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Economic burden of livestock disease and drought in Northern Tanzania

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Livestock-dependent communities face considerable livestock disease and drought risk, which can impact herd value, income and consumption. This paper summarizes economic data collected from 404 households in Arusha and Manyara regions of Northern Tanzania in 2016. They provide estimates for (i) herd loss due to disease and drought as a fraction of herd value and income, (ii) the relative risk of disease and drought in small versus large ruminants and (iii) the relationship between livestock disease outcomes and household expenditures. We find that disease and drought losses comprise 10 to 4% of sheep, cattle and goat herd value, and amount to an estimated 62.1% of household income. The drought and disease risk ratios for small versus large ruminants indicate that small stock face higher disease risk, while large ruminants are affected more by drought. Furthermore, cattle abortions are negatively related to schooling expenditure and positively associated with increases in off-farm food expenditure related to livestock management, presumably through increased investments in prevention and therapy. These results suggest that climatic variability and livestock diseases are an important source of economic vulnerability and reducing this burden may help alleviate poverty in livestock-dependent communities.

Key words: Household production, livestock disease, drought, herd management, Tanzania.

INTRODUCTION

An estimated 1.3 billion people worldwide and 300 million people in sub-Saharan Africa depend on livestock for livelihoods and food (HLPE, 2016; Staal et al., 2009; Thumbi et al., 2015). For most livestock-dependent households in Sub-Saharan Africa, livestock play an important role as a source of nutrition and income from animal source foods (ASFs), a store of wealth, a critical component of social connectivity and capital, and a focal point of household work activity and investment (Bhaskaram, 2002; Galvin, 2008; McPeak, 2006; Iannotti and Lesorogol, 2014; Mosites et al., 2015).

Major livestock diseases such as contagious bovine pleuropneumonia, peste des petit ruminants and foot and mouth disease (FMD) are often poorly controlled in sub Saharan Africa (Domenech et al., 2006). Tanzanian livestock production faces several risks in form of infectious and vector-borne diseases like East Coast Fever, rabies, FMD etc (Cleaveland et al., 2003; Sambo et al., 2013; Matemba et al., 2010; Lankester et al., 2015). These and many other diseases contribute directly to losses in livestock keeping households through mortality, reduced weight gain, lowered milk yield and reduced fertility. Reduction, prevention and elimination of livestock disease can therefore be a poverty alleviation tool for livestock-keeping households of Sub-Saharan Africa whose income is primarily tied to livestock productivity and health. There is still much to be learned about the burden of these diseases and drought through their impact on household wealth, income, and consumption.

This article contributes to the literature on the burden of livestock disease by quantifying direct impacts of livestock death and abortions in terms of financial loss, and some of the indirect impacts on households by examining relationships between livestock disease outcomes and household expenditures on important goods and services using cross-sectional data from northern Tanzania for the year 2016. Specifically, this paper (i) calculates the direct costs of livestock disease burden on households in terms of financial/asset loss as a proportion of income and herd value, (ii) calculates the risk ratios based on losses as proportion of herd value for small versus large stock, and (iii) examines the relationship between livestock disease incidence and death on household food, education, health, and livestock expenditures.

Estimating livestock disease burden can be complicated, because losses in herd value and growth due to disease can lead to several indirect consequences like reduced consumption because of financial losses and public health crises through zoonotic disease transmission. McInerney (1999) proposed an economic model for estimating livestock disease burden. The model accounts for direct as well as indirect impacts of livestock illness on household welfare. There are two main pathways through which livestock disease affects households: 1) Direct and indirect costs (increased management costs) and loss in livelihoods (lost output, livestock death) due to specific losses in a herd; and 2) Disease transmission within and outside the herd that lead to subsequent losses. These pathways then lead to further household and societal-level impacts such as constraints on trade (Bennett, 2003; James and Rushton, 2002; Narrod et al., 2012), negative impacts on overall livestock prices (Barrett et al., 2003), grazing lands with higher infection risk (Fèvre et al., 2001; Lankester et al., 2015), lost nutrition (Mosites et al., 2015; Rist et al., 2015) and higher zoonotic risk (Torgerson and Macpherson, 2011; McDermott et al., 2013). While this paper does not explicitly deal with the second pathway, that is, disease transmission risk within and outside the herd, it estimates direct and indirect costs in terms of loss of herd value and income due to drought and disease; and possible attenuation in household consumption expenditure due to livestock death and abortion. Economic and public health implications of these estimates are explored at the household as well as societal level.

MATERIALS AND METHODS

Data collection

Data were collected as part of the “Social, Economic and Environmental Drivers of Zoonotic Disease in Tanzania” (SEEDZ) project. A cross-sectional survey was conducted in northern Tanzania across six districts in the Arusha region (Arusha, Karatu, Longido, Meru, Monduli and Ngorongoro districts) and four districts in the Manyara region (Babati Rural, Babati Urban, Mbulu and Simanjiro districts) between January and December 2016. A multistage sampling design was used. Twenty villages were selected from a spatially referenced list of all villages in the study area (from the Tanzanian National Bureau of Statistics (NBS)) using a Generalized Random Tessellation Stratified sampling (GRTS) approach (Stevens and Olsen, 2004), implemented in R version 3.1.1 (R statistical Environment, 2014), which results in a spatially balanced, probability-based sample. Two to three sub-villages were selected randomly within each village. Within each sub-village, a ‘central point’ sampling approach was adopted, in which livestock keepers were invited to bring their animals to a pre-selected point within the sub-village, such as a livestock crush or dip tank. Sampling took place alongside sub-village-level disease control activities, such as tick and/or worm control, conducted in collaboration with representatives from the Tanzanian Ministry of Livestock and Fisheries (MoLF). During the sampling event, a list of all attending households was generated, and a maximum of ten households selected using a random number generator. On a subsequent day, typically within one week, households were revisited and the household head received an in-depth questionnaire that covered a wide-range of topics, including household demographics, economics, livestock management and livestock health. The geographic co-ordinates of the household were captured using a handheld GPS (Garmin Etrex). Household heads were considered to be the most knowledgeable members of

