Information sharing and willingness-to-pay for CBPP vaccine in rural Kenya

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ABSTRACT

The study estimates cattle owners' willingness-to-pay (WTP) for Contagious Bovine Pleuropneumonia (CBPP) vaccine in Samburu county, Kenya. Of particular policy relevance, the study presents findings on WTP for i) improved access to vaccines and ii) timely access to disease-risk information. The mean price for a CBPP vaccine was estimated at KES 66 (USD 0.64). This price relates to a CBPP vaccine that requires a 1.8 h commute, cattle owners' receipt of timely information that the CBPP disease risk is low-moderate and the vaccine lowers the risk of either tail-drop or post-vaccine abortion. The conditional WTP for mean travel duration and high-risk information are similar at KES 53.9 and KES 51.5. The marginal effect on demand for a 1 h additional travel duration and provision of CBPP disease risk information was estimated as a 1.5 per cent reduction and 2.3 increase. The results of this study indicate that cattle owners value greater levels of knowledge concerning the changing risk profile of CBPP in their community and improved access to CBPP vaccination services. Enhanced engagement with cattle owners concerning CBPP would likely result in a greater utilisation of available CBPP vaccines, conditional on the perceived CBPP disease risk.

1. Introduction

The estimated production loss due to contagious bovine pleuropneumonia (CBPP) in Africa in 2004 was USD 37.3 million [54]. Using more recent estimates from Kenya, production loss across Africa may now exceed USD 50 million [44,32]. The nominal growth in the estimated impact of CBPP in Kenya is an important indicator that policy action is required. While CBPP has been eradicated in high income countries, and some African, the disease continues to bedevil much of sub-Saharan Africa [28]. Eradication of CBPP requires a combined set of measures aimed at increasing cattle immunity, controlling the movement of cattle and thereby the spread of the *Mycoplasma mycoides* subsp. *mycoides* (Mmm) bacteria, and a program of testing and culling infected cattle [43]. However, promoting herd immunity through vaccinations is constrained by environmental and current vaccine formulation factors. These factors include: dependence on cold storage during transportation, duration of immunity, and likelihood of adverse reactions [43]. Limitations of previous formulations of CBPP vaccines [39] are being overcome with new strains of the CBPP vaccines (African Mmm strain T1) being developed that specifically target the needs of central and eastern Africa [42,45].

Despite continued improvements in the efficacy and effectiveness of CBPP vaccines the high cost of implementing eradication measures (vaccination and compensation for loss of infected cattle) has prohibited government up-take [43]. One avenue for reducing the eradication program costs on governments is for cattle owners to pay, at least in part, for the cost of cattle CBPP vaccination. Under such a scenario, the preferences of cattle owners towards CBPP vaccine attributes is an important policy issue. Moreover, economic estimates of consumer perceived value of on-going CBPP vaccine development are important and may help determine whether governments seek to implement CBPP eradication programs.

The literature addressing cattle owners' preferences towards CBPP vaccine attributes is limited. Consumer preferences for CBPP vaccine safety and efficacy, using a Contingent Valuation Method

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and data from Narok County Kenya (Welcome Trust Narok cohort), indicate that reducing the likelihood of adverse reactions among cattle, improving knowledge of the effectiveness of the vaccine and mandating that government veterinarians administer the vaccine are important CBPP vaccine attributes for consumers [30,29]. In these same studies parameters for post-cold storage stability and frequency of administration were not statistically significant.

The economics literature consistently indicates that providing consumers with 'new' choice relevant information has an effect on estimates of willingness-to-pay (WTP). This literature, across a range of topics from food labeling [40,20,37], transportation [17,51] and healthcare [6,26], consistently demonstrates that the amount of relevant information consumers hold is an important determinant in consequential choices. The relevance of 'new' disease risk information on cattle owners' WTP for vaccines may be hypothesized to also be relevant [46].

The current study estimates cattle owners' willingness to pay (WTP) for CBPP vaccine in Samburu County, Kenya. The vaccine attributes used include, measures of vaccine safety, consumer access to vaccine delivery and consumer access to CBPP risk status information. This study provides policy relevant information concerning consumer WTP for improved access to vaccines, timely access to CBPP-risk information and improved CBPP vaccine safety. Moreover, the study outlines a behaviourally robust method of collecting Stated Preference data. The advantages of using a Discrete Choice Experiment design, as opposed to Contingent Valuation Methods, are discussed.

