Stata 15 statistical software to derive point estimates. While the inferential statistics were analyzed in Winbugs 14 (Bayesian interface using Gibbs Sampling). Gibbs sampling was used to estimate the stochastic profit frontier in a single-stage approach.

3. Results and discussion

This section presents the key findings of this study and in turn, offers a discussion of the same. The section is organized as follows: Begins with a presentation of the background characteristics of the farmers, and in turn, presents the findings for profit efficiency analysis.

3.1. Descriptive statistics

To understand the farmers better, the characteristics of interest included gender, level of education, age, herd size, household size, crop-land area, extension services, credit services, income, production costs, and degree of specialization among others. Table 3 provides a summary of categorical variables used in the analysis. A total of 22.5% of the farmers were female implying that male farmers dominated goat production over the period 2010 to 2019. The results are similar to those...
found by Kaumbata et al. (2020) who indicated that 78% of the goat farmers in Malawi were male. Male dominance in goat production is not surprising as previous studies have established that women usually focus on small livestock like poultry while men focus on large livestock (Rota et al., 2010). The gender gap has persisted over all waves of data since 2010.

About 10.7% of the farmers had attained a primary school leaving certificate (PSLC), 13.1% achieved secondary education qualifications (JCE, MSCE/GCSE), and only about 1.6% achieved tertiary education. Further analysis from the gender lens showed that the majority of the farmers who had any form of formal education were male, implying that male farmers have had more access to education than female farmers. The findings are consistent with those of Chisamya et al. (2012) who found persistent gender disparity in basic education in Malawi. Further analysis showed that 69.8% of the farmers were literate, as defined by the ability to read and write any language.

Extension services facilitate the adoption of new production techniques and also provide access to marketing and production information for improved productivity (Tesema, 2021). Two kinds of extension services were explored. The first extension is advice on general animal care and the second is, an extension on livestock diseases and vaccinations. About 21.3% of the farmers had access to extension advice in general for livestock care and 19% had access to advice on diseases and vaccinations for livestock. Overall, 25% of the farmers had accessed any extension advice on livestock. There has been a general upward trend in access to extension services from 2010 to 2019.

Credit in agricultural production serves as an instrument to increase production through the timely purchase of required inputs and machinery for carrying out farm operations. However, as reported by (Kaumbata et al., 2020), formal credit services for small-scale livestock production are usually unavailable or limited. Only 22.8% of farmers had access to credit services. An inspection of the trend shows that there has been increasing access to credit between 2010 and 2019; from 12.1% in 2010 to 26.5% in 2019. For both gender groups, the result shows that the disparity in access is not huge which may point to the fact that both are facing constraints of credit constraints.

Commercialization and disease shocks can be seen as market transaction costs. Only 55% of the farmers produced goats for commercial. However, 16.1% of the farmers encountered disease shocks, the percentage is low because farmers always try to mitigate shocks, just as Ngigi and Birner (2013) observed. Table 4 is a summary of the continuous variable included in the analysis. Overall, the average age of the farmers was 47 years and the age ranged from 18 to 94 years old. Thus most farmers were within the economically active age group. These farmers had households with an average of 6 members. They kept an average of 4 goats. In a further analysis, 92% of the farmers had a small herd size of less than 10 goats. About 7.2% of the farmers had a medium herd size ranging from 10 to 20 goats and 1% had a large herd size of more than 20 goats. This finding is comparable to that of (Kaumbata et al., 2020) who found that farmers kept an average of single-digit goats.

Furthermore, the results showed that farmers who had access to credit were likely to have a small herd size. Farmers had a landholding average of 1.29 ha. The findings showed a positive correlation between herd size and landholding size. Those who had a herd size of less than 10 had 1.24 ha of land, those with a herd size of 10 to 20 had a landholding size of 1.76 ha and those with more than 20 goats had a land holding of 2.5 ha, and the maximum distance farmers had to travel from their community to the nearest major road was 46 km.

The result also reveals a gender disparity in landholding. Male farmers had on average higher landholding than their female counterparts. A farmer had to travel about 9 km to a major established road network. The average specialization (the inverse of the number of livestock types kept) was 0.53. The average profit per animal was MK17,065 with a standard deviation of MK 12,433. The large variability is caused by farmers operating at various levels of herd sizes and hence different scale economies.