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households with regard to livestock management and disease history, but field teams were instructed to seek and accept input and clarification from other knowledgeable household members in attendance as a matter of course.

Because the first sample was collected at sub-village central points and depended on households' voluntary participation in the survey, self-selection may be of concern population inference. Therefore, a second shortened version of the same questionnaire was conducted in a selection of livestock-keeping households who did not attend a central point sampling event. This was done in order to allow comparison of the characteristics of households attending the sampling event with non-attending households to assess whether the central-point data collection process led to sample selection bias in relation to our research questions. A list of non-attenders was generated for each sub-village by the sub-village chairperson or a knowledgeable elder. From this list, a convenience sample of up to five households were selected using random number generation and visited in their homes in order to complete the household questionnaire and collect geographic co-ordinates.

In total, data were collected from 404 households in 49 sub-villages at central points and shortened-survey data from non-attendees were collected from 193 households. The dataset is made up of one record (observation) per household collected from a questionnaire survey conducted with the household head. All questionnaire respondents provided written informed consent. The protocols, questionnaire and consent procedures were approved by the ethical review committees of the Kilimanjaro Christian Medical Centre (KCMC/832) and National Institute of Medical Research (NIMR/2028) in Tanzania, and in the UK by the ethics review committee of the College of Medical, Veterinary and Life Sciences, University of Glasgow.

Most of the data we use in this analysis were acquired through the data collection process described above. However, our survey did not collect household income or livestock market price estimates. For comparisons of livestock losses to income, we rely on average rural per capita income of $256.4 (2016 dollars) as estimated in Lusambo (2016) and multiply it by number of household members to get an estimate of household income. Calculations are shown in Table 1. This should be taken as a rough estimate, first because it is an average rural income estimate for Tanzania, and second, because the estimate itself is likely to reflect disease and other environmental burdens. Adding the value of livestock lost to disease and drought to Lusambo (2016) income estimate could reduce this potential bias; however, the estimates were produced in different years. For these reasons, our income-related measures should be taken as rough approximations, and the interpretation should account for these factors.

Livestock market price data were used to estimate herd value. The LINKS (2018) database provides several list options to filter and extract data by species, breed, gender and age of livestock. We extracted the average price data from *all* major livestock markets within Tanzania for *all* genders and breeds of adult cattle, sheep and goats. A similar data extraction was performed for calves, lambs and kids. We calculate herd market value by multiplying the price of each stock category by the average LINKS category price for from January 2015-2016. The combination of the LINKS price data and our herd composition survey data allow us to calculate herd category values by cattle/sheep/goat stock type. The value of each category of stock is calculated as the average LINKS price for that category times the number of animals in that category. Total household herd value is the sum over all categories. LINKS (2018) website performance and data availability is sporadic. Data used in this analysis are available from the contact author.

The study area is characterized by a diversity of agro-ecological systems, livestock management practices, and integration of livestock with crop agriculture. The study region comprises a range of ethnicities, including the Maasai and Barabaig, for whom rural livelihoods are traditionally based on extensive livestock production with limited crop agriculture ("pastoralists"), the Waarusha and Iraqw who have traditionally combined extensive cattle grazing and crop production ("agropastoralists"), and the Meru and Chagga who have traditionally reared small numbers of livestock that are closely integrated with crop agriculture ("smallholders"). Arusha Region has the largest livestock population in the country, with 5.6 million head of cattle, sheep and goats.

Methodology

Table 1 describes the variables used in the analysis and their sources, and Table 2 provides summary statistics. Based on these data, we carry out the following analyses: (i) calculate the direct costs of drought and disease on households in terms of financial/asset loss as a proportion of herd value, ii) calculate the direct costs as a proportion of income using estimates of rural income from Lusambo (2016), (iii) calculate risk ratios for small versus large ruminants based on losses as a proportion of herd values and (iv) estimate the relationship between livestock illness outcomes (death and abortion) and household expenditures on food, education and livestock.

For drought and disease as proportion of herd value, costs of each event (drought-death, disease-death and abortion) for each stock type are divided by the relevant stock herd value. The total loss percentages are estimated by dividing total costs for each event with total herd value, so that the percentages of losses are weighted by herd size for each stock type. For drought and disease as a proportion of herd value, we provide two-sample t-tests for differences across stock types based on in-sample data entirely from our survey. We do not conduct these tests for losses as a proportion of income, because standard errors would be biased downward by an unknown amount and tests would be uninformative due to the fact that we are relying on one average estimate for rural per capita income (Lusambo, 2016).

