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Uncertainty in milk production by smallholders in Tanzania and its implications for investment

RESEARCH ARTICLE

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Abstract

The study evaluates the impact of risk on enterprises of male, female and young farmers operating in the formal and informal smallholder dairy value chains in Tanzania. It also examines the effect of uncertainty on the decision to invest in milk production in the two value chains. Results indicate that youths in the informal dairy value chain face the greatest level of risk followed by men in the formal value chain, and then men in the informal value chain. Women in both value chains and youths in the formal value chain face relatively low risk. Overall, milk production in the informal value chain is found to be substantially riskier than production in the formal chain. Optimal investment triggers are found to be much larger than the conventional triggers and are sensitive to volatility of returns. The results' managerial and policy implications for inclusive dairy industry development in Tanzania are highlighted.

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1. Introduction

Generally, farmers face uncertainty in the biophysical and economic environments in which they operate. Uncertainty refers to random events whose probabilities of occurrence are not completely known. A concept that is closely related to uncertainty and one that Antle (1983: 1099) aptly labels 'the farmer's perennial problem', is risk. Risk refers to random events whose probabilities of occurrence can be quantified. Therefore in simple terms, both uncertainty and risk refer to randomness, with uncertainty being a necessary but not sufficient condition for risk (Gough, 1988). In other words, risk is uncertainty with real consequences. When randomness enters a farmer's optimization problem through, for instance, input prices, output prices, and technology, it renders the farmer incapable of behaving optimally (Antle, 1983). This is because optimality conditions that hold in a deterministic world might not necessarily hold with random variables in the optimization problem, and this could lead to sub-optimal production and investment decisions. Investment decisions in smallholder milk production in Tanzania would likely concern investments in dairy breeds, feeds, proper animal husbandry practices and milk handling. Risk is especially challenging for the resource-constrained or risk-averse farmer that is either excluded from the financial market or operates in an environment devoid of one. This means that insurance against risk is not so much of an option for such a farmer.

Hella *et al.* (2001) and Baker *et al.* (2015) document the existence of uncertainty and risk in livestock production in Tanzania. The country has a total population of 25.8 million heads of cattle, of which over 95% are reared for both milk and beef. Cattle are considered the most economically and socially important type of livestock. Uncertainty and risk are major concerns particularly for the dairy industry, which is seen as having relatively great potential to reduce poverty, improve nutrition and foster inclusive development. This is because milk production at the household level is for the most part a female preserve (Ministry of Livestock and Fisheries Development, 2016). In addition 30% of livestock's contribution to agricultural gross domestic product is from dairying, which takes place in five milk sheds, namely, Eastern (Pwani, Morogoro, Tanga), Northern (Arusha, Kilimanjaro, Manyara), Lake Victoria (Mwanza, Mara, Kagera), Central (Tabora) and Southern Highlands (Mbeya, Iringa, Njombe). To ensure that uncertainty and risk do not impede the industry from realizing its potential, there is need to identify and quantify their various sources and recommend farm management and investment strategies that account for uncertainty and risk in the economic environment. Also important is the need to identify risk mitigation strategies that can benefit from public-private investments. An example of where public investment has complimented private investment in mitigating risk is the index-based livestock insurance scheme that insures Kenyan pastoralists against losses due to adverse drought conditions (Chelang'a *et al.*, 2015).

There has been virtually no empirical work on the effects of uncertainty and risk on milk production in Tanzania and elsewhere in Africa. Existing literature on the effects of the two phenomena on enterprise profitability and feasibility of investment decisions has largely been in the context of developed-country agriculture. Therefore the study's contribution to the literature is to fill this information gap and demonstrate the application of the methods to a developing country context. This study has two objectives: the first objective is to identify the risk factors and their economic impacts in Tanzanian milk production, and the second one is to determine the effect of uncertainty on the decision to invest in milk production. The two objectives are related in the sense that the first objective provides parameters relevant to achieving the second objective. Specifically, the study seeks to identify the various sources of risk faced by milk producers, quantify their impact, and generate a single measure of risk in milk production. The study then uses the consolidated risk measure to estimate a risk-adjusted discount rate and hence the optimal investment trigger (Dixit, 1992; Dixit and Pindyck, 1994) if producers are to account for uncertainty and irreversibility of investment in their investment decisions.

There are three important considerations in this study. First, to the extent that the government of Tanzania views the dairy industry as being crucial to poverty alleviation and improving food and nutrition security, the analytical approach is intended to provide evidence relevant to inclusive value chain development. Inclusive value chain development is an approach to value chain development that not only focusses on the inclusion of smallholder farmers in value chains, but also recognizes the vulnerability of different categories of smallholder farmers. In Tanzania, the vulnerable are mainly women and the youths (United Republic of Tanzania, 2003). Therefore the study undertakes a disaggregated analysis of the risks that men, women, and the youths face in milk production.

Second, the study recognizes the two types of value chains that exist in the Tanzanian dairy industry; the formal value chain where milk is processed and often packaged before selling it to the final consumer, and the informal value chain where milk is sold to the final consumer in its raw form. Producers in the formal value chain sell their milk either directly to milk collection centers or to traders who in turn supply the milk to the collection centers. The centers are operated by individual agents, producer groups, cooperatives, or processing companies. Price discovery mechanisms and relationships between agents are different in the two value chains, and so are the prices and their fluctuations. For instance, although milk prices in the formal value chain are relatively low, they tend to be more stable than prices in the informal chain. This implies different levels of output price risk exposure for milk producers in the two value chains. Therefore for each of the three producer categories, the analysis is undertaken for the two value chains.

Third, the study recognizes seasonality in milk production as a permanent feature of the industry in Tanzania. But seasonality per se is not a source of risk. Rather, it is its effects on regularity of feed supply and hence unpredictable fluctuation in some production and price variables within each season that causes risk. In simulating the impact of risk, the study therefore accounts for fluctuations in some of the risk variables during the dry and wet seasons.

The rest of the paper is organized as follows: the second section presents a review of previous studies. The primary purpose of our literature review is to gain insights into the theory and empirical methods and how they can be substantively applied to a developing country context. The review is focused on issues pertinent to mathematical modeling and simulation of the effect of risk on a farm enterprise, and modeling the effect of uncertainty on the investment decision. The third section discusses the different sources of risk in milk production in Tanzania. This is followed by a conceptual discussion of the likely differential impact of risk on enterprises of male, female and young milk producers. Section five presents the analytical methods including a discussion of the representative farm approach, and data for examining risk and incorporating uncertainty and irreversibility of investment in the investment decision. Results are presented in section six and the last section concludes the paper.