The mean labour, feed, veterinary, other-input costs was MK2,060, MK1,955, MK2,100, and MK1,018, respectively. The nominal cost and

### Table 3. Summary of categorical variables.

| Sex               | 2010 | 2013 | 2016 | 2019 | Pooled |
|-------------------|------|------|------|------|--------|
| Male farmers      | 242  | 270  | 315  | 323  | 1150   |
| Advice on General animal care | 32  | 10.5% | 128  | 39.8% | 73  | 18.8% | 75  | 17.4% | 308  | 21.3% |
| Credit Access     | 37   | 12.1% | 75   | 23.1% | 104  | 26.8% | 114  | 26.5% | 330  | 22.8% |
| Livestock Disease shock | 0   | 0.0%  | 0    | 0.0%  | 36   | 9.3%  | 95   | 22.2% | 131  | 16.1% |
| Produce for commercial | 0   | 0.0%  | 199  | 61.4% | 300  | 77.3% | 300  | 69.8% | 799  | 55.2% |
| Primary education | 31   | 10.2% | 33   | 10.2% | 32   | 8.2%  | 59   | 13.7% | 155  | 10.7% |
| Secondary education | 41  | 13.4% | 45   | 13.9% | 49   | 12.6% | 54   | 12.6% | 189  | 13.1% |
| Literate          | 202  | 66.4% | 230  | 71.4% | 274  | 71.2% | 0    | 0.0%  | 706  | 49.8% |

### Table 4. Summary of continuous variables.

| Variable                | 2010 | 2013 | 2016 | 2019 | Pooled |
|-------------------------|------|------|------|------|--------|
| Household size (M SD)   | 6    | 3    | 6    | 2    | 7      |
| Age of farmer (M SD)    | 47   | 15   | 44   | 16   | 46     |
| Age-squared (M SD)      | 2453 | 1581 | 2216 | 1546 | 2331   |
| Herd size (M SD)        | 5    | 5    | 4    | 6    | 4      |
| Specialization (M SD)   | 5.62 | 0.32 | 0.5  | 0.3  | 0.5    |
| Profit (MK/Animal)      | 12,060 | 6,034 | 26,191 | 14,032 | 19,869 |
| Labor cost (M SD)       | 10,052 | 2,983 | 1772 | 2,990 | 4209   |
| Feed cost (M SD)        | 7815 | 3,233 | 1,158 | 1,987 | 1,568  |
| Veterinary cost (M SD)  | 2619 | 1,583 | 1,023 | 1,932 | 809    |
| Other costs (M SD)      | 1,397 | 1,932 | 2,067 | 1,562 | 2,681  |
| Distance Nearest Major Road (M SD) | 9.62 | 9.47 | 9.61 | 9.81 | 8.46   |
| Land possession in Hectares (M SD) | 1.07 | 0.88 | 1.22 | 0.98 | 1.47   |

C. Nyakwawa, A. Mulagha-Maganga and J.H. Mangisoni
Heliyon 8 (2022) e11318
revenue data were first adjusted for real equivalence, given that it included data from different years.

### 3.2. Model adequacy tests

The results covered in this section were estimated using the profit frontier model in the Gibbs Sampling framework. The model was estimated with a single chain and 35,000 iterations of which 5,000 were discarded to eliminate the influence of initial values and ensure convergence, while a thinning of 1 in 100 draws was retained to reduce the sensitivity of the chains. To ensure conformity to theoretical regularities, some tests were performed before inferences. These tests included functional consistency, the sensitivity of the precision of hyper-parameter priors, convergence of the chains, and the presence of autocorrelation.

To avoid the use of incorrect functional forms that would have generated errors, a test was done to select the appropriate model between the Translog and Cobb-Douglas functional forms. The application of the deviation information criteria (DIC) as suggested by Spiegelhalter et al. (2002) was used. The routine compares complex hierarchical functional forms; the appropriate model is the one that has a lower DIC. The DIC of the Translog and Cobb-Douglas models was implemented in WinBUGS software and the results as shown in Table 5 suggest that the Translog specification was the appropriate model.

The sensitivity test was done on the levels of profit efficiency results with various precision hyper-parameter values. Fig. 1 shows kernel densities from the posterior distributions of input variables with the precision hyper-parameter of priors set to 0.1, 0.01, and 1 which resembles changing the variance levels from 10 down to 1 and up to 100, which can be seen as a huge change in prior beliefs. Koop (2003) reported that if the outcome is the same for various priors, then it is reassured that researchers with different beliefs can find similar results with the same data. Hence, the kernel densities as presented in Fig. 1 show the results are similar, this implies that the posteriors of the efficiency model are not sensitive to changing variance (prior values) and the efficiency posterior estimates are fairly robust.