Estimates of loss relative to herd value are based on herd value at the time of the survey and not on herd value at the beginning of the year. This may cause an over or under-estimation of losses as proportion of herd value depending on the number of livestock entries and exits in that year. However, these estimates provide an illustration of the disease and drought threat to these households and how these risks affect small and large ruminants. Similarly, estimates of loss relative to income are based on an average income rather than income proportional to the herd, which may cause over or under-estimation of losses as proportion of income. However, the rough estimates of loss relative to income provide an illustration of the extent to which household income is attenuated by disease and drought in livestock-dependent households.

The relative risk of disease and drought on sheep, goats and cattle is estimated by dividing the percentage of sheep/goats losses by percentage of cattle losses. These ratios illustrate the relative magnitude of losses from disease and drought for cattle and small stock. These estimates are based on cross-sectional data and represent the disease and drought burden at a point in time. The cross-sectional nature of our data does not allow a more robust analysis of disease, drought, and herd dynamics over time.

To estimate the relationship between livestock losses and various categories of household expenditures, we relied on linear random effects regressions. Random effects (sub-village and village-level) were included to control for unobserved heterogeneity at each level. However, a likelihood ratio (LR) test rejected controlling for village-level random effects, hence random intercepts for sub-villages only are included in these regressions. Hausman Test provided further support for random effects regression

Table 1. Data descriptions.

Variable	Description
[Stock][a] price	The average price of cattle/sheep/goats (all breeds and genders) from January 2015 to January 2016 in Tanzania, in USD (LINKS 2018)[b]
Calf/lamb/kid price	The average price of calves/lambs/kids (all breeds and genders) in Tanzania from January 2015 to January 2016 in USD (LINKS 2018)[b]
[Stock] value	in the household herd, where *[Stock]* is one of (*Cattle, Sheep, Goats)* Measured in USD
Total herd value	Sum of Cattle, Sheep and Goat herd value in 1000s of USD
[Stock] disease death Cost	Number of *[Stock]* that died due to disease in the household in the past 12 months, multiplied by the average price of *[Stock]*
[Stock] drought death Cost	Number of *[Stock]* that died due to drought in the household in the past 12 months, multiplied by the average price of *[Stock]*
[Stock] abortion cost	Number of *[Stock]* abortions in the household in the past 12 months, multiplied by the average price of calf
Income	Mean per capita income (in USD) of rural households in Tanzania as estimated by Lusambo (2016), multiplied by size of the household Lusambo estimated monthly mean per capita income adjusted for inflation (base year 2007) for rural households in 2016 as 31,115 TZS Conversion into 2016 USD = Income per Year(TZS)*Inflation Adjusted Exchange Rate (2007 -2016) = , where1 USD = 1,255TZS (2007 exchange rate) Average Inflation Rate in US (2007 -2016) ≈ 16%
School expenditure	School expenditure of the household in the last 12 months in USD
Food expenditure	Out-of-farm food expenditure in last 12 months in USD
Livestock expenditure	Expenses borne for livestock management within a household in last 12 months in USD
Cattle abortions	Number of cattle abortions in a household within last 12 months
Cattle disease death	Number of cattle died due to disease in a household within last 12 months
Livestock value	Sum of cattle, sheep and goat value owned by household
Adult HH members	Number of household members above the age of 18
Children 5 to 18	Number of children in household aged from 5-18
Acres owned	The number of acres owned by the household
Crops	Dummy variable = 1 if household has planted crops, 0 otherwise
Transhumance distance	The Euclidean distance, measured in Kilometers, between household and seasonal grazing camp

[a]*[Stock]* indicates one variable each for *Cattle*, *Sheep*, and *Goats*. [b]The LINKS (2018) database provides several list options to filter and extract data by species, breed, gender and age of livestock. We extracted the average price data from *all* the major livestock markets within Tanzania for *all* genders and breeds of adult cattle, sheep and goats. A similar data extraction was performed for calves, lambs and kids. Website performance and data availability at (LINKS 2018) is sporadic. Data used in this analysis are available from the contact author.

estimates as statistically consistent for our application.

For the purposes of regression analysis, continuous variables were transformed to natural logarithm due to skewness in the expenditure and value data because this distribution better approximates error distributions. Regression parameters therefore represent elasticities: the estimated percent change of the regress and in response to a percentage change in the associated regressor. The standard errors are clustered at the sub-village level to account for within sub-village correlation in errors.

To account for potential self-selection bias in the self-selection of households attending the central point sampling event (n = 404), we ran a two-step Heckman selection regression to examine if the results for the selection model differ significantly from the other regressions (Heckman, 1979). Because of the potential for self-selection bias, we conducted a second more limited survey that represents a random sample of households stratified at the village level, with a small set of variables including the household's distance to the central point, socioeconomic indicators of the household, and herd sizes. This sample included 404 households that had attended the central point event and 193 households that had not. We used this sample to estimate a Probit regression for central point participation. The results of this regression allowed the calculation of an inverse Mills ratio for each observation in the central point dataset based on the regressors shared between the central point and at-home datasets. The inverse Mills ratio in our regressions of interest based on the broader set of variables collected at the central points was then included. It was found that our estimates of coefficients in the regressions do not substantively change with the selection model, and the inverse Mills ratio included in the second-step regression is statistically insignificant in all regressions at conventional test sizes (P-values for the parameter associated with the inverse Mills Ratio were 0.73, 0.86 and 0.57 for livestock, schooling and food expenditure regressions, respectively). Therefore, we report the regression without selection correction.

