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Predicting uptake of a malignant catarrhal fever vaccine by pastoralists in northern Tanzania: opportunities for improving livelihoods and ecosystem health

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Abstract: Malignant Catarhal Fever (MCF), transmitted from wildebeest to cattle, threatens livestock-based livelihoods and food security in many areas of Africa. Many herd owners reduce transmission risks by moving cattle away from infection hot-spots, but this imposes considerable economic burdens on their households. The advent of a partially-protective vaccine for cattle opens up new options for disease prevention. In a study of pastoral households in northern Tanzania, we use stated preference choice modelling to investigate how pastoralists would likely respond to the availability of such a vaccine. We show a high probability of likely vaccine uptake by herd owners, declining at higher vaccine costs. Acceptance increases with more efficaceous vaccines, in situations where vaccinated cattle are ear-tagged, and where vaccine is delivered through private vets. Through analysis Normalized Density Vegetation Index (NDVI) data, we show that the reported MCF incidence over 5 years is highest in areas with greatest NDVI variability and in smaller herds. Trends towards greater rainfall variability suggest that MCF avoidance through traditional movement of cattle away from wildebeest will become more challenging and that demand for an MCF vaccine will likely increase.

Keywords: vaccine, cattle, Malignant Catarhal Fever, Tanzania, stated preference, choice modelling, wilingness to pay

JEL codes: Q12, Q51, D12, H57, I19

1. Introduction

Malignant catarrhal fever (MCF) is a lethal, viral infection that affects cattle in eastern and southern Africa (Plowright, 1965). The disease is caused by a gamma herpes virus, Alcelaphine herpesvirus 1 (AIHV-1), which is excreted by wildebeest calves under four months of age and transmitted to cattle (Plowright 1960). In East Africa, peak transmission of malignant catarrhal fever typically occurs after the annual wildebeest calving season when large herds of wildebeest move into the savannah plains, with the timing of their arrival linked to seasonal rainfall (Boone et al., 2006). These calving grounds often include areas inhabited by cattle-owning communities, particularly Maasai pastoralists. It is in these calving zones that cattle and wildebeest meet, making them hotspots for MCF transmission and creating land-use conflict between pastoralists and conservation authorities (Lankester et al., 2016).

MCF is a serious concern for pastoralists in northern Tanzania and southern Kenya (Cleaveland et al., 2001; Bedelian et al., 2007) and the only reliable method of control that has been adopted so far is to separate cattle from wildebeest during the peak transmission period. The process of moving cattle away from prime grazing sites to protect them from becoming infected with AlHV-1 has serious impacts on herd productivity and the individual health of cattle (Bedelian et al., 2007, Lankester et al. 2015). Although pastoral livelihoods and diets are diversifying, livestock continues to provide the main source of income, and milk remains a critical component of the diet (Hansens et al., 2011). Lankester et al. (2015) explored the economic impact of MCF on pastoralist livelihoods in Tanzana, and showed that over the 5-month high risk period, 82% of cattle were moved away from home pastures to avoid MCF and, because the distance traveled to find safe pastures was over 20km away, this resulted in 64% of milk being unavailable for consumption by household members who stayed at home. Given current nutrional deficiencies reported in the region (Galvin et al., 2015) and that lower nutrional intake compromses the ability of children to engage with education (Marsh et al., 2016), the dietary consequences of this reallocation of nutritional resources can be severe, especially for children. In addition, the financial costs associated with MCF avoidance, which result primarily from lost opportunities to sell milk and the additional labor and time required to move the cattle away from the home pastures, are considerable (Lankester et al., 2015).

Over the past decades, MCF has been a growing source of conflict between pastoralists and conservation authorities. In the Serengeti ecosystem, wildebeest numbers have increased >7-fold since the 1960s, expanding from ~200,000 individuals to current levels of 1.5 million partly as a result of the elimination of rinderpest in cattle (Holdo et al., 2009). This increase in wildebeest numbers has been associated with an expansion in the range of the migration, compounding other problems faced by pastoralists, such as the widespread conversion of rangelands to crop-based agriculture, which is increasingly restricting access to grazing lands and limiting pasture options for avoiding wildebeest.

