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Farmer-friendly delivery of veterinary services: Experimental insights from the Kenyan dairy sector

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Abstract

Poor health conditions of livestock cause sizeable losses for many farmers in the Global South. Veterinary services, including vaccinations, could help but often fail to reach farmers under typical smallholder conditions. Here, we examine how the provision of a vaccine against East Cost Fever (ECF) – a tick-borne disease affecting cattle in Africa – can be designed to reduce typical adoption barriers. Using data from a choice experiment with dairy farmers in Kenya, we evaluate farmers' preferences and willingness to pay for various institutional innovations in vaccine delivery, such as a stronger role of dairy cooperatives, new payment modalities with a check-off system, vaccination at farmers' homestead, and bundling vaccinations with discounts for livestock insurance. Our data reveal that farmers' awareness of the ECF vaccine is limited and adoption rates are low, largely due to institutional constraints. Results from mixed logit and latent class models suggest that suitable institutional innovations – tailored to farmers' heterogeneous conditions – could significantly increase adoption. This general finding likely also holds for other veterinary technologies and services in the Global South.

Keywords: cooperatives; dairying; animal health; ECF

JEL Codes: Q13; Q16; Q1

1. Introduction

Livestock value chains employ up to 1.3 billion people worldwide and are critical for food security, income generation, and safety nets (Parlasca & Qaim, 2022; Salmon et al., 2020). This is especially true for many poor people in the Global South. In Sub-Saharan Africa, for example, livestock provides food and income to more than 70% of the rural population (Thorne & Conroy, 2017). At the same time, livestock systems continue to be challenged by several risks, including diseases that can cause significant production losses and lead to morbidity and mortality amongst animals and humans.

Different types of veterinary services that can help mitigate animal health challenges exist, but – as for many other agricultural innovations – such services are often under-used (Enahoro et al., 2021). Adoption of veterinary services, including vaccines, is often hampered by low accessibility, liquidity constraints, shortages of veterinary officers, or insufficient knowledge and awareness among livestock farmers. Logistical complications associated with distributing drugs and vaccines can represent additional barriers to adoption (Aina et al., 2018; Marsh et al., 2016). In this paper, we analyze how the provision of veterinary services can be improved to reduce adoption barriers for farmers.

We use a vaccine against East Coast Fever (ECF) as a prominent example of a valuable veterinary service for livestock farmers in the Global South. ECF is a tick-borne disease-causing calf mortality rates of up to 80% in severe situations (Gachohi et al., 2012; Homewood et al., 2006; Marsh et al., 2016). Since its vector, the tick Rhipicephalus appendiculatus, is an abundant pathogen in Eastern, Central, and Southern Africa, ECF represents the leading cause of mortality in cattle among all tick-borne diseases (Chepkwony et al., 2020). The vaccine against ECF is an interesting case for our study, as it offers lifetime protection, has been existing for many years (Radley et al., 1975), but uptake in Eastern and Southern Africa (ESA) remains low. In Tanzania, for example, only 11% of livestock farmers have taken up the vaccine (Teufel et al., 2021), even though vaccination would be financially viable for farmers (Babo Martins et al., 2010; Nyangito et al., 1996).

A promising strategy to reduce adoption barriers, and one which forms the practical backdrop to this paper, is an aggregated supply of ECF vaccine that involves the coordination of vaccination events with dairy cooperatives and vaccinators. An aggregated approach can possibly overcome issues of reaching out to dispersed farmers in different locations (i.e., Brown et al., 2021; Hollifield & Donnermeyer, 2003), but so far it has not been analyzed to what extent aggregation and coordination of supply chains may help to spur the adoption of veterinary services. This research gap is addressed here with choice experimental methods. Our results may provide general insights and may also help in the design of concrete ongoing initiatives. For instance, a larger project by the International Livestock Research Institute (ILRI) and the University of California, Santa Cruz (UCSC), is currently working with Kenyan dairy cooperatives and vaccinators to implement an aggregation strategy for the ECF vaccine in the field.

Our choice experiment with dairy farmers in Kenya analyzes farmers' preferences for different attributes of ECF vaccine provision. In particular, we test several institutional innovations not yet available in the market, including a combination of the ECF vaccine with livestock insurance and the possibility of using a check-off system for vaccine payments (Nhantumbo et al., 2016). Depending on their economic, social, and geographic situation, farmers may have distinct preferences and needs for the delivery of veterinary services. To allow for such preference heterogeneity, we also test if farmers can be classified into different consumer types. Accounting for such heterogeneity in the design of technical solutions was shown to be important for livestock farmers in similar settings (Linhoff et al., 2023).

Our analysis of different strategies to increase the demand for ECF vaccine through dairy cooperatives adds to the growing literature on the farmer-friendly design of veterinary services in the Global South (Bennett & Balcombe, 2012; Ouma et al., 2021; Patel et al., 2016) and also to the literature concerning critical determinants of provision and utilization of vaccines and other veterinary services (Enahoro et al., 2021; Karanja-Lumumba et al., 2015; McKune et al., 2021). Furthermore, we contribute to the broader research and policy question if and how cooperative societies may improve access to animal health care in the Global South.

The remainder of this paper is organized as follows. Section 2 provides a brief background of veterinary services, dairy cooperatives, and input access among dairy farmers in Kenya. Section 3 describes the study area, data, and estimation strategy. Section 4 presents the empirical results and discussion. We conclude and give policy implications of our findings in section 5.