2. Materials and methods

2.1. Study area

Samburu County, Kenya is assessed as having low-moderate risk of CBPP outbreaks by the Kenyan Government [30]. The county has a human population of 224,000, with the largest town (Maralal) having a population of 16,000 [49]. Maralal is positioned approximately 350 km north of Nariobi and connected via an, in part, unsealed road. The central and western areas of Samburu County, the focus of this study, are classified as semi-arid that maintains predominantly agro-pastoral livelihoods [57]. Fig. 1 spatially identifies the location of three of the five study locations in Samburu County, Kenya [19]. The towns of Losuk and Olabore is missing from the map due to non-identification on Google Maps.

2.2. Description of Sampling

Sampling took place in five townships surrounding Maralal. These townships include: Kisima, Losuk, Olabore, Porro and Sirata. All townships were within a 20 km radius of Maralal. These townships were selected due to their spatial distribution around Maralal and because they reflect a range of climatic and geographical conditions. Losuk, Porro and Sirata are located in small mountainous ranges and therefore experience cooler climates. Kisima and Olabore are located on the plains south of Maralal. Each of the five study sites facilitate child sponsorship through Compassion International, Kenya. Local Samburu cattle owners were recruited with the aid of local Samburu community leaders. These community leaders had strong and active relationships with the respective communities due to their role in administrating a child sponsorship program. The vast majority of households with children in each township were eligible for schooling and clothing assistance through the sponsorship programme. Approximately 95 percent of the sample were currently or had children enrolled in the programme. The largest two sources of income from respondents were from livestock and crops. There is no evidence suggesting that the sample was not representative of agro-pastoralists in Samburu County.

A total of 250 respondents completed the necessary survey tasks. The minimum sample size estimate of the Bayesian Discrete Choice Experiment design was 153. This lower bound sample size estimate assumes that the priors used in the DCE design are correct and that a Multinomial Logit estimator is used [3,4]. This estimate
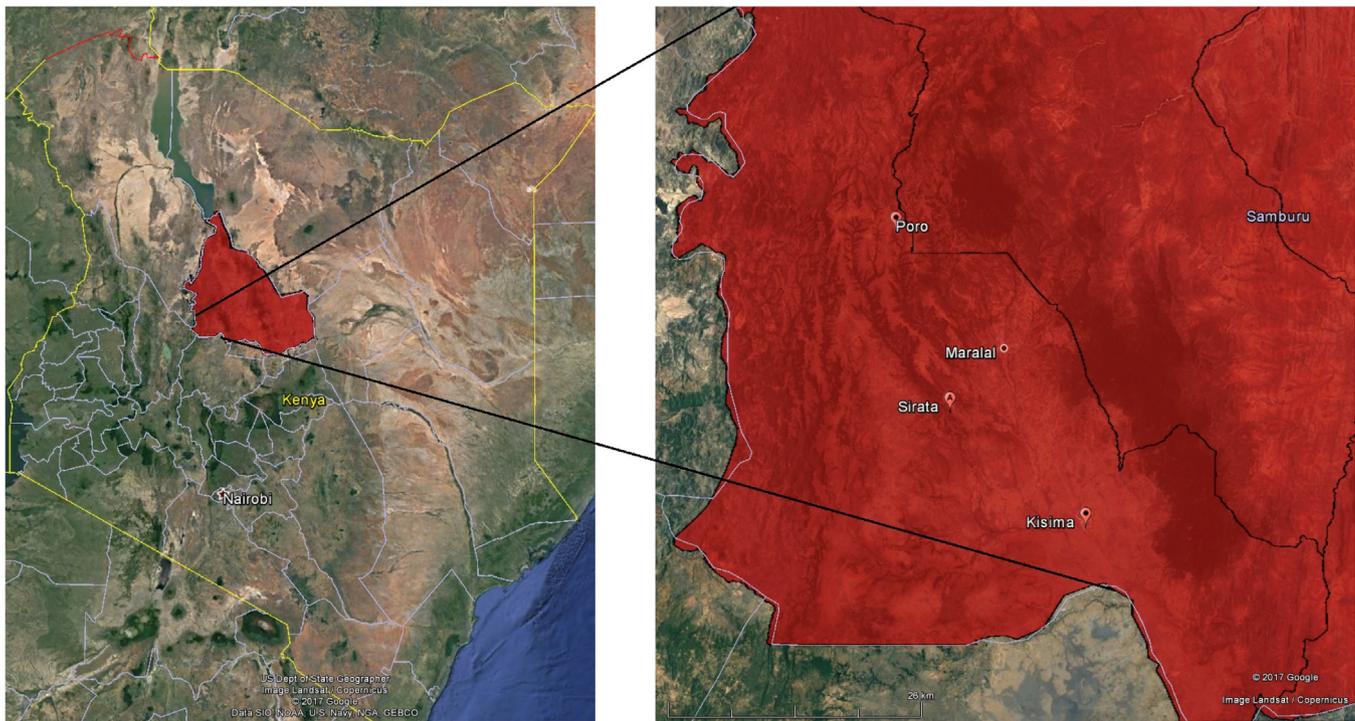

