Quantifying farmers' preferences for antimicrobial use for livestock diseases in northern Tanzania

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Abstract

Understanding the choice behaviours of farmers around the treatment of their livestock is critical to counteracting the risks of antimicrobial resistance (AMR) emergence. Using varying disease scenarios, we measure the differences in livestock species' treatment preferences and effects of context variables (such as grazing patterns, herd size, travel time to agrovet shops, previous disease experience, previous vaccination experience, education level and income) on the farmers' treatment choices for infections across three production systems - agro-pastoral, pastoral and rural smallholder - in northern Tanzania, where reliance on antimicrobial treatment to support the health and productivity of livestock is high. Applying a context-dependent stated choice experiment, we surveyed 1224 respondents. Mixed logit model results show that farmers have higher preferences for professional veterinary services when treating cattle, sheep and goats, while they prefer to self-treat poultry. Antibiotics sourced from agrovet shops are the medicine of choice, independent of the health condition to treat, whether viral, bacterial or parasitic. Nearness to agrovet shops, informal education, borrowing and home storage of medicines, and commercial poultry rearing increase chances of self-treatment. Based on our findings, we propose interventions such as awareness and education campaigns aimed at

addressing current practices that pose AMR risks, as well as vaccination and good livestock husbandry practices, capacity building and provision of diagnostic tools.

Keywords: Antimicrobial use, antimicrobial resistance, antibacterial resistance, livestock production systems, Tanzania, preferences, context-dependent choice experiment, context variables

1. Introduction

Minimising risks of antimicrobial resistance (AMR) through reducing antimicrobial use (AMU) in livestock (Gozdzielewska *et al.* 2020) is an important public health goal (Frumence *et al.* 2021). However, globally, the demand for antimicrobials in the livestock sector is high, with further increases (of up to 67%) predicted by 2030 (Mangesho *et al.* 2021). This expected upsurge is driven by intensified livestock production systems in low-and-middle-income countries (LMICs) to support the growing need for animal protein in an expanding human population (Kimera *et al.* 2020; Mangesho *et al.* 2021). In sub-Saharan Africa, demand for antimicrobials is also likely to increase in traditional systems due to the importance of livestock to national and local economies (Ducrot *et al.* 2021). Here, livestock contributes to the economic and mental well-being of subsistence farmers by providing access to animal protein, cash income and trading opportunities (Nuvey *et al.* 2020). In addition, income from livestock enables farmers to meet basic needs such as food and medical care (Husøy *et al.* 2018).

In this context, infectious diseases of livestock, including those caused by antimicrobial-resistant pathogens, have major impacts (Bernabé *et al.* 2017; Tebug *et al.* 2021), threatening the livelihoods and wellbeing of farmers. In Tanzania, for example, bacterial resistance to frequently used antibiotics such as tetracyclines and ampicillin has been reported in different livestock species, including cattle, and sheep and goats (Frumence *et al.* 2021). There are several possible reasons for this. First, animal health professionals are poorly supported in making treatment decisions (Mangesho *et al.* 2021) due to a lack of veterinary infrastructure and of tailored antimicrobial stewardship programmes. Second, livestock keepers are often forced to self-administer antimicrobials to their livestock without professional advice (Caudell *et al.* 2017; Caudell *et al.* 2020) on recommended treatment doses, correct routes of administration and withdrawal periods (Frumence *et al.* 2021). Third, there is an assumption that discouraging the misuse and overuse of antimicrobials as understood in AMR interventions in high-income countries apply directly to LMIC settings. However, this is inconsistent with empirical research findings (Caudell et al. 2022) and could exacerbate the already high burden of infectious diseases on populations disadvantaged by poverty and limited access to healthcare. Fourth, livestock rearing, and veterinary care practices are associated with varying cultural beliefs, sociocultural and economic factors. These should be considered in the design of antimicrobial stewardship programs (Caudell *et al.* 2022). Fifth, LMIC governments suffer financial constraints (Rosenkrantz et al. 2019) and prioritisation of resources is necessary while addressing the needs of communities. Finally, more attention has been paid to tackling AMR in humans whilst very little has been done to counter AMR in livestock.

Due to the challenges we outline above, Tanzania, which is the focus of our study, adopted the agenda of the sixty-eighth World Health Assembly of May 2015 that encouraged member states to develop National Action Plans (NAPs) for antimicrobial resistance. Tanzania launched their own NAP (NAP-AMR 2017-2022) in 2017 based on One Health principles and approaches to address the complexities of AMR in systems where human and livestock health and wellbeing are tightly linked. The situational analysis presented in the NAP highlights inadequate regulation of antimicrobials, control, and prevention of infectious diseases (NAP-AMR 2017-2022). The Tanzania NAP-AMR outlines several research gaps and policy-related weaknesses. Those relevant to our study include limited information on patterns of and choices around antimicrobial use in livestock in agricultural communities as well as shortcomings in (i) policies on antimicrobial use and regulation in livestock, (ii) livestock husbandry practices, (iii) national livestock vaccination programs, (iv) enforcement of regulations around antimicrobial consumption and (v) awareness and knowledge of antimicrobial resistance amongst stakeholders, particularly in relation to the risks associated with antimicrobial use in livestock. To address these research and policy gaps, information is needed to develop tailored evidence upon which stewardship programs can be designed to counter AMR in Tanzania and similar systems. Currently, very little is known about the choice behaviours around antimicrobial treatment in livestock in communities across production systems in Tanzania and East Africa more generally. Our study was designed specifically to fill this gap in support of the Tanzanian NAP-AMR 2017-2022. We sought to understand the practices and choices around the use of antimicrobials in the treatment of common infections in livestock, identify the sources of the antimicrobials and whether professional advice to acquire them is available to communities, as well as investigate the husbandry practices they use.

By generating this evidence, we aimed to acquire critical information to inform behavioural change interventions that consider contextual differences to enable farmers to preserve the health of their livestock through improved treatment practices while minimising AMR risks. A successful intervention needs to be informed by an understanding of farmers' choice[1] patterns, their preferences, and drivers of AMU, and how these vary across and within livestock production systems. However, choice data as well as data on AMR and AMU more broadly are typically lacking (WHO, 2014).

Economists often obtain choice data and quantify individual preferences using discrete choice experiments (DCEs). In stated preference applications of DCEs, individuals face hypothetical choice situations containing two or more alternatives from which their preferences are estimated from their choice patterns. Such preference estimates are used to understand people's actual choice behaviour and priorities (Salampessy *et al.* 2015). In the area of animal health economics, single-context DCEs have been applied to understand and quantify farmers' preferences for treating Newcastle disease in poultry, and tuberculosis and contagious bovine pleuropneumonia vaccine attributes and uptake in cattle (Bennett and Balcombe, 2012; Kairu-Wanyoike *et al.* 2014; Isenge *et al.* 2020). Such preferences have been used to draw insights aimed at developing more acceptable vaccines that meet farmers' demand for a specific disease context. However, outcomes from DCEs based on a single context are hard to generalise to other contexts (Molin and Timmermans, 2010; Salampessy *et al.* 2015; Guo *et al.* 2021). This is because in a single-context DCE, it is assumed that individuals make rational choices which are independent of external circumstances other than those which the analyst can control for (Molin and Timmermans, 2010).

By contrast, a "contextual" DCE attempts to account for the variation of contexts within which individuals make decisions (Molin and Timmermans, 2010). The decision-making idea behind this thinking is that, when a particular decision problem is presented to an individual, they make an assessment and judgement based on their knowledge and expectations about the problem at hand, alongside personal specific attributes (Beresford and Sloper, 2008). Many studies have focused on understanding the variation of choices based on individual differences across various health-related contexts (e.g. Salloum *et al.* 2019; Richardson *et al.* 2020; Oluoch-Aridi *et al.* 2020). A growing body of literature demonstrates that choice patterns and preferences are indeed contextual (Guo *et al.* 2021). For instance, context-dependent choice

[1] A choice is an outcome of an evaluation process which consists of assessing and judging alternatives with perceived value to the individual making the choice (Beresford and Sloper, 2008).

patterns and preferences have been well researched and quantified in neuroscience (Louie *et al.* 2012; Spitmaan *et al.* 2019) and in transport (Molin and Timmermans, 2010; Guo *et al.* 2021). However, contextual variables are under-researched in the animal health literature and more specifically in understanding farmers' choice patterns and quantifying their AMU preferences in livestock. Contextual settings imply to changes in attributes that form the choice set, in the choice scenarios and the socio-cultural situations that constitute the environment within which choices are made. When considered, these aid the validation of the outcomes of the DCE (Molin and Timmermans, 2010).

Therefore, a context-dependent choice experiment is most suited to study AMU choice behaviour because the problem of AMR is not attributable to farmers' responses to risks connected to a single disease or animal species. Different diseases, affecting different livestock species, are likely to trigger varying responses. In the context-dependent choice experiment that we report in this study, we, therefore, focus on a range of disease syndromes[2] across different livestock species and production systems, and individual-specific characteristics to obtain farmers' choice patterns to quantify AMU preferences in livestock health.

We sampled households from three livestock production systems (smallholder, agro-pastoral and pastoral) in three districts (*Mwanga*, *Misungwi* and *Ngorongoro*, respectively) of northern Tanzania. We targeted households owning cattle, poultry, sheep and goats and presented them with three different treatment options for infectious diseases widespread in these settings: contagious bovine pleuropneumonia (CBPP), foot-and-mouth disease (FMD), peste des petits ruminants (PPR), Newcastle disease and coccidiosis. The attributes included source of treatment advice, medicine source, medicine type, action after treatment and cost of medicine. The rationale behind our design was that farmers choose treatment options from a set of available actions depending on (i) the clinical signs they observe, (ii) the type of livestock species (here, whether cattle, sheep and goats, or poultry) in which the clinical signs are observed, and (iii) the type of production system under which a farmer operates.

Our study contributes to the small but growing economics literature on AMR linked to livestock diseases. Whilst the specific empirical findings relate solely to the production systems studied in Tanzania, we believe that our approach is suited to a broad range of circumstances

[2] In the absence of diagnostic test to confirm agents causing disease, treatment is only restricted to disease syndromes that individuals can recognise (Bernabé *et al.* 2017).

where society wishes to intervene in livestock disease management as one means of reducing AMR.

2. Determinants of antimicrobial use

In LMIC settings, antimicrobials are not restricted to prescription-only use as is the case in developed countries, instead they are readily available to farmers (Caudell *et al.* 2022). As a result, farmers often self-administer them directly to their livestock without consulting a professional animal health specialist (Rosenkrantz *et al.* 2019; Caudell *et al.* 2022) and without observing the recommended administration practices (Frumence *et al.* 2021). Such practices can lead to the development of antimicrobial resistance, particularly in contexts where high infectious disease burdens create high demand for antimicrobials (Rosenkrantz *et al.* 2019). Antimicrobial use behaviours may vary depending on livestock husbandry practices. For instance, pastoralism, whereby livestock owners migrate in search of pasture and water for their animals, increases risks of livestock's exposure to pathogens, hence the need for antimicrobials (Caudell *et al.* 2017). The consequences of AMR include failure of treatments, prolonged and costly treatment and mortality of animals (Murray *et al.* 2019). Given the importance of livestock for livelihoods, AMR also threatens food security. It also threatens human health as a result of exposure to resistant bacteria through the environment or consumption of animal products (Caudell *et al.* 2020). The use of antimicrobials is projected to increase (Caudell *et al.* 2017) within a weak regulatory framework (Frumence *et al.* 2020), whilst a limited understanding of antimicrobial use persists. For more effective interventions to counter the externalities of AMR in animal health, it is important to establish how sociocultural and economic factors influence the antimicrobial treatment choices of farmers across a range of livestock systems and disease contexts.

Before tackling these specific questions, let us turn to the limited DCE literature on livestock diseases in LMIC settings. Kairu-Wanyoike *et al* (2014) quantified farmers willingness to pay (WTP) for CBPP vaccination in Kenya and the factors that influence it. The authors found that herd composition, duration since previous CBPP experience, income and education level influence WTP. Further, Isenge *et al* (2020) measured WTP and demand for Newcastle disease vaccine in poultry in DR Congo. The study determined that higher perception of risk and trust in veterinary support increase WTP. Frick *et al* (2003) also assessed WTP for the use of azithromycin to treat trachoma in Tanzania. In this study, female-headed households, marital status and lower income levels led to lower WTP. Higher WTP was more likely to result from a perceived potential benefit. However, these studies used single-context DCEs. This approach is not suited to contexts where a diversified range of livestock species co-exist and does not consider the internal and external contexts of decision-making. In addition, the studies reviewed above did not examine antimicrobial use in livestock.

Understanding the drivers of AMU in resource-poor settings is complex. From an economic perspective, factors that influence AMU can be classified into macro- and micro-level factors. Macro determinants are associated with higher-level (government) factors. These include a lack of up-to-date guidelines on antimicrobial prescription and of information on the negative consequences of their use, un-regulated access to antimicrobials, inadequate supply of diagnostic tools, poor availability of quality antimicrobials and insufficient mechanisms to generate AMR surveillance data (Bernabé *et al.* 2017; Kimera *et al.* 2020). Micro determinants relate to the choice behaviour of individuals in terms of factors which are (i) individual-specific, (ii) livestock-specific, (iii) production system-specific, (iv) disease-specific and (v) treatment-specific.