2. Veterinary service dairy cooperatives, and input access in Kenya

Prior to the 1980s, veterinary services in Kenya and many other countries of Africa were considered a public good and hence organized by the government. However, with increasing fiscal challenges, the World Bank advocated for more market-oriented approaches to service provision (Ilukor, 2017; Oruko & Ndung'u, 2009). Consequently, governments privatized the management of animal health services, giving rise to different delivery systems, including public and private veterinary surgeons, animal health assistants, community-based animal health workers, and informally trained para-vets (Irungu et al., 2006). However, up till now most of these systems have failed to solve the inefficiencies in service delivery largely due to institutional and governance issues (Ilukor, 2017). Especially the high costs of reaching out to many dispersed farmers coupled with farmers' limited awareness have contributed to low uptake of animal health services (Ilukor et al., 2015).

High transaction costs are a general issue in the small-farm sector, which can often be addressed through collective action in the form of farmer groups or cooperatives (Fischer & Qaim, 2012; Markelova & Mwangi, 2010; Twine et al., 2019). In Kenya's dairy sector, farmers mainly market their milk through cooperative societies. However, traditionally these cooperative societies are mostly focused on the output market and not on connecting farmers to inputs and veterinary services (Omondi et al., 2017). More recently, some of the dairy cooperatives were further developed into so-called dairy hubs, trying to build up new links to input and animal health service providers (Kilelu et al., 2017; Omondi et al., 2017).

Coordinating livestock vaccination through cooperatives would likely reduce transaction costs and improve the flow of information among farmers. Vaccine distribution through cooperatives could also address farmers' liquidity constraints through a "check-off system", where farmers pay for the vaccines and related services through deductions from the milk proceeds (Rao et al., 2019). Nevertheless, the spread of the dairy hub concept, which intends to develop and offer such approaches within cooperatives, has been slow (Ngeno, 2018). So far, input and health service provision in the Kenyan dairy sector is limited to only a few strong and well-organized cooperative societies. In this study, we analyze how vaccine delivery services of cooperative societies could potentially be improved.

3. Materials and methods

3.1 Study area and sample selection

To analyze farmers' adoption of the ECF vaccine and their preferences for new approaches of vaccine provision, we collected data from dairy farmers in nine Kenyan counties, namely Baringo, Bomet, Elgeyo-Marakwet, Kericho, Nakuru, Nandi, Trans-Nzoia, Uasin-Gishu and West Pokot (Rift Valley Region); Nyandarua (Mount Kenya Region); and Makueni (Eastern Region). These counties represent semi-intensive to extensive dairy production systems with a high risk of exposure to ticks and ECF (Karanja-Lumumba et al., 2015). The selected counties are also part of a larger research project by ILRI and UCSC, trying to address ECF vaccine adoption constraints through institutional innovations in cooperative societies.

The sample of dairy farmers was randomly selected jointly with the larger ILRI project, using a multi-stage sampling technique. First, the nine counties were selected purposively. Second, in these counties a census of dairy cooperative societies was conducted, resulting in 188 dairy cooperatives. Third, from all cooperatives we determined those that were active and had sub-units with membership numbers between 30 and 800. This process yielded 39 cooperatives with 361 sub-units, out of which we selected 210 sub-units randomly. Fourth, in each subunit, five farmers were randomly selected for the baseline survey, resulting in a total of 1050 farmers. Fifth, out of these 1050 farmers, we randomly selected 625 dairy farmers to participate in the choice experiment, which was conducted together with the baseline survey between October and December 2021.

3.2 Choice experiment

We use a discrete choice experiment (DCE) to assess farmers' preferences for an ECF vaccine package that is offered through the cooperatives. The DCE allows the assessment of the values of and possible trade-offs between different attributes of the vaccine package, using farmers' stated preferences in hypothetical choice scenarios (Lancaster, 1966). DCEs are consistent with random utility theory (McFadden & Train, 2000). Rational individuals will prefer choices that yield the highest utility given a set of finite alternatives (Louviere et al., 2000). Appropriate methods can then be applied to reveal the value of utility from the attributes of the choices.

Choice experiments have been widely used in different disciplines including the valuation of environmental goods (Kouser & Qaim, 2013), agricultural value chains (Abebe et al., 2013; Ochieng et al., 2017), and decision-making in livestock regarding genetics, marketing, risk management, and health (Linhoff et al., 2023; Ouma et al., 2007, 2021). To identify relevant vaccine package attributes for our experiment, we first conducted a review of the literature on livestock vaccination and risk management (Acosta et al., 2019; Gachohi et al., 2012; Jumba et al., 2020; Shee et al., 2021). This was followed by key informant interviews with experts in

Kenya's livestock sector and validation with farmers to ensure that the design of the experiment closely aligns with local circumstances and that all attributes and attribute levels are realistic and consistent.

We selected four attributes in the final design of our choice experiment. The first attribute relates to the mode of payment. We consider two levels, payment by cash and use of check-off. Farmers currently have to pay for vaccinations in cash, which can be challenging due to liquidity constraints. Check-off payment means that farmers can pay later through deduction from the milk proceeds (Omondi et al., 2017; Rao et al., 2019). Currently, in some cooperatives, farmers are using check-off to pay for animal feed and some other inputs. The system is not yet used for ECF vaccination but could be further developed in this direction with relatively low additional costs.

The second attribute relates to the location of the vaccine administration. Two levels are considered, either administration at a common area in the village or at the farmer's homestead. Vaccination at a common area, such as the cattle dip in the village or the livestock market, represents the traditional approach used in Kenya's small-farm sector. This approach means relatively low transaction costs for the vaccinator, but high costs for farmers in terms of moving their animals (Acosta et al., 2019). In addition to the time and effort, moving the animals to a common area is also associated with higher exposure to other diseases (Railey et al., 2018). Hence, vaccinations at farmer's homestead may lead to a higher willingness to pay.