In contrast, conservationists are concerned about the impact of escalating human activities on the integrity of protected area systems. In the Serengeti ecosystem, there is evidence that ecological degradation at the borders of the protected area is squeezing wildlife into the core protected areas and altering ecosystem dynamics (Veldhuis et al., 2019). Although it has been suggested that growing livestock populations have contributed to the 'squeeze' in the Serengeti, there is no evidence of an increase in cattle numbers in pastoral communities (where MCF transmission occurs) over recent decades. Furthermore, in semi-arid rangelands, traditional land management systems are known to be able to support high densities and diversities of wildlife (Niamir-Fuller et al., 2012) and have resulted in much less harm to wildlife than has been seen in areas where mechanised crop-based agriculture has replaced traditional pastoral land use (Serneels and Lambin, 2002). One trend that has become apparent in terms of livestock impacts is a switch from cattle to small ruminants which has been associated with major declines in wildlife in Kenya (Ogutu et al., 2016). This shift is also thought to be occurring in northern Tanzania in response to restricted access to grazing land and to climate change (Wynants et al., 2019).

New strategies to minimise the risks of MCF through cattle vaccination provide one solution to reducing conflict between pastoralists and conservationists, with opportunities for more equitable co-existence of livestock and wildlife. Further, by increasing access of cattle to high-quality grazing, a MCF vaccine may counteract the shift away from keeping cattle to keeping small ruminants. An experimental field study in Tanzania demonstrated that a novel MCF vaccine had a 56% efficacy at protecting cattle from infection (Lankester et al., 2016), whilst, a more recent trial in Kenya reported by Cook et al. (2019) found the same vaccine had a 81% protective effect. However, partly due to a lack of understanding of the potential demand from cattle owners and how this demand might vary with respect to different delivery strategies, there is currently no commercial production of this vaccine.

To investigate potential demand for a new vaccine for MCF, we designed and implemented a stated preference choice experiment with at-risk households in northern Tanzania. A choice experiment (also known as choice modelling) is a method originally implemented in market research that is now widely used in environmental economics, health economics and transport planning (Hanley and Czajkowski, 2019). Choice experiments allow the researcher to estimate the values that a sample of respondents place on different attributes of a product, treatment or policy option, and their willingness to pay for increases in desired attributes. The method has been used to provide evidence for policy-making in the USA and UK (Johnston et al., 2017) and has also been employed to understand farmers' willingness to engage with livestock disease risk reduction strategies (Sok et al., 2018).

Using choice experiment responses, we were able to quantify the willingness of respondents to participate in a future vaccine programme, and the determinants of variations in this demand across households. We speculate that one important determinant is the number of MCF cases experienced, and so estimate this and its dependence on wildebeest abundance, grazing resources and cattle numbers.

2. Methods

The study was carried out in pastoral communities selected at random from villages at risk from MCF in Ngorongoro, Simanjiro and Monduli Districts in northern Tanzania (Fig. 1). Wildebeest distribution and abundances in this region have been relatively well-documented through population-level surveys (Hopcraft 2015; Morrison et al., 2016) which, based on the distribution and relative abundances of wildebeest during the main MCF transmission period, allowed the study area to be stratified into low, medium and high categories of use by wildebeest. A household survey was carried out between October 2018 and May 2019. Within each village, respondents were selected at random from a list of livestock-owning households provided by village leaders. Potential participants were informed about the purpose of the survey, how the information would be collected, used and stored, and finally asked to sign a consent form if they agreed to participate. A pilot survey of 20 households in the same study area was used to test the main survey design. The main survey involved face to face interviews with 204 heads of household, or another household representative, that lasted approximately 40 minutes. All surveys were conducted in either KiSwahili or Maa according to the respondent's preferences.

The choice experiment was used to estimate the preferences of sampled households for a novel vaccine which could, hypothetically, be offered to them for purchase at some date in the near future. Choice cards were developed with different combinations of five attributes that were used to describe the circumstances under which the vaccine could be offered for sale. These attributes were informed by our experience of MCF and livestock diseases in Tanzania, including issues raised by livestock-owners in relation to animal health service providers, their experience with previous livestock vaccination programmes, and uncertainties around future potential MCF vaccination protocols and vaccine efficacy.