Convergence of an MCMC is referred to a situation where the chain has reached its equilibrium and can generate posterior values. One of the ways of monitoring convergence is through trace plots. Ntzoufras (2008) suggested that convergence can be reached when all values are within a zone without strong periodicities and tendencies. As shown in Appendix A, all generated values are within a parallel zone and there are no systematic tendencies, hence convergence was attained.

Monitoring autocorrelations is very important since low or high values of the posterior distribution indicate fast or slow convergence, respectively, whereby slow mixing indicates a high correlation between parameters and vice-versa (Griffin and Steel, 2007; Ntzoufras, 2008). Autocorrelation plots in Appendix B showed that the spikes completely faded after 40 lags indicating that the posterior distribution was mixing well implying the absence of autocorrelation and that the parameter estimates are efficient.

### 3.3. Profit frontier model posterior results

Table 6 shows the posterior results for the profit frontier model. Ntzoufras (2008) postulated that if the value of MC error is low in comparison to its posterior estimates, especially its standard error, then the results are estimated with accuracy. The results in Table 6 can be seen to be accurately estimated as the values of the MC errors are lower than those of standard deviation.

The coefficient estimates of the profit frontier for the input variables; labor, feed, veterinary, and other inputs are -0.057, -0.042, -0.036, and -0.040 respectively. The negative signs show that the input variables met their prior expectation. In comparison to the other variables, the labor input variable has the largest magnitude; the coefficient means that a percentage rise in labor costs will result in a 0.057% loss in the farmers’ profit margin. The coefficients of feed, veterinary, and other inputs imply that a percentage increase in cost will lead to a 0.042%, 0.036%, and 0.040% decrease in profit margin, respectively. All of the coefficients of the squared input variables have negative signs which correspond to their prior expectation. This implies that when input costs rise, profit margins will fall at first, then continue to fall as more and more inputs are added hence cutting farmers’ profit margins even further in the long run.

Except for cross-products of the labor-veterinary, feed-veterinary, and feed-other-inputs whose estimated coefficients are -0.003, -0.002, and -0.002, respectively, estimated coefficients for the other cross-input variable are positive. The negative coefficients imply that the inputs are substitutes, meaning an increase in any of the two inputs demands a decrease in the level of the other. For instance, if the cost of feed on a farm increases because a farmer switches to a more nutritious feed, then the level of veterinary costs has to decrease. While the cross-inputs with positive coefficients; Labor-Feed, Labor-Other-inputs, and Vet-Other-inputs can be considered complementary.

Furthermore, in contrast to the standard econometric technique, the Bayesian approach generates posterior kernel densities for all of the frontier parameters rather than just a single point estimate, allowing for additional information to be extracted from the parameters. The kernel densities generated from the beta parameters have an unequivocal negative relationship with the outcome variable implying that the profit frontier is well-behaved and is decreasing in inputs. See Appendix C.

### 3.4. Time-varying profit efficiency posterior estimates

The time variable (trend) previously presented in Table 6 was introduced to portray non-monotonic technological evolution. The time variable’s coefficient is negative, meaning that the rate of technical progress is slowing down with time and efficiency levels are barely improving. As demonstrated in Table 7, profit efficiency ranged from 24.6% in the year 2010 to 39.7% in 2019, with a mean efficiency of 28.9%. This means that the goat industry is losing 71.1% of its potential income. For example, if goat farmers make an average profit of MK17,065 the farmer might boost earnings by about MK59,048.

Further analysis showed that goat farmers have a wide range of profit efficiency, ranging from 3.7% to 84.2%, and about 76% of goat farmers have a wide range of profit efficiency, ranging from 3.7% to

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**Table 5. DIC values for various models.**

| Functional Form (model) | DIC   |
|-------------------------|-------|
| Cobb-Douglas            | 5,677.13 |
| Translog               | 5,672.89 |

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**Fig. 1. Kernel densities of efficiency with different precision prior values.**

Own computation.
84.2%, and about 76% of goat farmers are clustered around the mean profit efficiency level of 28.9%. However, the huge variation in the profit efficiency levels is not shocking as similar results were attained in Benue State, Nigeria by Okewu and Iheanacho (2015), who found a mean profit efficiency level of 67% and a range of 1% to 89%, and the wide variation in profit efficiency results were also obtained in other sectors too (Arbolo et al., 2018; Rahman, 2003).