Fig. 1. Study Sites in Samburu County, Kenya.

Table 1
Sample summary statistics.

	Age		Female	Christian	No Education	Head of House	Cattle Owned		Ravens Progressive Matrices (max.20)		Sample Size
Sample Locations	Mean	Std Dev	Proportion	Proportion	Proportion	Proportion	Mean	Std Dev	Mean	Std Dev	n
Kisima	41.1	15.5	0.69	0.98	0.74	0.38	2.0	2.1	4.8	2.3	58
Losuk	38.1	12.7	0.40	0.98	0.54	0.65	2.8	3.1	5.0	2.6	52
Maralal	48.9	13.4	0.02	0.87	0.65	0.87	3.5	3.6	3.7	2.1	55
Porro	38.8	13.5	0.58	0.96	0.64	0.58	0.9	0.9	5.3	2.7	50
Sirata	46.0	14.5	0.40	0.94	0.57	0.71	1.8	1.6	5.1	2.2	35
TOTAL	**42.4**	**14.5**	**0.42**	**0.97**	**0.64**	**0.63**	**2.2**	**2.7**	**4.7**	**2.4**	**250**

is automatically provided in *Ngene* design output [8]. Demographic and socio-economic descriptive statistics of the sample are presented in Table 1. These statistics come from self-reported data. Research design and associated tools used in the study were approved by the Washington State University Institutional Review Board in the United States and the Kenyatta National Hospital and University of Nairobi Human Ethics Committee in Kenya.

2.3. Description of vaccine attributes

Four vaccine attributes defined the key characteristics of the proposed CBPP vaccine. These included: price, travel duration to receive vaccine, level of information given to the cattle owners concerning level of CBPP risk in their district, and likelihood of vaccine side-effects on cattle. The *price* and *travel duration* attributes were selected due to their importance in defining consumers' level of service accessibility. The price levels used in the study reflect the range of WTP estimates found in the literature. The median value of KES 150 used in the design is close to the mean estimated cost of CBPP vaccine at KES 130 [54]. This range includes Kenyan CBPP price estimates above KES 200 [29,56] and the current price of KES 15 per dose [48]. The time cost associated with accessing CBPP vaccines and their administration is an important component in choosing to access services [31]. The system of open cattle grazing used in Samburu, which fosters a traditional semi-nomadic lifestyle, supports the inclusion of travel durations of up to 5 h. A survey among the same respondents reported that 90 percent of respondents freely graze their cattle within 5–10 kms of their main residence, and 75 percent stated that during the recent drought they grazed their cattle further away. Given Samburu County's classification as an area of low-moderate risk of CBPP outbreak, cattle owners' level of CBPP relevant *risk information* is assumed to be an important contributor to CBPP vaccine utilisation decisions. CBPP vaccine *side-effects* are widely reported to be important among cattle owners in Kenya [30,29,56].

3. Analytical methods

WTP estimates for the hypothetical vaccine were generated through the collection of stated preference data. Discrete Choice Experiment (DCE) design is an alternative to Contingent Valuation methods (CVM), and allows for the incorporation of a wide range of respondents' behavioural characteristics [1]. Both methods draw on Lancaster's theory of consumer demand and the econometric structures and behavioural assumptions of Random Utility Theory [35,41]. Both methods are commonly used to measure preferences for non-market goods. However, DCEs are preferred as a method of stated preference elicitation due to the reduced impact of 'hypothetical bias' and strategic behaviour on estimates [2,25]. The implicit need for respondents to make attribute trade-offs when completing DCE tasks and the added flexibility to incorporate attri-

bute non-attendance within DCE model estimates is believed to lower the risk of over-stated mean estimates of WTP [23]. Measurement weaknesses associated with respondent fatigue and disengagement are inherent in DCEs as is the case for other survey and experimental methods.