Table 1 provides information on the levels selected for each of these atributes, which formed the experimental design, and on the way these choices were described to repondents. Respondents were presented with a series of 12 choice cards, and, for each card, asked to choose one of two options: i) buy the vaccine with specified properties at a given price, or ii) do not buy. An example is given in Figure 2. Multinomial logit models (Greene, 2018) with both linear and non-linear price (vaccine cost) effects were then estimated in Matlab, using a Discrete Choice Experiment (DCE) package available at https://github.com/czaj/DCE. The code and data for estimating the specific models presented in this study, as well as supplementary results, are available from http://czaj.org/research/supplementary-materials.

Respondents were also asked to provide details on livestock owned, experience of MCF during the previous 5 years (2014-2018), and actions taken to reduce risks of MCF infection, as potential determinants of demand for vaccine (see Table A2 in SI). With respect to possible determinants of MCF incidence, we predicted this would be highest (1) in areas with abundant grazing resources that attract both cattle and wildebeest during the period of MCF tranmission, and (2) in areas where grazing resources were more unpredictable from year to year such that partoralists may have had difficultly anticipating whether wildebeest would be present. Grazing resources were quantified using the Normalized Difference Vegetation Index (NDVI), a metric of vegetative greenness often used in studies of grazers as a proxy for grass forage availability (Pettoreli et al., 2005). NDVI values were generated from images collected aboard NASA's MODIS satellite (product 'MOD13Q') every 16 days at a spatial resolution of 250m^2 per pixel. It was assumed that mean(NDVI) reflected the relative availability of grazing resources for both wildebeest and cattle, and that sd(NDVI) reflected the intrinsic unpredictability of a location's grazing resources across years. Because the grazing locations of cattle may have varied across the five years and were difficult to ascertain through interviews, we used the NDVI values at the household location to represent vegetative greenness for each herd. Mean(NDVI) was calculated across the five-year period (2014-2018) in which MCF cases were reported, while sd(NDVI) was calculated across all years of available NDVI data (2000-2018). NDVI variables were rescaled to a mean of 0 and standard deviation of 1 prior to analysis.

MCF incidence was calculated as the number of reported cases reported by respondents over the previous five years, divided by the current number of cattle reported in the herd, and standardized as cases per 1000 cattle. We fitted a generalized linear model to MCF incidence data and assumed a negative binomial error distribution. We included several linear predictors in the model: (1) wildebeest use ('low', 'medium' and 'high'), (2) number of cattle per household (i.e. 'herd size'), (3) mean vegetative greenness (i.e. 'mean(NDVI)') and (4) standard deviation of vegetative greenness (i.e. ‘sd(NDVI)’). We compared a set of four nested candidate models using likelihood ratio tests. The model set evaluated the importance of wildebeest use, mean(NDVI) and sd(NDVI), relative to a global model.

3. **Results**

3.1 Choice Experiment

The choice experiment involve a total of 2688 choice observations from 224 respondents, since pilot survey choice responses could be pooled with main survey responses. No respondent chose only the “purchase vaccine” or the “do not purchase vaccine” option in all 12 of their choices. Results from the multinomial logit models are presented in Table 2.

The first (baseline) model is used to illustrate the general effect of choice attributes on farmers choosing to vaccinate or not. The estimated coefficients do not have direct interpretation as economic demand parameters[1], but their signs and relative values illustrate the relative impact of the treatment attributes on respondents’ choices. We find that efficacy of the vaccine substantially and significantly increased the probability of choosing the treatment. The frequency of vaccine administration was not seen as an important factor on average. However, ear tagging vaccinated cattle made the program seem significantly more attractive and more likely to be accepted. Vaccines administered by private vets were seen as preferrable to NGO vets, with government vets in between, on average. As expected, we find that the higher the cost of the vaccine, the less likely it is to be purchased.

The ratios of the estimated coefficients of the choice model can be interpreted as marginal rates of substitution: the trade-offs that respondents were willing to make between the attribute levels. Using the cost of treatment as a common denominator we can calculate willingness to pay (WTP) for changes in the other attributes (what changes of cost would be required to compensate changes in other attribute levels, so that respondents’ choice probabilities would remain the same). The estimated WTP values implied by the baseline model are presented in Table 3. They show that respondents would be willing to pay 325 TZS extra for each percentage point increase of efficacy of the vaccination and that programs that include ear tagging of cattle were valued at over 14,000 TZS more. WTP for vaccines administered by private vets was approximately 1,450 TZS higher, than by NGO vets. Overall, the average value of the treatment offered in a hypothetical program was estimated at approximately 42,474 TZS, with a 95% confidence interval of 37,072 to 49,467 TZS.