2. Related literature

Modeling the effect of uncertainty and risk on a dairy farm enterprise necessitates accounting for biological and economic factors that affect milk production. In smallholder production systems, environmental factors too are an important consideration since milk production is highly weather-dependent. Seasonality affects prices and quantities of outputs and inputs including non-marketed inputs such as water, forage and some types of fodder. Le Gal *et al.* (2013) demonstrate how a whole dairy farm simulation model that captures seasonal variation in availability of feed can be used to understand farmers' decisions. The model was applied to six smallholder dairy farmers in Brazil.

Livestock enterprise simulation studies can be based either on total herds or individual animals or both. Herd-based models consider the entire herd as a single unit and use aggregate herd data. Therefore they are relatively simple to construct and simulate. Individual animal-based models treat and follow each animal in the herd separately. This makes them more realistic but also more computationally demanding than herd-based models. However, in smallholder dairy production systems where farmers typically rear one to five animals (with only one or two animals lactating at any given point in time), individual animal-based models can easily be constructed for the farmer's entire herd. Humphry *et al.* (2005) used the case of an outbreak of bovine viral diarrhea in a beef herd to compare a stochastic herd-based model with stochastic individual animal-based models. They concluded that although individual animal-based models are structurally relatively complex, they are theoretically more credible and hence more appropriate for research and decision support than a herd-based model.

Applying the individual animal-based model to a smallholder dairy farm situation with limited information on animal performance would likely require drawing upon already empirically established relationships. For instance, in incorporating production risk in smallholder dairying in Tanzania, instead of attempting to separately model changes in body condition scores and daily milk yield, it would, in the absence of data, suffice to consider only the latter since it has been found to be dependent on the former (Msangi *et al.*, 2005).

Bewley *et al.* (2010) constructed a stochastic model for a typical U.S dairy farm to determine the feasibility of investing in precision dairy farming technologies, and the effect of input and output price risk on the costs associated with culling, days open, and disease. Available data enabled them to construct a herd-based model (1000 milking cows) that also contained an individual animal-based module for an average cow. The individual animal module was used to calculate, on a daily basis, several parameters including daily milk yield, dry matter intake, costs and revenues, which were fed into modules for body condition scoring, herd demographics, and retention pay-off. The model was then simulated over a ten-year horizon. Stochastic input and output prices were found to impact costs of culling, days open, and disease. The study is appealing insofar as it is able to integrate an individual animal-based module into a herd-based model. But such an exercise requires availability of good and sufficient data, and attempting to apply it to the context of smallholder dairy farmers in Tanzania is bound to be onerous and yield a level of complexity that would not necessarily accurately capture real farm-level management decisions.

Hyde and Engel (2002) analyzed the feasibility of investing in a robotic milking system by a dairy farm in the U.S. They used Monte Carlo simulations to incorporate randomness in milk output, milk price, maintenance costs, the parlor's useful life, inflation rate, and salvage value, considering three herd sizes. The metric used was the breakeven value of the robotic milking system, defined as the maximum amount of money that could be paid for the system given costs of alternative milking equipment and other factors. In two other studies, Engel and Hyde (2003) and Hyde *et al.* (2003) used the real options approach to analyze the feasibility of replacing a traditional milking system with an automatic one on a dairy farm with 60 cows. They opted for the real options approach rather than traditional capital budgeting techniques in order to account for the uncertainty and irreversibility inherent in such an investment decision.

A study that is perhaps the most closely related in spirit to our study is by Tauer (2006). He applied the real options approach to analyze entry and exit decisions of New York dairy farmers. He found the optimal investment trigger (price of milk) to be $17.52 per hundredweight. Our study adopts this approach to analyze the option of a prospective Tanzanian smallholder dairy farmer to enter dairy farming. However, unlike previous studies that have considered output price as the only source of uncertainty, our study considers additional sources of uncertainty. They include input prices, input quantities and output quantity. As in Twine *et al.* (2016), we use Monte Carlo simulations to obtain a combined measure of uncertainty.

3. Sources of risk in milk production

Generally, farm enterprises face two broad types of risks, namely, business risk and financial risk, also known as leverage risk (Unterschultz, 2000). Business risk is risk that arises directly from production and marketing activities of an enterprise and can therefore be sub-divided into production risk and market (price) risk. Financial risk stems from an enterprise's association with the financial market and it refers to the level of indebtedness of the enterprise. Unterschultz (2000) notes that the two broad types of risks are related in that an increase in business risk could lead to greater indebtedness of the enterprise. Covarrubias *et al.* (2012) and Twine *et al.* (2015) have found the incidence of credit to be considerably low among cattle keepers in Tanzania and therefore this study disregards financial risk. However, the results have implications for lending.

Milk producers face both production risk and price risk. Production risk is fluctuation in output and is usually caused by variation in weather conditions, hence variation in availability of water and feed, and variation in animal health status due to diseases. Hella *et al.* (2001) attribute the highly risky nature of livestock production in the semi-arid region of Dodoma to the large variation in the amount of rainfall. Changes in herd health due to disease can be severe and result in death loss. Swai *et al.* (2010) estimate dairy cattle mortality rates to be 8.5 and 14.2 per 100 cattle years at risk[1] for Tanga and Iringa regions, respectively, and are mainly due to East Coast fever, a tick-borne disease. Ultimately, production risk manifests itself in fluctuations in daily milk yield or milk yield per lactation period, quality of milk produced and herd size. Quality of milk produced and sold also depends on milking and milk handling practices, which could be considered an internal source of risk. Milking and milk handling practices could be dictated by attitudes and cultural norms, but are also likely to vary depending on the cost of inputs used to avoid contamination before, during and after milking.

Price risk is fluctuation in output and input prices, with fluctuation in output prices being mostly seasonal. Even though producers are aware of seasonality, the real source of risk is the unpredictable fluctuation in seasonal patterns such as the variation in the onset and duration of different seasons, which may in turn change the variance of prices. Input price risk is associated with the cost of the animal, the cost of labor, animal health services and feed. Compound feeds are in the form of maize bran, cotton seed cake and sunflower seed cake, and their prices closely follow prices of the respective raw materials. Heavy dependence on maize for concentrate feed is a serious concern for the industry because of the large fluctuation in maize prices (Geerts, 2014). Maize production in Tanzania is heavily dependent on rainfall whose variability during the growing season has been found to reduce maize yields (Rowhani *et al.*, 2011).