Individual-specific characteristics are those that relate to the respondents themselves such as education level, age and income. Gender has also been reported to play a major role, for example in influencing the preferences for vaccines against Rift Valley fever and lumpy skin disease among farmers in South Africa (Masemola *et al.* 2021). Livestock-specific attributes include factors such as the age of the animal considered at risk (Torsson *et al.* 2017). The third group of factors are production-system specific. For instance, herd size, livestock rearing practices and grazing patterns influence antibiotic use (Caudell *et al.* 2017). Animal health-seeking behaviours also vary. For example, farmers under smallholder production systems have more access to professional advice from animal health workers before using antimicrobials, whilst pastoralists tend to consult traditional healers and agrovet attendants (Caudell *et al.* 2020). The fourth category includes disease-related characteristics. Three main factors have been found to be relevant in different contexts, namely previous disease experience (Ahmed *et al.* 2017), perceived risk of infection (Masemola *et al.* 2021) and previous vaccination experiences. Finally, the characteristics of the treatment sought include factors such as veterinary costs (Fels-Klerx *et al.* 2011) and perceived side effects (Ancillotti *et al.* 2020).

3. Case study area: infectious diseases in northern Tanzania

Tanzania is a middle-income country with over 68% of its total population residing in rural areas and 22% of them deriving their income from livestock and livestock activities (Torsson *et al.* 2017). It has the third largest population of livestock in Africa after Ethiopia and Sudan with 17 million cattle and 21 million sheep and goats (Kivaria, 2003; Torsson *et al.* 2017).

Livestock production in northern Tanzania can be broadly classified into three main production systems - smallholder, agro-pastoral and pastoral (de Glanville *et al*. 2020). According to de Glanville et al (2020), these classifications suggest smallholder systems are characterised by mixed farming of small livestock herds and crop growing for subsistence and commercial purposes (de Glanville *et al*. 2020). Agropastoral systems involve medium to large herd sizes with crop production for own consumption and sale (de Glanville *et al*. 2020). Finally, the pastoral system is associated with large herd sizes and consistent migration of livestock in search for water and pasture (de Glanville *et al*. 2020). Using the classifications proposed by de Glanville *et al.* (2020), we categorise the three livestock production systems investigated in our study as smallholder (*Mwanga*), agro-pastoral (*Misungwi*) and pastoral (*Ngorongoro)*.

In this study, we focus on five infectious diseases of major importance in Tanzania: CBPP, FMD, and PPR in ruminants, and coccidiosis and Newcastle disease in poultry. CBPP is a highly infectious bacterial disease of cattle that causes high mortality and economic losses due to a decline in productivity (Kairu-Wanyoike *et al.* 2014). In Tanzania, CBPP impacts exceed an estimated $11 million per annum due to mortality, vaccination, disease surveillance, antibiotic costs, and reduced meat and milk production (Msami *et al.* 2001; Swai *et al.* 2013; Kairu-Wanyoike *et al.* 2014). FMD is a viral disease that affects cloven-hooved ruminants (cattle, sheep and goats) and non-ruminants (pigs) (Casey-Bryars *et al.* 2018; Kerfua *et al.* 2018). In Tanzania, direct and indirect losses affect households (Casey-Bryars *et al.* 2018; Ahmed *et al.* 2019). Further impacts arise from restriction of livestock movement within and across borders, and of the export of livestock products (Kivaria, 2003). PPR is a viral disease that affects sheep and goats and has a fatality rate of up to 100% (Torsson *et al.* 2017). In Tanzania, the economic costs of PPR are around $67.9 million per annum (Torsson *et al.* 2016). Coccidiosis is a protozoan disease affecting poultry, sheep and goats (Swai *et al.* 2013). Finally, Newcastle is a viral disease endemic in poultry (Campbell *et al.* 2019), whose likelihood of transmission is enhanced by the free-ranging nature of poultry production in Africa (Yongolo *et al.* 2011).

4. Context-dependent choice experiment

The choice experiment that we include in this study has three levels of design. The first level involves varying hypothetical disease scenarios based on the diseases described above and the livestock species affected. The second level consists of varying treatment options across livestock species, while the third level consists of varying choice sets across different livestock keepers.

4.1 Context-specific variables

The question of what individuals prefer in terms of antimicrobial use and what drives the decisions they make can be described by two main components: (i) the treatment and (ii) individual, livestock, production-system and disease-specific characteristics. From the former, we draw the attributes from which farmers' preferences are based. The drivers of such preferences are derived from the latter. However, disease-specific and treatment characteristics cannot be studied separately because people make choices of treatment options based on the disease in question. With this in mind, we draw unique contextual variables from livestock and production system characteristics and interact them with treatment attributes and disease contexts to explain behaviours around antimicrobial use for the treatment of livestock in northern Tanzania. We select our variables using a similar approach as that used by Molin and Timmerman (2010) and Guo *et al* (2021) to identify contextual variables for the choice of different transport modes.

The first contextual variable is *grazing type* which varies depending on whether livestock is kept under pastoral, smallholder or agro-pastoral systems (see de Glanville *et al*. 2020). The second variable is *herd size*, which also varies based on the production system (see Caudell *et al.* 2017; de Glanville *et al*. 2020). The third variable is the length of time individual farmers require to travel from their homestead to the agrovet/veterinary shops to purchase drugs. The fourth variable is whether a household keeps antimicrobials at home or not. The fifth and sixth variables are disease context-specific, and they include previous disease and vaccination experiences, respectively (for summaries of these variables see supplementary materials – S2 for Tables 4, 5 and 6).

To further explain how local settings shape individual decision-making, we consider two individual-specific characteristics - education level and household income - to act as proxies for health literacy and poverty levels, respectively. It is also worth noting that, especially in pastoral communities, household income is mainly derived from livestock, with cattle considered particularly valuable (Mugisha *et al.* 2008). For instance, when a cow succumbs to disease, small ruminants are sold to generate cash to buy antibiotics (see Caudell *et al.* 2017).

4.1 Experimental design

Before the main data collection, we conducted focus group discussions (FGDs) and in-depth interviews (IDIs) in the period between April – May 2019. We recruited farmers based on gender, age and education level to create heterogenous groups of 8-10 community members per FGD. Participants were representative of the three livestock production systems described above: smallholder, pastoral and agro-pastoral in *Mwanga, Ngorongoro* and *Misungwi* districts, respectively. In total, we conducted 6 FGDS and 2 IDIs on animal health issues only and 4 FGDs on both human and animal health issues.

These FGDs sought to first understand local perceptions of good and bad health in animals and people. Then we gathered information on the actions community members take when their livestock show signs of ill-health. We also asked them to list common diseases/disease syndromes in their community, their causes, names of medicines they use, the source of these medicines, the medicine costs and whether they were recommended by an animal health worker or not.

The resulting information was used to define attributes and attribute levels as well as choice scenarios. The attributes and attribute levels were developed for cattle, sheep and goats, and poultry separately (see Table 1). All the levels represent treatment options for clinical signs of diseases that commonly affect the different livestock types based on information provided by the community members who took part in the FGDs and IDIs. The disease syndromes that formed our hypothetical scenarios therefore were: CBPP and FMD in cattle, FMD and PPR in sheep and goats, and Newcastle disease and coccidiosis in poultry.

Table 1: Attribute and attribute levels for treatment options in cattle, poultry, sheep and goats

Attribute and attribute levels for treatment options for cattle		Attribute and attribute levels for treatment options for poultry	Attribute and attribute levels for treatment options for sheep and goats	
Attribute	**Levels**	**Levels**	**Attributes**	**Levels**
Action taken	▪ Call friends, relatives or neighbours ▪ Treat by yourself ▪ Call livestock officer	▪ Call friends, relatives or neighbours ▪ Treat by yourself ▪ Call livestock officer	**Action taken**	▪ Call friends, relatives or neighbours ▪ Treat by yourself ▪ Call livestock officer
Medicine type	▪ Medicine type A – Painkillers ▪ Medicine type B – Anti-parasites ▪ Medicine type C – Antibiotics	▪ Medicine type A - Herbal medicine ▪ Medicine type B – Antibiotics	**Medicine type**	▪ Medicine type A – Painkillers ▪ Medicine type B – Anti-parasites ▪ Medicine type C – Antibiotics
Medicine sources	▪ From vendors in open-air market ▪ From friends/relatives/neighbours ▪ From agrovet/veterinary drug shops	▪ From friends/relatives/neighbours ▪ From open air market ▪ From agrovets	**Action after medication**	▪ Slaughter ▪ Sell ▪ Isolate
Cost of treatment in Tanzania shillings	▪ 5000 (\$2.17) ▪ 9000 (\$3.90) ▪ 12000 (\$5.20) ▪ 15000 (\$6.50)	▪ 6000 (\$2.60) ▪ 9000 (\$3.90) ▪ 12000 (\$5.20) ▪ 15000 (\$6.50)	**Cost of treatment in Tanzania shillings**	▪ 9000 (\$3.90) ▪ 12000 (\$5.20) ▪ 15000 (\$6.50) ▪ 20000 (\$8.67)

The first attribute we included is *action taken* which represents the source of advice or lack thereof sought when a farmer observes clinical signs in cattle, sheep and goats, and poultry. The second attribute relates to the *medicine type* used to treat the disease syndromes hypothesised and it varied depending on the livestock species considered. *Medicine source* attributes included three options, namely open-air market, agrovets/veterinary drug shops or borrowed from friends/relatives/neighbours. In the sheep and goat design, the third attribute was adjusted to *action taken after medicine administration,* which comprised options such as selling, isolating or slaughtering sick animals. The latter was based on information obtained from FGDs, i.e. livestock keepers slaughter or sell their livestock only when they are sick and/ or when treatment fails. The fourth attribute is treatment *cost* in Tanzania shillings.

4.2 D-efficient designs

Bayesian D-efficient designs for cattle, sheep and goats, and poultry attributes and attribute levels were generated separately in Ngene Software. In the formulation of utility functions, the attribute levels of medicine type and source were fixed to ensure the resulting choice sets were logical. Generating D-efficient designs requires prior parameter estimates which we initially obtained based on expert judgment and preference rankings (see Bliemer and Collins, 2016). To avoid efficiency losses as we move from the experimental design to data analysis, we used a mixed logit model to generate the designs because it allows the variation of random parameters across respondents and alternatives (Bliemer and Rose 2010). We designed 24 unlabelled choice tasks per livestock species with four alternatives: ‘Option 1’, ‘Option 2’, ‘Option 3’ and ‘None of these’ (status quo). Choosing the status quo meant farmers chose to do nothing with the hope that clinical signs would disappear or gave the sick animal leftover medicine/local herbs harvested from the wild. The cost for the status quo option was assumed to be zero.

The choice cards were incorporated into a draft questionnaire which was piloted in selected villages in Kilimanjaro Region in October and November 2019. Ninety respondents were involved in the pilot phase. The choice data obtained were analysed in the R environment for statistical computing using the Apollo Package (see Hess and Palma, 2022) and the prior parameter estimates generated were used to update the Bayesian efficient designs used in the final data collection phase. The final version was accompanied by a set of 24 choice cards per livestock species. The resulting choice sets were organised and visualised using images to enhance comprehension among respondents (see Fig.1, Fig. 2 and Fig. 3).

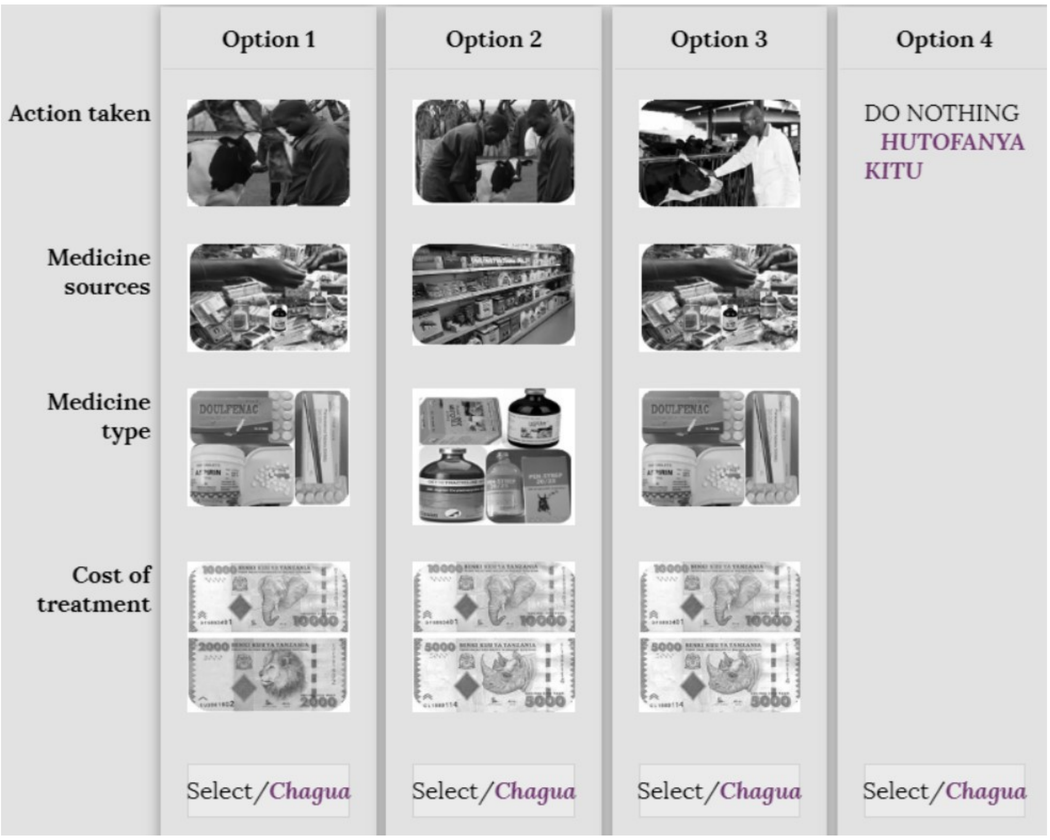


Fig.1: Example of a choice card for cattle scenarios.