[1] This is because their absolute magnitude effect on utility (choice) is confounded with a scale parameter.

The next model presented in Table 2 includes individual-specific covariates that enter as interactions with the choice attributes. This model offers some insight into observed heterogeneity of respondents' preferences. The significant interaction terms show that respondents who experienced more MCF cases in the past have stronger preferences for programs that include ear tagging. Respondents with more cattle prefer programs that require less frequent administration of vaccines and appear less in favor of government vets administering the vaccine compared with NGO vets. Lastly, we observe that respondents who move a larger share of their cattle stock to avoid MCF are less concerned with efficacy of the vaccine and at the same time find programs that include ear tagging more attractive.

The final model presented in Table 2 extends the baseline model with a Box-Cox transformation of the cost attribute. This allows for a more flexible framework for capturing the relationship of the cost of treatment and the probability of its acceptance by respondents (Tuhkanen et al., 2016). We use this model to predict the probability of accepting the treatment offered in a hypothetical program at various cost levels. The results are presented in Figure 3. As expected, the probability of accepting the vaccination program approaches 1 for costs close to 0. As the cost increases, the probability of acceptance becomes lower – for costs exceeding 50,000 TZS it falls below 0.1. The estimated probability of acceptance translates to the expected share of farmers adopting the treatment at different cost levels. As a result, it can be used to design future policies offering MCF treatments.

3.2 Predictors of MCF incidence

The most parsimonius model of MCF incidence in cattle included wildebeest use, sd(NDVI) and herd size as significant predictors (Table A1). MCF incidence increased in cattle herds that occurred in'medium wildebeest use' areas, relative to herds in 'high wildebeest use' areas (β=0.48 ± 0.19, z-value=2.53, p=0.011; Fig 4a), though MCF incidence was not different between low and high use areas (β=0.07 ± 0.21, z-value=0.32, p=0.75). MCF incidence in cattle herds also increased positively with variability in NDVI (β=0.20 ± 0.09, z-value=2.2, p=0.03; Fig 4b). Herd size was negatively associated with MCF incidence (β=-0.91 ± 0.11, z-value=-8.12, p<0.001; Fig. 4c).

4. **Discussion**

MCF has long been a threat to pastoral livelihoods in East Africa, with pastoralists living in risky areas consistently ranking MCF as among the livestock diseases of greatest concern (Cleaveland et al., 2001; Bedelian et al., 2007). Over the past six decades, efforts have been made to develop effective cattle vaccines (Wambua et al., 2015) to minimise disease risks and to reduce the high costs of movement avoidance strategies (Lankester et al., 2015). Now that a partially-protective vaccine has been developed (Lankester et al., 2016; Cook et al., 2019), this study set out to identify factors influencing the likely adoption of MCF cattle vaccines in pastoral communities.

We found that as vaccine price increased the probability of farmers choosing to adopt the vaccine decreased (Figure 3). However, the probability of acceptance was high across all prices included in the choice experiment (up to TZS 25,000) reflecting the anticipated high demand for vaccine. Vaccine efficacy was a further significant factor in herd-owners choosing to vaccinate. Studies of foot-and-mouth disease (FMD) vaccination among agropastoral farmers in Tanzania similarly show that vaccine performance is a key factor underlying farmers' decisions on vaccination (Railey et al., 2018). Pastoral livestock-owners in this area are also well aware of problems associated with livestock vaccine performance, for example, in relation to currently-available FMD vaccines, which have limited effectiveness against circulating FMD virus strains in Kenya (Lyons et al., 2015). Existing vaccines against another cattle disease, contagious bovine pleuropnuemonia, also have low efficacy (52-77%, Nkando et al., 2012), although willingness-to-pay studies in Kenya indicate that, for this disease, pastoralists are influenced more by concerns about harmful side effects of vaccination and the frequency of vaccination than factors affecting efficacy (Kairu-Waryoike et al., 2014). Given that field trials showed only partial protection of the new MCF vaccine (up to 81%), information about vaccine efficacy will need to be conveyed very clearly for effective decision-making.

In our study, frequency of vaccination was not generally seen as an important factor although, understandably, owners of large herds preferred less frequent vaccination. This finding provides reassurance that the current two-dose administration required for the new MCF vaccine, along with annual boosters, will not deter most cattle owners. Side effects were not included among the attributes, as field trials have not raised any safety concerns (Lankester et al., 2016; Cook et al., 2019).