4. Differential impact of risk

The notion that risk has different impacts on different gender groups of milk producers derives from observed differences in the degree of vulnerability of the different groups to external shocks. For instance, although the different sources of production risk are largely external, their impact may be exacerbated by internal risk factors such as the farmer's animal husbandry practices, level of education, access to social networks and resources including credit, and extent of participation in making decisions. These factors influence the degree of vulnerability and tend to vary with gender. Individuals lacking formal education may not know enough about risk to incorporate it into their decision making, and even if they do, they may not be able to institute adequate risk mitigation measures if they are severely constrained by resources. This is the case for Tanzania's women and youths, whose vulnerability is attributed to lack of or limited access to land (Tsikata, 2003). Without access to land, the ability of these groups to undertake long-term economic activities that require land is constrained, and so is their access to credit.

In addition to lack of or limited access to land, the vulnerability of women entrepreneurs in particular can be attributed to some of the challenges they face in trying to establish their businesses (Mori, 2014): competition for their time between their reproductive roles and business activities, and lack of adequate support from their spouses to formalize their businesses. The agricultural and livestock policy of 1997 explicitly recognized the limited access by women to productive resources, business services (such as credit) and agricultural income, and hence the need to promote their access and that of the youths to land, credit, education and information (Ministry of Agriculture and Cooperative Development, 1997). Given the perceived vulnerability of women and the youths, this study assesses the impact of risk on their dairy enterprises relative to the impact on male-owned enterprises.

[1] This is an epidemiological measure of risk of mortality and is different from the measure used in this empirical analysis.

5. Methods

5.1 The representative farm approach

The study relies on representative smallholder dairy farms as the study units. The representative farm approach has been used in previous empirical studies on, *inter alia*, supply response and adoption of beneficial management practices (e.g. Cortus, 2005; Koeckhoven, 2008; Sharples, 1969; Taylor *et al.,* 1992; Trautman, 2012; Yang, 2009). Ideally, representative farms should embody characteristics of actual farms in the study area, and should be selected based on the factors that have the most influence on the problem of interest (Nuthall, 2011). Some studies have constructed hypothetical representative farms based on data on only the physical characteristics of a farm population. But Nuthall (2011) cautions that such hypothetical units might not be representative of real farms, and that instead, actual farms should be used. According to Plaxico and Tweeten (1963), non-physical factors such as human resources and institutions greatly impact farm organization, efficiency and revenues, but these factors are difficult to quantify and it is difficult to determine their distribution within a farm population. They observe that such factors are usually conveniently ignored in selecting representative farms. In this study, we did not have information on the most important factors affecting uncertainty and risks faced by dairy farmers. As such, we were unable to survey and stratify all farms into homogeneous groups and construct hypothetical farms. Instead, we use real smallholder farms, and we caution that our analysis is normative rather than predictive.

The primary criteria for defining a representative milk producer for each gender category were that the producer undertakes commercial milk production and owns the dairy enterprise. In this regard, internal risk due to inability to make decisions regarding the enterprise does not arise. In addition, producers were selected based on their willingness and ability to provide accurate and substantial enterprise data.

5.2 Study area and data

The study was undertaken in August 2016 in Lushoto district, located in the northern part of Tanga region in the Eastern milk shed. 75% of the district is covered by the Western Usambara Mountains. The topography allows for only intensive dairy cattle feeding, and therefore the results and conclusions of the study might not apply to milk production in the country's extensive cattle feeding system. Lushoto district was selected on the basis of having a large number of typical smallholder dairy farmers (Mgeni *et al.*, 2013). They have historically benefited from most of Tanzania's smallholder dairy development projects and as a result, they keep improved dairy breeds and milk production tends to be market-oriented. In addition, the district is one of the four districts of the More Milk in Tanzania (MoreMilkiT) project that is led by the International Livestock Research Institute. This research for development project aims to generate evidence on mechanisms for improving the participation of smallholder dairy farmers in input and output markets. Lushoto district is the only MoreMilkiT project district where dairy farmers practice intensive cattle feeding. Farm sizes, herd structures and geography in Lushoto are typical of locations elsewhere in Tanzania where smallholder intensive dairy farms are found such as in the northern zone near Kilimanjaro and Arusha and in southern highlands. It is estimated that some 220,000 households keep about 700,000 heads of improved dairy cattle on such farms in Tanzania currently; typically, about 2 cows and their followers per farm.

Data on variables related to milk production cash flows were obtained from representative milk producers in three gender categories: men, women and the youths. The Tanzanian government defines youths as persons from the age of 15 years up to 35 years (Ministry of Labour, Employment and Youth Development, 2007). Following this definition, the study analyzes the dairy enterprise of a male youth as there are hardly any female youths in the study area that own dairy enterprises. Non-youth male and female farmers were above 35 years of age. For each gender category, two representative producers were selected: one producer sells milk into the formal value chain and the other sells into the informal value chain. Therefore data were collected from a total of six dairy enterprises. We estimate the percentage of dairy farms represented by each group using data from the 2014 monitoring and evaluation survey of the MoreMilkiT project sites (International

Livestock Research Institute, 2015); the proportions of dairy enterprises individually owned and controlled by men, women, and male youths in Lushoto district are 20, 31 and 6%, respectively. The rest are jointly owned by spouses. Each selected producer provided data (Table 1, with the exception of death loss) on their best performing cow that was lactating or had finished lactating in the last one year. Clearly, the data are typical of a low-input low-output production system.

Since data for each category of producers were obtained from a single farm, we examine how reliable they are by comparing them with values found in the literature. But most of the existing information on the variables of interest is not necessarily disaggregated by gender, type of value chain and season. Nonetheless, comparison with aggregate averages enables us to somehow conceptualize some of the variations among the groups analyzed in this study and establish a better context for evaluating our findings. However, keep in mind that for each representative farm, it is the fluctuation in values of its parameters (within and between seasons) rather than their levels that is important in this type of risk analysis.