WTP is calculated as the ratio of the change in marginal utility of one attribute to the change in the marginal utility for the price/-cost attribute.

Controlling for attribute non-attendance (ANA) is widely practiced in the DCE literature [22,50,24,34,27]. Within a range of choice heuristics that consumers often use to simplify choice decisions, ANA is but one [22]. The use of ANA allows respondents to acknowledge that when considering any choice they did not equally consider all attributes. Correcting model estimates for ANA is likely to improve model fit to the data. Given the use of ANA to simplify a choice task, the employment of ANA is found to be positively associated with the degree of difficulty of a choice decision, or cognitive load [22]. There exists a general consensus that increasing the number of attributes in any experimental design increases the cognitive load on the respondent [21,7,22]. ANA was collected directly after answering each individual choice task.

The DCE design used was Bayesian and was estimated in *Ngene* [8]. The choice task consisted of two unlabelled alternatives and a 'status quo' (options: A, B and Neither). Each alternative was defined by four attributes: price, travel duration, CBPP risk information, and CBPP vaccine side-effects. Table 2 summarises the characteristics of the choice task. The design consisted of 72 choice tasks that were blocked into 12 groups of six. Each respondent was allocated one group of tasks and also answered a seventh task in which all the attribute levels of one option were preferable (i.e. dominated) the levels in the alternative. The levels for CBPP-risk information and CBPP vaccine side-effects were effects coded. In each case the status quo level was the reference level. As a measure of the efficiency of the DCE design the determinant of the Asymptotic Variance Covariance matrices (i.e. D-error) is used. The mean

Table 2
Discrete choice experiment task features.

Alternatives	Attributes	Levels	Level Units
A	Price	50, 100, 150, 200, 250	KES
B	Travel duration	1, 2, 3, 4, 5	hours
Neither	CBPP-risk information	1, 2, 3	(1) status quo, mobile phone delivered 'message' of (2) low-moderate CBPP-risk, (3) high CBPP-risk
	CBPP vaccine side-effects	1, 2, 3, 4	(1) status quo, lower risk of (2) tail drop, (3) post-vaccine abortion, or (4) both

	Option A	Option B	Neither
Price	3	4	
Travel Distance	1 hour	3 hours	
CBPP-risk information	High Risk (1/4'ly)	Current status	
Side-effect likelihood	Risk / Risk	Risk / Risk	

Fig. 2. Choice Task display.

D-error of the design was 0.0492. In a similar respect to log-likelihood measures of regression results, the D-error in isolation provides no goodness-of-fit information. A description of DCE designs and D-error comparisons across designs is provided in Iles and Rose [27]. Fig. 2 is an example of the presentation of the choice tasks. Images and text were used to convey the meaning of individual levels. Of the six choice-tasks answered by respondents three had a fixed ordering of the attributes (1st Price, 2nd Travel duration, 3rd Information and 4th Side-effects), and three mixed ordering. The mixed ordering of attributes ensured that Travel duration, Information and Side-effects were each the first attribute listed. This mixing of attribute orders aimed to reduce any potential 'anchoring effects' [11]. Respondents in many contexts (e.g. when selecting from any menu) tend to favour items listed at the top, over those listed at the bottom [55]. No ordering effects were identified via analysis of choice heuristic - ANA - use. Any potential ordering effect on incidence of rationality was not controlled. Choice tasks were presented and choices recorded on tablets using *OpenDataKit* [5].

Several models were used to generate parameter and WTP estimates. These included: Multinomial Logit (MNL), Scaled MNL, Random Parameter Logit and Generalized Mixed Multinomial Logit. Due to the differing behavioural assumptions each model was used. The inclusion of the Random Parameter and Generalised Mixed models, despite their need for relatively large sample sizes, demonstrates the merit of planning studies to cater for these requirements. The Scaled MNL model enables for better control of individual heterogeneity. Parameter estimates of the Random and Generalized specification of the Multinomial Logit are provided in the Supplementary documents. These models were estimated in *Nlogit* [15]. The WTP estimates are mapped from the preference-space. Confidence Intervals are calculated using the Delta method.

