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Stochastic bio—economic modeling of mastitis in Ethiopian dairy farms

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ABSTRACT

Mastitis is an inflammation of the mammary gland that is considered to be one of the most frequent and costly diseases in the dairy industry. Also in Ethiopia, bovine mastitis is one of the most frequently encountered diseases of dairy cows. However, there was no study, so far, regarding the costs of clinical mastitis and only two studies were reported on costs of subclinical mastitis. Presenting an appropriate and complete study of the costs of mastitis will help farmers in making management decisions for mastitis control. The objective of this study was to estimate the economic effects of mastitis on Ethiopian market-oriented dairy farms. Market-oriented dairy farming is driven by making profits through selling milk in the market on a regular basis. A dynamic stochastic Monte-Carlo simulation model (bio-economic model) was developed taking into account both clinical and subclinical mastitis. Production losses, culling, veterinarian costs, treatment, discarded milk, and labour were the main cost factors which were modeled in this study. The annual incidence of clinical mastitis varied from 0 to 50% with a mean annual incidence of 21.6%, whereas the mean annual incidence of subclinical mastitis was 36.2% which varied between 0 and 75%. The total costs due to mastitis for a default farm size of 8 lactating cows were 6,709 ETB per year (838 ETB per cow per year). The costs varied considerably, with 5th and 95th percentiles of 109 ETB and 22,009 ETB, respectively. The factor most contributing to the total annual cost of mastitis was culling. On average a clinical case costs 3,631 ETB, varying from 0 to 12,401, whereas a sub clinical case costs 147 ETB, varying from 0 to 412. The sensitivity analysis showed that the total costs at the farm level were most sensitive for variation in the probability of occurrence of clinical mastitis and the probability of culling. This study helps farmers to raise awareness about the actual costs of mastitis and motivate them to timely treat and/or take preventive measures. As a results, the dairy industry will improve.

1. Introduction

The rapidly increasing urban population size in Ethiopia creates a growth of demand for milk and dairy products. Following this, in the recent decade, milk production in Ethiopia has been evolving from a byproduct of draft power by indigenous breeds to market-oriented milk production. Generally, the dairy farming system in Ethiopia classified as pastoralists, agro-pastoralists, mixed crop–livestock producers, the *peri*-urban and urban dairy systems (Azage and Alemu, 1998; Ketema, 2000; Zegeye, 2003; Dereje et al., 2005). In the first three farming systems, most of the milk produced is retained for home consumption. However, in the *peri*- urban and urban dairy system, that constitute 14.3% of the dairy production system in Ethiopia (Tolosa, 2013), most of the milk produced is sold in the market. Market-oriented dairy farming is driven by making profits through selling milk in the market on a regular basis. In the market-oriented production system, cross-breeds (cross between local and exotic-breeds) are mainly used so that the milk production level has increased. A cross- breed cow in these dairy farms produces an average of 8.5 kg of milk per day (Yoseph et al., 2003). Typically, farms in the market-oriented dairy system are small (8 lactating cows on average) but relatively intensive. However, this production system is subjected to diseases of intensification including mastitis (Lemma et al., 2001).

Mastitis is an inflammation of the mammary gland that is considered to be one of the most frequent and costly diseases in the

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dairy industry (Halasa et al., 2007). The economic effects of mastitis are due to production losses, treatment, veterinarian costs, discarded milk, culling and changes in product quality; and using the basic cost elements around mastitis and mastitis management, costs can be calculated (Hogeveen, 2005). The economic effects of mastitis and mastitis control have been estimated in several ways ranging from budget calculations (Swinkels et al., 2005), dynamic stochastic models (Huijps and Hogeveen, 2007) to dynamic optimization models (e.g. Cha et al., 2011).

In Ethiopia, the available information indicated that bovine mastitis is one of the most frequently encountered diseases of dairy cows (Lemma et al., 2001). However, to our knowledge there was no study, so far, regarding the total costs of mastitis. Two studies were reported on costs of subclinical mastitis (Mungube et al., 2005; Gebreyohannes et al., 2010). In those two studies the authors used the average milk production per year to estimate the costs associated with milk production losses due to subclinical mastitis. However, those studies were quite rough and did not contain much detail, such as differences in milk production throughout the lactation with regard to the occurrence of mastitis. This is important because milk loss will vary with both stage of lactation and time after the occurrence of the disease (Grohn et al., 2004).

Relevant estimations about disease costs can be used in evaluating the benefits of applying preventive measurements to decrease disease incidence, disease losses, or both, and in the process allow the evaluation of individual cow disease treatment options (Bar et al., 2008). Similarly, presenting the full costs of mastitis will help farmers make management decisions on mastitis control. According to Seegers et al. (2003) to estimate the costs of a disease, the use of dynamic models that permit modeling the herd dynamics is more appropriate than the use of static models. Therefore, the objective of this study was to estimate the economic effects of clinical and subclinical mastitis in Ethiopian market oriented dairy farms by representing the best available knowledge in a dynamic stochastic simulation model.