The third attribute relates to discounts on annual premiums for insurance cover against livestock mortality. Apart from ECF, farmers face additional risks from other diseases as well as natural disasters with potential losses. A key barrier to insurance uptake is the high cost of insurance premiums (Shee et al., 2021). Vaccination against ECF reduces mortality risk, which means that insurance companies could either lower the premium or offer new insurance contracts with wider risk coverage. During our key informant interviews we learned that insurance companies do require prior vaccination of animals for several of their improved insurance products. In our choice experiment, we include three discount levels, namely the base value of no discount, a discount of 300 Kenyan Shillings (KES), and a discount of KES 600 per animal and year.

The fourth attribute relates to the price of the vaccine per animal. The average price for vaccination at the time of the survey was KES 1,000 (approximately US $9). We use four price levels, namely the base price of KES 1,000, a somewhat higher price of KES 1,200, a somewhat lower price of KES 800, and a much lower price of KES 500, which is what farmers are sometimes offered in subsidized vaccination drives. The price attribute is treated as numerical. We apply effects coding techniques for the other attributes to allow the measurement of nonlinear effects in the attribute levels (Hensher et al., 2015). All four attributes and their attribute levels are summarized in table 1.

Table 1: ECF vaccine package attributes and levels used in the choice experiment

Attribute	Level		Coding
Mode of payment	1	Direct cash	Base level
	2	Check-off at cooperative	Dummy
Vaccine administration point	1	Vaccination done in a common area in the village e.g., cattle dip	Base level
	2	Vaccination done at farmer's home	Dummy
Livestock insurance discount (KES[1])	1	No discount on insurance premium	Base level
	2	A reduction of KES 300 on insurance premium	Dummy
	3	A reduction of KES 600 on insurance premium	Dummy
Cost of vaccination which includes service fee for the veterinarian/health worker (KES[1])	1	KES 500	Numerical
	2	KES 800	Numerical
	3	KES 1000	Numerical
	4	KES 1200	Numerical

Notes: [1]Exchange rate at time of survey 1 US $ = 110 Kenyan Shillings (KES).

We used NGENE software and a fractional factorial design to generate meaningful choice sets. Following Caputo et al. (2017), we conducted a pilot survey with choice sets developed using an orthogonal design and estimated a multinomial logit model to get coefficient estimates (priors) used in the Bayesian D-efficient design. The pilot study also gave insights on farmers' level of understanding of the choice experiment and helped improve the design of the choice cards and provide additional information about the vaccine. The process yielded 18 choice sets that were randomly blocked into three blocks of six choice sets. The blocks were then randomly assigned to farmers. Each farmer was asked to respond to only one block containing six choice sets to reduce non-response, fatigue, and response bias (Loosveldt & Beullens, 2017). Each of the choice sets included an opt-out option. Farmers were provided with pictorial versions of the cards as shown in figure 1.

Prior to the implementation of the DCE, farmers were sensitized about the purpose of the exercise, the contents of the choice cards, and how to correctly participate and respond to the choices. Additionally, farmers were also given a brief description of the ECF vaccine, how the vaccinations are conducted today, and the effectiveness of the vaccine.

Attribute	Vaccine option 1	Vaccine option 2	Neither option 1 nor 2
Mode of payment	Pay with cash 	Pay through deduction from cooperative 	
Vaccine administration	Vaccination at common area in village 	Vaccination at farmer's home 	
Insurance premium rate	Get a discount of KES 600 	Get a discount of KES 300 	
Cost of vaccine (KES)	Pay KES 1,000 	Pay KES 800 	

Figure 1: Sample of choice card

3.3 Econometric framework

To analyze farmers' preferences for ECF vaccination, we apply mixed logit (ML) models rather than the standard logit and probit models for a number of reasons. First, ML models allow taste parameters to vary randomly across decision-makers, accounting for preference heterogeneity (Train, 2009). Second, ML models allow for correlation in unobserved factors and unrestricted substitution patterns over choice situations (Hensher et al., 2015). In our case, farmers responded to six choice sets increasing the probability of correlation in unobserved utility. Third, ML models relax the assumption of independence from irrelevant alternatives (IIA) that is required when using conditional logit models. Hausman specification tests suggest violation of the IIA assumption in our case, so that ML models are preferred.

Following the random utility framework, a sampled farmer i selects their preferred alternative from a set of j ECF vaccine profiles representing different attributes and attribute levels for every k choice situation. The utility function for farmer i can be expressed as:

$$U_{ijk} = \beta_i x_{ijk} + \varepsilon_{ijk,} \qquad (1)$$

where β_i is a vector of individual-specific taste coefficients, x_{ijk} is a vector of observed attributes of the ECF vaccine and socioeconomic characteristics of the farmer, ε_{ijk} is a stochastic term assumed to be independent, and identically distributed (Gumbel distribution). For each farmer i, the parameter β varies in the population with the density denoted as $f(\beta|\theta)$, where θ is a vector of parameters representing the mean and covariance of β in the population (Train, 2009). In the mixed logit framework, we focus on estimating population parameters (θ) as opposed to β_i (Ouma et al., 2007). Therefore, conditioned on β_i, we can estimate the probability of a farmer selecting alternative C as follows:

$$L_{iCk}(\beta_i) = \frac{e^{\beta_i x_{iCk}}}{\sum_{j=1}^{i} e^{\beta_i x_{ijk}}} \tag{2}$$

Equation (2) represents the specification of the conditional logit (McFadden, 1973). However, in our case, β_i is unknown. We, therefore, use unconditional probability. Taking the integral of equation (2) over all possible values of β, we can express the probability in a mixed logit as follows:

$$P_{iCk}(\theta) = \int L_{iCk}(\beta_i) f(\beta_i|\theta\,)\, d\beta_i \tag{3}$$

Assuming β is normally distributed and there is no closed form of the integral in equation (3), we simulate it by taking draws of β from the population density $f(\beta|\theta)$. We employ the use of Halton draws that yield more accurate approximation compared to Antithetics draws (Ouma et al., 2021; Train, 2009). Models are estimated while allowing correlation of the taste parameters and assuming the parameters to be random and normally distributed with the exception of the price attribute. We also include an alternative specific constant (ASC) in the utility function to capture preference for the status quo option coded as unity if a farmer chooses the current practice of accessing the vaccine through the local government programs or private animal health practitioners (or no vaccination at all), and zero if any of the alternative experimental options of vaccination through the cooperative society was chosen. A negative coefficient of the ASC can be interpreted as a positive utility of vaccinating animals through the cooperative as opposed to the current practice.