A clear finding from our study was that ear tagging vaccinated cattle made the program significantly more likely to be accepted. This suggests that such visible demonstrations of vaccination status are likely to have benefits for farmers in relation to an increased value of cattle that can be shown to have been vaccinated. This is consistent with results of a household survey in northern Tanzania carried out by GALVmed, showing that farmers vaccinating against East Coast Fever (ECF) expect their cattle to have a 10-20% greater market value than non-adopters and that, for indigenous cattle, sale value of of vaccinated animals was 10-20%

higher than for unvaccinated animals. (N. Gammon, GALVmed, personal communication). An important point in interpreting results of our study in relation to ECF study is that farmers may not have been aware of differences in the duration of immunity between ECF and MCF vaccines. For ECF, a single vaccination confers life-long immunity whereas the MCF vaccine is likely to need regular booster vaccinations, and tagging may therefore not provide such a reliable indicator of protection as for ECF.

Attitudes of Tanzanian pastoralists towards animal health providers have been shaped by many social, economic and historical influences (Davis and Sharp, 2019). We were therefore interested to investigate whether vaccine was administered by government, private or NGO vets would affect adoption. In this study, owners expressed a preference for vaccine delivered by private vets over government and NGO vets. Further work will be needed to explore the reasons for these preferences and how this may affect future vaccination efforts.

Reported MCF incidence over 5 years was highest in areas with greatest NDVI variability, reflecting high variability in grazing resources. With changes in climate likely resulting in increasing unpredictability in rainfall patterns in East Africa (Nicholson, 2017; Borhara et al. 2020), and reduced availability of grazing lands (Reid 2012), our results suggest that pastoralists are likely to face increasingly difficult decisions about movement avoidance. As a result, options for preventing MCF through cattle vaccination are likely to look increasingly attractive.

The challenges of climate change are reinforced by results showing that areas with medium wildebeest use experience the highest incidence of MCF. In areas with consistently high levels of wildebeest use, transmission risk is likely to be deemed large enough for pastoralists always to choose to move cattle away from wildebeest to avoid MCF. In areas with low levels of wildebeest use, transmission risk and disease incidence are both likely to be low, regardless of whether people move cattle or not. However, in areas with medium wildebeest use, the decision around expected costs and benefits of avoidance may be less clear, leading to high-incidence years when a 'wrong' decision is made.

Given that MCF is transmitted only from wildebeest, and not from cattle to cattle, we would not have expected incidence to increase with herd size. However, the finding of a higher incidence of MCF in smaller herds suggests that small herds are at greater risk from exposure to MCF from wildebeest. Several factors may explain these findings. First, cattle owning families with small herds may be less likely than families with large herds to move cattle away from the permanent boma to avoid MCF. Pastoral families with small herds are likely to be more impoverished and suffer greater insecurity than families with large herds, and the loss of available milk associated with moving cattle away from the permanent household in order to avoid MCF may not be tolerable. Second, families with small herds may have a lower social status and are less influential than families with larger herds, who are likely to have preferential access to 'safer' village grazing areas away from wildebeest. The finding of a higher incidence of MCF in smaller herds highlights the problem that MCF, like many other infectious diseases, is likely to have a disproportionate impact on more impoverished families. Vaccine affordability is therefore likely to be a major consideration if MCF vaccination is to achieve optimal benefits in addressing livelihood and food security needs of the poor.

5. **Conclusions**

Results from this study indicate a high willingness among pastoralists to adopt efficacious vaccines to prevent MCF in their cattle. Adoption of an MCF vaccine is likely to have important consequences for livestock movement and grazing patterns in pastoral rangeleands adjacent to the Serengeti National Park and in other areas where wildebeest can be found, with cattle being able to graze more safely in proximity to wildebeest herds during the MCF risk period. By grazing on higher quality pasture nearer to permanent boma, cattle would gain body condition more rapidly after the dry season and yield a more reliable supply of milk to families, thereby improving pastoralist nutrition.