Nevertheless, the results imply that the farmers were operating far below the profit frontier. Since profit efficiency requires both technical and allocative efficiency to be achieved, thus an improvement in allocative and technical efficiency by using the right allocation of input resources and producing the right amount of output can have a positive impact on the profit margins obtained by farmers in goat production.

3.5. Factors influencing profit inefficiency - posterior estimates

Drivers of profit inefficiency must be identified so that the right policy implications are drawn. Table 8 presents the posterior means along with credible intervals for factors influencing profit inefficiency in goat farming. The dependent variable is profit inefficiency. This has implications for the interpretation of the posterior means. A negative sign implies that a factor is a positive driver of efficiency, whereas, a positive sign implies that the effect on profit efficiency is negative.

The findings reveal that a negative but insignificant association exists between being a male farmer (δ1) and profit efficiency, meaning that female farmers are much more efficient than their male counterparts. Conversely, Okewu and Iheanacho (2015), showed that gender (male) also had a positive relationship but was not significantly affecting efficiency, while Tchale (2009) found that being a male farmer negatively influenced efficiency, however, it was not significant. Nonetheless, according to Qushim et al. (2015), female farmers had a significant positive influence on efficiency.

The land variable (δ2) also positively impacted efficiency, implying that farmers with large landholding are more efficient compared to farmers with small landholding. The small-scale goat farmers in Malawi are mostly based in rural areas. There usually do not have designated pasture lands for grazing. As such most farmers rely on crop residues. Thus, those farmers with large landholdings will have better access to the low-cost feed from crop residues which can increase profit efficiency. These results are similar to those of Bahta and Baker (2015), who found a positive influence of land size on efficiency.

The herd size was categorized into three; small (base category), medium (δ3), and large (δ4). Both posterior means for medium and large herd sizes have a positive association with profit efficiency, increasing in the direction of herd size. This implies that farmers with larger flocks are more efficient than those with small or medium herds. The result is significant at larger flock sizes, in this case for those with more than 20 goats. Those with large herd sizes take advantage of scale economies and leverage more goats on unchanging fixed costs. These findings mirror those of Qushim et al. (2015) who found that big and medium-sized goat farms were much more efficient than small farms. The positive association can be attributed to the fact that farmers with large herd sizes take advantage of scale economies and leverage more goats on unchanging fixed costs.

The posterior estimate of the age variable of the farmer was included in two dimensions, first raw age (δ5), and second, age squared (δ6) to capture the long-run effect of the same. The coefficients of these two categories showed that the short-run effect of profit efficiency is positive and significant while it reverses in the long run but tends to be insignificant. The positive influence on efficiency can be attributed to the fact that young farmers are usually energetic and economically active. These findings mirror those of Bahta and Baker (2015) and Qushim et al. (2015).
Levels of education of the household heads were categorized into groups; primary education, secondary education ($\delta_1$), and tertiary education ($\delta_2$). All levels of education were not important in determining profit efficiency. Further analysis showed that education in the form of livestock extension ($\delta_3$) was key for profit efficiency. Extension advice explored in this study was specific to livestock (general livestock care and disease control) to ensure determined the appropriate effect on goat profit efficiency. The result shows a positive significant effect of extension on livestock profit efficiency. The positive influence is expectable because, with better information on livestock care and livestock markets, a farmer can raise healthy goats which could fetch better market prices, hence, enhancing the profit efficiency of their enterprise.

While credit services would help to improve the farm input purchasing power and in turn boost production and profit margins, to the surprise, credit ($\delta_4$) services played a negative role on profit efficiency. However, the result could make sense in the Malawian farming context. Most farmers primarily are crop farmers with a primary objective of food security from their crop production. Livestock production is usually taken as a buffer. As such, with access to credit, priority goes to the purchase of fertilizer and seeds for crop production.

Household size ($\delta_5$), which is the number of persons in a household that had a positive effect on profit efficiency. Household size is a proxy for family labour. With more family members it may imply that there is more free family labour available for taking up goat production related tasks those which otherwise would attract costs for hired labour. As such, the use of family labour reduced the cost of production and in turn increases profit efficiency in goat enterprise.