In addition to gathering DCE responses, survey instruments also included a measure of cognitive ability. Given the identification of the association between poverty and changes in short-term cognitive ability (see: [18,38]), the measure of cognition was included to better control for inconsistent results. A set of Ravens Progressive Matrices (RPM) tasks were given to respondents. The RPM is a test that has gained wide support for its ability to identify fluid intelligence - a form of cognition that is associated with abstract reasoning and intelligence [47]. A version of the standard RPM is also widely used among children [9,10]. The standard short-form version of the RPM was administered. The 20 tasks included a range of tasks that varied by difficulty. This perception of difficulty is based on empirical findings from US applications [16,52].

4. Results

Table 3 presents the mean price and travel duration according to the design and respondent choice. The mean statistics 'by design' provide insight into the average price or travel duration shown to the full sample of respondents. The corresponding 'by choice' reflect the mean statistics only across those choice tasks nominated as preferred. There is no statistical difference between the design and choice means. This indicates that the design given to respondents, including the price and distance levels and the range, had contextual meaning. This is indicated by the fact that respondents did not consistently choose extreme attribute levels.

Fig. 3 characterises, in part, the relationship between respondents' cognitive capacity, per capita income and the likelihood of the respondent not correctly identifying a strictly dominant choice task. Each plot depicts a histogram of the number of observations (y-axis) by monthly per capita household income, using KES 100 intervals (x-axis). The upper bound of KES 3299 represents the Kenyan rural nominal poverty-line. The first plot's secondary y-

Table 3
Mean price and travel duration, by design and choice.

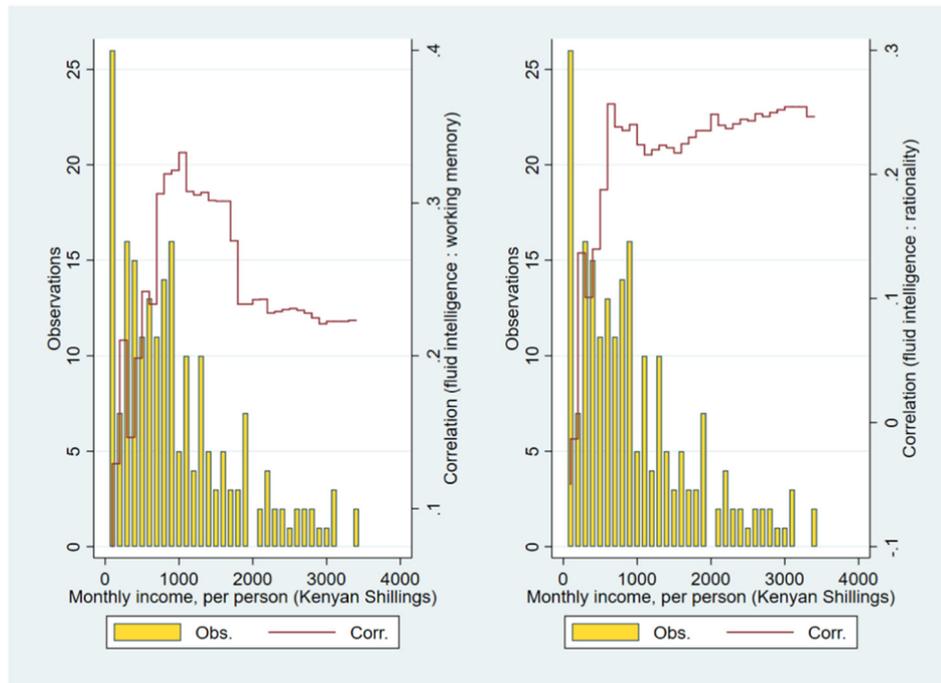|	By Design			By Choice		
	A	B	Mean	A	B	Mean
Price	70.0	69.2	69.6	66.5	66.1	66.3
Travel Dur.	2.0	1.9	1.9	1.8	1.8	1.8

Fig. 3. Correlation of cognition measures and rationality, by monthly income, per person.

axis is a measure of the correlation between two measures of cognition: Ravens Progressive Matrices (fluid intelligence measure) and Counting Span tasks (working memory capacity measure). The correlation of these cognition measures of 0.195 corresponds well with those from the United States using other measures of working memory and fluid intelligence [12]. The second plot's secondary axis is a measure of the correlation between the Ravens Progressive Matrice score and whether the respondent was 'rational' (i.e. correctly identified a dominant choice task). In each plot a strong positive relationship is evident between income, cognitive capacity and rationality is present among ultra-poor households - those on less than KES 500 per person, per month.