Sustaining traditional livestock-based livelihoods through adoption of an MCF vaccine could also help counteract the ecologically damaging trend towards fragmentation and fencing of rangelands that has been seen in parts of East Africa. Potential shifts in livestock grazing patterns may also have negative ecosystem health outcomes if more intensive grazing pressure results in degradation of critical buffer zones near the boundaries of protected areas, changes to wildebeest behaviour or movements, or increasing levels of livestock predation and retaliatory killing of predators. These could all excacerbate the 'squeezing' of wildlife into increasingly confined areas of the Serengeti National Park, threatening the long-term integrity of the ecosystem (Veldhuis et al. 2019).

The prospect of an MCF vaccine is tantalising and challenging, but the opportunity now needs to be taken to explore how MCF vaccination could support an ecologically sustainable and more equitable model of wildlife-livestock co-existence.

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Table 1. Attributes and levels used in the choice experiment design

Attribute	**Levels and description**
Vaccine price (TZS*)	5 levels *(5000, 10000, 15000, 20000, 25000)*
Vaccine Efficacy	3 levels (*50%, 75%, 90%)*
Authority providing vaccine	3 levels (*Private vet, government vet, NGO vet)*
Ear tagging provided	2 levels (*Yes and no)*
Vaccination frequency to achieve immunity	3 levels (*once a year, twice a year, once for life)*
	Respondents were told: *"The hypothetical programs we are about to present will be described using five different attributes. They are as follows:* *1. Cost of Vaccine- refers to what the vaccine may be priced at. Please consider it carefully when deciding if you would participate in a given program and vaccinate your cattle or not.* *2. Vaccination Efficacy- even if vaccinated, some cows may still get ill. Vaccines differ in terms of how effective they are. While some work in 50% of cases others may protect up to 90% of vaccinated cattle.* *3. Authority- the new program could be administered by the government vet, Non-Governmental Organisation, or a private vet, and for some respondents this can matter and affect whether they participate or not.* *4. Tagging- the program may require vaccinated cattle to be tagged, by putting a clip on the cows' ears. This way vaccinated cattle can be easily distinguishable from untagged cows which have not been vaccinated.* *5. Vaccination Frequency- some vaccines are only administered once per cow's life, while others may need to be administered every year, or twice a year to be effective.* *Put together, these attributes describe different vaccination schemes. For each of the cases we are about to present to you we would like to know whether you would be willing to participate in such a program and pay the cost - or not participate and pay no cost."*

*At the time of the study, xxx TZS were equivalent to one US$.

Table 2. Estimated coefficients from multinomial logit model from whole sample and subsamples run in preference space

		Model with covariates				
	Baseline model	Main effect	Interaction - MCF cases in the past (log)	Interaction - Cattle owned (number)	Interaction - Cattle moved away (share)	**Model with non-linear cost effects**
No vaccine (alternative specific constant)	0.3897	0.4577	0.1157	-0.3707	-0.0846	0.7258**
	(0.2835)	(0.2913)	(0.2844)	(0.2950)	(0.3578)	(0.3077)
Efficacy (%)	2.6762***	2.8549***	-0.0668	-0.5125	-1.2336**	2.5806***
	(0.3542)	(0.3724)	(0.3614)	(0.3708)	(0.5918)	(0.3590)
Frequency (per year)	0.0036	-0.0075	0.0761	-0.1316**	0.0520	0.0089
	(0.0592)	(0.0615)	(0.0613)	(0.0661)	(0.0952)	(0.0594)
Tagging	1.1620***	1.1433***	0.2919***	-0.0300	0.3893***	1.1419***
	(0.1078)	(0.1125)	(0.1083)	(0.1085)	(0.1503)	(0.1083)
Private vet	0.3083**	0.2777**	0.1321	-0.0488	0.0783	0.3615***
(vs. NGO vet)	(0.1300)	(0.1328)	(0.1314)	(0.1606)	(0.1508)	(0.1334)
Government vet	0.1221	0.1354	0.1328	-0.2690**	-0.0912	0.1186
(vs. NGO vet)	(0.1055)	(0.1091)	(0.1096)	(0.1278)	(0.1686)	(0.1056)
Cost (10,000 TZS)	-0.8223***	-0.8099***	-0.0796	0.1416	0.1675*	0.6378***
	(0.0732)	(0.0758)	(0.0751)	(0.0874)	(0.0971)	(0.1360)
Box-Cox transformation parameter						1.6267***
						(0.4036)
Model diagnostics						
LL at convergence	-1,478.63	-1,450.59				-1,477.18
LL at constant(s) only	-1,673.40	-1,673.40				-1,673.40
McFadden's pseudo-R^2	0.1164	0.1331				0.1173
Ben-Akiva-Lerman's pseudo-R^2	0.5813	0.5880				0.5816
AIC/*n*	1.1054	1.1001				1.1050
BIC/*n*	1.1207	1.1616				1.1226
n (observations)	2,688	2,688				2,688
r (respondents)	224	224				224
k (parameters)	7	28				8

Note: *, **, *** indicate significance at 10%, 5%, and 1% level, respectively. Standard errors given in parentheses.