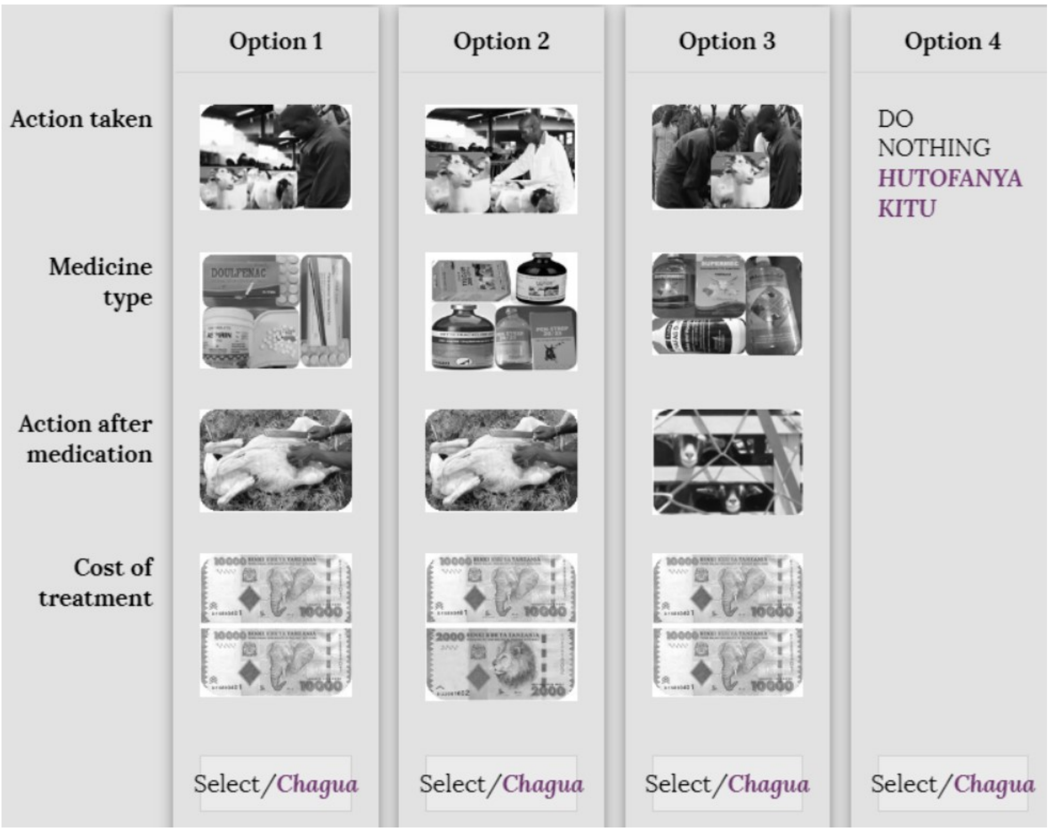


Fig. 2: Example of a choice card for sheep and goat scenarios.

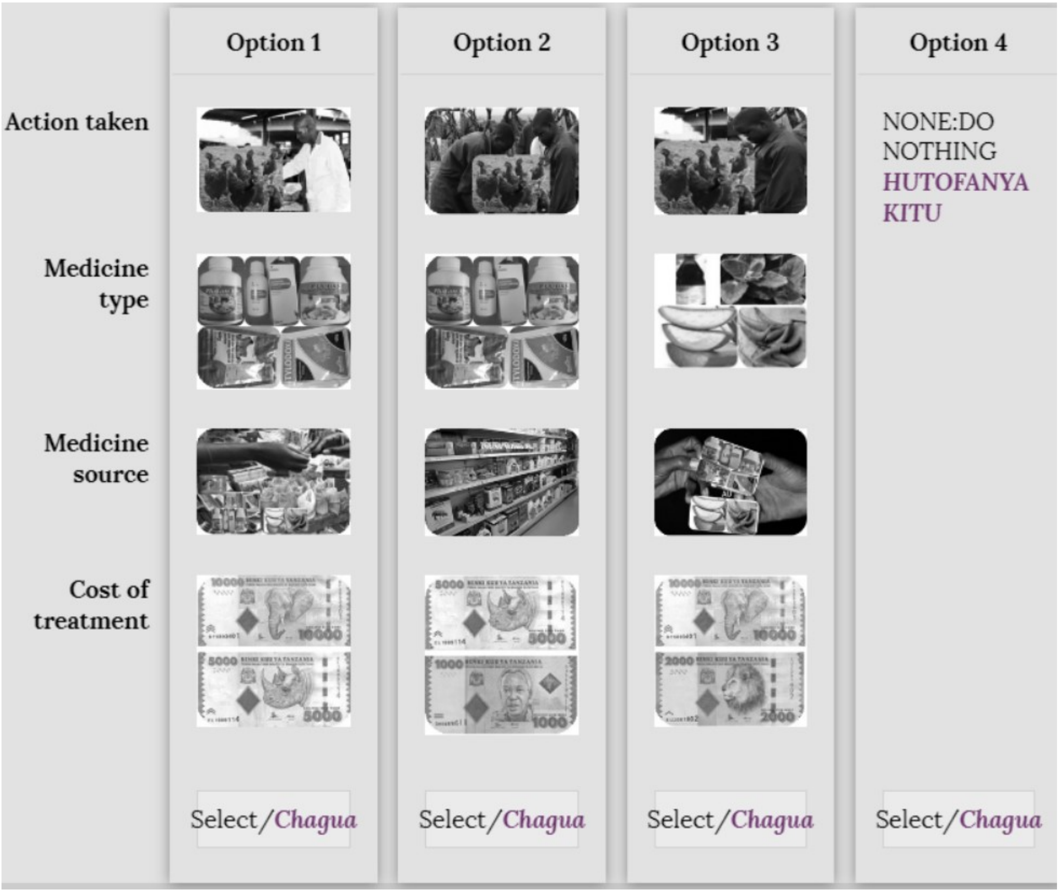


Fig. 3: Example of a choice card for poultry scenarios.

4.3 Survey design and administration

The web-based survey was designed using Light House Studio 9.6.1 and was administered during January – August 2021 by a team of 6 well-trained local research assistants using tablet computers. The survey was made up of two main sections, a human health part and an animal health part, but, in this paper, we concentrate on the section relevant to animal health. The first part of the survey collected data on individual and household-specific details such as gender, education level and income among others. The second section tackled information on livestock and production system: grazing patterns, livestock types in the household and herd/flock size. The third section assessed knowledge and awareness around previous disease experiences and associated treatment in livestock in the past 6 months. Respondents were presented with livestock disease scenarios and asked whether the disease had affected any animal in the household, who diagnosed it, perceived sources/causes, the number of animals affected, source of advice sought, name of the medicine used, source of medicine, cost and what the outcome was. The fourth section contained information on the choice experiment which consisted of two disease scenarios and follow-up questions aimed at assessing the reasons for the choices individuals made. The fifth section covered cattle disease prevention measures, particularly on whether the animal was vaccinated against the diseases hypothesised and if not why.

4.4 Sampling strategy

Respondents were selected from a total of six villages, with two villages per district: Msangeni and Lomwe (Mwanga), Soit Sambu and Engaresero (Ngorongoro), and Mbarika and Kijima (Misungwi). A multi-stage random sampling design was applied from district to village, sub-village and household level.

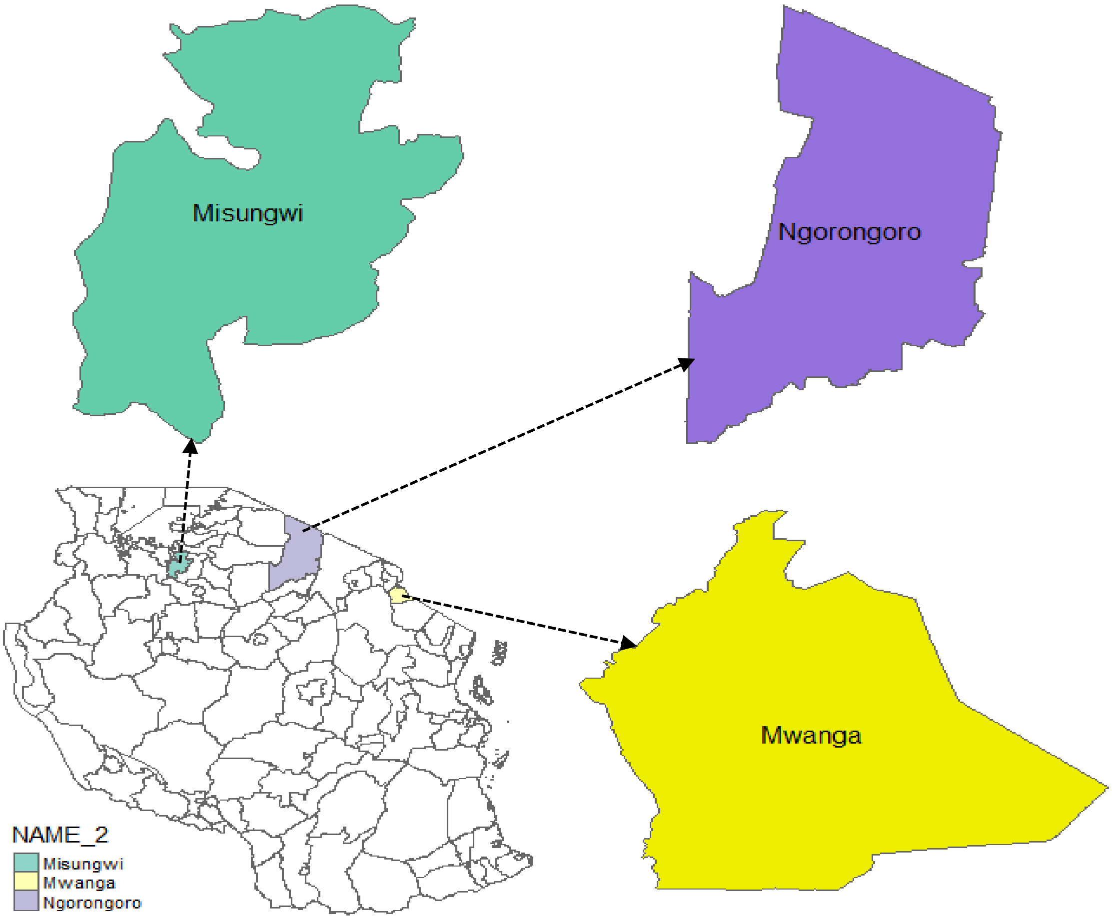


Fig 4: Map of the study area showing Mwanga, Ngorongoro and Misungwi districts of northern Tanzania.

Respondents comprised household heads and their spouses to ensure gender parity on experiences around livestock health and antimicrobial use. In each household, we presented two separate scenarios of disease syndromes for a single livestock species at a time. For instance, in the first household, the household head and spouse separately were presented with four sets of choice cards each at a time per scenario, to establish trade-offs between attributes of treatment options for CBPP and FMD in cattle. The same was done in the second household, but the disease scenarios and attributes of choice sets represented treatment options for Newcastle disease and coccidiosis in poultry. In the third household, the pair of respondents were treated the same way as in the cattle and poultry case but made trade-offs for treatment attributes' levels for PPR and FMD in sheep and goats.

4.5 Econometric analysis

Data were analysed using the multinomial logit model and mixed logit models. The multinomial logit (MNL) is the basic model used to analyse choice data, but the model structure restricts the variation of preferences. Therefore, to incorporate the identified contextual variables, a mixed logit model was selected as the most suited in estimating preference heterogeneity with changing decision contexts (see also Guo *et al*. 2021). We assume that the indirect utility (U_{kzy}) that individual k obtains from choosing alternative z in a choice situation y is made up of two components: a deterministic part V_{kzy} and random error ε_{kzy} and is formulated as

$$U_{kzy} = V_{kzy} + \varepsilon_{kzy} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Respondents' preferences for the chosen treatment option are assumed to vary according to the context within which their choices are made. As such the deterministic component is divided into two parts: a part-worth utility V_{kzy}^{p} and context-dependent utility V_{kzy}^{c} which assumes a linear relationship (see Guo *et al.* 2021). The indirect utility function is formulated as

$$U_{kzy} = V_{kzy}^{p} + V_{kzy}^{c} + \varepsilon_{kzy}, \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (2)$$

We assume that the part-worth utility V_{kzy}^{p} and the context-dependent utility V_{kzy}^{c} combined form a linear relationship with treatment attributes. To further understand how respondent's preferences for antimicrobial use are influenced by contextual variables, we included interaction effects such that the choice model is formulated as

$$U_{kzy} = \alpha_i + \beta_k X_{kzy} + \varepsilon_{kzy}, \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (3)$$

where X_{kzy} is a vector that contains treatment characteristics such as action taken, medicine type, medicine source, action after medicine administration and cost, interacted with contextual variables such as grazing patterns, herd size, travel time to reach an agrovet, previous disease experience, previous vaccination experience, education level and household income.

Further, since each respondent gets to choose from a total of 8 choice cards, then we formulate a panel mixed logit model whose choice probability is expressed as

$$P_{kzy} = \int \prod_{z=1}^{Z} \prod_{k=1}^{K} \frac{\exp(\beta_k X_{kzy})}{\sum_{k=1}^{K} \exp(\beta_k X_{kzy})} f(\beta\theta) d\beta. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

where β are the coefficient estimates that explain the distribution. The attribute and attribute levels in these studies are qualitative in nature and were coded using hybrid coding scheme (see supplementary material – S4).