Based on this framework, we can estimate the willingness to pay (WTP) for the vaccine attributes as the rate of change in the attribute divided by the rate of change in the vaccine price attribute (marginal rate of substitution):

$$WTP_i = -\frac{\beta_i}{\beta_{price}} \tag{4}$$

While the ML model accounts for preference heterogeneity, it does not explain the sources of heterogeneity (Boxall & Adamowicz, 2002; Greene & Hensher, 2003). The sources may relate to socioeconomic characteristics of farmers and a possible solution would be to interact the characteristics with vaccine attributes. However, this requires a prior selection of key individual-specific variables (Ouma et al., 2007). As an alternative, in addition to the ML, we employ the latent class (LC) model that intrinsically sorts individuals into latent classes to explain the sources of heterogeneity. Taste preferences are considered homogenous within classes but heterogeneous across classes (Boxall & Adamowicz, 2002). Classes are not observable, and the assignment of classes is probabilistic based on the socioeconomic characteristics of individuals. The probability that farmer i chooses alternative C in a choice set k given that they belong to class d is given by:

$$P(iCk\,|d|) = \prod_{k=1}^{K} \frac{\exp(\beta_d x_{iCk})}{\sum_{j=1}^{J} \exp\left(\beta_d x_{njk}\right)} \tag{5}$$

where x_{iCk} is a vector of ECF vaccine attributes associated with alternative C in choice situation k. The class-specific parameter β_d captures preference heterogeneity across classes. Using a multinomial logit form, we can estimate the probabilities of class membership as:

$$P(d) = \frac{\exp(\theta'_d z_k)}{\sum_{d=1}^{D} \exp(\theta'_d z_k)}, \qquad \theta'_d = 0 \tag{6}$$

where z_k represents observable characteristics that determine class membership, and θ'_d is a vector of parameters which is normalized to zero for one class to ensure identification of membership parameters for the other classes. We determine the optimum number of classes based on the Akaike information criterion (AIC), the Bayesian information criterion (BIC), and the consistent Akaike information criterion (CAIC) as proposed by Boxall & Adamowicz (2002).

4. Results and discussion

4.1 Descriptive results

Table 2 shows household and farm characteristics of sampled dairy farmers. Household heads are largely men. The long average experience in dairy farming of 20 year suggests substantial technical know-how in animal production. Farmers have an average farm size of 6.4 acres that includes both land for grazing and crop cultivation. However, 72% of the farmers practice zero-grazing dairy production. Nearly all herds consist of cows of improved breed, which is not surprising given that most farmers produce milk primarily for commercial sales. While improved breeds have higher milk output, they are more susceptible to ECF infection than local breeds.

Table 2: Household and farm characteristics

Variables	Mean	Std dev
Male household head (male = 1)	0.80	
Age of household head (years)	53.61	13.70
Education of household head (years of schooling completed)	12.35	4.61
Dairy farming experience (years)	20.06	12.84
Household size (count)	4.26	2.35
Wealth index	33.53	13.60
Income from off-farm activities (yes = 1)	0.70	
Distance to local market (kilometers)	4.05	4.52
Distance to a motorable road (kilometers)	0.85	3.02
Farm size (acres)	6.40	11.70
Herd size (TLU cattle)	4.73	13.18
Proportion of improved breed to total herd size	0.97	0.15
Confined/zero-grazing system (yes =1)	0.72	
Past experience in taking credit (yes = 1)	0.34	
Access to extension (yes = 1)	0.33	

Notes: N = 625. TLU = tropical livestock units with conversion factors based on Njuki et al., (2011) for Sub-Saharan Africa: cow and ox = 1, local cow = 0.8, heifer = 0.5, immature male cattle = 0.6, calf = 0.2; At the time of survey 1 USD = 110 Kenyan Shillings.

We measured household resource constraints using the wealth scorecard adopted from (Schreiner, 2018). Farmers are asked a total of ten questions that are used to rate the poverty likelihood of the household. We then use the national poverty line for Kenya[1] to interpret the score and corresponding estimates of poverty likelihood. The wealth index score for the sampled households is 33.5 on average. To put this into perspective, the likelihood that a household with a wealth index of 33.5 falls below the national poverty line is around 55% (Schreiner, 2018). Table 2 also shows that access to agricultural extension and credit is low, at around 33% each.

To better understand the relevance of ECF and other livestock diseases for farming operations in Kenya, we asked respondents about the incidence and cases of mortality for several diseases within the last twelve months preceding the survey. Self-reported disease incidences are shown in Panel A of Figure 2. Panel B shows self-reported case fatality for animals associated with a certain disease. ECF had by far the highest incidence rate compared to all other reported diseases. The case fatality rate of ECF is also high at 19%. Due to imperfect knowledge and recognition of ECF symptoms, the real figure of infection may even be higher. These results clearly emphasize the seriousness of animal health problems caused by ECF.