The Multinomial Logit estimates are presented in Table 4. Models 1 and 2 use the base dataset. Models 3 and 4 use a dataset that corrects for attributes that were ignored by respondents (i.e. attribute non-attendance - ANA). Model 5 corresponds to the Scaled MNL model output using ANA dataset and controls for monthly income (per person) heterogeneity. The categorical variables High-Risk and Low-Risk refer to CBPP risk information given to cattle owners. The parameter labels Side1, Side2 and Side3 correspond to the following categorical variables: reduced risk of tail-drop,

reduced risk of post-vaccine abortion and reduced risk of both. The proportions that each alternative was chosen by respondents were 'A' = 0.473, 'B' = 0.456 and 'Neither' = 0.071.

The following proportion of respondents indicated that they ignored respective attributes: price (0.31), travel duration (0.35), risk information (high and low − 0.31) and side-effects (0.30). This correction uses respondents' direct feedback on attributes that were not considered in making their selection, if any. Goodness-of-Fit measures are also provided in Table 4. These include: Log-Likelihood (LL), Akaike Information Criterion (AIC), Bayesian Informational Criterion (BIC) and rho^2. The rho^2 statistic (or pseudo rho^2) is analogous to the R^2 measure used in linear regression. The rho^2 statistic is calculated as 1-($LL_{model\ estimate} - LL_{base\ model}$). The constants-only rho^2 are reported. The base model used is a constant only model. A rho^2 statistic of 0.3 equates to an R^2 statistic of 0.6 to 0.7 [14]. The Goodness of Fit measures of Model 3 and 4 are uniformly better than for the corresponding Models 1 and 2.

The use of Random Parameter Logit and Generalised Mixed Multinomial Logit models allows for the estimation of non-fixed parameters (i.e. random draws from a distribution), scale effects and heterogeneity in parameters. Controlling for these common

Table 4
Multinomial logit - non-ANA and ANA.

	Model 1	Model 2	Model 3	Model 4	Model 5
Constant	0.054	0.050	0.039	0.045	0.064
Price	−0.001	−0.002**	−0.002**	−0.002**	−0.002**
Travel Dur.	−0.051**	−0.053**	−0.115***	−0.116***	−0.121***
High Risk	0.019	0.006	0.102	0.098	0.115*
Low Risk	0.078*	0.094**	0.134**	0.143***	0.147**
Side1	0.069	–	0.054	–	–
Side2	0.036	–	0.039	–	–
Side3	0.024	–	0.050	–	–
Neither	−2.145***	−2.228***	−2.199***	−2.210***	−2.255***
LL	−1471.4	−1474.0	−1254.1	−1256.1	−1219.3
AIC	2960.9	2960.0	2526.2	2524.2	2454.5
BIC	3009.7	2992.5	2573.6	2555.7	2496.3
rho^2	0.014	0.013	0.021	0.019	0.020

Table 5
Goodness of fit measures.

	Model 5	Model 6	Model 7
LL	−1219.3	−1408.8	−1400.9
AIC	2454.5	2833.6	2821.8
BIC	2496.3	2876.7	2875.7
rho²	0.020	0.030	0.036

features in data often allow for better model fit. Table 5 presents the Goodness of Fit measures for two additional models - Models 6 and 7 - both of which uses the ANA dataset. Model 6 uses a Random Parameter Logit (RPL) specification - see Supplementary documents for details). A Generalized Mixed Multinomial Logit (GXMNL) is used in Model 7. It should be noted that RPL and GXMNL specifications are data intensive, requiring larger datasets to adequately model potential behavioural features within data. Therefore, it is not surprising that the more behaviourally restrictive models provide a better statistical fit when using a small sample. The rho^2 statistic increases for each of the two MNL specifications above 0.020 provided by Model 5. However, the AIC and BIC are both higher than the Model 5 statistics.

The low rho^2 statistics presented in Table 4 may in part be explained by the interaction between the cognitive demands of the choice tasks and the cognitive abilities of respondents. Table 6 presents a series of rho^2 statistics according to the rationality and cognitive ability of respondents. These results are based on using Model 4 specifications. Rationality is defined as a respondent's correct answer to an additional choice task constructed to have a strictly dominant choice task. *Strictly dominant* refers to an alternative that had all attribute levels preferred to those in the other alternative (i.e. lower price, travel duration and side effects) [27]. Sixty-eight per cent of the sample were deemed to be rational when ANA choice heuristic was not controlled. Eliminating non-rational respondents improved model fit from $\rho = 0.019$ to $\rho = 0.023$, while restricting the sample to those with a RPM score above 4 improved model fit to $\rho = 0.030$.