We dealt with the effects of the no-choice option during analysis by introducing an alternative specific constant (ASC) into the utility function for the opt-out option to capture unobservable effects beyond the attributes present in the utility function (Meyerhoff and Liebe, 2009; Campbell and Erdem, 2018). More specifically, the choice alternative entered the utility function as a constant, $\gamma_{\ no\ choice\ i}$ where, γ is the alternative specific constant, and $no\ choice_i$ represents 0 if an individual selects opt_out option (i.e owing to the hybrid coding scheme where status quo is coded as 0), and 1 otherwise.

4.6 Estimation of willingness to pay (WTP) for random parameters

To obtain standard errors and willingness to pay confidence intervals, we use the Delta method (Hole, 2007; Daly *et al.* 2012; Bliemer and Rose, 2013). Our non-cost attributes followed a normal distribution while cost attributes assume a log-normal distribution (see Daly *et al.* 2012). A random cost coefficient allows preferences to vary across respondents and avoid potential biases in WTP estimates (Bliemer and Rose, 2013). We estimated the true variation of the mean willingness to pay as we move away by estimating confidence limits at 95%, (SE $\pm$ 1.96) which gives us information on the maximum and minimum values beyond which 2.5% of the likelihood lies (Daly *et al.* 2012). According to Meginnis *et al (*2020), the mathematical description of the willingness to pay for random parameters is as follows.

$$WTP_x = \frac{\beta_{x + \sigma_x + \emptyset_x}}{\beta_{cost}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where WTP_x is the willingness to pay for treatment attribute x e.g. veterinary officer, self-treatment etc, while σ_x is the standard error estimated using Delta method and $\emptyset_x$ represents each draw from the standard normal distribution of the non-cost attribute x and β_{cost} is the cost coefficient estimate.

5. Results

5.1 Characteristics of the sample

We collected data from 1224 respondents (equivalent to a total of 612 households). The data we collected were almost evenly distributed across questions on cattle (33%), poultry (34%) and sheep and goats (33%). There were equal proportions of male (50%) and female (50%) respondents across the three livestock species scenarios, owing to the sampling procedure targeting both household heads and their spouses. In terms of age, respondents keeping cattle (65%) and sheep and goats (73%) were relatively younger, while more elderly respondents (72%) kept poultry. Most of the respondents among the cattle (65%), sheep and goats (73%), and poultry (78%) keepers had received some formal education. Concerning income[3], we classified respondents into two categories, low-income (TSh 1 – 300,000 equivalents to \$0.00043 - 129.98 per month) and high-income (TSh > 300,000, equivalent to >\$129.98 per month) earners. More low-income earners kept cattle (72%), and sheep and goats (50%), while more high-income earners kept poultry (85%). Most farmers keeping cattle (67%), and sheep and goats (64%) practised communal grazing. A substantial number of bird keepers (66%) reared poultry for commercial reasons. Herd sizes were estimated and expressed using a common measure known as Tropical Livestock Units (TLUs)[4] (Nthambi *et al.* 2021). TLUs per respondent were calculated by multiplying each of the livestock species with a conversion factor, and then summed up per respondent.

[3] Our classification followed the World Bank's definition of a low-income earner as someone living with less than \$1.90 (Tshs 4,385.20) a day (World Bank, 2022). Therefore, farmers in our study earning TSh 1 - 300,000 (\$0.00043 -\$129.98) per month, which, on an average 30-day month, translates to \$0.00001 – \$ 4.333 a day, were considered low-income earners, while those earning >\$4.333 were classified as high-income earners.
[4] Livestock numbers were converted into common Tropical Livestock Units as follows: cattle = 0.7, sheep = 0.1, goats = 0.1, chickens = 0.01 units (Nthambi *et al.* 2021).

We found that very few households had experienced the diseases of interest in the previous 6 months in all species of focus: cattle (FMD [13%] and CBPP [17%]), sheep and goats (FMD [2%] and PPR [12%]), and poultry (Newcastle [9%] and coccidiosis disease [1%]). Low rates of previous vaccination were also reported in all species: cattle (FMD [9%], and CBPP [6%]), sheep and goats (FMD [6%] and PPR [8%]), and poultry (Newcastle [21%] and coccidiosis disease [7%]). Few farmers kept medicines at home for livestock treatment of cattle (13%), sheep and goats (15%), and poultry (16%). Table 2 summarises further the characteristics of the respondents sampled in the study area.

Table 2: Summary characteristics of respondents sampled in the study area.

	Cattle		Sheep and goats		Poultry	
Covariate's description	**Count**	**%**	**Count**	**%**	**Count**	**%**
Age						
-Young 20-50 years	231	57	211	52	117	28
-Elderly/old >= 51 years	173	43	194	48	298	72
Gender						
-Male	201	50	202	50	208	50
-Female	203	50	203	50	207	50
Income level*						
-Low (TSh 1 - 300,000 [$0.00043 - $129.98])	289	72	297	50	56	15
-High (TSh > 300,000 [>$129.98])	115	28	297	50	312	85
Education level						
-Formal training	33	65	296	73	324	78
-No formal training	18	35	109	27	91	22
Vaccination cattle						
-Vaccinated against CBPP	25	6				
-Not vaccinated against CBPP	379	94				
-Vaccinated against foot-and-mouth disease	36	9				
-Not vaccinated against foot-and-mouth disease	368	91				
Vaccination sheep and goats						
-Vaccinated against PPR			34	8		
-Not vaccine against PPR			371	92		
-Vaccine against foot-and-mouth disease			22	6		

-Not vaccinated against foot-and-mouth disease			371	94		
Vaccination poultry						
-Vaccinated against Newcastle disease					84	21
-Not vaccinated against Newcastle disease					316	79
-Vaccinated against coccidiosis disease					30	7
-Not vaccinated against coccidiosis disease					374	93
Experienced disease in cattle						
-Foot-and-mouth disease	54	13				
-No foot-and-mouth disease	350	87				
-CBPP	69	17				
-No CBPP	335	83				
Experienced disease in sheep and goats						
-Foot-and-mouth disease			9	2		
-No foot-and-mouth disease			396	98		
-PPR			50	12		
-No PPR			355	88		
Experienced disease in poultry						
-Newcastle disease					37	9
-No Newcastle					378	91
-Coccidiosis					6	1
-No coccidiosis					409	99
Grazing type						
-Communal grazing	271	67	258	64		
-Other grazing types	133	33	147	36		
Rearing type						
-Commercial purposes					275	66
-Other poultry rearing systems					140	34
Medicines kept at home for livestock treatment						
-Yes	52	13	61	15	15	16
-No	352	87	344	85	85	84
Proximity to agrovet in minutes (average time)	58		41		52	
Average herd size in Tropical Livestock Units	25		19		21	

*TSh -Tanzania shillings, CBPP = contagious bovine pleuropneumonia, PPR = peste des petits ruminants, FMD = foot and mouth disease

We interacted the above variables with treatment attributes to account for preference heterogeneity. Using the approach of Hess and Palma, (2022), for the Appollo Package in R, we computed interactions of attributes and contextual variables prior to the definition of the actual utility functions by creating new parameters for each treatment attribute carrying the effect of the specific attribute's alternative specific constant and its interaction impact with contextual variables. The new parameter entered each utility function once instead of being repeated across all utilities which could lead to unnecessary calculations (Hess and Palma, 2022).

More specifically, if farmers chose to call a veterinary officer, their decision was determined by their education level, previous experience with vaccination against hypothesised diseases and the grazing type. For self-treatment attributes, education, home storage of medicines, time to agrovet and grazing type influenced farmers' decisions. We used grazing patterns as a proxy for the livestock production system, where we assumed that communal grazing was common among pastoralists and agro-pastoralists, while zero-grazing was practiced by small-holder farmers. However, in poultry, in place of grazing pattern, we interacted action taken attribute levels with poultry rearing patterns.

The medicine type that farmers selected was determined by whether they had gained previous knowledge from treating the hypothesised disease in the household in the last 6 months. Medicine source depended on the size of the livestock herd where we hypothesised that farmers with smaller herd sizes were more likely to borrow medicines, while those with large herd sizes were likely to purchase antimicrobials from agrovet shops and open-air markets. Further, for biosecurity measures in sheep and goats, a farmer's decision to isolate or sell ill animals depended on their education level and the size of their herds. Finally, the amount an individual chose to pay for the treatment of a disease depended on household's income and education level in cattle and poultry, and income and herd size in sheep and goats. Therefore, we hypothesised that farmers with higher income, education levels, and larger herd sizes would pay more.

5.2 Choice modelling results

We fitted multinomial logit models as a first check on the choice data before estimating a series of mixed logit models for cattle, sheep and goats, and poultry. Estimates from the multinomial logit model show that preferences are the same across individuals, while those of the mixed logit models denote heterogeneity across individuals, hypothetical scenarios and alternatives (Nthambi *et al.* 2021). For the cattle mixed logit model results (Table 3), farmers have a positive and significant marginal utility for a call to the veterinary officer and a negative insignificant marginal utility for self-treatment. The coefficient estimate for antibiotic use is positive and significant while that of anti-parasites is negative and significant - implying a higher preference for antibiotics over anti-parasites. The preferred medicine source for cattle keepers would be an agrovet shop over borrowing from friends/relatives/neighbours or purchasing from open-air markets. We find significant differences in choice behaviour based on herd size, medicine storage at home for livestock, grazing type, proximity to agrovet, previous FMD illness, and previous FMD and CPBB vaccination experiences. The coefficient estimate for herd size is negative and statistically significant when interacted with time to agrovet shops, suggesting a potential for borrowing medicines from friends/relatives/neighbours among farmers with smaller herd sizes. Further, preference variation is observed based on medicine storage at home and travel time to an agrovet. Farmers who make use of communal grazing would have a higher probability to consult a vet.

There is also heterogeneity in choice behaviour regarding the specific medicine type chosen to treat cattle. The "previous FMD illness experience" estimate is negative and significant when interacted with antibiotics as medicine type, meaning that farmers who have previously treated cattle with FMD are less likely to use antibiotics when they observe similar signs in cattle in the future. We find hesitation to consult a veterinary officer for cattle vaccinated against FMD and CBPP in the previous 6 months.

Table 3: Marginal coefficient estimates for the treatment attributes of foot-and-mouth disease (FMD) and contagious bovine pleuropneumonia (CBPP) in cattle.

Attributes and covariates	Multinomial logit Coeff. (St. error)	Mixed logit model Coeff. (st. error)	Mixed logit model St. Dev (st. error)
Action taken			
•Call a livestock health officer	0.580*** (0.044)	0.726*** (0.136)	2.732*** (0.134)
•Treat cattle by yourself	0.046 (0.043)	0.124 -0.169	2.499 (0.124)
•Call friends/relatives/neighbours[a]	-0.626	-0.85	
Medicine type			
•Antibiotics	0.299*** (0.034)	0.642*** (0.064)	1.284*** (0.064)
•Anti-parasites	-0.279** (0.036)	-0.551*** (0.061)	1.231* (0.061)
•Pain killers[b]	-0.02	-0.091	
Medicine source			
•Agrovet shop	0.456*** (0.037)	0.982*** (0.080)	1.601*** (0.080)
•Friends/relatives/neighbours	-0.006 (0.035)	-0.071 (0.080)	1.605 (0.080)
•From vendors in open-air market[c]	-0.45	-0.911	
Cost of treatment	-0.055*** (0.010)	-1.068*** (0.131)	2.629*** (0.131)
No choice	-6.231*** (0.581)	-6.516*** (0.601)	
Interaction effects			
Education level * vet *self*cost	0.019* (0.010)	0.014 (0.029)	
Herd size*agrov*frnds	-0.0005* (0.0002)	-0.001** (0.001)	
Medicine kept home for livestock*self	0.016 (0.069)	-0.481** (0.195)	
Grazing type*vet*self	-0.206*** (0.032)	0.321* (0.164)	
Time to agrovet * self	0.0004 (0.0003)	0.002*** (0.001)	
Previous FMD * antib	-0.184*** (0.072)	-0.335*** (0.132)	
Previous CBPP * antip	0.041 (0.040)	0.120 (0.083)	
Previous FMD vaccination * vet	-0.325 *** (0.084)	-1.066*** (0.321)	
Previous CBPP vaccination * vet	-0.477*** (0.106)	-1.482*** (0.442)	
Income level * cost	0.009 (0.013)	0.017 (0.023)	
Log-likelihood	-3353.126	-3204.873	
Akaike information criterion (AIC)	6744.25	6461.75	
Bayesian Information Criteria (BIC)	6859.79	6619.85	
Number of individuals	404	404	

*** = $p < .01$, ** = $p < .05$, * = $p < .1$

*[a,b,c] These base levels of the effects-coded attributes are not set to zero in hybrid coding scheme rather we estimate them as the negative sum of the coefficient estimates of the other two levels (Cooper *et al.* 2012; Nthambi *et al.* 2021).

vet - *call to a livestock health officer*, self - *treat cattle by yourself*, antib - *antibiotics*, antip - *anti-parasites*, agrov – *from agrovet shop*, frnds – *from friends/relatives/neighbours*, cost - *the cost of the treatment*

Findings from the sheep and goat mixed logit model (Table 4) show that the marginal utility coefficient for a call to a veterinary officer is positive and significant, while that of self-treatment is negative and insignificant, meaning farmers prefer to consult a vet over self-treatment. Further, farmers prefer to use antibiotics to treat their sheep and goats instead of using anti-parasites. The preferred biosecurity measure is isolation which has a positive and significant coefficient estimate over selling or slaughtering ill sheep and goats. Preference heterogeneity in choice behaviour among sheep and goat's farmers is observed based on education level, home storage of livestock medicine, time to agrovet shop, previous FMD vaccination and PPR illness experiences.