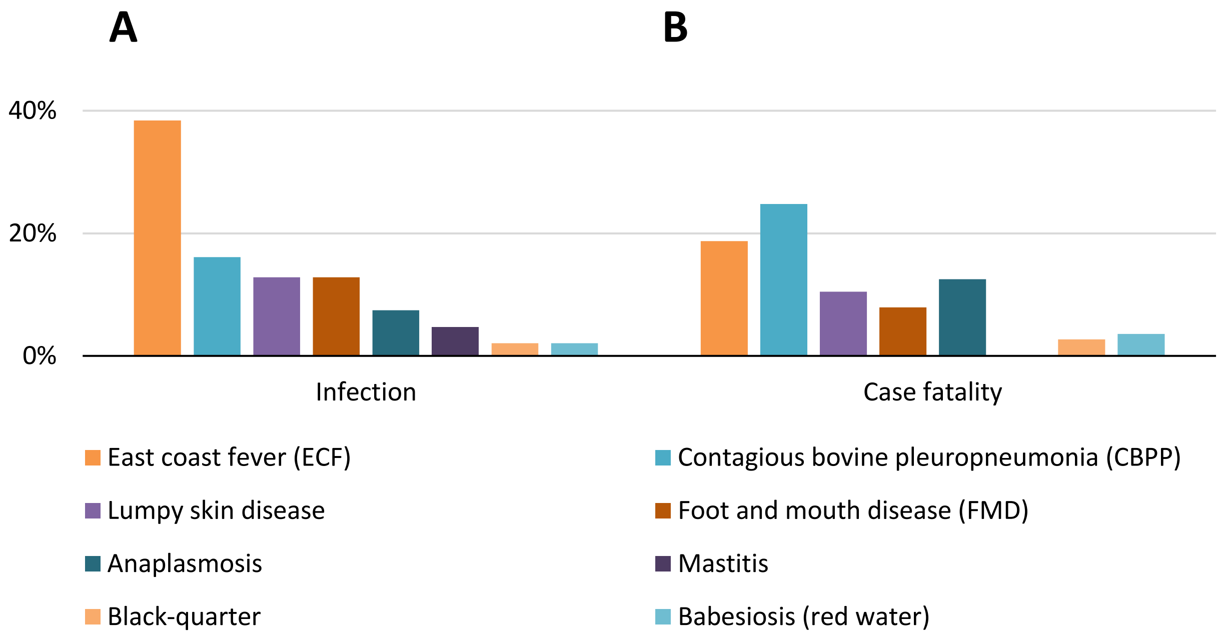

Figure 2: Reported incidence and case fatality of livestock diseases affecting dairy farmers in Kenya.

In the survey, we also asked about farmers' knowledge of ECF and the vaccine as a preventive measure. Table 3 shows that most farmers have heard of the disease and can correctly identify related symptoms. Awareness of the vaccine, in contrast, is much lower at 41%, and only 10.6% of the farmers said to have ever used the vaccine. These low adoption levels are comparable to other African contexts (Teufel et al. 2021).

[1] Per adult equivalent national lines based on the 2015 Kenya Integrated Household Budget Survey

Table 3: Farmers' knowledge of ECF and use of the ECF vaccine

Share of farmers who:	
1) Have heard of ECF	91.5
2) Correctly identified ECF symptoms	79.7
3) Are aware of the ECF vaccine	41.1
4) Have ever used the ECF vaccine	10.6

Notes: N = 625

The divide between the relevance of ECF for farming operations on the one hand, and the low use of vaccines on the other, raises the question why not more farmers choose to vaccinate their livestock. In Figure 3, we summarize self-reported reasons for non-adoption of the vaccine. Limited knowledge about the vaccine is the most frequently mentioned reason. However, limited accessibility also seems to be an important problem. Increasing farmers' access to the vaccine by involving cooperatives in vaccine provision could therefore help raise farmers' adoption. This is also supported by the finding that neither the cost nor a lack of trust in the effectiveness of the vaccine appear to be major adoption barriers.

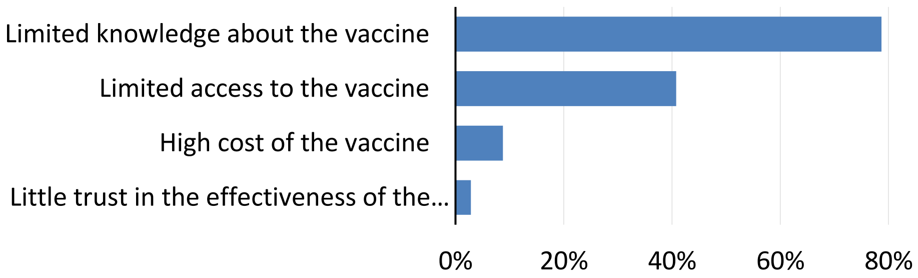

Figure 3: Reported reasons for non-adoption of ECF vaccine among dairy farmers in Kenya.
Multiple answers were possible. N= 559.

Previous research suggested that using the ECF vaccine is actually profitable for farmers on average (Babo Martins et al., 2010; Muraguri et al., 1998). Because these existing studies are all several years old and input and output prices tend to change over time, we used our own survey data to check whether the profitability finding still holds today. Employing partial farm budget analysis, we find that the net present value of vaccine adoption is still positive and actually quite high at around $188 (table A1 in the appendix). Even if this calculation is not the focus of this study, it underlines that the ECF vaccine should be commercially attractive for farmers if the existing adoption constraints can be overcome.

4.2 Results of the choice experiment

We report simulated maximum likelihood estimates for the ML model (using 500 Halton draws) in Table 4. The negative and statistically significant ASC coefficient indicates that farmers generally prefer aggregated delivery of the ECF vaccine through the cooperative over the current delivery channels through individual public and private surgeons. To test if prior awareness of the vaccine and the information provided before the choice experiment may have biased farmers' choices, we also estimated a model with interaction terms between the ASC and awareness of the vaccine. Based on the results of this model, we do not find any evidence for such bias (table A2 in the appendix).