A subset of results by village classification was reported. Villages

Table 2. Summary statistics.

Parameter	N	Mean	Median	St. Dev	Min	Max
Cattle price	134	270.1	265.7	112.8	90.0	540.0
Goat price	134	50.6	49.3	10.62	12.17	78.57
Sheep price	134	45.3	45.3	7.39	18.00	54.16
Calf price	134	130.5	122.0	11.96	81.76	175.5
Lamb price	134	18.06	18.00	6.23	12.15	24.3
Kid price	134	10.12	10.00	0.379	9.83	11.26
Cattle value	387	14,470	1,888	33,141	0	324,120
Sheep value	314	2,873	720.0	7,863	45.3	81,006
Goats value	353	3,059	1000	6,005	50.6	50,100
Cattle disease death cost	404	406.2	0.00	1,701	0	27,010
Sheep disease death cost	404	192.9	0.00	680.9	0	8,154
Goats disease death cost	404	272.4	0.00	885.5	0	10,120
Cattle drought death cost	375	752.8	0.00	4,106	0	54,020
Sheep drought death cost	388	107.9	0.00	734.5	0	11,778
Goats drought death cost	404	132.3	0.00	716.3	0	10,120
Cattle abortion cost	358	77.4	0.00	353.2	0	5,220
Sheep abortion cost	371	11.37	0.00	54.49	0	789.4
Goat abortion cost	363	38.00	0.00	105.2	0	903
Income	404	1801.2	1538.4	1291.4	256.4	9,486.8
Schooling expenditure	295	259.6	0.00	971.6	0	14,184
Food expenditure	295	624.1	141.8	1,107.5	6.00	13,793
Livestock expenditure	295	305.5	172.4	54.7	0	5,531.9
Cattle abortions	358	0.592	0.00	2.71	0	40
Livestock value	295	18,106	5,547	34,392	406.7	324,120
Adult HH members	295	6.52	6.00	3.98	1	27
Children 5 to 18	295	3.04	3.00	2.46	0	15
Acres owned	295	8.32	4.00	12.95	0	120
Crops	295	0.92	1.00	0.264	0	1
Transhumance distance	404	10.36	0.00	21.5	0	156.8

were classified as those in which livestock rearing (rather than crop agriculture) was considered to be the primary livelihood activity (‘pastoral’ villages) and those in which a mix of crop and livestock were important (‘agro-pastoral and small holder’). Village classification was performed in consultation with District-level government officials, typically the District Veterinary Officer or District Livestock Officer.

RESULTS

Table 2 and Figure 1 illustrate the distributions of herd values and losses due to disease-related death and abortions across stock type. The medians for these types of losses are zero as more than 50% of the households do not report these losses. The distribution of herd sizes suggests that the sample consists of mostly small and medium sized farm enterprises. Given that the median losses in our sample are equal to zero, that is, more than 50% households do not experience a negative livestock event; average losses may reflect that household livestock losses tend to be severe when they do occur.

There is variation in herd sizes within our sample, and we investigate the relationship between herd size and disease losses. Figure 2 depicts the proportions of *[Stock]* losses as a function of *[Stock]* herd values. The figure shows a heterogeneous and weak relationship across herd sizes within our sample, but if anything, smaller herds appear to suffer more as a proportion of herd size than do large herds, as suggested by the kernel regression lines sloping down to the right. Such a relationship may exist because large-herd holders may be able to respond to and rebound from livestock losses due to drought and disease, while those with smaller herds may be more cash and input constrained and potentially have less ability to protect their herds against negative shocks and to replenish them when they happen (McPeak 2006). The risk of their herd being wiped out by negative shocks is possibly also more acute (Lybbert et al., 2004). In addition, abortion or death of an animal may have a larger impact on current consumption capacity for