Table 4: Marginal coefficient estimates for the treatment attributes of foot-and-mouth disease (FMD) and peste des petits ruminants (PPR) in sheep and goats.

Attributes and covariates	Multinomial logit Coeff. (st. error)	Mixed logit model Coeff. (st. error)	Mixed logit model St. Dev (st.error)
Action taken			
• Call a livestock health officer	0.487*** (0.045)	0.616*** (0.180)	3.621*** (0.180)
• Treat sheep and goats by yourself	-0.015** (0.064)	-0.376** (0.172)	3.461** (0.172)
• Call friends/relatives/neighbours[a]	-0.502	-0.24	
Medicine type			
• Antibiotics	-0.066** (0.032)	0.280*** (0.074)	1.484*** (0.074)
• Anti-parasites	0.050 (0.034)	-0.036 (0.073)	1.469 (0.073)
• Pain killers[b]	-0.116	-0.244	
Action after treatment			
• Isolate ill sheep/goats	0.970*** (0.051)	3.193*** (0.162)	3.261*** (0.162)
• Sell ill sheep/goats	-0.247*** (0.041)	-0.089 (0.114)	2.291 (0.114)
• Slaughter sheep/goats[c]	-0.723	-3.104	

Cost of treatment	-0.059*** (0.007)	-0.923*** (0.129)	2.587*** (0.129)
No choice	-6.651*** (0.588)	-8.014*** (0.881)	
Interaction effects			
Education level*vet*self*isol*sell	0.031 (0.021)	-0.252*** (0.080)	
Herd size * sell * isol * cost	-0.0002** (0.00007)	-0.0002 (0.0002)	
Medicine kept home for livestock * self	0.414*** (0.076)	0.839*** (0.216)	
Grazing system * vet * self	-0.406*** (0.037)	-0.227 (0.148)	
Time to agrovet * self	0.0009*** (0.0003)	0.002* (0.001)	
Previous foot-and-mouth disease vaccination * vet	0.375*** (0.116)	0.765* (0.001)	
Previous PPR vaccination * vet	-0.216** (0.091)	0.365 (0.340)	
Previous FMD * antib	-0.008 (0.163)	0.225 (0.421)	
Previous PPR * antip * antib	0.078* (0.044)	0.161* (0.090)	
Income level * cost	-0.00008 (0.0001)	0.0005 (0.0004)	
Log-likelihood	-3039.512	-2920.812	
Akaike information criterion (AIC)	6117.02	5893.62	
Bayesian Information Criteria (BIC)	6232.61	6051.79	
Number of individuals	405	405	

*** $= p < .01$, ** $= p < .05$, * $= p < .1$

*[a,b,c] These base levels of the effects-coded attributes are not set to zero in hybrid coding scheme rather we estimate them as the negative sum of the coefficient estimates of the other two levels (Cooper *et al.* 2012; Nthambi *et al.* 2021).

Vet – *call to a livestock health officer*, self – *treat sheep and goats by yourself*, antib – *antibiotics*, antip – *anti-parasites*, isol – *isolate ill sheep/goats,* sell –*sell ill sheep/goats*, cost – *the cost of the treatment*

Farmers who keep poultry have a positive and significant coefficient estimate for both self-treatment and calling a veterinary officer (see Table 6). However, a larger and more significant coefficient estimate for self-treatment shows a higher preference for self-medication in poultry over consulting a vet. Farmers also prefer to treat coccidiosis and Newcastle disease using both antibiotics and herbal medicine but have a slightly higher preference for herbal medicine. A larger and positive marginal coefficient estimate indicates a higher preference for use of agrovet shops over sourcing medicines from friends/relatives/neighbours and open-air markets. In poultry, farmers' preferences differ based on the type of rearing system, their education and income levels. For example, farmers with a greater education level have a higher probability of seeking professional veterinary services, whilst we find changes in price sensitivity of treatment options as income increases.

The cost of treatment coefficients for cattle, sheep and goats and poultry models are all negative and significant. The coefficient estimates for the alternative specific constants (ASC) for all our scenarios are negative and statistically significant which means that farmers prefer alternative treatment options over those proposed in our choice cards. These other options may include the use of leftover medicines, medicines sourced directly from veterinary officers, the use of herbs, or husbandry practices such as culling of sick animals to separate them from the healthy ones.

Table 5: Marginal coefficient estimates for the treatment attributes of Newcastle disease and coccidiosis in poultry.

Attributes and covariates	Multinomial logit Coeff. (st. error)	Mixed logit model Coeff. (st. error)	Mixed logit model St. Dev. (st. error)
Action taken			
• Call a livestock health officer	0.372*** (0.059)	0.274* (0.152)	3.090* (0.152)
• Treat poultry by yourself	0.321*** (0.040)	0.476*** (0.081)	1.662*** (0.081)
• Call friends/relatives/neighbours[a]	-0.693	-0.75	
Medicine type			
• Antibiotics	-0.095 (0.101)	2.316*** (0.141)	2.873*** (0.141)
• Herbal medicine	0.086 (0.077)	2.687*** (0.113)	2.306*** (0.113)
Medicine source			
• Agrovet shop	0.412*** (0.057)	0.393*** (0.075)	0.531*** (0.075)
• From friends/relatives/neighbours	-0.154*** (0.055)	0.265*** (0.143)	2.913* (0.143)
• From vendors in open-air market[b]	-0.258	-0.658	
Cost of treatment	-0.103*** (0.010)	-6.480*** (1.021)	20.823*** (1.021)
No choice alternative	-4.188*** (0.178)	-3.157*** (0.312)	
Interaction effects			
Education level * vet * self * cost	0.049*** (0.010)	0.035* (0.021)	
Herd size * agrov * frnds	0.0001 (0.0004)	-0.0004 (0.003)	
Medicine kept home for livestock * self	0.253*** (0.062)	0.176 (0.123)	
Rearing system * vet * self	-0.158*** (0.034)	-0.208*** (0.080)	
Time to agrovet *self	0.0001 (0.0003)	0.0006 (0.0006)	
Previous coccidiosis *antib *herb	-0.005 (0.096)	0.259 (0.276)	
Previous Newcastle disease vaccination *vet	0.150* (0.082)	0.153 (0.213)	
Previous coccidiosis vaccination * vet	-0.154 (0.121)	-0.154 (0.318)	

Income level * cost	0.0006*** (0.0002)	0.001** (0.0004)
Log-likelihood	-3527.742	-3199.802
Akaike information criterion (AIC)	7091.48	6449.6
Bayesian Information Criteria (BIC)	7201.42	6602.3
Number of individuals	415	415

*** $= p < .01$, ** $= p < .05$, * $= p < .1$

*[a,b,c] These base levels of the effects-coded attributes are not set to zero in hybrid coding scheme rather we estimate them as the negative sum of the coefficient estimates of the other two levels (Cooper *et al.* 2012; Nthambi *et al.* 2021).

vet - *call to a livestock health officer*, self - *treat poultry by yourself*, antib - *antibiotics*, herb- *herbal medicine*, agrov – *from agrovet shop,* frnds –*from friends, relatives and neighbours*, cost - *the cost of the treatment*

5.3 Willingness to pay for treatment of livestock diseases

In Table 6, we present WTP for the treatment attributes of FMD and CBPP in cattle, FMD and PPR in sheep and goats, and Newcastle and coccidiosis diseases in poultry. For the cattle WTP estimates we describe all other attribute levels except for self-treatment and medicine source from farmers/friends/relatives, both of which are statistically insignificant in the preference model. Farmers' WTP for access to a veterinary officer is TSh 680 ($0.29). On the other hand, the WTP for antibiotics is TSh 602 ($0.26) while that for anti-parasites is estimated at TSh (-516) ($ -0.22). Farmers' WTP for an agrovet shop as a source of these medicines is estimated at TSh 919 ($0.40).

For the sheep and goats WTP to pay estimates, we describe all treatment attributes except for one attribute level medicine type - *anti-parasites* - and the action taken after treatment level – *sell ill sheep/goats,* because their marginal coefficient estimates were insignificant. Farmers' mean WTP estimate for a veterinary officer when clinical signs of FMD and PPR are observed is TSh 668 ($0.29). The mean WTP for antibiotics is TSh 303 ($0.13) while that of isolation of ill animals is TSh 3459 ($1.50).

Finally, the mean WTP to consult a veterinary officer is estimated at TSh 42 ($0.018), while that of self-treatment in poultry is TSh 74 ($0.032). Regarding medicine type, the mean WTP for herbal medicine is TSh 415 ($0.18) and is slightly higher than that of antibiotics at TSh 357 ($0.15).

Table 6: Mean willingness to pay for the treatment of foot-and mouth disease (FMD) and contagious bovine pleuropneumonia (CBPP) in cattle, foot-and-mouth disease (FMD) and peste des petits ruminants (PPR) in sheep and goats, and Newcastle and Coccidiosis diseases in poultry.

Treatment attributes for cattle	**Mean willingness to pay in Tanzania shillings in cattle (TSh) (95% Confidence Interval)**	**Treatment attributes for poultry**	**Mean willingness to pay in Tanzania shillings (TSh) in poultry (95% Confidence Interval)**	**Attribute attributes for sheep and goats**	**Mean willingness to pay in Tanzania shillings (TShs) in sheep and goats (95% Confidence Interval)**
Action taken		**Action taken**		**Action taken**	
Call a livestock health officer	680 (310, 1049)	Call a livestock health officer	42 (-104, 188)	Call a livestock health officer	668 (71, 1264)
Treat by yourself	-158 (-455, 139)	Treat by yourself	74 (34 113)	Treat by yourself	-408 (-864 49)
Medicine type		**Medicine type**		**Medicine type**	
Antibiotics	602 (388, 815)	Antibiotics	357 (107, 606)	Antibiotics	303 (15 592)
Anti-parasites	-516 (-711, -321)	Herbal medicine	415 (137, 692)	Anti-parasites	-39 (-308, 231)
Medicine source		**Medicine source**		**Action after treatment**	

From Agrovet shop	919 (575, 1264)	From Agrovet shop	61 (21, 100)	Isolate ill animals	3459 (2154 4764)
From friends/relatives/neighbours	-66 (-233, 100)	From friends/relatives/neighbours	41 (-89, 171)	Sell ill animals	-97 (-391, 197)
Opt-out option		**Opt-out option**		**Opt-out option**	
No choice	-6102 (-8,623, -3,581)	No choice	-487 (-960 -14)	No choice	-8682 (-13312 -4052)

6. Discussion

Our study assessed farmers' heterogeneity preferences for and contextual effects of different treatment options across livestock production systems - agro-pastoral, pastoral and smallholder -, and livestock species - cattle, sheep and goats and poultry - in northern Tanzania, using a context-dependent discrete choice experiment which incorporates use of antimicrobials for a range of diseases. Overall, we show that choice behaviour for treatment advice, medicines and their sources differ across individual farmers and livestock species. These results highlight the need to draw from our understanding of the diversified use and demand for antimicrobials in order to develop antimicrobial stewardship programs, since these will likely vary across livestock production systems and disease contexts.

More specifically, we show that farmers would prefer to seek professional veterinary services when they observe clinical signs consistent with FMD and CBPP, and FMD and PPR in cattle, and sheep and goats, respectively. Caudell *et al.* (2017) also observed variations in use of professional services but these were mainly associated to the type of livestock production with rural smallholders being more likely to consult a veterinary officer. High willingness to pay among cattle keepers in our study implied a higher chance to consult veterinary officers to treat cattle probably because of their high asset value (Caudell *et al.* 2017). However, poultry farmers prefer to self-treat their birds over consulting a veterinary professional when coccidiosis and Newcastle disease occur on their farms. Nonga *et al.* (2008) also report self-administration of antimicrobials in poultry in Morogoro, Tanzania.

Farmers prefer to use antibiotics when treating FMD and CBPP in cattle, FMD and PPR in sheep and goats, and coccidiosis and Newcastle diseases in poultry. These results are consistent with other studies that have reported antibiotic use for diseases such as CBPP, FMD, PPR and Newcastle disease (FAO, 2007; Balamurugan *et al.* 2014; Rugumisa *et al*. 2016; Caudell *et al.* 2017). This is problematic because in most of these cases antibiotic treatment does not have therapeutic benefit. For example, farmers in Africa use antibiotic treatment in cattle with CBPP because it reduces disease pressure and mortality rates, although it does not cure the disease (FAO, 2007). FMD, PPR and Newcastle disease are viral infections that cannot be treated with antibiotics. While there may be benefits arising from using antibiotics to prevent secondary infections in animals with FMD or PPR, there is no therapeutic advantage in terms of the diseases. However, there are potentially high repercussions in terms of development of bacterial resistance (Ekakoro and Okafor, 2019) and environmental contamination with antibiotic residues (FAO, 2007). For example, antimicrobial residues have been detected in eggs produced for commercial purpose in Tanzania (Nonga *et al.* 2008). Overall, our findings highlight the need for improved antibiotic stewardship in communities.