Generally, farms selected for this study are representative of the general population of market-oriented smallholder dairy farms in Lushoto district. For instance, Njehu and Omore, (2014) report average daily yield (ADY) across all producer categories, value chains and seasons in Lushoto district to be 4.2 liters per day, of which an average of 60% was sold. The average yields across seasons for farms in this study appear to be close to this average except for male- and youth-owned farms operating in the formal value chain; theirs are substantially above 4.2 liters and quite close to each other. Dairy farmers in Lushoto district rear cross-bred cattle[2] and the composition of their feed that includes fodder and forage does not vary significantly. In a study undertaken in North-East Tanzania, Msangi *et al.* (2005) found milk yield to be mainly determined by the body condition score of cows at calving, which is in turn determined by the ability of the farmer to cut and carry fodder. It is reasonable to expect dairy farmers in the formal value chain to be able to ensure a steady supply of cut fodder given the assured nature of the market for their milk. But this is perhaps not the case for female farmers as they are likely to be relatively more constrained by insufficient land and labor for producing fodder. Also notice that there is a relatively large variation in daily yield across seasons

[2] The degree of genetic variation among the animals on these farms is not fully known. The phenotypic expressions that farmers usually rely on for breed selection may not necessarily reflect the true genetic composition of the animals. But in the intensive feeding system, cross-bred cattle are generally products of the exotic (*Bos taurus*) breeds and indigenous (*Bos indicus*) breeds (Ojango *et al.,* 2016).

Table 1. Data on some of the parameters used in the cash flow models.[1]

Parameter	FI	FF	MI	MF	YI	YF
ADY – wet season (liters/day)	4.00	6.00	4.00	12.50	6.00	10.00
ADY – dry season (liters/day)	3.00	2.50	2.75	4.50	6.00	9.00
% of ADY sold – wet season	75.00	83.30	50.00	84.00	67.00	80.00
% of ADY sold – dry season	66.70	80.00	54.50	67.00	67.00	78.00
Av. price of milk– wet season ($/liter)	0.35	0.23	0.55	0.23	0.23	0.23
Av. price of milk – dry season ($/liter)	0.35	0.23	0.55	0.23	0.35	0.23
Av. quantity of feed – wet season (kg/day)	1.50	0.00	1.43	2.00	1.30	0.00
Av. quantity of feed – dry season (kg/day)	1.50	0.00	1.43	1.00	0.40	0.00
Av. price of feed – wet season ($/kg)	0.09	NA	0.12	0.20	0.15	NA
Av. price of feed – dry season ($/kg)	0.09	NA	0.12	0.16	0.31	NA
Av. cost of medicines ($/day)	0.00	0.00	0.00	0.008	0.00	0.00
Annual death loss (%)	9.20	9.20	9.20	9.20	9.20	9.20

[1] ADY denotes average daily yield, while FI, FF, MI, MF, YI, and YF denote producer categories and the value chains they operate in as follows: female informal, female formal, male informal, male formal, youth informal and youth formal, respectively. NA denotes not applicable as these farmers did not purchase compound feed over the reference period. However, they did indicate use of compound feed in previous lactation periods.

for male and female farmers in the formal value chain; their milk production more than doubles in the wet season. We do not know why this is the case, but we suspect it is caused by a confluence of internal risk and production risk factors.

The proportion of ADY sold by five of the six producer categories is higher than the average reported by Njehu and Omore (2014) probably because one of our criteria for selecting representative farms emphasized market-oriented production. Non-marketed milk is consumed by the household, and on some farms, some of it is bucket-fed to calves. Although this milk has economic value, it does not constitute actual cash receipts that directly determine the farms' liquidity. Therefore for purposes of this analysis, it would not be instructive to include non-marketed milk in calculating farm revenues. However, as shown below, it still is encapsulated in ADY, whose variability we simulate to capture the impact of production risk. Milk prices in each value chain depend on the type of market outlet and are comparable to those in the literature. Njehu and Omore (2014) report average prices ranging from USD 0.34 per liter (received from milk traders) to USD 0.54 per liter (restaurants) in the informal value chain. In the formal value chain, processors pay an average price of USD 0.23 per liter (International Livestock Research Institute, 2015).

The type of compound feed purchased by farmers in this study is maize bran. Although it is the preferred feed supplement in Lushoto district (Paul *et al.*, 2016), it is used by only 30% of dairy farmers (Mangesho *et al.*, 2013; Shikuku *et al.*, 2017). These are likely to be the highly market-oriented farmers. Previous studies have not been able to establish a reliable estimate of the quantity of maize bran given to animals in Lushoto district and elsewhere, but it could be anywhere between 0.5 kg (Shikuku *et al.*, 2017) and 1.6 kg per cow per day (Faida MaLi, 2014). Faida MaLi (2014) reports an average price of USD 0.14 per kg. These figures are comparable to those used in this study.

The cost of veterinary medicines seems to be relatively small. Baseline information for the MoreMilkiT project indicates that farms in Lushoto district incurred the lowest cost of veterinary drugs estimated at USD 10.10 annually (CGIAR Research Program on Livestock and Fish, 2014). With an average of 1.2 cows per farm, this translates to about USD 6.92 per cow per lactation or USD 0.023 per cow per day.

5.3 Examining risk

Following Twine *et al.* (2016), the impact of risk is examined using a Monte Carlo cash flow model of milk production by a single cow for one lactation period (300 days). A cash flow model illustrates the flow of cash in and out of the dairy enterprise and can therefore be used to predict the enterprise's financial performance and any imminent financial constraints. Because a cash flow statement reveals the enterprise's liquidity (ability to pay its bills), it is an important tool for assessing the short-term viability of milk production. An individual animal-based cash flow model is constructed for each representative producer. Conceptually, the potential cash flow for each producer in any given month is calculated as:

$$CF = (P \times Q) - CH - (W \times X) - \sum OC - OHC - DL \tag{1}$$

where CF is cash flow in \$ (USD), P is average price per liter of milk (\$), Q is quantity of milk sold in liters, CH is cost of an in-calf heifer (\$), W is average price of feed per kilogram (\$), X is average quantity of feed, OC are other operating costs (\$), OHC are overhead costs (\$), and DL is death loss (\$).

Q in any given month for a given season is calculated as the percentage of ADY sold in that season multiplied by ADY for that season multiplied by 30 days. That is, Q=% of ADY sold×ADY×30. For CH, it is assumed that the animal is purchased with a loan and loan repayment is half of monthly revenues. This is the practice by Covenant Bank, which offers dairy cattle loans to smallholder farmers. All selected farmers reported that OC mainly comprised of the cost of veterinary medicines although only one representative farmer had incurred the cost in the last twelve months. For all farmers, there were zero OHC. Regarding DL, it is not necessarily a cash outflow but because it represents loss in cash inflows in the event of death of the animal, it enables accounting for production risk due to death. Mortality rates are used to calculate the amount of milk lost that would have been sold.