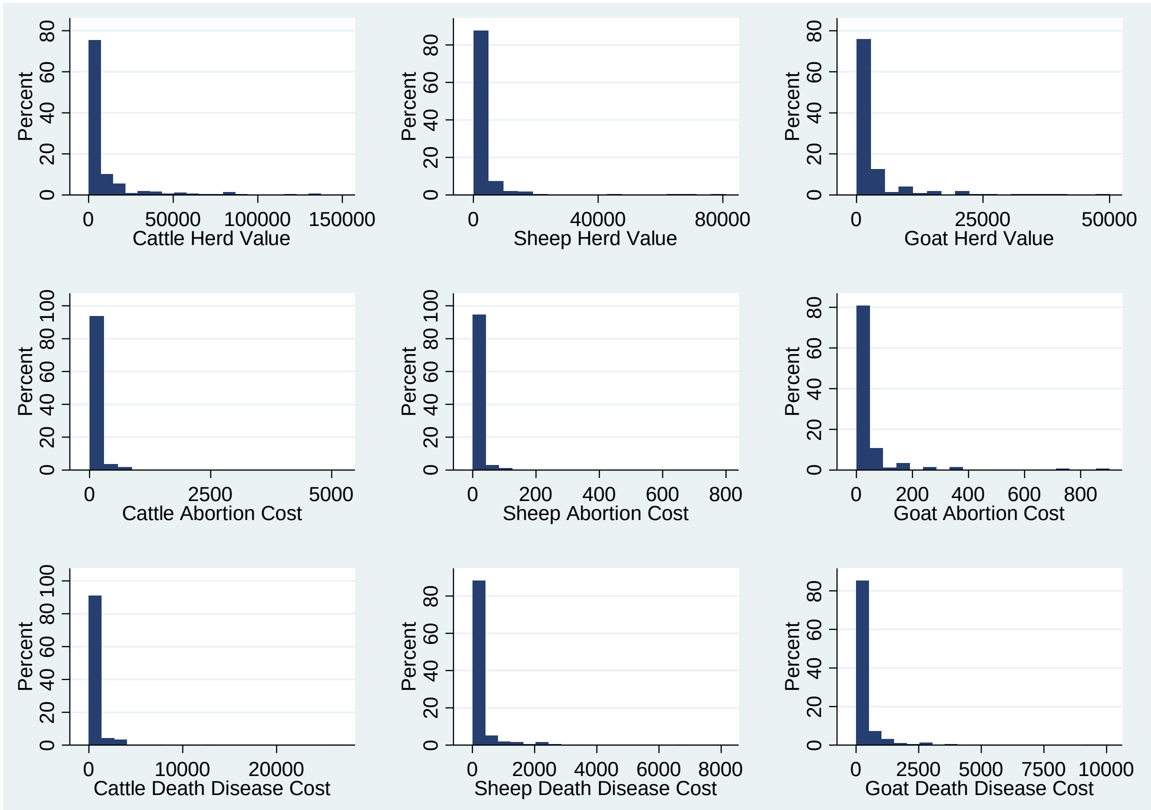

Figure 1. Histograms of Herd Value, Abortion and Disease Death Costs (in USD).

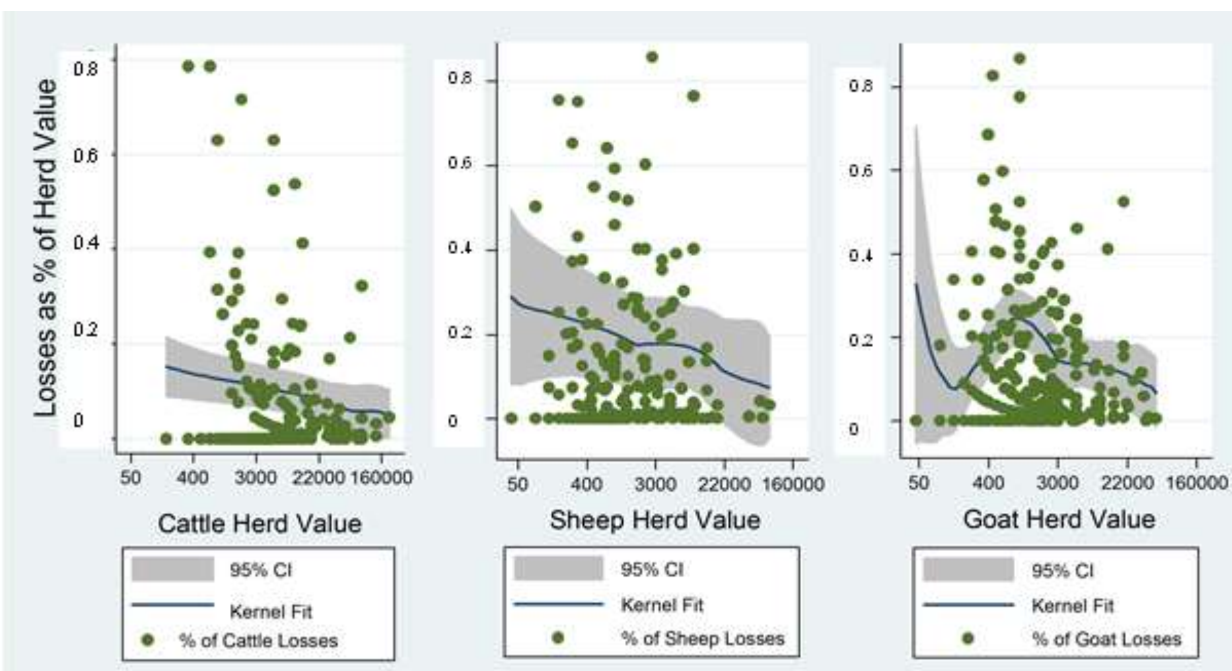

Figure 2. Scatter plot of proportion of *[stock] herd loss* from both drought and disease over *[stock] herd value* with kernel-weighted local polynomial regression fit.

Table 3. Average losses as a percent of herd value and income, by livestock type.

Parameter	Loss as % of herd value								Loss as % of Income			
	Cattle	Sheep	Goats	Sheep and goats	Total	Risk Ratio (Sheep/Cattle)	Risk ratio (goat/cattle)	Risk ratio (sheep and goat/ cattle)	Cattle	Sheep	Goats	Total
Abortions	0.5	0.4(0.101)[a]	1.24(0.089)	1.21(0.35)	1.20	0.8[0.24, 1.36]	2.48[1.61, 3.35]	2.42[1.8, 3.02]	3.5	0.5	2.1	6.1
Disease death	2.8	6.7(0.053)	8.9(0.003)	8.1(0.000)	7.7	2.39[1.49, 3.29]	3.17[2.04, 4.3]	2.89[1.56, 4.22]	17.3	10.2	15.2	42.7
Total disease	3.3	7.1(0.036)	10.14(0.000)	9.3(0.008)	8.9	2.15[1.39, 2.91]	3.07[1.89, 4.25]	2.81[1.41, 4.2]	20.8	10.7	17.3	48.8
Drought death	5.2	3.75(0.05)	4.3(0.003)	3.8(0.018)	4.8	0.72[0.39, 1.05]	0.82[0.32, 1.32]	0.73[0.5, 0.96]	18.4	5.5	6.7	30.6
Disease + drought	8.5	10.85(0.008)	14.44(0.001)	13.1(0.044)	13.7	1.28[0.88, 1.68]	1.69[1.1, 2.28]	1.54[1.12, 1.96]	39.2	16.2	24.0	79.4