Table 4: Simulated maximum likelihood estimates from the mixed logit model

Vaccine trait	Mean coefficient	Derived S.D. coefficient
Non-random parameters in the utility function		
ASC	-6.66*** (0.38)	
Price of the vaccine	-6.12*** (0.0.08)	0.73*** (0.06)
Random parameters in the utility function		
Check-off	0.66*** (0.09)	1.67*** (0.12)
Vaccine administration at farmer's homestead	0.72*** (0.08)	1.26*** (0.11)
Insurance discount of KES 300	0.17 (0.21)	1.41*** (0.32)
Insurance discount of KES 600	0.39* (0.21)	1.69*** (0.34)
Log-likelihood at start values	-2569.65	
Simulated log-likelihood at convergence	-2279.49	
Likelihood ratio test	606.03 ($\chi 2$ (15)) ***	
Halton draws	500	
Number of observations	3,750	

Notes: ***, **, and * represent statistical significance at 1%, 5%, and 10% levels, respectively. Standard errors in parentheses.

The price coefficient in table 4 is negative and statistically significant, implying that farmers prefer low vaccine prices over higher prices, as one would expect. In terms of the other vaccine package attributes, farmers exhibit a positive preference for a vaccine package that is paid through a check-off with the cooperative as opposed to paying upfront with cash. This can be explained by low liquidity among farmers and widespread credit constraints. In addition, payment through check-off tends to reduce farmers' exposure to the risk that a cow dies or has extremely low milk productivity. Other credit options, such as microfinance through savings and credit cooperatives, typically involve some form of guarantee beyond the milk income, for example, through cosigning of another member of the cooperative in addition to the member's savings in case of a default.

The positive and statistically significant coefficient for the location of vaccine administration suggests that farmers prefer to have their animals vaccinated at their homestead as opposed to moving the animals to a common location in the village. As mentioned earlier, this result can be explained by reduced transaction costs for farmers and lower exposure of their animals to other diseases. Considering livestock insurance discounts, we only observe a positive and statistically significant preference for a discount of KES 600 on the insurance premium against mortality. This could suggest that farmers have limited interest in livestock insurance, such that a small discount on the insurance premium would not change their evaluation of the vaccination package. Indeed, uptake of livestock insurance is very low among Kenyan dairy farmers.

To better understand farmers' trade-offs between vaccine attributes, we estimate the WTP (Greene & Hensher, 2003; Hole & Kolstad, 2012). We highlight results for vaccine attributes with significant coefficients estimates in the base model in Table 5. The estimates can be interpreted as incremental values over the base price of the vaccine. On average, the ECF vaccine today costs KES 1,000. The results indicate that farmers are willing to pay 21% more for the vaccine with the check-off payment option. Further, farmers are willing to pay 25% more if vaccinations are provided at their homestead. Finally, farmers would be willing to pay 10% more if the vaccination is associated with a KES 600 discount on the premium for insurance against livestock mortality. While the check-off and vaccination location results are encouraging and useful for designing concrete delivery packages to increase uptake, the insurance result rather suggests that bundling ECF vaccines and livestock insurance is not necessarily a promising option to entice vaccine adoption. A 10% higher WTP means KES 100, which is well below the KES 600 discount on the insurance premium.

Table 5: Marginal willingness to pay estimates for ECF vaccine attributes from the mixed logit model

Vaccine trait	Mean WTP	SD	Lower CI	Upper CI
Check-off	0.21	0.52	0.15	0.26
Vaccine administration at farmer's homestead	0.25	0.41	0.21	0.30
Insurance discount of KES 600	0.10	0.07	-0.01	0.20

Notes: Confidence intervals (CI) refer to the 95% confidence level. Mean values are interpreted as a marginal rate of substitution (MRS) between individual-specific coefficients for the attribute level and the price attribute. MRS is multiplied by 100 for interpretation as a percentage change (%).

As shown in Table 4, all attributes have statistically significant standard deviation estimates, indicating the presence of preference heterogeneity among farmers. To further examine preference heterogeneity and identify possible sources, we estimate latent class models. Boxall & Adamowicz's (2002) comparison of the goodness-of-fit measures (i.e., log-likelihood function (LL), AIC, BIC, and CAIC) indicates that a model with two classes is the most parsimonious. The addition of more classes resulted in numerical non-convergence (table A3 in the appendix). Around 40% of the farmers can be assigned to class 1, and the remaining 60% of farmers to class 2.

Comparisons of selected socio-demographic characteristics between farmers in the two classes are presented in Table 6. There are several important and statistically significant differences between the groups. For example, we find that farmers in class 2 have higher levels of education, have invested more in a zero-grazing production system, and are generally better-off in terms of ownership of assets and access to extension services. Farmers in class 1, on the other hand, have better access to roads and off-farm income, have more experience with credit, and are more aware of ECF.

Table 6: Selected characteristics of respondents among latent classes

Socioeconomic characteristics	**Class 1**	**Class 2**	**p-value**
Male household head (male = 1)	0.82	0.78	0.00***
Education of household head (years of schooling completed)	11.98 (4.79)	12.61 (4.46)	0.00***
Distance to a motorable road (kilometers)	0.56 (0.02)	1.02 (0.05)	0.00***
Wealth index	32.13 (13.48)	34.50 (13.60)	0.00***
Income from off-farm activities (yes = 1)	0.71	0.69	0.01***
Herd size (TLU cattle)	4.26 (3.52)	5.06 (16.89)	0.00***
Proportion of improved breed to total herd size	0.97	0.99	0.22
Confined/zero-grazing system (yes =1)	0.69	0.74	0.00***
Awareness of ECF (yes =1)	0.74	0.72	0.01**
Awareness of ECF vaccine (yes =1)	0.41	0.41	0.37
Previous use of ECF vaccine (yes =1)	0.11	0.10	0.03**
Past experience in taking credit (yes =1)	0.38	0.31	0.00***
Previous use of check-off (yes =1)	0.56	0.54	0.02**
Access to extension (yes =1)	0.32	0.35	0.00***

Notes: TLU = Tropical Livestock Unit. Standard deviations in parentheses. p-values for t-test and Chi^2 tests.