Production risk is incorporated in the producer's cash flow model using *DL*, fluctuations in ADY, and fluctuations in *X*. Price risk is captured through fluctuations in *P* and *W*. The cash flow model in equation (1) is simulated using Monte Carlo simulation in which triangular distributions are specified for *P*, ADY, *W*, *X* and *DL*. Values of parameters of the triangular distributions were obtained from the producers. In essence, the variables *P*, *Q*, *W*, *X* and *DL* are made stochastic, implying a stochastic rather than deterministic cash flow model. Cash flows are obtained after 10,000 iterations.

Cash flow at risk (CFaR) is used to quantify the effect of risk on cash flows in the dry (Jan and Feb; Jun to Sep) and wet (Mar to May; Oct to Dec) seasons. CFaR of the enterprise is defined at a given confidence level, c, as the probability that the future cash flow value, cf, is less than or equal to a given cash flow value CF^* and is at most (1-c). As specified in Jorion (2001),

$$P(cf \leq CF^*) = 1 - c = m \tag{2}$$

It is either the probability, m, for a given CF^*or the CF^* at a given probability, m. In order to obtain a combined measure of risk from the different sources of risk, we use cash flows to calculate the monthly volatility of returns from milk production, σ_m. This is the standard deviation of the average monthly return on investment. Following Copeland and Antikarov (2001) and Hull (2005), the annual volatility, σ_a, is then calculated as:

$$\sigma_a = \sigma_m \times \sqrt{12} \tag{3}$$

5.4 Examining investment in milk production

The decision to invest in milk production can be analyzed using traditional capital budgeting methods such as net present value, adjusted present value, internal rate of return, modified internal rate of return, accounting rate of return, payback period, and cost-benefit analysis. However, these methods do not account for uncertainty in the economic environment and irreversibility of investment decisions. There is considerable uncertainty in smallholder milk production in Tanzania, which is exacerbated by the fact that investments in milk production are generally sunk costs and hence irreversible. Irreversibility means that once an investment has been made, it cannot be easily reversed; milk production technology is industry-specific, and even if it were not, it would fetch less than its original value on a secondary market. Given uncertainty and irreversibility, waiting to invest until more information becomes available to the decision maker might be of value. Therefore in the face of uncertainty and irreversibility, the decision is not only about whether or not to invest but when to invest.

This study employs the real options approach to capital budgeting. The approach emanates from the theory of financial options analysis. Pioneered by Myers (1977), the approach has had a wide range of empirical application as outlined in Lander and Pinches (1998), including natural resources, real estate, manufacturing and research and development. Unlike traditional capital budgeting approaches, the real options approach is able to account for uncertainty and a producer's flexibility in making investment decisions. For instance, a farmer might alter the timing of an investment in dairy production or the size of a dairy project already in progress as he or she obtains better market information. An option is a decision maker's right but not obligation to undertake a business transaction. If the transaction involves a tangible asset, the option is real. If the transaction involves a traded asset such as a stock or bond, the option is financial. Essentially, a real option is an opportunity to invest in a physical asset. For instance, a farmer might have an opportunity to invest in milk production if they own unutilized land or are knowledgeable about dairy cattle husbandry and dairy business management. Common types of real options include the option to defer an investment, time to build option, option to adjust the scale of operation, option to abandon an investment project, option to switch, growth options, and multiple interacting options (Trigeorgis, 1993). Usually, a decision maker will tend to exercise the option to delay an investment (also known as the option to wait or deferral option) because of uncertainty. Therefore a deferred investment opportunity is not necessarily a missed opportunity.

The three common approaches to analyzing real options are the Black-Scholes option pricing model (Black and Scholes, 1973), the Binomial option pricing model (Cox *et al.*, 1979) and the Dixit-Pindyck model (Dixit and Pindyck, 1994). The Dixit-Pindyck model has been widely applied in agricultural and resource economics studies, and it is the preferred framework for this study. It modifies the Black-Scholes model to analyze investment decisions under irreversibility and uncertainty. The model provides an analytic (closed-form) solution to an option pricing problem and as such, it is easy to perform a sensitivity analysis. Studies that have applied the Dixit-Pindyck model include Carey and Zilberman, 2002; Elmer *et al.,* 2001; Engel and Hyde, 2003; Insley, 2002; Isik *et al.,* 2001; Lempiö, 1997; Price and Wetzstein, 1999; Purvis *et al.,* 1995; Richards and Patterson, 1998; Salin, 2000; Steigert and Hertel, 1997; Tauer, 2006.

Following Dixit (1992) and Dixit and Pindyck (1994), consider an individual that intends to invest in milk production. Let I denote the sunk cost that they would incur, and V the flow of net operating revenues per unit time that lasts in perpetuity. Uncertainty means that future milk revenues are not exactly known, but in each time period, it is assumed that V follows a geometric Brownian motion[3]. The individual aims to maximize the expected (average) present value of profits, and therefore future revenues are to be discounted at a positive discount rate, ρ, equal to the opportunity cost of riskless capital. The Marshallian criterion for the decision to either invest now and get V/ρ-I or not investing at all and thus get 0 is that investment should occur (or that the option should be exercised) if $V/\rho>I$. The prospective investor will be indifferent between investing now and not investing at all if

$$M = \rho I \tag{4}$$

where M is the Marshallian investment trigger – the borderline level of the current revenue flow. Traditional investment analysis would recommend investing when current flow of revenue exceeds M. At M, waiting is better than either investing immediately or not investing at all, and will remain better for initial values of V slightly greater that M. When current revenue exceeds a certain level, H, investment then becomes optimal. We refer to H as the critical or trigger level of current revenue flows. It is larger than M and it shows that the farmer benefits from waiting for some time before investing. The optimal investment decision can be illustrated graphically (Figure 1) when H is exogenously given, and when it is endogenously determined by the farmer. Both the value of investing immediately (V/ρ-I) and the value of the option to wait are denoted by P, and are plotted against revenues, V. If the project is undertaken yet V=0, then the farmer loses I. As revenues increase, so does the value of investing immediately as shown by the straight line i_1i_2. The point at which the line i_1i_2 crosses the horizontal axis is the Marshallian trigger, M. The optimal investment decision when H is exogenously given occurs where the value of the option to wait as given by the convex curve w_1w_2 intersects i_1i_2. The value of the option to wait is the segment w_1h. Beyond this point, the option to wait has no value. If the investment trigger H is to be optimally determined by the farmer, it has to be increased above the value it had when it was exogenously given. This requires shifting the graph of the value of waiting until it is tangent to the line i_1i_2 as illustrated by the dotted curve. This is called the smooth pasting condition. It is a condition where the slope of the value of waiting is equal to the slope of the value of investing.