[a]P-values in parenthesis are based on two-sided test for differences in cattle losses as a proportion of herd value to sheep losses or goat losses as a proportion of their respective herd value. The mean comparison tests illustrate that disease losses are high as a proportion of herd value for small stock, while cattle experience higher average drought losses as percentage of herd value.
95% confidence intervals for risk ratios are given in brackets.

owners of small herds. On the other hand, herd size is a risk factor for many infectious diseases in livestock, with individual risk of infection typically higher in larger herds (Makita et al., 2011; Rizzo et al., 2016). Therefore, a systematic relationship between herd size and livestock losses is not obvious.

Direct losses as a proportion of herd value

Table 3 presents the average livestock death and abortion losses as percentage of *[Stock] Value*, where *[Stock]* refers to *Cattle*, *Sheep* and *Goats*. In our sample, cattle abortions accounted for 0.5% loss in *Cattle Value*, and cattle death due to disease accounted for an average loss of 2.8% of the *Cattle Value.* Cattle deaths due to drought, on average, accounted for a loss of 5.2% in *Cattle Value* per year. In total, an average household experienced a loss in *Cattle Value* of 8.5% per year [95% CI: 6.4%, 10.6%] due to drought and disease.

Sheep deaths due to disease accounted for a loss of 6.7% of the *Sheep Value* in a representative household. Sheep abortion losses were 0.4% of the *Sheep Value*. Sheep deaths due to drought accounted for a loss of 3.75% of the *Sheep Value*. In total, an average household experienced a loss in *Sheep Value* of 10.85% per year [95% CI: 9.5%, 14.3%] due to drought and disease.

Goat deaths due to disease accounted for a loss of 8.9% of *Goats Value* per year. Goat abortion losses were 1.24% of *Goat Value*. Goat deaths due to drought accounted for a loss of 4.3% of *Goat Value*. In total, an average household experienced a loss in *Goat Value* of 14.4% [95% CI: 11.35%, 18.4%] due to drought and disease. Losses for sheep and goats combined account for 13.1% of the *Sheep* and *Goat Value*.

Total abortion, disease-death and drought losses account for 1.2, 8.9 and 4.8% of the total household herd value, suggesting that disease losses are two-thirds of total losses. These results suggest that drought and disease risk are a serious threat to households' asset base in northern Tanzania. Furthermore, the well-being of a livestock-keeping household in rural Tanzania relies relatively heavily on herd value, and any losses in the herd value may affect consumption, nutrition and even schooling (Marsh et al., 2016). Table 3 presents mean comparison t-tests between the proportions of cattle disease losses and sheep and goat disease losses. The means of losses due to disease as a percentage of herd value are larger for small stock than cattle. The hypothesis that there was no difference in the mean value of goat disease death losses and cattle disease death losses was rejected against the alternative that difference was not equal to zero (p-value = 0.003). Similarly, the combined sheep and goat disease-related losses are greater than cattle losses (p-value ≤ 0.001). For the sheep disease death losses, the null hypothesis that difference in means in comparison to cattle disease losses is equal to zero is rejected against the hypothesis that the difference is greater than zero (p-value = 0.053). Means of total disease losses (abortions plus death) for goats and sheep are also greater than total cattle disease losses (p-values < 0.001 and 0.036, respectively).

Table 3 presents the risk-ratios of disease and drought losses for small versus large stock. The relative risk of abortion in goats versus cattle is 1.24/0.5=2.48 [95% CI: 1.61, 3.35], sheep versus cattle is 0.8 [95% CI: 0.24, 1.36], and sheep and goats combined versus cattle is 2.42 [95% CI: 1.8, 3.02]. Sheep are 2.15 times more likely to die of a disease or abort than cattle [95% CI: 1.39, 2.91], whereas goats are 3.07 times more likely to die of a disease or abort than cattle in our sample [95% CI: 1.89, 4.25]. The risk ratio of drought losses between sheep and goats combined versus cattle is 0.73 [95% CI: 0.5, 0.96], suggesting that cattle are more likely to be affected by drought. However, the drought effects are statistically weaker when comparing cattle to sheep and goats separately, such that the confidence intervals (Column 6-7, Row 4) for these risk ratios contain 1 (which represents no difference in loss rates). Overall, losses of sheep and goats together are about 1.5 times those of cattle.

A pattern that emerges from the mean comparison tests and risk ratios in Table 3 is that cattle tend to be more severely affected by drought as a percentage of herd size, and the economic impacts of drought is most severe through the loss of cattle. Conversely, while the aggregate economic impact of disease is greatest for cattle, disease death as a proportion of herd size is larger for small stock than for cattle.