These differences between the two classes can explain some of the results of the latent class analysis in Table 7. For example, farmers in class 1 have a much higher preference for check-off payments than farmers in class 2, which is plausible given that farmers in class 1 are significantly less wealthy. Moreover, farmers in class 1 are more likely to have used check-off payment options for other farm inputs in the past, which may contribute to more trust in such modalities offered by the cooperatives. These results suggest that check-off systems work well and could be an interesting mechanism to increase vaccine adoption, at least for farmers in class 1.

In contrast, farmers in class 2 have a stronger preference for vaccine administration at their homestead than farmers in class 1. This difference may be caused by the fact that farmers in class 2 are farther away from critical infrastructure such as roads. Furthermore, farmers in class 2 have larger average herd sizes than farmers in class 1, meaning that more animals would need to be moved to common areas. Also, a larger proportion of farmers in class 2 practice confined/ zero-grazing production systems, meaning that moving animals may be associated with higher risks of the animals contracting other livestock diseases.

Table 7: Maximum likelihood estimates from the latent class model

Vaccine Trait	Class 1	Class 2
Utility function coefficients		
ASC	-3.21*** (0.40)	-5.78*** (0.74)
Price of vaccination per animal	-0.002*** (0.0003)	-0.002*** (0.0001)
Check-off	1.68*** (0.20)	-0.17** (0.08)
Vaccine administration at farmer's homestead	-0.10 (0.12)	0.75*** (0.07)
Insurance discount of KES 300	-0.51 (0.28)	0.27 (0.17)
Insurance discount of KES 600	-0.22 (0.28)	0.34** (0.17)
Class membership coefficients		
Constant	0.08 (0.41)	
Distance to a motorable road (kilometers)	-0.31** (0.16)	
Wealth index	-0.02*** (0.01)	
Access to off-farm income (dummy)	-0.03 (0.24)	
Past experience in taking credit (dummy)	0.37 (0.24)	
Awareness of ECF (dummy)	0.33 (0.26)	
Awareness of ECF vaccine (dummy)	0.09 (0.24)	
Number of observations	1444	2306
Class share	38.5%	61.5%
Log-likelihood	-2360.02	

Notes: ***, ** and * represent significance at 1%, 5% and 10% levels, respectively. Standard errors in parentheses.

With regards to discounts on livestock insurance premiums, we find that only farmers in class 2 have a positive and statistically significant preference for such arrangements and only for the higher discount of KES 600. This is consistent with findings from the literature that wealthier farmers are often more interested in formal agricultural insurance than poorer farmers (Binswanger-Mkhize 2012). However, even for farmers in class 2, the additional WTP for insurance discounts is small, meaning that bundling vaccine delivery with livestock insurance is not a promising option.

5 Conclusion

Veterinary services, including vaccines, remain underused in many parts of the Global South. While limited awareness and financial constraints among farmers are widespread problems, inappropriate delivery channels for many animal health services are also a relevant issue that keeps adoption rates low. In this study, we have analyzed preferences of dairy farmers in Kenya for new institutional strategies to improve the delivery of vaccinations against a common disease, namely East Coast Fever (ECF), which causes high economic losses. Our survey data show that – in spite of high ECF incidence rates and the availability of an effective ECF vaccine – only around 10% of the farmers have ever used the vaccine. The data further suggest that low levels of farmers' awareness and problems in terms of accessing the vaccine are major barriers to wider adoption.

Current ECF vaccine delivery systems are not sufficiently tailored to the needs and conditions of local dairy farmers, who typically only keep a small number of cows and calves on their dispersed farms. The standard model is that either private or public veterinary surgeons deal with individual farmers, who are asked to bring their animals to a common area in the village for vaccination. In this context, dairy cooperatives could play an important role in terms of increasing farmers' awareness of vaccination services and in terms of aggregating demand. We conducted a choice experiment to better understand farmers' preferences. Results show that farmers have a positive general attitude towards vaccination options channeled through their cooperative societies. Farmers prefer a check-off system over cash payments for vaccinations. They also prefer vaccinations done at their homestead rather than in a common village area. For these two features farmers are willing to pay significantly more than for current vaccination practices: the average additional WTP for the check-off option is 21%, and for the vaccination at home option it is 25%. These results clearly suggest that designing vaccination delivery services in these directions could increase adoption considerably. In contrast, bundling ECF vaccination with discounts for livestock insurance premiums does not seem to be a very promising option.

However, we also find notable preference heterogeneity among dairy farmers. Wealthier farmers with larger herd sizes have a much stronger preference for getting their animals vaccinated at home than poorer farmers. In contrast, poorer farmers have a stronger preference for vaccination payments through a check-off system, whereas wealthier farmers prefer cash payments. These differences suggest that vaccination delivery options should be somewhat flexible, considering farmers' economic and social conditions in a particular setting. Such flexibility should be relatively easy to implement with more active involvement of the cooperative societies.

A few limitations of our study should be mentioned. First, the hypothetical nature of the choice experiment may not perfectly reflect farmers' real-life choices. However, our study analyzes delivery options that are not yet implemented in practice so that real market data are not available. That said, discrete choice experiments are able to reduce some of the hypothetical bias typically associated with stated preference methods (Penn & Hu, 2018). Second, our approach utilizes cross-sectional data on preferences for the vaccine package so that the relationship between preferences and socioeconomic variables remains associational. Even though preferences are often assumed to be stable, future studies could compile panel data to further investigate this relationship. Third, ECF is an important economic issue for livestock farming in Africa, but the supply of ECF vaccines is only one example of many underused veterinary services. Further research on different types of veterinary services would be helpful to better understand the possible external validity of our results.