[3] This is a continuous-time stochastic process (also known as a Wiener process or standard Brownian motion) that is exponentiated to ensure that it is always positive. That is, V can trend upward and downward in equal proportions and the distribution of its logarithm is approximately normal (i.e. lognormal).

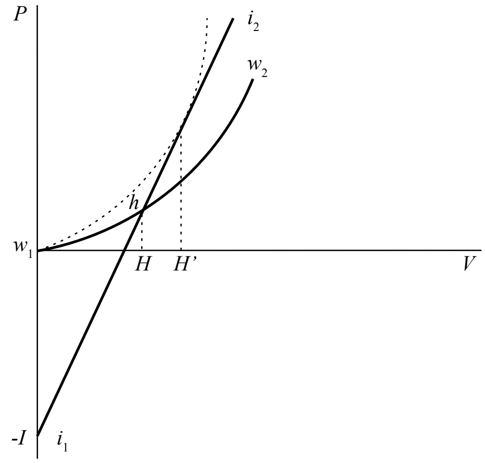

Figure 1. Optimal investment decision (adapted from Dixit, 1992).

After some calculus and algebra, the optimal investment trigger chosen by the farmer is given as:

$$H = (\beta / (\beta - 1))\, \rho I \tag{5}$$

where

$$\beta = 0.5\ (1 + \surd(1 + (8\rho / \sigma_a)) \tag{6}$$

The optimal investment trigger can be expressed in a manner similar to the Marshallian trigger in equation (4) as: $H = \rho^r I$

where

$$\rho^r = (\beta / (\beta - 1))\, \rho \tag{7}$$

is the discount rate adjusted for the value of waiting. It is also known as the hurdle rate.

A discount rate of 0.135, which was the Government of Tanzania risk-free interest rate on treasury bonds issued on December 7, 2016 (Bank of Tanzania, 2016) is applied to the model. Other data used to implement the model are obtained from the cash flow model. We examine the sensitivity of the hurdle rate and optimal investment trigger to changes in volatility and discount rate.

6. Results and discussion

6.1 Impact of risk on cash flows

Average cash flows and their standard deviations are calculated for each month and are noncumulative across months (Table 2). Positive cash flows are obtained for all producers in each month except for youths in the informal value chain who obtain negative cash flows in the wet seasons. The representative youth reported that in order to induce animals to drink water in the wet season, they feed the animal with more concentrate feed. This does not seem to be economically feasible considering that unlike the other categories of producers, the price the young farmer receives for his milk declines in the wet season.

Cash flows in the formal value chain are higher than those in the informal chain except for male milk producers in the dry seasons. Overall, youths in the formal value chain have the largest cash flows in both seasons, and

Table 2. Cash flows of dairy enterprises by gender and type of value chain.[1]

CF ($)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
FI	5.05	5.05	8.24	8.24	8.24	5.05	5.05	5.05	5.05	8.24	8.24	8.24
	(0.02)	(0.02)	(0.75)	(0.75)	(0.75)	(0.02)	(0.02)	(0.02)	(0.02)	(0.75)	(0.75)	(0.75)
FF	5.67	5.67	14.18	14.18	14.18	5.67	5.67	5.67	5.67	14.18	14.18	14.18
	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)
MI	5.78	5.78	7.52	7.52	7.52	5.78	5.78	5.78	5.78	7.52	7.52	7.52
	(0.22)	(0.22)	(1.22)	(1.22)	(1.22)	(0.22)	(0.22)	(0.22)	(0.22)	(1.22)	(1.22)	(1.22)
MF	4.89	4.89	20.26	20.26	20.26	4.89	4.89	4.89	4.89	20.26	20.26	20.26
	(0.49)	(0.49)	(0.40)	(0.40)	(0.40)	(0.49)	(0.49)	(0.49)	(0.49)	(0.40)	(0.40)	(0.40)
YI	15.03	15.03	-0.63	-0.63	-0.63	15.03	15.03	15.03	15.03	-0.63	-0.63	-0.63
	(2.20)	(2.20)	(4.25)	(4.25)	(4.25)	(2.20)	(2.20)	(2.20)	(2.20)	(4.25)	(4.25)	(4.25)
YF	19.85	19.85	22.69	22.69	22.69	19.85	19.85	19.85	19.85	22.69	22.69	22.69
	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)	(0.05)

[1] Figures in parentheses are standard deviations; while FI, FF, MI, MF, YI, and YF denote producer categories and the value chains they operate in as follows: female informal, female formal, male informal, male formal, youth informal and youth formal, respectively; CF = cash flow.

whereas female formal value chain producers have slightly higher cash flows than their male counterparts in the dry seasons, the latter have considerably larger cash flows than the former in the wet seasons. In the informal value chain, youths have significantly higher cash flows than male and female producers in the dry season, but have negative cash flows in the wet season. Cash flows for male and female informal chain producers are comparable. Therefore regarding liquidity, the key finding that could be of concern is that youths in the informal value chain do not feasibly produce milk during the wet seasons. However, their cash flows in the dry seasons seem to be large enough to offset the negative cash flows in the wet seasons.