However, such programs need to consider the differences in sociocultural and economic settings. Our findings show that antimicrobial use behaviour is context dependent. After we accounted for both choice and context dependent variables in our model, we identified preference heterogeneity of treatment attributes in cattle, sheep and goats, and poultry. Although farmers across all three livestock production systems and species obtain medicines from agrovet shops as in Mangesho *et al* (2021), farmers with smaller herd sizes may borrow medicines from friends/relatives/neighbours. In cattle, the most important context variable is time to the agrovet shop where shorter durations increase WTP for self-treatment. As such, living close to agrovet shops increases self-treatment likely owing to easy access to antimicrobials (Mangesho *et al.* 2021). In sheep and goats, informal education and previous FMD experience is likely to lead to lower WTP to isolate infected animals and consult a vet, while previous PPR experience increase WTP for anti-parasites and antibiotics. Therefore, farmers without formal education were more likely to self-treat and sell ill animals compared to those with higher education levels. In communal grazing systems, farmers were more likely to consult a veterinary officer (see also Caudell *et al.* 2017) but self-treatment was associated with high WTP in poultry even under commercial poultry rearing systems where potential economic losses could occur (see also Nonga *et al.* 2008). Our findings on self-treatment conform to those of Davis *et al* (2022) who argue that choosing to self-medicate is driven by multiple factors beyond failure to seek professional help, including inadequate health services and a lack of trust between farmers and health care providers (see also Davis *et al.* 2021).

7. Conclusions and policy recommendations

This paper uses stated preference choice modelling to estimate farmers' preferences for livestock disease treatment in Tanzania, focussing on factors which need to be considered in the context of antimicrobial resistance. We find that decisions over whether to "self-treat" or consult a professional advisor vary across livestock species, but that preferences for medicine type (i.e. antibiotics) and medicine source (i.e. agrovet shops) remain the same in cattle, sheep and goats, and poultry. Antibiotics are not the only medicines used in the treatment of livestock. For example, we found a high preference for use of herbal medicine in poultry and lower preferences for anti-parasites in cattle and sheep and goats. Although farmers are willing to pay for professional veterinary services, self-treatment choices may be associated with limited access to these services especially in the most remote areas.

We acknowledge a potential bias of our findings based on respondents' prior knowledge that consulting a veterinarian is the correct course of action. Nonetheless, we assumed that respondents gave true answers based on how much value they place on different livestock species. Caudell *et al* (2017) argues that farmers place higher value on cattle and that small stock are more disposable. However, even assuming that respondents provided accurate answers, we still believe that antimicrobials use will overlap across livestock production systems as we observe farmers' high preferences and WTP to consult a vet across production systems. Farmers' understanding that the correct choice is seeking professional help may have led to an over-estimation of WTP to consult a vet. In addition, if farmers decide to use more expensive drugs to treat cattle disease, they will have less budget available to make similar choices for poultry, sheep and goats. A belief that partly drives AMU in cattle is likely to also drive use in other livestock types.

Overall, our study provides evidence of practices around antimicrobial use across communities and livestock species, and the underlying factors driving such practices. Our results enable us to provide a number of recommendations in support of the research and policy gaps outlined in the Tanzania NAP-AMR 2017-2022. First, we provide evidence that is useful in informing antibiotic stewardship programs tailored to traditional livestock production systems of Tanzania, information which, according to NAP-AMR (2017-2022), is lacking. Although our findings show that farmers obtain higher satisfaction from consulting a vet to treat their cattle, and sheep and goats, there is still a significant proportion of farmers who favour self-treatment (especially in poultry). Recognising the limited availability of veterinary infrastructure in these settings, stewardship programs directed to farmers would benefit from encouraging them to consult a professional animal health worker for diagnostic (even if based on syndromic evaluation) and treatment advice, and to discourage self-treatment. Second, we show that antibiotics are commonly used to treat viral infections in all livestock species. Increasing awareness as to the conditions that require antibiotic treatment and those against which this is ineffective would be a valuable contribution to stewardship programs in these and similar communities. Information to improve practices around antibiotic use should not be restricted to consumers only but extend also to medicine vendors. For example, we show that farmers have high preference and WTP for sourcing antibiotics from agrovets which in this area does not typically require consultation with a professional to obtain a prescription. This is particularly common among farmers who live close to drug shops. We also see farmers borrowing antibiotics from each other. Providing medicine vendors with tailored training and information to enable them to serve their communities in a way that enables access to essential treatment but does not perpetuate practices that could lead to AMR risks should be prioritised. Further, we show that low education levels among farmers are associated with a higher tendency to self-treat and poor husbandry practices. Therefore, awareness-raising programs should focus on the risks of antibiotic misuse and encourage farmers to focus on husbandry practices (for example, isolation and discouraging sale and slaughter of ill livestock) that prevent infection and reduce the need to resort to antibiotic treatment. We also demonstrate low vaccination rates and lower preferences for antibiotics among households who have experienced vaccination against viral infections. These findings would be relevant in designing messages to improve uptake of vaccination as a disease prevention and infection control measure both locally and nationally.

In the long-term, a capacity-building fund (through taxation or voluntary donations from livestock keepers) could be established to support the local veterinary workforce. However, durable changes can only occur if Tanzania and other LMICs experiencing the same challenges are supported financially and technically to establish better pharmaceutical, diagnostic and disease surveillance capacity. Such infrastructural improvements are going to be key to creating an enabling environment antimicrobial users and providers alike that improves practices and reduces AMR risks amongst antimicrobial users and providers alike.

Our methodological approach and the issues we highlight here can be generalised beyond our study area to other regions in Tanzania and East Africa and across low-and-middle income countries more broadly. This study also provides a basis for future research. First, we demonstrate that choice behaviour around antimicrobials is context dependent and can vary significantly across livestock species and production systems. Second, we show that farmer treatment choices alone are not sufficient to explain farmers' treatment preferences and that contextual variables are important to consider to prevent biased conclusions. However, farmers' attitudes towards and knowledge of antibiotic resistance in livestock could play a major role in explaining whether the treatment choices and husbandry practices we observed are due to poor knowledge, which could be addressed through access to information, or food insecurity, which would require government-level intervention, or both. Third, as an extension to the current study, it would help to compare antimicrobial preferences between humans and livestock in order to identify whether such issues extend also to human treatment. Fourth, there is limited literature that demonstrates the spatial distribution of farmers preferences. More information in this area would help identify groups towards which education programs and health improvements should be directed in order to optimise use of limited resources.

Acknowledgments

We acknowledge all the participants who took part in our survey. We also appreciate the contributions of our field team Steven Kapolo, Nairisha Olanana, Mohammed Iddy, Matayo Melubo, Joseph Charles Kiwale, Neema Laizer, Sambeke Melubo Kiruswa and Dominic Ole Lenga for their support in the survey preparation and data collection process, and Happyness Jeremiah Mshana for overall project coordination. We are grateful to the Ministry of Health, Community Development, Gender, Elders and Children and Ministry of Livestock and Fisheries in Tanzania for permission and support in the study areas.

Funding

We acknowledge the financial support of the Antimicrobial Resistance Cross-Council Initiative through a grant from the Medical Research Council, a Council of UK Research and Innovation and the National Institute for Health Research (MRC/AMR/ MR/S004815/1).

Ethics approval and consent to participate

Our study was approved by the Kilimanjaro Christian Medical University College Ethics Review committee with certificate n. 2408 and the Catholic University Health and Allied Sciences committee with certificate n. CREC/318/2018; National Institute for Medical Research (NIMR), Tanzania, with Reference Number NIMR/HQ/R.8a/Vol. IX/3017; Tanzanian Commission for Science and Technology (Nthambi, permit n. 2020–336-NA-2019–205; Lembo, permit n. 2020–333-NA-2019–205; Davis, permit n. 2020–335-NA-2019–205; Matthews, permit n. 2019–482-NA-2019–205); and College of Medical Veterinary & Life Sciences ethics committee at the University of Glasgow (project application number 200180046). The necessary research permission in communities was sought and granted by local and district authorities. Informed consent forms and participant sheets were approved by the ethical committee. During the data collection process, verbal and written consent was obtained from all participants.

Author contributions

Author contributions to this paper are as follows: Mary Nthambi – conceptualization, data curation, formal analysis, investigation, methodology, validation, visualisation, software, writing – original draft, writing – review & editing; Tiziana Lembo – conceptualization, funding acquisition, project administration, supervision, writing – review & editing; Nicholas Hanley – conceptualization, funding acquisition, methodology, supervision, writing – review & editing; Alicia Davis – conceptualization, funding acquisition, project administration, writing – review & editing; Fortunata Nasuwa – investigation; Blandina Mmbaga – funding acquisition, project administration, writing – review & editing; and Louise Matthews - funding acquisition, data management, writing – review & editing. All authors have read and approved the final manuscript.

Data availability

The data used to produce the findings of this study are also attached to our article. Any further information will be made available by the corresponding author upon request.

Supplementary material

SM.1: Structure of the household survey based on different choice sets

The data we analyse in this study was collected as part of a larger digital survey divided into two main parts. The first part was aimed at collecting data on human health and the second, animal health. The human health part had two disease scenarios hypothesised to affect children between the age of 0-5 years and adults over the age of 18 years. This means in the first phase we had two main questionnaire versions named “children” and “adults” which we separately combined based on the different choice sets and livestock species to form a total of 18 survey versions (Figure S1.1).

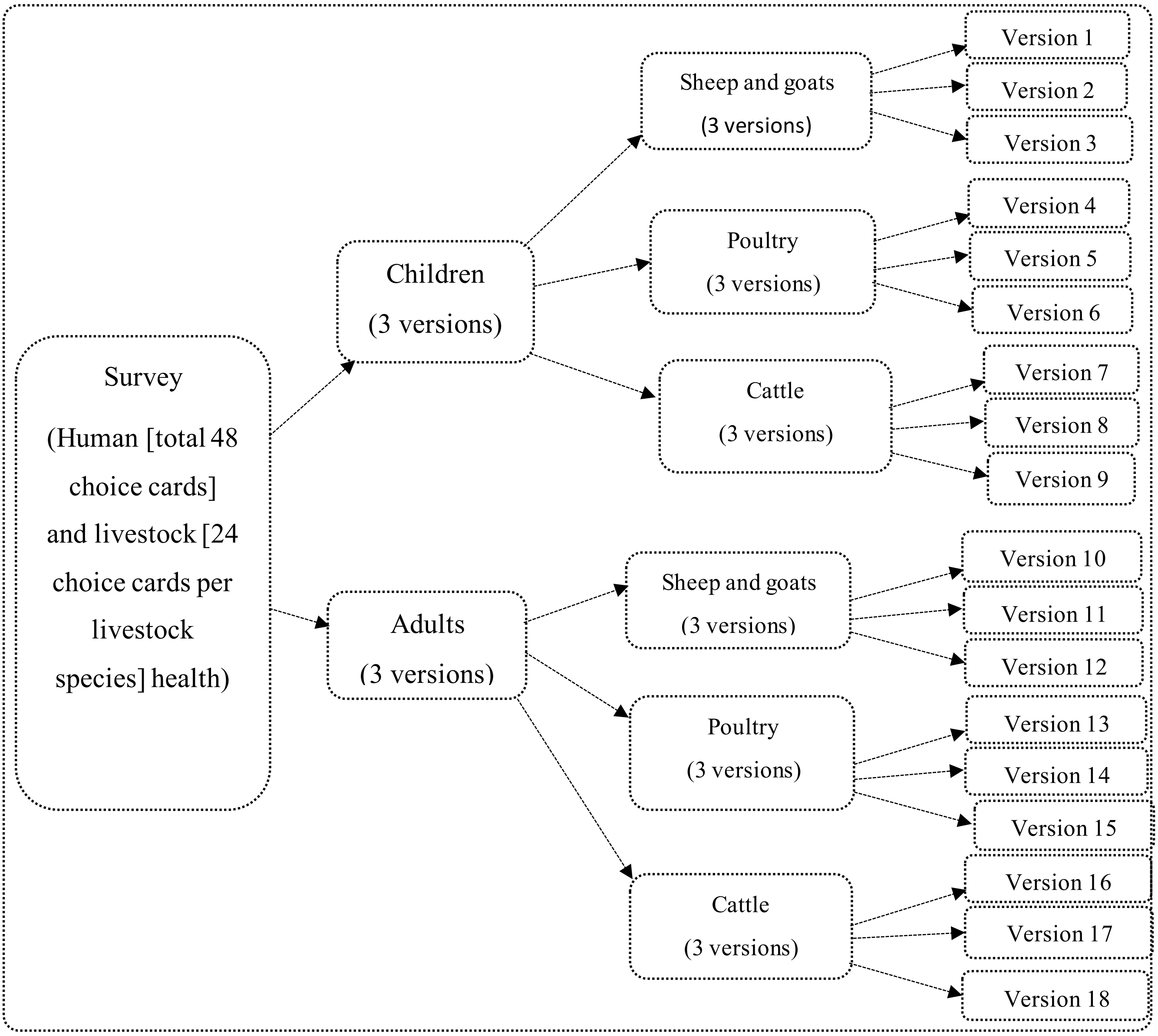


Figure S1.1: Schematic diagram showing the structure of the survey

The survey was administered by three pairs of research assistants. In each household, a pair would separately interview the household head and spouse simultaneously. An individual respondent would therefore be presented with a survey with two sets of disease scenarios, namely human and animal health questions. Each pair of research assistants was allocated a unique identification number. To be more specific, a pair consisted of a research assistant presenting a disease context hypothesised for children, and the other disease contexts hypothesised for adults plus the same livestock species. Therefore, survey administration was based on livestock species and respondents would answer questions for a single livestock species - either cattle or sheep and goat or poultry. For instance, if a household was allocated to the investigation of cattle health issues, a pair of research assistants would present the household head and spouse separately with four sets of choice cards per disease scenario. This enabled us to assess trade-offs between attributes of treatment options for contagious bovine pleuropneumonia (CBPP) and foot-and-mouth disease (FMD). In the second household, the same pair of research assistants presented respondents with choice cards to choose treatment options for Newcastle disease and Coccidiosis in poultry. In the third household, the pair would expose the household head and spouse to choice cards related to treatment options for Peste des petits ruminants (PPR) and foot-and-mouth disease (FMD) in sheep and goats. Therefore, no household answered questions or made choices for more than one livestock species, neither did any household choose from the same set of choice cards. The procedure was repeated for all other pairs until the desired sample size was reached across all livestock production systems.