At least three aspects of this pattern are of particular interest. Firstly, cattle herd value is an order of magnitude larger on average than the value of sheep and goat herds, so it was not surprising that the value of economic losses are higher, despite disease losses as a proportion of the herd size being smaller. Secondly, the finding that losses associated with disease in small stock are higher than those for cattle may be linked to cerebral coernurosis, an emerging disease issue in sheep and goats in the study setting. This disease is caused by the larval form of the dog tapeworm, *Taenia multiceps,* which encysts in the brain and spinal cord of small ruminants (the reservoir hosts) typically causing a progressive neurological disease leading to death (Miran et al., 2015). Anecdotally, mortality rates associated with cerebral coernurosis, locally known as *Ormilo*, are increasing in northern Tanzania (Queenan et al., 2017; Hughes et al., 2019). Thirdly, there is some evidence that livestock holders in this region have been substituting away from cattle and buying small stock in response to increasing climatic variability (Bollig, 2006; Goldman and Riosmena, 2013; McCabe et al., 2010). The higher rate of drought loss in cattle as a proportion of herd size relative to small stock (Table 3) reflects a motivation for this substitution. Reasons for substitution toward small stock are likely to include the lower cost of purchasing small stock, their higher reproduction rates, and their capacity to browse and graze more successfully in diverse forage environments and to survive drought (Silanikove and Koluman 2015). Nonetheless, given the finding that small stock are more susceptible to disease (for a given herd size) than cattle, the risk ratios in Table 3 suggest that as a result of this substitution towards small stock, herd owners are trading drought loss risk against disease risk.

Livestock keepers were asked to report deaths due to disease and those due to drought separately. In general, it would be expected that livestock deaths that occurred in highly emaciated animals during the dry season or shortly after the onset of rains (when animals are often at high risk of mortality) would be attributed to drought, while deaths following an obvious illness or that were otherwise unexplained would be linked to disease. It is important to note however that droughts may make animals more susceptible to infectious disease, and infectious disease may reduce the ability of the animal to survive drought, further complicating the attribution of a livestock mortality events to a particular cause. Identifying the true cause of mortality would require post-mortem based examination, which was beyond the scope of this study.

Direct losses as a proportion of household income

Table 3 provides the percentage of *[Stock]* losses as a proportion of average rural *Income*. In our sample, cattle deaths due to disease and cattle abortions accounted for an average loss of 17.3 and 3.5% of *Income*, respectively. Cattle deaths due to drought accounted for an average loss of 18.4% as a proportion of *Income*. Cattle losses as a proportion of income are found to be much higher in pastoral production systems with drought losses averaging 39.1% of *income*, but 4.5% of *income* for agro-pastoral and smallholder households.

Sheep deaths due to disease and sheep abortions accounted for a loss of 10.2 and 0.5% as a proportion of household *Income*, respectively. Sheep deaths due to drought account for a loss of 5.5% of *Income*. In total, the sheep losses due to disease and drought can add up to 16.2% as a proportion of *Income*. Sheep losses as a proportion of income are found to be much higher in pastoral production systems with drought losses averaging 8.7% of *Income*, but 0.3% of *Income* for agro-pastoral and smallholder households.

Goat deaths due to disease and goat abortions account for a loss of 15.2 and 2.1% of *Income*, respectively. Goat deaths due to drought account for a loss of 6.7% of *Income*. In total, goat losses due to disease and drought can add up to 24% of rural household's *Income*. Goat losses, as in the case of cattle and sheep, are found to be much higher in pastoral production systems with drought losses averaging 9.8% of *Income*, but 0.7% of *Income* for agro-pastoral and smallholder households.

In total, reported cattle, sheep and goat death losses average 79.4% of estimated average rural household income as estimated by Lusambo (2016). This relatively large magnitude of loss in relation to income is possible because households in our sample, and in low-income rural communities more generally, frequently hold a large proportion of their wealth in the form of livestock and land, while monetary savings and income amount to only a small percentage of their total wealth (Rosenzweig and Wolpin, 1993). Furthermore, other studies have demonstrated that the rate of return (effective income) of livestock among herd owners in low income settings is relatively low and variable, heavily depends on herd size, breed composition and environmental conditions like drought and disease, and as a result may sometimes be negative (Anagol et al., 2017; Attanasio and Ausburg, 2018; Gehrke and Grimm, 2018).

While drought is a common characteristic of the semi-arid rangelands in the region, drought frequency and severity is increasing (Lyon and DeWitt, 2012; Vigaud et al., 2017). Indeed, in the last few months of data collection, toward the end of 2016, severe dry season conditions persisted across East Africa after minimal rain fell during the period of short rainy period (November-December), a situation which was exacerbated by the scant long rains (March-May 2017). As a consequence, in early 2017, Kenya (but not Tanzania) declared a drought state of emergency (AllAfrica, 2017; Huffington Post, 2017). The year 2016 provides one representation of weather and climate trends in east Africa, but our drought-related results should be interpreted with these conditions in mind and would surely vary depending on drought conditions. The cross-sectional nature of our data precludes us from mapping drought risk and severity overtime.

Indirect impacts of livestock disease

We have estimated some of the indirect relationships between livestock disease and other household economic outcomes. We focused on cattle because of their relatively high value as a proportion of wealth, and on food, livestock and education expenditures because of their importance for both long and short-run family wellbeing.