The CBPP-vaccine total WTP estimates are presented in Table 7. WTP estimates by attribute provide insights into cattle owners' preferences for innovative or new vaccine features. WTP estimates using the Scaled MNL are provided, along with those using standard MNL. Model 5 (using monthly income to control individual heterogeneity) and Model 5.1 (using 'rationality' to control for individual heterogeneity) are also included in Table 7. In Model 4 none of the WTP estimates are statistically significant at the 95 per cent level. However, the estimates for Model 5 indicate that Travel Duration and Low Risk are statistically significant.

5. Discussion

The mean hypothetical price of a proposed CBPP vaccine at KES 66, is conditional on the mean travel duration to access CBPP vaccines (1.8 h), respondents' knowledge that CBPP presented a low-medium risk to cattle and that the hypothetical feature of a CBPP vaccine offered reduced risk to tail-drop or post-vaccine abortion. To the extent that these constraints are reasonable for livestock owners in Samburu County, Kenya the mean price is policy relevant. This value is approximately half the estimated KES 130 per dose cost of the CBPP vaccine, but is above the current subsidized price of KES 30 per average herd size. With a rural Kenyan poverty-line threshold of approximately KES 3132 per person per month, an increase in the current household annual average CBPP cost of KES 30 seems realistic. The WTP estimate of KES 130 per herd per year for the hypothetical vaccine, information delivery system and improved average accessibility appears viable. The WTP KES 130 estimate per average herd size for annual CBPP vaccinations should be further contextualized by acknowledging that the estimated average monthly household income in the sample was KES 1600-1800. All estimates were conducted at the end of a prolonged drought between 2015 and 2017. When interpreting WTP estimates consideration of possible 'reference effect' (i.e. respondents' true preferences are biased due to the values given in the design) of the selected price level range selected in the DCE design should be acknowledged. This potential effect may bias results. However, the use of a realistic price range in the current study mitigated this effect.

Establishing this mean hypothetical CBPP price provides important context for interpreting the WTP estimates for reductions in travel duration and increasing risk information. Due to the conditional nature of any model estimates, WTP estimates are also conditional. This estimate includes consideration of other variables, although these other variables are 'held constant'. Therefore, WTP estimates should be interpreted as the valuation of incremental changes above (below) the mean. The mean price of KES 66 includes mean travel distance of 2 h and the base level of information - 'status quo' (i.e. 'word-of-mouth'). The WTP of KES 53.9 for reductions in travel distance time minus the mean price of KES 66 equates to an aggregate WTP of KES 12.2 per CBPP dose for a 1 h reduction from 2 to 1 h. In a similar way, the quarterly mobile phone messaging that the CBPP-risk was low-moderate represents a KES 0.2 per CBPP dose valuation by cattle owners. A corresponding WTP of KES 14.6 is available for information concerning CBPP during a high-risk period. The estimated increases in CBPP vaccine demand (i.e. willingness-to-pay) by Samburu County cattle owners due to improved access to vaccine delivery and risk information

Table 6
Goodness of fit by rationality and cognition.

	RPM = All	Rational RPM = All	RPM>=4	Rational RPM>=4	RPM>=8	Rational RPM>=8
rho2	0.019	0.023	0.030	0.035	0.058	0.063

Table 7
WTP measures.

	Model 4			Model 5 (het = monthly inc.)			Model 5.1 (het = rationality)		
	Travel Dur.	High Risk	Low Risk	Travel Dur.	High Risk	Low Risk	Travel Dur.	High Risk	Low Risk
Mean	56.9	48.2	70.0	53.9	51.5	65.8	51.0	37.2	75.0
St Dev	29.4	38.8	37.0	24.3	28.4	23.5	26.2	33.9	37.8
Lower (95%)	−0.7	−27.9	−2.5	6.2	−4.3	19.8	−0.3	−29.2	0.9
Upper (95%)	114.5	124.3	142.5	101.6	107.2	111.8	102.4	103.5	149.2

highlights policy avenues to increase CBPP vaccine up-take. If CBPP eradication is a policy objective, improving the vaccination rate is an important first step.