SM.2: Presentation of choice scenarios to respondents

The scenarios were presented as follows. A respondent was asked to imagine that their cattle or sheep/goats or poultry showed clinical signs of illness. The farmer was told to imagine he/she was looking for a treatment option for the signs observed. Before presenting a sequence of four choice cards with each displaying four alternatives, Option I, Option II, Option III and Option IV, the research assistant described each attribute and attribute level to each respondent (see Figures 2.1 – 2.12). Then the respondent was asked to answer the question "If these were your only treatment options, which one would be your best choice?". Then the respondent was presented with a set of four choice cards one after the other after which he/she would answer follow-up questions before the second set of disease context and 4 choice cards were presented. Option IV had no attributes and respondents were asked to choose it, if they were not interested in any of the proposed treatment options provided in each card. Since we had undertaken a preliminary investigation prior to our main data collection, we assumed farmers would take other actions in the event they chose Option IV, which we further confirmed through a follow-up question that was asked as follows. "If you chose 'option IV' in all choice situations, which one of the following best describes why you would "not" be willing to pay for treatment?

The hypothesised disease contexts – Cattle

For the disease contexts, we formulated the disease scenarios without mentioning the specific name of the disease because respondents would be presumed to treat disease syndromes and not specific diseases. However, for the sake of the reader, scenario 1 represents the clinical signs of contagious bovine pleuropneumonia (CBPP), while the second of foot-and-mouth disease (FMD).

Scenario 1: Please imagine this situation: You woke up this morning and gave your cattle some feed. Then you notice most of your animals have lost their appetite, their hair is rough and are breathing very fast in pain. They also have fever, running nose and are coughing. You also observe they prefer to stand under the shade compared to the sun, are looking tired and weak. The cattle are generally unwell.

Scenario 2: Please imagine this situation: You woke up this morning and visited the cattle shed with an aim of inspecting your animals before they are taken out for grazing. You discover some of your animals have blisters or sores on their mouths and feet. Their lips seem to tremble, and the teats of the diary ones have sores. You remember that in the last three days, the milk volume has really gone down from those producing milk. In general, your observe that your cattle may be unable to walk properly to the grazing land to feed.

The attributes and attribute levels presented for these two disease scenarios in cattle were as follows.

Attribute17

First attribute: Action taken / ***Sifa ya kwanza: Hatua utakayoweza kuchukua***

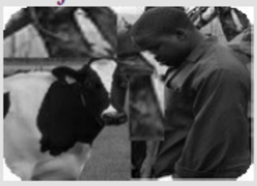
Action taken / *Hatua utakayoweza kuchukua*	Description of attribute levels / *Maelezo ya kiwango cha sifa*
Call livestock officer / *Ita afisa mifugo* 	You can decide to call a livestock field officer to diagnose your cattle. / *Unaweza ukaamua kumuita afisa mifugo kuchunguza ng'ombe wako.*
Self/ *Binafsi* 	You can diagnose your animals yourself / *Unaweza kumchunguza ng'ombe wako wewe mwenyewe*
Call friends, relatives or neighbours / *Ita marafiki, ndugu au majirani* 	You can call your friends, neighbours and relatives to diagnose your cattle/ *Unaweza kuwaita marafiki/majirani kukusaidia kuchunguza ng'ombe wako*

Figure S2.1: Description of first attribute - action taken to treat CBPP or FMD disease in cattle.

Attribute18

Second attribute: Medicine type */ Sifa/tabia ya pili: Aina ya dawa*

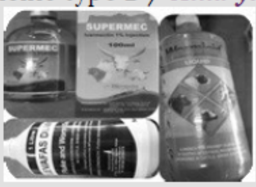
Medicine type / *Aina ya dawa*	Description of attribute level / *Maelezo ya kiwango cha sifa/tabia*
Medicine type A / *Aina ya dawa ya A* 	You can decide to give your cattle this medicine to treat them / *Unaweza ukaamua kumpa ng'ombe dawa hizi kuwatibu*
Medicine type B / *Aina ya dawa ya B* 	You can give cattle this medicines / *Unaweza ukaamua kumpa ng'ombe dawa hizi*
Medicine type C/ *Aina ya dawa ya C* 	You can decide to give cattle this medicine / *Unaweza ukaamua kumpa ng'ombe dawa hizi*

Figure S2.2: Description of second attribute – medicine type to treat CBPP or FMD disease in cattle.

Attribute19

Third attribute: Medicine sources / *Sifa ya tatu: Vyanzo vya dawa*

Medicine sources / *Vyanzo vya madawa*	Description of attribute levels / *Maelezo ya kiwango cha sifa*
From agrovet/veterinary drug shops / *Duka la dawa ya mifugo* 	You can decide to buy the medicine from the agrovet shop of your choice / *Unaweza kuamua kununua dawa kutoka kwenye duka la dawa utakalochagua*
From vendors in open air market / *Wauzaji wa madawa mnadani* 	You can decide to buy medicine from an open-air market vendor to treat the ill cattle / *Unaweza kuamua kununua dawa kutoka kwa muuzaji wa madawa mnadani ili kutibu ng'ombe*
From friends/relatives/neighbours / *Kutoka kwa marafiki/ndugu/majirani* 	You can also ask your neighbour, friends or relatives who keep cattle to give you medicine that they could be having in their home / *Unaweza ukamuomba jirani yako, rafiki zako au ndugu wanaofuga ng'ombe wakupe dawa ambayo watakuwa nazo nyumbani*

Figure S2.3: Description of third attribute – medicine sources to treat CBPP or FMD disease in cattle.

Attribute20

Fourth attribute: Cost of treatment / ***Sifa/tabia ya nne: Gharama za matibabu***

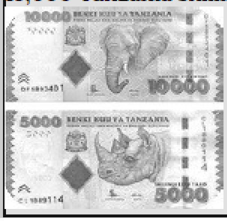
Cost of treatment / ***Gharama ya matibabu***	Description of attribute level / ***Maelezo ya kiwango cha sifa/tabia***
5,000 Tanzania shillings 	You can pay an average of 5,000 Tshs to treat your cattle / ***Unaweza kulipa wastani wa 5,000 tshs kutibu ng'ombe wako***
9,000 Tanzania shillings 	You can pay an average of 9,000 Tshs to treat your cattle / ***Unaweza ukalipa kwa wastani wa 9,000tshs kutibu ng'ombe wako***
12,000 Tanzania shillings 	You can pay an average of 12,000 Tshs to treat your cattle / ***Unaweza kulipa wastani wa 12,000 Tshs kutibu ng'ombe wako***
15,000 Tanzania shillings 	You can pay an average of 15,000 tanzania shillings to treat your cattle / ***Unaweza kulipa kiasi cha 15,000 pesa za tanzania kutibu ngombe wako***

Figure S2.4: Description of third attribute – cost to treat CBPP or FMD disease in cattle

The disease contexts – sheep and goats

Scenario 1 represented the clinical signs of peste des petits ruminants (PPR), while scenario 2 referred to those of foot-and-mouth disease (FMD).

Scenario 1: Imagine this situation: You went to the market today and bought a new flock of sheep/goats, brought them home and mixed them with an existing flock in the same shed. After 3-6 days you discover they have fever, reduced appetite and there is light mucus coming from their noses. You also notice they have difficulty breathing. The mouth muscles are swollen and they have sores on the lower gums, on the teeth and on the tongue. You also realize that there is diarrhoea on floor around the area wheree the new flock sleeps. Generally, the new flock appears unwell and seems to have lost body weight.

Scenario 2: Imagine this situation: You woke up this morning and visited the sheep / goat shed to inspect your animals before taking them out for grazing / giving them their feed. On examining the sheep / goats, you see blisters or sores on their mouths and feet. The lips are trembling and their mouth is full of saliva. For the female ones, their teats have sores and you remember in the last three days their milk production has gradually declined. Generally, the animals look ill and are reluctant to walk in or outside their shed.

Attribute9

First attribute: Action taken */ Sifa ya kwanza: Hatua utakayoichukua*

Action taken / *Hatua iliyochukuliwa*	Description of attribute levels / *Maelezo ya kiwango cha sifa*
Call a livestock field officer/ *Kumuita afisa mifugo* 	You can decide to call a livestock field officer for further diagnostics / *Unaweza ukaamua kumuita afisa mifugo kufanya uchunguzi*
Self/ *Binafsi* 	You can decide by yourself the illness to treat / *Unaweza kufanya uchunguzi wewe mwenyewe*
Call friends, relatives or neighbours / *Kuwaita marafiki, ndugu au majirani* 	You can call your relatives, friends or neighbours to ascertain the illness to treat/ *Unaweza ukamuita ndugu/rafiki au jirani yako kufanya uchunguzi*

Figure S2.5: Description of first attribute - action taken to treat FMD or PPR disease in sheep and goats.

Attribute10

Second attribute: Medicine type *// Sifa/tabia ya pili: Aina ya dawa*

Medicine type / ***Aina ya dawa***	Description of attribute level / ***Maelezo ya kiwango cha sifa/tabia***
Medicine type A / ***Aina ya dawa ya A*** 	You can decide to give your sheep/goats this medicine to treat them / ***Unaweza ukaamua kumpa kondoo/mbuzi dawa hizi kuwatibu***
Medicine type B / ***Aina ya dawa ya B*** 	You can give sheep/goats this medicines / ***Unaweza ukaamua kumpa kondoo/mbuzi dawa hizi***
Medicine type C/ ***Aina ya dawa ya C*** 	You can decide to give sheep/goats this medicine / ***Unaweza ukaamua kumpa kondoo/mbuzi dawa hizi***

Figure S2.6: Description of second attribute – medicine type to treat FMD or PPR disease in sheep and goats.

Attribute11

Third attribute: Action after treatment / *Sifa ya tatu: Hatua baada ya matibabu*

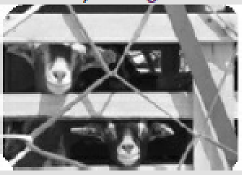
After treatment / ***Hatua baada ya matibabu***	Description of attribute levels / ***Maelezo ya kiwango cha sifa***
Isolate / ***Tenga*** 	You can decide to isolate them after giving them medicine / ***Unaweza ukatenganisha baada ya kuwapa dawa***
Slaughter / ***Unaweza ukachinja*** 	You can decide to slaughter the sheep/goats / ***Unaweza kuamua kuchinja kondoo/mbuzi***
Sell /***Uza*** 	You can decide to sell the sheep/goats / ***Unaweza ukamuuza kondoo/mbuzi sokoni***

Figure S2.7: Description of third attribute – action after medication with FMD or PPR disease in sheep and goats.

Attribute12

Fourth attribute: Cost of treatment / *Sifa/tabia ya nne: Gharama za matibabu*

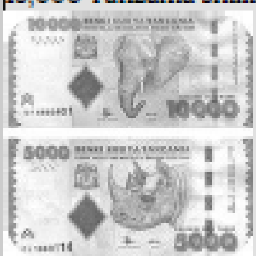
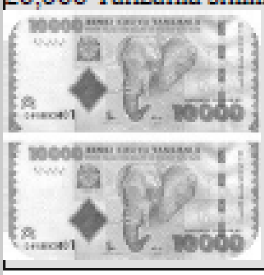
Cost of treatment / *Gharama ya matibabu*	Description of attribute level / *Maelezo ya kiwango cha sifa/tabia*
9,000 Tanzania shillings 	You can pay an average of 9,000 Tshs to buy medicine from an agrovet / *Unaweza kulipa wastani wa 9,000 tshs kutibu kondoo/mbuzi*
12,000 Tanzania shillings 	You can pay an average of 12,000 Tshs to buy medicine agrovet / *Unaweza kulipa wastani wa 12,000 tshs kutibu kondoo/mbuzi*
15,000 Tanzania shillings 	You can pay an average of 15,000 Tshs from an agrovet / *Unaweza ukalipa kwa wastani wa 15,000tshs kutibu kondoo/mbuzi*
20,000 Tanzania shillings 	You can pay an average of 20,000 Tshs to buy medicine / *Unaweza kulipa wastani wa 20,000Tshs kutibu kondoo/mbuzi*

Figure S2.8: Description of third attribute – cost to treat FMD or PPR disease in sheep and goats.

The disease contexts – Poultry

Scenario 1 represents clinical signs of Newcastle disease, while scenario 2 those of coccidiosis.

Scenario 1: Imagine this situation: You woke up this morning and visited the poultry house and found out that some of your poultry are coughing, sneezing, gurgling and shaking. The birds' necks are numb and twisted, and there is yellowish-green diarrhoea on the floor. When you put feed on their feeding troughs you realize that they have lost appetite and are not feeding well. Generally, your poultry looks weak and depressed.

Scenario 2: Imagine this situation: You woke up in the morning and went to the poultry house and discovered that there were bloody droppings on the floor. When you put feed and water on the troughs you observe that your poultry have no appetite to eat and drink. You also observe that the birds are weak, seem to have lost weight and their feathers are rough. While observing these symptoms you also recall that the egg production count has gone down in the last three days.

The attributes and attribute levels presented were as follows.