Specialization ($\delta_6$) was a positive driver of profit efficiency. Specialization was defined as that reciprocal of the number of livestock types a farmer is producing. As the farmer reduces the number of livestock to concentrate efforts more on goat production it aids in improving profit efficiency. Whereas, farmers that want to spread the risk of keeping only goats and engage in the production of different livestock types, the findings reveal a shrinkage in profit efficiency. The positive correlation may be because farmers who rear only one type of livestock tend to put all their efforts, money, and time into that livestock, unlike the farmers with multiple livestock.

Disease shocks ($\delta_7$) were found to positively influence profit efficiency this is expectable because farmers always try to come up with mitigation mechanisms such as selling to reduce the probability of suffering adverse shocks, just as Ngigi and Birrer (2013) observed. At early signs of diseases in goats, farmers will likely sell them before it dies.

Distance to an established road network ($\delta_8$) for vehicles was an important predictor of profit efficiency. Road network is an important infrastructure towards access to better markets for agriculture commodities. The closer the road was to the farmer, the more profit efficient the farmer was and vice versa, this might be so because higher transaction costs brought on by a greater road distance lessens the benefits that flow to the farmer and vice versa.

Lastly, commercialization ($\delta_9$) was a positive driver of profit efficiency. Commercially oriented production pushed farmers more towards the profit frontier than those who were producing goats without commercial objectives. This is the case because a farmer producing as a commercial enterprise probably has a profit maximization objective and hence pays attention to controlling costs and searching for better prices to meet their objective.

4. Conclusions and policy implications

This study employed a Bayesian Stochastic Profit Frontier model to assess profit efficiency and factors that influence profit inefficiency among goat producers. The model has more advantages than the frequentist (classical) approach as it gives more precise estimates of profit efficiency. The results based on costs of inputs show that farmers are operating in phase 1 of production (inefficient stage). This provides a large room for improvement in the profits of goat farmers. The study concludes that goat farmers in Malawi are 29% profit efficient, an indication of profit inefficiency. This suggests that 71% of the profit was lost due to individual inefficiencies in resource allocation. Without changing the profit frontier, farmers’ profit can be increased by 71% through allocative and technical efficiency. The results derived from the profit inefficiency model can be concluded that landholding, herd size, age, livestock extension contact, specialization, and commercialization have an important effect on profit efficiency.

The policy implications are clear. The study recommends that goat producers need intensive extension training on goat management practices, disease control, and marketing. Second, proximity to the road network has an important implication on profit efficiency. While it may be costly or impossible to establish good access roads for farmers who reside in remote locations, farmers may still be assisted with market linkages to buyers who may buy in bulk at better prices. With proper linkage to buyers who can buy in bulk, transaction costs on the part of the farmers could be reduced and hence shifting them towards the profit frontier. Third, there are prospects for improving profit efficiency through increased scale economies. This provides an opportunity of organizing farmers into goat production and marketing farmer groups to exploit the benefits of scale economies other than each farmer keeping a small flock of goats. Lastly, even though credit services negatively affected efficiency because the money goes into crop production instead, the study recommends that the government of Malawi aids goat farmers with the provision of tailor-made livestock microfinance loans, and the government can also incorporate goat farming into women’s empowerment programs.

5. Areas for further research

The limitation of this study is that it focused only on determining the levels of profit efficiency and its determinants. However, it is not known how technical, allocative, and scale efficiency respond to changes in economic variables, and to what extent they contribute to profit efficiency. Thus. It is recommended that a study be conducted to find out the exact levels of technical, allocative, and scale efficiency of goat production in Malawi. A further study can be done using a Data Envelope Analysis Model to compare the results since this study only used the stochastic frontier approach.

Declarations

Author contribution statement

Chifundo Nyakawa: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper. Assa Mulagha-Maganga: Wrote the paper; Critically revising its important intellectual content; Julius Mangisoni: Designed the experiments; Wrote the paper

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.
Appendix A. Convergence chains for the other parameters of the Translog model

![Convergence chains for the other parameters of the Translog model](image)

Appendix B. Autocorrelation functions of the chain for the other parameters of the translog model

![Autocorrelation functions of the chain for the other parameters of the translog model](image)

Appendix C. Kernel densities for all the parameters of the model

![Kernel densities for all the parameters of the model](image)

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