Table 3. Estimated willingness to pay (in TZS) for the characteristics of treatment program

	WTP (s.e.)	95% confidence interval
No treatment (alternative specific constant)	4,738 (3,540)	-2,025 – 11,850
Efficacy (%)	325*** (41)	251 – 412
Frequency (per year)	43 (733)	-1,407 – 1,468
Tagging	14,131*** (1,897)	10,828 – 18,232
Private vet (vs. NGO vet)	3,749** (1,644)	721 – 7,145
Government vet (vs. NGO vet)	1,485 (1,315)	-989 – 4,209
Aggregate WTP	42,474*** (3,187)	37,073 – 49,468

Note: *, **, *** indicate significance at 10%, 5%, and 1% level, respectively. Aggregate WTP for a vaccine with efficacy = 90%, frequency of administration of once per year, tagging included, private vet

List of figures, illustrations and maps

Figure 1: map of study area

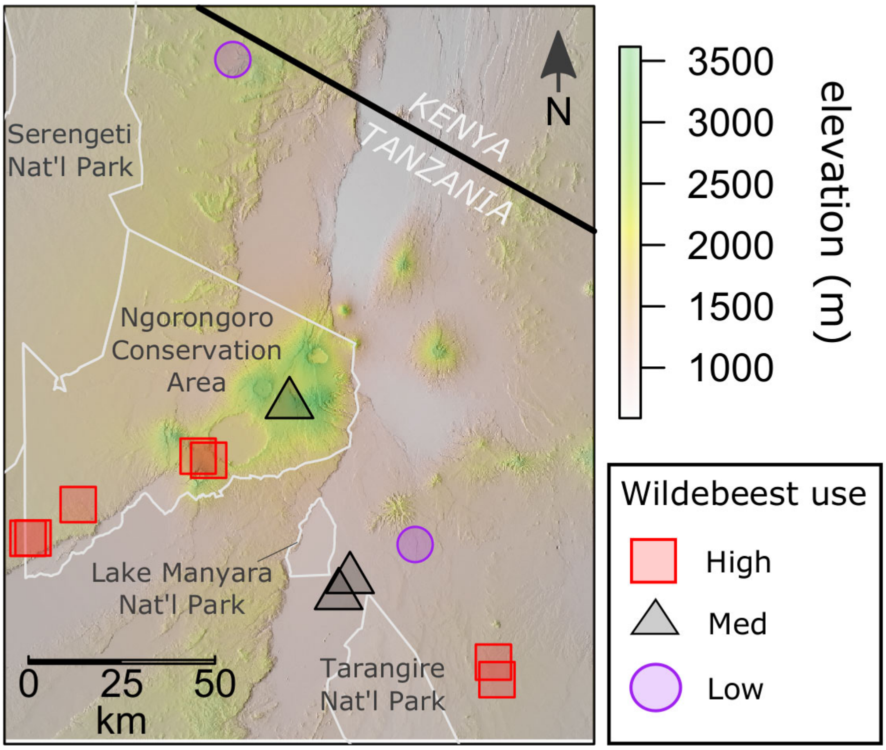


Figure 2: Example of a choice card. Each respondent was presented with 12 such cards. Respondents ticked one of the choice boxes in each card to show whether they would purchase a vaccine with these characteristics or not.