In spite of these limitations, a few cautious policy implications should be in order. ECF vaccines and other potentially effective veterinary technologies and services are currently underused by livestock farmers in the Global South due to various institutional constraints. Institutional innovation is required for more effective delivery and adoption. Addressing technology adoption gaps will lead to economic and social gains for farmers and – through higher productivity – also to environmental benefits, for instance by reducing the climate footprint of livestock production. Farmer cooperatives and other types of producer organizations could play a larger role in raising awareness and in organizing the delivery of veterinary services. Delivery approaches should develop new institutional mechanisms to overcome typical farmer adoption barriers, such as liquidity constraints and high transaction costs. New information and communication technologies could possibly ease logistical challenges. Delivery approaches should be flexible and tailored to farmers' needs and conditions in particular contexts. Some public support may be needed to strengthen cooperative capacities to develop and implement such new types of services. However, public support does not necessarily mean that the veterinary technologies and services themselves will need to be subsidized, as our results clearly suggest that farmers' have a positive willingness to pay for services that meet their needs and preferences.

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Appendix

A.1 Benefits cost analysis of ECF vaccination

Investment appraisal of livestock systems is often difficult to conduct given the distinct characteristic of livestock reproducing and the length of time taken to mature. Therefore, in order to appraise the cost/benefit of disease prevention and control, one ought to conduct the impact assessment using methods similar to partial budgeting. Rushton (2009)argues that the focus in such an assessment is not on the entire livestock system but rather on the effects on outputs from intended changes in animal health management practices. As such, given the paucity of our survey data, we limit our assessment to the direct costs and benefits associated with the management of ECF to draw a conclusion on the commercial viability of vaccine adoption.

First, we consider only the economic costs of ECF being the cost of morbidity measured by the value of milk lost, treatment costs, and vaccination costs. For benefits, we consider the value of milk produced annually per cow (area under the lactation curve) and the cost saving due to reduced acaracide use.

Table A**1: Partial farm budget analysis of benefits and costs of ECF vaccination**

	Year	Net benefits
	1	4,228
	2	5,828
	3	5,828
	4	5,828
	5	5,828
	6	5,828
	NPV (KES)	**22,532.71**
	NPV (USD)	**204.84**
Disease incidence rate (%)	0.30	
Mortality rate as a result of ECF (%)	0.30	
Average annual milk output (litres)	2,916.59	
Average annual milk loss due to ECF (litres)	150	
Average price of milk (KES)	35	
Average cost of ECF vaccination (KES)	1,200	
Average annual cost of tick control with vaccine (KES)	12,000	
Average annual cost of tick control without vaccine (KES)	15,353	
Savings in tick control (KES)	3,353	
Average cost of treating ECF (KES)	3,000	
Average market value for a lactating cow (KES)	50,000	
Transaction cost involved in vaccine administration	400	
Discount rate (%)	0.12	

Notes: At the time of survey 1 USD = 110 Kenyan Shillings (KES). We use the commercial banks' central bank reference interest rates for the year 2021. NPV, net present value.

Secondly, we limit our assessment to cows of improved breeds because they are more susceptible to ECF infection compared to local breeds. Thirdly, we consider the productive life of a dairy animal to be six years. The results from our assessment indicate that the use of ECF vaccine remains economically attractive to farmers (NPV USD 187.86). The findings are similar to those of (Muraguri et al., 1998; Nyangito et al., 1996) and therefore, adoption should be scaled up to benefit more farmers that are constrained by the prevalence of ECF.

A.2 Sensitivity analysis of the mixed logit model

We ran a sensitivity analysis by introducing an interaction term between awareness of ECF vaccine and ASC. The results show no significant influence of the farmers' choice to opt out of the choice situation and thus, prior awareness did not bias the results.

Table A2: Simulated maximum likelihood estimates from the mixed logit model with interaction terms

Vaccine trait		Mean coefficient	Derived S.D. coefficient
Non-random parameters in the utility function			
ASC		-6.38*** (0.38)	
Price of the vaccine		-6.14*** (0.0.08)	0.70*** (0.06)
Random parameters in the utility function			
Check-off		0.64*** (0.09)	1.57*** (0.11)
Vaccine administration at farmer's homestead		0.73*** (0.08)	1.22*** (0.10)
Insurance discount of KES 300		-0.05 (0.17)	0.08 (0.18)
Insurance discount of KES 600		0.17 (0.21)	0.42 (0.20)
Interaction			
ASC X Awareness of ECF vaccine (dummy)		0.65 (0.40)	
Log-likelihood at start values	-2573.28		
Simulated log-likelihood at convergence	-2294.48		
Likelihood ratio test	573.75 ($\chi 2$ (5)) ***		
Halton draws	500		
Number of observations	3,750		

Notes: ***, ** and * represent significance at 1%, 5% and 10% levels, respectively. Standard errors in parentheses.

A.3 Determining number of latent classes

Table A3: Criteria for determining the optimal number of classes

Classes	Log-likelihood (LLF)	AIC	CAIC	BIC	|Δ AIC (%)|	|Δ BIC (%)|
2	**-2414.33**	**4,856.66**	**4,927.16**	**4,914.16**	**-**	**-**
3	-2303.08	4,646.17	4,754.63	4,734.63	4.53	3.79
4	-2243.84	4,541.68	4,688.11	4,661.11	2.30	1.58
5	-	-	-	-	-	-