Abortions may be associated with at least two types of losses: the loss of an addition to the herd, thereby reducing expected herd asset value, and loss due to morbidity, reduced milk production, and other production value that might have otherwise been available to consume. Table 4 shows that cattle abortions tended to be strongly statistically related to expenditures on food, school and livestock. From Column 1, a 1% increase in cattle abortions is related to a decrease of 1.2% in schooling expenditure (p-value = 0.063). This decrease in education expenditure may be the result of an income effect from the perceived loss of wealth or income from the abortion of an expected addition to the herd, or illness in the herd associated with abortion. Through this income effect, livestock disease may have important implications in terms of educational attainment in livestock-dependent households. Testing the exact mechanisms through which livestock losses take a toll on household expenditure is beyond the scope of this work. However, Marsh et al. (2016) established the link between educational attainment and livestock health, demonstrating that vaccinations, through decreased livestock mortality and increased productivity, translated into higher education expenditure and school attendance, particularly for girls. Because education is linked with higher lifelong productivity and income, the effects can be farther reaching still.

It was found that cattle abortions are positively related to food expenditure (Table 4). A one percent increase in cattle abortions is related to a 0.68% increase in food expenditure (p-value = 0.036). If livestock morbidity from abortion-related disease reduces the animal source food production via the household herd, the household may choose to buy more food from outside the farm to feed the family. Through this channel, livestock illness can lead to food expenditure that could have been saved if livestock were healthier, and instead spent on education, saving or investing to build further productive assets.

Lastly, the results suggest that cattle abortions are related to higher livestock expenditures. A 1% increase in cattle abortions are related to 0.66% increase in livestock expenditures (p-value = 0.004). This may arise as a result of higher veterinary costs for immediate treatment of the animal (e.g. with antibiotics). It is worth emphasizing that these regressions should be interpreted as correlations, not causal relationships. Livestock health outcomes like abortion and death may be correlated with a host of unobserved characteristics like farmer's managerial ability.

Table 4 shows a consistently positive and significant coefficient on livestock value in all of these regressions, which suggests that there is a strong relationship between herd size and expenditure capacity. Any reduction in herd value may result in a host of indirect effects which may result in lost wellbeing for livestock-dependent households. While the effects of cattle disease death on school, food, and livestock expenditures are not statistically significant at conventional test sizes, the signs of the estimate are interesting. Increases in cattle disease death are weakly negatively correlated with school and food expenditures, and weakly positively related to livestock expenditures, which is not inconsistent with the income effects of losses attenuating household expenditures on goods and services, while simultaneously leading to a need for more health care expenditures to care for sick livestock.

Disease incidence may also affect future costs,

Table 4. Relationship between schooling expenditure, food expenditure and cattle health outcomes – random effects regression.

Parameter	School expenditure	Food expenditure	Livestock expenditure
Cattle abortions	-1.205*(0.647)	0.68**(0.30)	0.662***(0.232)
Cattle disease death	-0.579(0.629)	-0.369(0.46)	0.209(0.261)
Livestock value	0.42**(0.176)	0.052**(0.026)	0.071**(0.033)
Land area	-0.11(0.54)	-0.517(0.434)	-0.27(0.511)
Crops	-0.024(1.83)	2.73**(1.35)	1.71*(0.89)
Adult HH members	-1.02(1.93)	-0.36(1.53)	-0.145(1.16)
Children 5 to 18	3.34***(1.21)	1.081(1.087)	0.382(0.827)
Number of observations	295	295	295

***, **, * indicate statistical significance at 1, 5 and 10% respectively. Standard errors (in parentheses) are clustered at the sub-village level.

increase subjective disease risk assessment, and result in increased future use of preventive medications. Increased use of antibiotics is of concern in relation to the emergence and spread of antimicrobial resistance, which may be costly for the society as a whole (Ahmed et al., 2018; Althouse et al., 2010). There may be several other costs related to livestock management and disease control. Opportunity cost of livestock management time, and costs associated with herd restocking and livestock grazing are among the most noteworthy, though not captured in our data. While herd restocking and other management practices like communal livestock grazing and transhumance provide vital benefits, especially in areas with high rainfall variability over time and space (Agrawal, 2001; Ostrom, 2015), these practices may also be related to higher disease transfer and livestock morbidity and mortality due to disease (Fèvre et al., 2001).

Conclusion

This paper examines disease and drought losses as proportions of herd value and income and estimates the relationships between livestock health outcomes and household expenditures of livestock-dependent households. We conceptualized livestock disease impacts following McInerney (1996; 1999) and used cross-sectional data from northern Tanzania for estimation purposes. The paper contributes to the understanding of pathways through which livestock diseases and droughts decrease household welfare. We find that these negative shocks account for 10-15% of loss in herd value and roughly around 80% of household income in our sample. Since farmers in low-income countries generally have a higher asset base than disposable income, these asset losses are significant and represent a large proportion of income.

It was found that the risk of disease-associated mortality in small stock is 2.8 times than in cattle for our sample. On the other hand, cattle are more vulnerable to drought. These results are based on a cross-section of data representing a specific point in time. The data do not allow a more robust analysis of the dynamics of disease, drought risk, and herd composition over time.

It was also found that cattle abortions were negatively related to households' education expenditure and positively related to out-of-farm food costs and livestock management costs. Richer data to support identification would be needed to estimate the causal impacts of livestock disease on household expenditure.

Livestock disease and drought can be major contributing factors in poverty of livestock-dependent communities through their impact on herd value and income. Interventions and management strategies aimed at reduction of livestock disease and drought losses may improve herd and household welfare and alleviate poverty.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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