2. Material and methods

2.1. Model description

A dynamic stochastic discrete event bio-economic model was developed using @risk 6.2 (Palisade Corporation, Ithaca, NY, USA) software to calculate the costs of mastitis at the farm level. Monte-Carlo simulation is a computer technique used to simulate the reaction of a model under repeated iterations. By taking different values from appropriate distributions of a parameter, the model becomes stochastic and thus can take the variation into account (Huijps et al., 2009). The basis of our model (biological part) was the simulation of the dynamics of mastitis. Results of these simulations were then used to calculate the economic effects of mastitis. The basic stochastic process was carried out at the cow level using 26 time steps of 2 weeks to simulate one complete year.

2.2. Herd dynamics

A specific parity, lactation stage and calving interval were assigned to each cow, based on different distributions. The parity and the lactation stage of a cow changed when either the cow gave birth or was culled. When the cow gave birth, the parity increased by one whereas it became one if the cow was culled in the previous time step. In both events the lactation stage went to 1. Before calving, a cow was assumed to have a dry period of 8 weeks. Calving interval (CI) of each cow (i) was determined with a pert distributions with minimum, most likely and maximum value:

$$CI_i = \text{Pert}(CI_{min}, CI_{ml}, CI_{max}) \quad (1)$$

where, CI_{min} is the minimum, CI_{ml} is the most likely, and CI_{max} is the maximum values of calving interval. Parity was classified into six distinct categories and it was determined based on a discrete distribution as follows:

$$\text{Par}_{it} = \begin{cases} t = 1 \rightarrow \text{Discerete}([1,2,3,4,5,6], [\text{PPar1}, \text{PPar2}, \text{PPar3}, \text{PPar4}, \text{PPar5}, \text{PPar} \geq 6]) \\ \text{Cull}_{it-1} > 0 \rightarrow 1 \\ \text{LS}_{it-1} > (\text{CI}) - 14 \rightarrow \text{Par}_{it-1} + 1 \\ \text{Par}_{it-1} \end{cases} \quad (2)$$

where, PPar1, PPar2, PPar3, PPar4, PPar5, PPar ≥ 6 are the probabilities of the distribution of parity 1, 2, 3, 4, 5, 6 and above in a farm respectively. Par_{it} indicates the parity of each cow (i) at a time period (t). Cull_{it-1} and LS_{it-1}denote the status of culling (0 = not culled and > 0 = culled) and lactation stage for each cow (i) in the previous time period (t - 1)respectively. Lactation stage (days after calving) was determined using uniform distribution according to Eq. (3).

$$\text{LS}_{it} = \begin{cases} t = 1 \rightarrow \text{Round}(\text{Uniform}(1,26); 0) \\ \text{Cull}_{it-1} > 0 \rightarrow 1 \\ \text{LS}_{it-1} > (CI) - 14 \rightarrow 1 \\ \text{LS}_{it-1} + 1 \end{cases} \quad (3)$$

where LS_{it} is the lactation stage (days after calving) of each cow (i) at a time period (t). Cull_{it-1} and LS_{it-1} were explained previously. The lactational milk yield (LMY_i), which is a 305 days of milk yield, was assigned to each cow using normal distribution with average annual milk production and standard deviation, and adjusted to parity(k) and calving seasons (s) as follows:

$$\text{LMY}_{iks} = \text{Normal}(\text{MeanLMY}, \text{Sd}) \times \text{AdjPar}_k \times \text{AdjCas}_s \quad (4)$$

where AdjPar_k and AdjCas_s are the adjustement factor for each parity and calving season respectively. The calving seasons were categorized into three groups as dry season (October to February), short rainy season (March to May) and long rainy season (June to September). The basic milk production of each cow, during each time period (BMP_{ikst}) was modeled using Wood's curve (Wood, 1976) based on the following equation:

$$\text{BMP}_{ikst} = \frac{\text{LMY}_{iks} \times a \times (\text{LS}_{it} \times 2 - .5)^{b} \times e^{-c \times (\text{LS}_{it} \times 2 - .5)}}{14 \times \sum_{LS=1}^{22} (a \times (\text{LS}_{it} \times 2 - .5)^{b} \times e^{-c \times (\text{LS}_{it} \times 2 - .5)})} \quad (5)$$

where; a, b and c, or Wood's constants represent the slope of the lactation curve during the different lactation stages of each cow (i). The rest of the acronyms were explained previously.

2.3. Mastitis dynamics

Modeling the dynamics of mastitis was based on the schematic representation given in Fig. 1. Depending on the status of the previous time period, each cow had different transition probabilities for each time period (t). Cows can remain longer than one time period in a status except for the clinical status. Cows in the clinical mastitis status were assumed to be treated with antibiotics and either