The relative low valuation of travel time savings by cattle owners appears reasonable among Samburu pastoralist, many of whom are willing to move their cattle, by foot, up to 25 kms during dry-seasons in search for improved grazing conditions. An hour savings of time has relatively small value. The aggregation of the WTP results masks individual differences among cattle owners' valuation of regular CBPP risk information. Nevertheless, the estimates provide support that regular disease risk information is valued among Samburu cattle owners.

The low rho^2 estimates across all the models indicates that the data contains considerable noise. This noise may in part be due to the cognitive demands of the choice tasks to make consistent trade-offs across the four attributes and across the six choice tasks. One effect of this noise in the data was that dropping the side-effect attributes improved model fit. The level of cognitive demand presented by the choice tasks is relative to respondents' cognitive capacity at a given point in time, which is known to vary over time [10,38]. Controlling for various levels of cognitive ability and 'rationality' improved the predictive value of the model from 0.020 to 0.063. Moreover, the ability of less restrictive multinomial logit models to account for preference heterogeneity also helped improve the explanatory power. However, models 6 and 7 did not improve model fit as measured by the log-likelihood and information criteria. As a result, responses from the full sample using a MNL model are used in the WTP estimates (i.e. irrespective of 'rationality' and cognitive ability).

A strong correspondence between rationality and cognition is evident. The correlation plots of Fig. 3 and the improved goodness-of-fit measures when rationality and/or cognitive ability are controlled underscore this relationship. The apparent associated influence of income on these measures suggests that exclusion of 'irrational' respondents will limit the generalisability of any findings. The desire not to restrict available preferences from analysis and controlling for ANA before analysis did not merit the exclusion of apparent "irrationality" among responses without controlling for ANA [36,13]. Use of the full sample ensures that results are generalisable to the sample communities.

Considerable market externalities exist when considering vaccine pricing, and this is also true when considering CBPP vaccinations [29]. The CBPP price and WTP estimates presented above do not include the positive non-market benefits associated with herd immunity for cattle not vaccinated, but protected by the immunity of surrounding cattle, nor the negative non-market costs of disease transmission among non-vaccinated cattle. Therefore, the social benefits of CBPP vaccine use are likely higher than that estimated. The existence of such externalities is often the basis of arguments promoting the role of governments to subsidise the delivery of vaccines. However, such an argument is complicated by conflicting government resource priorities and the relative importance of CBPP within the wider animal infectious disease landscape. The cost of implementing CBPP eradication programmes is believed to be a significant reason for the lack of government action in parts of sub-Saharan Africa. Therefore, despite the merits of government subsidies for CBPP vaccine the magnitude of the current subsidy should reevaluated. This evaluation should consider possible improvements to vaccine formulation and information sharing and revised government subsidies for CBPP vaccinations.

Providing cattle owners with more information concerning CBPP risk-levels and vaccination locations and services is likely to promote more informed decision-making by cattle owners and a greater up-take of CBPP vaccines. Despite the natural tendency for cattle owners to desire that CBPP vaccine cost should be borne by someone else (i.e. governments), there exists evidence that a sizeable minority of cattle owners acknowledge their responsibility in helping to manage CBPP [53]. As a second-best alternative to the implementation of a CBPP eradication program throughout sub-Saharan Africa, better engagement and information sharing with cattle owners is a promising strategy. Caution is needed in extrapolating results from a low-moderate CBPP risk area to those in high risk areas. Moreover, these results were collected at the conclusion of a protracted and severe drought between 2015 and 2017. Further work spanning the three CBPP risk regions in Kenya is needed to allow for wider extrapolation and control for possible seasonal and cognitive changes.

6. Conclusion

Promoting greater cattle owner engagement in the management of cattle health is a positive step towards increasing the take-up of CBPP vaccinations in sub-Saharan Africa. A central part of a policy towards greater community engagement is improved information sharing concerning the risks and available services for the management of CBPP. Results from this study support the argument that cattle owners value greater levels of knowledge concerning the changing risk profile of CBPP in their community. This value is demonstrated by cattle owners' willingness-to-pay higher vaccine prices in the presence of enhanced knowledge. Heightened engagement with cattle owners concerning CBPP would likely result in greater utilisation of available CBPP vaccines according to communities' estimated disease risk. Further empirical research is warranted in sub-Saharan Africa to identify how government agencies can best share information with local communities and the associated benefits and costs.

7. Conflict of interest statement

Declarations of interest: none.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.vaccine.2019.01.072.

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