Next is a quantification of the impact of risk on the cash flows of milk producers. This is done by calculating the 20% CFaR values and the probability of obtaining net cash flows that are less than their seasonal averages (Table 3). CFaR values at 20% are a realistic measure that indicates likely losses to the enterprise for one in five chances. At the 20% level, losses are observed only for youths in the informal value chain during the wet seasons; there is one chance in five that a loss of $4.37 or more will occur. The probabilities of cash flows falling below their seasonal averages do not vary much across the different producer categories and seasons. For instance, in the informal value chain, the probability of youths' cash flows being less than their seasonal average is about 45% for both seasons and is nearly the same for male producers in both seasons and for female producers in the wet seasons. In the dry season, the probability increases to about 51% for women. In the formal value chain, the probabilities are slightly higher but quite invariant across seasons; about 51%

Table 3. Cash flow at risk values by gender, value chain and season.[1]

	CF at 20%		Prob CF<seasonal average	
	Dry season ($)	Wet season ($)	Dry season (%)	Wet season (%)
FI	5.03	7.55	50.5	44.5
FF	5.66	14.15	50.5	50.5
MI	5.57	6.40	44.2	44.6
MF	4.61	20.06	55.7	55.3
YI	13.20	-4.37	44.9	44.6
YF	19.81	22.64	50.5	50.5

[1] CF = cash flow; FI, FF, MI, MF, YI, and YF denote producer categories and the value chains they operate in as follows: female informal, female formal, male informal, male formal, youth informal and youth formal, respectively.

for youths and female producers, and 56% for male producers. The probability of cash flows falling below their seasonal average suggests insignificant seasonal variation in risk for each producer category and among producer categories in each value chain. In fact an examination of the risk variables with the largest effect on cash flows reveals that for four of the six producer categories, the same risk variable has the largest impact on cash flows in both seasons (Table 3).

Holding other factors constant, fluctuation in quantity of concentrate feed given to the animal accounts for the largest variation in cash flows of youths in the informal value chain (Table 4). Availability of concentrate feed varies seasonally because most of it is locally produced from maize. Supplies are low during the wet season when the maize crop is still in farmers' fields and they are high in the dry season after harvest. However, young milk producers opt to feed animals with more concentrates in the wet season, a practice that can be avoided. As such, they expose themselves to greater risk. This is a typical case of external risk being compounded by a producer's internal risk factors, which in this case is the producer's husbandry practices.

For youths in the formal value chain, death loss is the greatest risk factor. Likewise, death loss is the greatest risk factor for women in the formal value chain, and for those in the informal value chain, it features prominently in the dry seasons. The finding that death loss is a major risk for women and the youths can be explained by the finding of Swai *et al.* (2010); cattle mortality is lower among farmers that receive training in animal husbandry than among those that do not. Data collected by the authors from a recent survey in the study area shows that a smaller proportion of women and the youths have received training on dairy husbandry than men.

Fluctuation in ADY is important for men and women in the informal chain, while fluctuation in feed prices and quantity are important for men in the formal chain. Interestingly, fluctuation in milk prices is not a major source of risk for any of the producer categories. Overall, these results point to the need to tailor risk mitigation measures to individual categories of producers to reflect the specific sources of important risks they face.

In order to obtain a better comprehension of the magnitude of risk faced by the different gender categories, a consolidated measure of risk that accounts for all the risks faced by each category of producers is calculated (Table 5). The measure is based on returns to milk production and is calculated on an annual basis. Youths in the informal value chain are found to face the highest annual volatility of returns to milk production of 35.14% compared to only 1.60% obtained for their counterparts in the formal value chain. Men in the formal value chain experience the second highest level of volatility of 10.02% followed by men in the informal value chain (7.90%). Contrary to what was expected *a priori*, female milk producers in either value chain face relatively low levels of risk. This could be attributed to women generally having more experience in milk production than men and youths as mentioned earlier. In fact Kaliba *et al.* (1997) found that the probability of women in Tanzania participating in intensive dairy farming was 27.5% higher than that of men.

Table 4. Risk variables with the largest effect on cash flows.[1]

	Wet season	**Dry season**
FI	ADY (6.80-9.23)	Death loss (5.02-5.09)
FF	Death loss (14.12-14.24)	Death loss (5.65-5.70)
MI	ADY (5.19-9.10)	ADY (5.35-6.06)
MF	Feed price (19.75-21.01)	Feed quantity (4.26-5.83)
YI	Feed quantity (-8.17-4.40)	Feed quantity (12.08-16.89)
YF	Death loss (22.60-22.79)	Death loss (19.77-19.94)

[1] Figures in parenthesis are ranges of cash flows in USD; ADY = average daily yield; FI, FF, MI, MF, YI, and YF denote producer categories and the value chains they operate in as follows: female informal, female formal, male informal, male formal, youth informal and youth formal, respectively.

Table 5. Annual volatility of returns to milk production.

	Formal value chain (%)	Informal value chain (%)
Youths	1.60	35.15
Men	10.02	7.90
Women	1.60	4.03
Combined	4.41	15.69

We now depart from gender disaggregation in order to focus on the value chains as a whole and compute values of parameters necessary for evaluating the effect of uncertainty on investment. Combining all producer categories in each value chain, we find greater risk in the informal value chain than in the formal one, with annual volatilities of 15.69 and 4.41%, respectively. That milk production in the formal value chain is significantly less risky than production in the informal chain is to be expected. Since the mid-1970s when the Government of Tanzania started supporting commercialization of smallholder dairying, emphasis has been on the formal value chain[4]. In the study area in particular, farmers operating in the formal value chain are relatively well-linked to input and output markets and extension services, and have benefited from donor-supported dairy development programs courtesy of their membership in primary dairy cooperatives. Several of these cooperatives constitute the Tanga Dairies Cooperative Union, a secondary cooperative that owns Tanga Fresh Ltd., the largest dairy processor in the country. Through the company's projects such as the Modern Dairy Services Network, producers have gained access to risk mitigating services and technologies including information, better dairy breeds, milk collection centers, and credit.

The preceding analysis has provided values of parameters (Table 6), except the risk-free discount rate, that are relevant to analyzing the effect of uncertainty and irreversibility on the decision to invest in milk production. The cost of investing in the formal value chain is about a half of the cost of investing in the informal value chain. This is because of the relative ease with which a prospective formal value chain producer is able to access the necessary support from the organizational infrastructure that already exists in the value chain. Moreover, the country's milk processing capacity utilization is only 26% of total installed capacity mainly because of supply-side constraints. As such, milk processors are generally supportive of smallholder farmers willing to enter the formal value chain.

However, the analysis undertaken thus far raises a fundamental question: if milk production in the formal value chain is relatively less risky and investing in the value chain is less costly than investing in the informal value chain, why does the majority of smallholder farmers operate in the informal value chain, supplying 97% of the milk consumed in the country? The answer to this question can best be provided by an analysis of producers' risk preferences. Such an analysis, however, is beyond the scope of this study. But disregarding risk preferences, a probable answer lies in the importance that farmers attach to high milk prices given the low-input low-output nature of smallholder milk production. Milk prices received by producers in the informal value chain are higher than (sometimes twice as high as) prices in the formal value chain. And indeed, Rao

[4] However, Quaedackers *et al*. (2009) contend that government support for the development of the formal value chain has been less than sufficient.