Attribute9

First attribute: Action taken / ***Sifa ya kwanza: Hatua iliyochukuliwa***

Action taken / ***Hatua iliyochukuliwa***	Description of attribute levels / ***Maelezo ya kiwango cha sifa***
Call a livestock field officer/ ***Kumuita afisa mifugo*** 	You can decide to call a livestock field officer to diagonize/ ***Unaweza ukaamua kumuita afisa mifugo kuchunguza kuku wako***
 Self/ ***Binafsi***	You can treat your poultry yourself / ***Unaweza kutibu kuku wako wewe mwenyewe***
Call friends, relatives or neighbours / ***Kuwaita marafiki/ndugu/majirani*** 	You call for help from friends/neighbours/relatives to diagnose your poultry/ ***Unaweza kuwaita marafiki/majirani kukusaidia kukagua kuku wako***

Figure S2.9: Description of first attribute - action taken to treat Newcastle and coccidiosis disease in poultry.

Attribute10

Second attribute: Medicine type / *Sifa ya pili: Aina ya dawa*

/ Sifa hii inaelezea aina mbalimbali ambayo unaweza kutumia kumtibu kuku/ ndege anayeumwa

Medicine type / ***Aina ya dawa***	Description of attribute level / ***Maelezo ya kiwango cha sifa/tabia***
Type A / ***Aina ya A*** 	You can decide to give poultry this medicine type to treat them / ***Unaweza ukaamua kuwampa kuku dawa za aina hii kuwatibu***
Type B / ***Aina ya B*** 	You can decide to give them this medicine type / ***Unaweza ukaamua kuwapa kuku aina hii ya dawa***

Figure S2.10: Description of second attribute – medicine type for Newcastle and coccidiosis diseases in poultry

Attribute11

Third attribute: Medicine sources / *Sifa ya tatu: Vyanzo vya dawa*

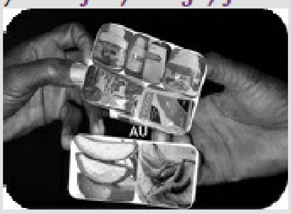
Medicine sources / ***Vyanzo vya madawa***	Description of attribute levels / ***Maelezo ya kiwango cha sifa***
Agrovets / ***Duka la pembejeo*** 	You can decide to buy the medicine from the agrovet shop of your choice / ***Unaweza kuamua kununua dawa kutoka kwenye duka la pembejeo la chaguo lako***
Open air market / ***Wauzaji wa madawa mnadani*** 	You can decide to buy medicine from an open-air market vendor to treat the ill birds / ***Unaweza kuamua kununua dawa kutoka kwa muuza madawa mnadani ili kutibu kuku wanaougua***
From friends/relatives/neighbours ***/Marafiki/ndugu/jirani*** 	Ask friends/relatives/neighbour for medicine / ***Pata kutoka kwa marafiki/ndugu/jirani***

Figure S2.11: Description of third attribute – medicine sources to treat Newcastle or coccidiosis disease in poultry.

Attribute12

Fourth attribute: Cost of treatment / *Sifa/tabia ya nne: Gharama za matibabu*

For your poultry to be treated, there is a certain amount of money that you need to pay an amount ranging between 6000 – 15,000 Tanzania shillings/ *Kwa kutibu kuku, unahitaji kiwango cha hela 6000 - 15000 za tanzania*

Cost of treatment / *Gharama ya matibabu*	Description of attribute level / *Maelezo ya kiwango cha sifa/tabia*
6,000 Tanzania shillings 	You can pay an average of 6000 Tshs to treat poultry/ *Unaweza kulipa wastani wa 6,000 kutibu kuku*
9000 Tanzania shillings 	You can pay an average of 9,000 Tshs to treat poultry/ *Unaweza kulipa wastani wa 9,000 tshs kutibu kuku*
12,000 Tanzania shillings 	You can pay an average of 12,000 Tshs to treat poultry / *Unaweza ukalipa kwa wastani wa 12,000 tshs kutibu kuku*
15,000 Tanzania shillings 	You can pay an average of 15,000 Tshs to treat poultry / *Unaweza kulipa wastani wa 15,000 Tshs kutibu kuku*

Figure S2.12: Description of fourth attribute – cost to treat Newcastle or coccidiosis disease in poultry.

SM.3: Livestock numbers captured

Here we provide a screenshot from our survey to show how we captured different livestock numbers in each household for the different livestock species.

Q257

257: Enter the number of livestock you own and if none, enter 0 / *Ingiza idadi ya mifugo unaowamiliki na kama hakuna, ingiza 0*

	Number owned and kept in the household / *Idadi zinazomilikiwa na kufugwa kwenye kaya*	Number owned and kept outside the household / *Idadi zinazomilikiwa na kufugwa nje ya kaya*
Adult cattle / *Ng'ombe wakubwa*	Q257_r1_c1	Q257_r1_c2
Calves / *Ndama*	Q257_r2_c1	Q257_r2_c2
	Number owned and kept in the household / *Idadi zinazomilikiwa na kufugwa kwenye kaya*	Number owned and kept outside the household / *Idadi zinazomilikiwa na kufugwa nje ya kaya*
Adult goats / *Mbuzi wakubwa/waliokomaa*	Q257_r3_c1	Q257_r3_c2
Young goats / *Mbuzi wachanga*	Q257_r4_c1	Q257_r4_c2
	Number owned and kept in the household / *Idadi zinazomilikiwa na kufugwa kwenye kaya*	Number owned and kept outside the household / *Idadi zinazomilikiwa na kufugwa nje ya kaya*
Adult sheep / *Kondoo wakubwa/waliokomaa*	Q257_r5_c1	Q257_r5_c2
Young sheep / *Kondoo wachanga*	Q257_r6_c1	Q257_r6_c2
	Number owned and kept in the household / *Idadi zinazomilikiwa na kufugwa kwenye kaya*	Number owned and kept outside the household / *Idadi zinazomilikiwa na kufugwa nje ya kaya*
Adult chicken / *Kuku wakubwa/waliokomaa*	Q257_r7_c1	Q257_r7_c2
Chicks / *Vifaranga*	Q257_r8_c1	Q257_r8_c2

Figure S3.1: Screenshot showing how we captured the different livestock numbers in the household

SM.4: Hybrid coding of attributes and attribute levels

To establish non-linear relationships, dummy, effects or hybrid coding can be used. Dummy coding consists of the use of 0s and 1s, while effects coding involves the use of 1s for the chosen alternative, 0s for other attributes and -1s for the status quo/opt-out alternative. Most of our study's attributes have at least 3 levels each and an opt-out option, and, if we use dummy coding or effects coding, it is more likely it will lead to perfect confounding of the baseline alternative with at least one of the non-baseline levels. We therefore used hybrid coding (Hensher *et al.* 2015; Nthambi *et al.* 2021) where the status quo was dummy coded zero (0) and the lowest level of each attribute level was effects coded (-1). In hybrid coding scheme, Hensher *et al.* (2015) propose that one alternative/attribute level other than the opt-out option is set as a baseline level coded as -1 (see Tables S4.1, S4.2 and S4.3).

Table S4.1, S4.2 and S4.3 show how we coded the treatment attributes and attribute levels using hybrid coding scheme.

Table S4.1: Treatment attributes and attribute levels coding - cattle

Attribute	Levels	Data type and Hybrid coding
Action taken	Call livestock health officer	1 if a farmer calls livestock health officer, -1 if call to friends, relatives, or neighbours, 0, otherwise
	Treat by yourself	1 if a farmer treats cattle by himself/herself, -1 if call friends, relatives or neighbours, 0, otherwise
Medicine type	Medicine type C – Antibiotics	1 if a farmer chooses antibiotics, -1 if the choice is pain killers, 0, otherwise
	Medicine type B – Anti-parasites	1 if a farmer chooses anti-parasites, -1 if the choice is pain killers, 0, otherwise
Medicine source	From agrovet/veterinary drug shops	1 if a farmer chooses to obtain medicines from agrovet shop, -1 if it's an open-air market, 0, otherwise
	From friends/relatives/neighbours	1 if a farmer chooses to borrow medicine from friends/relatives/neighbours, -1 if the medicine source is open air market, 0, otherwise

Cost of treatment in Tanzania shillings	1. 5000 TShs ($2.17) 2. 9000 TShs ($ 3.90) 3. 12000 TShs ($ 5.20) 4. 15000 TShs ($6.50)	Discrete

Table S4.2: Treatment attributes and attribute levels coding – sheep and goats

Attribute	Levels	Data type and Hybrid coding
Action taken	Call livestock officer	1 if a farmer calls livestock health officer, -1 if call friends, relatives or neighbours, 0, otherwise
	Treat by yourself	1 if a farmer treats cattle by himself/herself, -1 if call friends, relatives or neighbours, 0, otherwise
Medicine type	Medicine type C – Antibiotics	1 if a farmer chooses antibiotics, -1 if the choice is pain killers, 0, otherwise
	Medicine type B – Anti-parasites	1 if a farmer chooses anti-parasites, -1 if the choice is pain killers, 0, otherwise
Action after medication	isolate	1 if a farmer chooses to isolate stock, -1 if a farmer chooses to slaughter ill sheep/goats, 0, otherwise
	Sell	1 if a farmer chooses sell ill animal, -1 if a farmer chooses to slaughter ill sheep/goats, 0, otherwise
Cost of treatment in Tanzania shillings	1. 9000 TShs ($3.90) 2. 12000 TShs ($ 5.20) 3. 15000 TShs ($6.50) 4. 20000 TShs ($8.67)	Discrete

Table S4.3: Treatment attributes and attribute levels coding – poultry

Attribute	Levels	Data type and Hybrid coding
Action taken	Call livestock officer	1, if the choice is to call livestock health officer, -1 if choice is to call friends, relatives or neighbours, 0, otherwise
	Treat by yourself	1, if choice is to treat by yourself, -1 if choice is to friends, relatives or neighbours, 0, otherwise
Medicine type	Medicine type A – Antibiotics	1 if a farmer chooses antibiotics, -1 if the choice herbal medicine, 0, otherwise
	Medicine type B – Herbal medicine	1 if a farmer chooses herbal medicine, -1 if the choice is antibiotics, 0, otherwise
Medicine source	From agrovet/veterinary drug shops	1 if choice is to obtain medicines from agrovet shop, -1 if it's an open-air market, 0, otherwise
	From friends/relatives/neighbours	1 if a farmer chooses to borrow medicine from friends/relatives/neighbours, -1 if the medicine source is open-air market, 0, otherwise
Cost of treatment in Tanzania shillings	1. 6000 TShs ($ 2.60) 2. 9000 TShs ($ 3.90) 3. 12000 TShs ($ 5.20) 4. 15000 TShs ($ 6.50)	Discrete

Some of our contextual variables were dummy coded (see Molin and Timmerman, 2010) and interacted with the hybrid coded treatment attribute levels (see Tables S2.4, S2.5 and S2.6).

Supplementary material – S5

Tables S5.4, S5.5 and S5.6 show the covariates of cattle, sheep and goats, and poultry interacted with treatment attributes.

Table S5.4: Cattle multinomial logit and mixed logit models' covariates

Covariates	Description, data type and coding
Education level	1, if a farmer has formal training – primary school education level and above ,0, if a farmer has never gone to school
Income level	1, if income is high > 300,000, and ,0, otherwise, -99 if respondent chose not to state their income level meaning for this respondent it was treated as a missing value
Previous FMD disease experience	1, if farmer agrees FMD affected cattle in the household in the last 6 months ,0, otherwise
Previous CBPP disease experience	1, if farmer agrees CBPP affected cattle in the household in the last 6 months ,0, otherwise
Previous FMD vaccination	1, if cattle were vaccinated against FMD in the last 6 months ,0, otherwise
Previous CBPP vaccination	1, if cattle were vaccinated against CBPP in the last 6 months ,0, otherwise
Herd size	Discrete
Grazing type	1, if grazing type is communal ,0, otherwise
Leftover medicine for livestock treatment	1, if farmer keeps medicine at home for treatment of livestock ,0, otherwise

Table S5.5: Sheep and goats multinomial logit and mixed logit models' covariates

Covariates	Description and coding
Education level	1 if a farmer has formal training – primary school education level and above ,0, if a farmer has never gone to school
Income level	I if income is > 300,000, and ,0, otherwise, -99 if respondent chose not to state their income level
Previous FMD disease experience	1, if farmer agrees that FMD affected sheep/goats in the last 6 months in the household ,0, otherwise
Previous PPR disease experience	1, if farmer agrees PPR affected sheep/goats in the household in the last 6 months ,0, otherwise
Previous FMD vaccination	1, cattle were vaccinated against FMD in the last 6 months ,0, otherwise
Previous CBPP vaccination	1, cattle were vaccinated against PPR in the last 6 months ,0, otherwise
Herd size	Discrete
Grazing type	1, if grazing type is communal ,0, otherwise
Medicine kept at home for livestock treatment	1, if farmer keeps medicine at home for treatment of livestock ,0, otherwise

Table S5.6: Poultry multinomial logit and mixed logit models' covariates

Covariates	Description and coding
Education level	1, if a farmer has formal training – primary school education level and above ,0, if a farmer has never gone to school
Income level	1, if income is high >300,000, and ,0, otherwise, -99 if respondent chose not to state their income level

Previous Newcastle disease experience	1, if farmer agrees Newcastle occurred in the last 6 months in the household ,0, otherwise
Previous coccidiosis disease experience	1, if farmer agrees coccidiosis occurred in the household in the last 6 months ,0, otherwise
Previous Newcastle vaccination	1, poultry were vaccinated against Newcastle in the last 6 months ,0, otherwise
Previous coccidiosis vaccination	1, cattle were vaccinated against coccidiosis in the last 6 months ,0, otherwise
Herd size	Discrete
Rearing type	1, if rearing type is commercial system ,0, otherwise
Medicine kept at home for livestock treatment	1, if farmer keeps medicine at home for treatment of livestock ,0, otherwise

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