Attribute	Vaccine	No vaccine
Price per animal treated 	TZS 5,000	0
Efficacy 	75%	
Authority 	Private Vet	
Tagging 	Yes	
Vaccination Frequency 	Twice a year	
Choice (please choose ONE option only)		

Figure 3. The estimated probability of accepting the treatment program at various levels of its cost

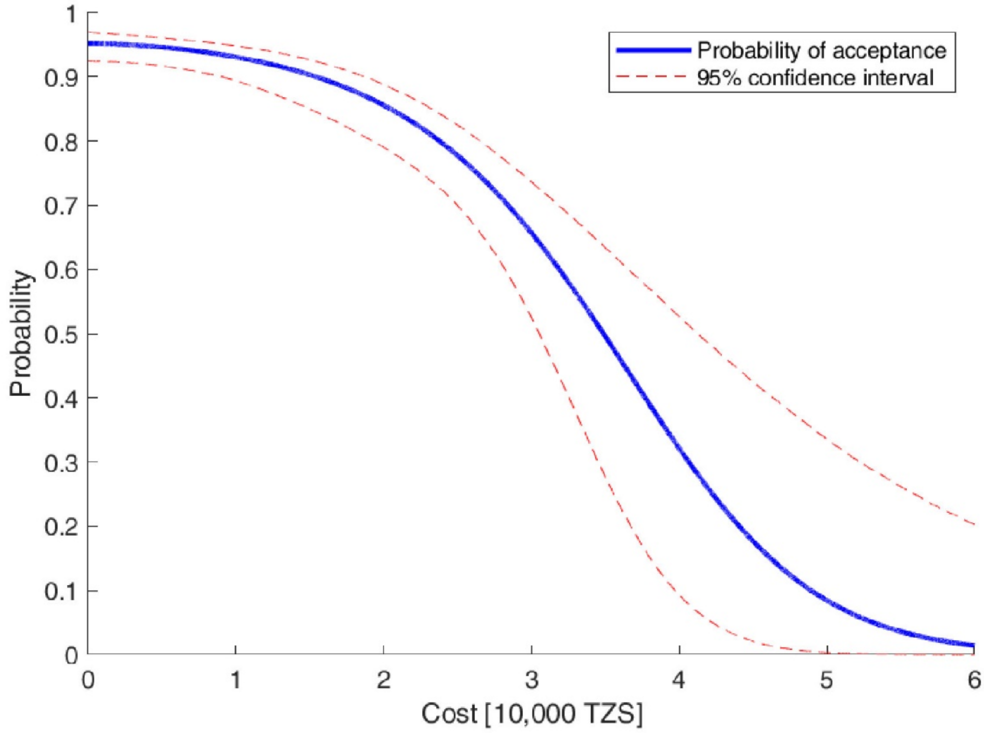
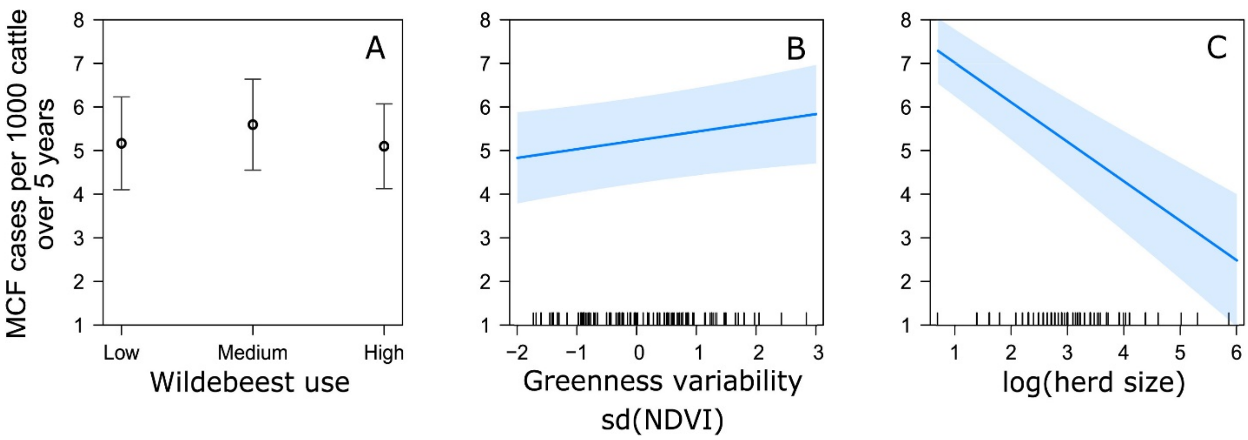


Figure 4: explanation of reported MCF incidence over last 5 years as a function of wildebeest use, variability in vegetative greenness and herd size.



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