Table 6. Data on parameters used in the real options model.

	Formal value chain	Informal value chain
Volatility of returns (%)	4.41	15.69
Risk-free discount rate	0.135	0.135
Beta	1.06	1.02
Investment cost ($/liter)	0.13	0.27

et al. (2016) have found that most smallholder milk producers prefer marketing arrangements that offer the highest milk price possible to those that do not, even though the latter might have other economically beneficial attributes.

6.2 Effect of uncertainty on the investment decision

The real options model yields hurdle rates that are substantially larger than the conventional discount rate (Table 7). The resulting optimal investment triggers of \$0.33 and \$2.15 per liter of milk for the formal and informal value chains, respectively, are much larger than the Marshallian investment triggers. Therefore owing to the uncertainty that currently exists in the dairy industry, the option to wait to invest in milk production is of value. For the formal value chain, the current price of milk of \$0.23 per liter (Table 1) has to increase by \$0.10 before waiting to invest ceases to be optimal. This, however, is much less than the increase in price that is needed to make investment in the informal value chain optimal. The current farm gate price of milk in the informal value chain, averaged across the three producer categories, is \$0.38 per liter. It would have to increase nearly six-fold to make investing in the informal value chain optimal.

Notice that if a prospective milk producer is to disregard uncertainty and go by the Marshallian criterion, they should invest immediately since current farm gate prices in both value chains are way greater than the Marshallian triggers. But anecdotal evidence indicates farmers are reluctant to adhere to the Marshallian criterion. This study was undertaken in Tanga region where the authors were involved in implementing a research-for-development project that supported greater investment in milk production. In the course of project implementation, farmers consistently argued that the milk prices they receive are low and discourage further investment in milk production. These results suggest that the farmers are right and are perhaps aware of the risks and uncertainty they face.

6.3 Sensitivity analysis

Sensitivity of the hurdle rate and optimal investment trigger are examined by increasing and decreasing the discount rate and volatility of returns each by 10%. Generally, the hurdle rate and optimal investment trigger are not sensitive to changes in the risk-free discount rate (Table 8). For instance, a 10% increase in the discount rate, holding other factors constant, does not increase the optimal trigger for the formal value chain, and only does so by a mere 0.5% for the informal value chain. However, the two parameters do respond to changes in volatility by nearly the same degree; for instance, a 10% increase in volatility, holding other factors constant, causes a 9.1 and 9.8% increase in the optimal investment trigger for the formal and informal value chains, respectively. Similarly, reduction in volatility by 10% lead to almost proportional reduction in optimal investment triggers.

Table 7. Hurdle rates, optimal and Marshallian investment triggers.

	Formal value chain	**Informal value chain**
Hurdle rate	2.47	8.11
Optimal investment trigger (\$/liter)	0.33	2.15
Marshallian investment trigger (\$/liter)	0.02	0.04

Table 8. Hurdle rates and optimal triggers for different discount rates and volatility levels.

	Formal value chain		Informal value chain	
	Optimal trigger	**Hurdle rate**	**Optimal trigger**	**Hurdle rate**
Discount rate				
0.149	$0.33	2.50	$2.16	8.14
0.122	$0.32	2.44	$2.15	8.09
Volatility (formal chain)				
4.85%	$0.36	2.69		
3.97%	$0.30	2.25		
Volatility (informal chain)				
17.26%			$2.36	8.90
14.12%			$1.95	7.33

7. Concluding remarks

It is well-known that the persistently low level of dairy farm productivity in Tanzania has been perpetuated mainly by insufficient and unstable supply of animal health services, breeding services, and feed (International Livestock Research Institute, 2013). The sources of production risk addressed in this study are directly associated with these three factors, and whereas these factors could be mitigated through policy interventions in output and factor markets, the markets themselves are inherently risky. The end result, as established by this study, is a level of uncertainty that discourages private investment in milk production in both the formal and informal value chains, but more so in the latter.

The study's findings have four major implications for the management of dairy enterprises. First, existing and prospective farm managers should equip themselves with proper knowledge and skills in animal husbandry to be able to adequately deal with the various sources of production risk. For instance, they need to understand the use of body condition scoring as a dairy herd management tool to minimize fluctuations in daily milk yield. Also, given their limited access to animal health services, managers ought to improve their capacity to prevent animal diseases and hence minimize death loss. Second, managers need to ensure feed self-sufficiency. This could be achieved through allocating enough land to produce fodder including maize specifically for maize bran. Third, in the absence of market-based insurance as is the case in rural Tanzania, self-insurance through income diversification would help dairy enterprises cope with negative shocks. Last but not least, since it is impossible to completely eliminate uncertainty in the economic environment, managers should be flexible in decision making. This would require them to have access to market information and knowledge of the implications of alternative production decisions.

Milk producers in rural Tanzania have limited access to credit (Twine *et al.*, 2015), another hindrance to achieving greater farm productivity (International Livestock Research Institute, 2013). Although the study disregarded credit risk, the results have implications for lending. The overall finding that the two value chains face significantly different levels of risk exposure means that lenders to smallholder farmers should be cognizant of this fact. The different levels of risk exposure, in conjunction with the individual producers' risk profiles, should enable lenders determine the appropriate risk (insurance) premiums and hence interest rates to charge on cattle and other loans. Currently, the practice by lenders that provide dairy cattle loans is to charge uniform risk premiums that account neither for the individual producer's risk profile nor for the riskiness of the value chain they operate in. It is possible for cash flow-based lenders to use cash flow models such as the one developed in this study to determine appropriate risk premiums.

From a policy perspective, attaining inclusive dairy industry development will necessitate that the Tanzanian government recognizes that the impacts of uncertainty vary by gender of producer and type of value chain. Therefore assuming that smallholder farmers are risk averse and government is to support implementation of risk mitigation measures, it should ensure that the measures are tailored to the needs of the different gender categories and value chains.

An important subject for future research is to examine and compare the distribution of risk preferences of milk producers in the formal and informal value chains. The goal would be to determine which producers are risk-averse, risk-neutral or risk-loving, and what factors influence their risk preferences. The results would be instructive in targeting producers with respect to interventions for risk mitigation.

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