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Adoption and Impacts of Animal Health Management Practices in Kenya's Dairy Sector

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Abstract

Current trends in population growth and increased demand for animal-sourced foods (ASF) present opportunities for many livestock farmers in the Global South. However, poor health conditions in livestock production continue to cause sizeable losses. Accessing and utilizing important animal health services is still challenging for many resource-constrained farmers. Thus, interventions to increase access to these services would be an important policy objective towards sustainable livestock intensification. However, to better design policies, there is a need to also understand the potential implications - both social and environmental - of these animal health management practices. This dissertation seeks to contribute to the literature through three essays, focusing on various relevant aspects in dairy systems in Kenya. The research uses primary data collected through surveys and experiments with dairy farmers and econometric methods for data analysis.

In the first essay, we explore how to better design animal health service provision through dairy cooperatives using a choice experiment. Results provide evidence of farmers' preferences for institutional innovations that overcome technical and liquidity constraints in accessing the East Coast Fever (ECF) vaccine. This is also likely to hold for other animal health services. In the second essay, we provide empirical evidence that the adoption of these practices is associated with more labor demand for men and women in livestock production activities. The findings also show negative associations with different aspects of women empowerment including access to and control over income and productive resources. Lastly, in the third essay, using regressions and the environmental impact quotient (EIQ), we show improper acaracide use practices – an important preventive practice against ticks – are associated with increased potential negative effects on the environment and human health.

The findings of this study underscore the important role that collective institutions such as dairy cooperatives can play in providing last-mile access to technologies including animal health services. However, future policy interventions on sustainable intensification of livestock production should be gender-sensitive. Further, we advocate for the design of policies that promote the responsible use of acaricides and call for the promotion of environmentally friendly approaches in vector control in livestock systems.

Zusammenfassung

Die aktuellen Trends des Bevölkerungswachstums und die steigende Nachfrage nach tierischen Lebensmitteln (ASF) bieten vielen Viehzüchtern im globalen Süden Chancen. Schlechte Gesundheitsbedingungen in der Viehzucht verursachen jedoch weiterhin erhebliche Verluste. Der Zugang zu wichtigen Tiergesundheitsdiensten und deren Inanspruchnahme ist für viele ressourcenbeschränkte Landwirte immer noch eine Herausforderung. Daher wären Maßnahmen zur Verbesserung des Zugangs zu diesen Diensten ein wichtiges politisches Ziel. Um die Politik besser gestalten zu können, müssen jedoch auch die potenziellen Auswirkungen dieser Tiergesundheitspraktiken - sowohl in sozialer als auch in ökologischer Hinsicht - verstanden werden. Diese Dissertation lesitet einen Beitrag zur Literatur, indem sie im Rahmen von drei Aufsätzen verschiedene relevante Aspekte für Milchviehbetriebe in Kenia untersucht. Die Forschung verwendet Primärdaten von Befragungen und Experimenten mit landwirtschaftlichen Haushalten sowie ökonometrische Methoden zur Datenanalyse.

Im ersten Aufsatz untersuchen wir mithilfe eines Choice Experiments, wie die Bereitstellung von Tiergesundheitsdiensten durch Molkereigenossenschaften besser gestaltet werden kann. Die Ergebnisse zeigen, dass Landwirte institutionelle Innovationen bevorzugen, die technische und Liquiditätsbeschränkungen beim Zugang zum Impfstoff gegen Ostküstenfieber (ECF) überwinden. Dies dürfte auch für andere Tiergesundheitsdienste gelten. Im zweiten Aufsatz liefern wir empirische Belege dafür, dass die Einführung dieser Praktiken mit einem höheren Arbeitsbedarf für Männer und Frauen in der Viehzucht verbunden ist. Die Ergebnisse zeigen auch negative Assoziationen mit verschiedenen Aspekten des Empowerments von Frauen, einschließlich des Zugangs zu und der Kontrolle über Einkommen und produktive Ressourcen. Schließlich zeigen wir im dritten Aufsatz anhand von Regressionen und des Umweltbelastungsquotienten (EIQ), dass unsachgemäße Praktiken bei der Anwendung von Akariziden - einer wichtigen Präventionsmaßnahme gegen Zecken - mit erhöhten potenziellen negativen Auswirkungen auf die Umwelt und die menschliche Gesundheit verbunden sind.

Die Ergebnisse dieser Studie unterstreichen die wichtige Rolle, die kollektive Institutionen wie Molkereigenossenschaften beim Zugang zu Technologien und Tiergesundheitsdiensten auf der letzten Meile spielen können. Künftige politische Maßnahmen zur nachhaltigen Intensivierung der Viehzucht sollten jedoch geschlechtsspezifisch ausgerichtet sein. Darüber hinaus plädieren wir für eine Politik, die den verantwortungsvollen Einsatz von Akariziden fördert, und fordern die Förderung umweltfreundlicher Ansätze zur Vektorkontrolle in der Tierhaltung.

Dedication

This dissertation is dedicated to my family, mentors, colleagues, and friends. You made the impossible feel within reach. Your unwavering support has been my greatest source of inspiration in my PhD journey.

May this dissertation be an inspiration to those that dare to dream, it is possible.

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List of Acronyms and Abbreviations

AI	Active Ingredient
AIC	Akaike Information Criterion
ASF	Animal Sourced Foods
BIC	Bayesian Information Criterion
DCE	Discrete Choice Experiment
ECF	East Coast Fever
EIQ	Environmental Impact Quotient
GHGs	Greenhouse Gases
HHPs	Herd Health Management Practices
ILRI	International Livestock Research Institute
IV	Instrumental Variable
KES	Kenya Shillings
KLS	Kinky Least Squares
LC	Latent Class
LED	Low Emission Development
LMIC	Low and Middle-Income Countries
ML	Mixed Logit
OLS	Ordinary Least Squares
SAPLING	Sustainable Animal Productivity for Livelihoods, Nutrition, and Gender Inclusion
TLU	Tropical Livestock Units
UCSC	University of California Santa Cruz
WELI	Women Empowerment in Livestock Index
WTP	Willingness To Pay
ZEF	Center for Development Research

1 General Introduction

Demand for animal-sourced foods (ASF) is increasing in Africa occasioned by a rise in population, rapid urbanization, and growth in the middle-income class (Bosire et al., 2016; FAO, 2023c). This is important from a nutritional perspective – an important source of proteins and micronutrients even to vulnerable groups (Clay & Yurco, 2020). But also tricky from an environmental and climate perspective – livestock production already accounts for 15% of annual human-induced greenhouse gas (GHG) emissions (FAO, 2023a, 2023b; Gerber et al., 2013). At the same time, livestock continues to be challenged by the effects of climate change such as increased incidence of drought and the re-emergence of diseases (Herrero et al., 2015; Shikuku et al., 2017).

Livestock production is essential from a social welfare perspective, providing livelihoods to farming communities in low and middle-income countries (LMICs) (Baltenweck et al., 2020; FAO, 2019). Thus, more and better investments in the sector are needed to support the transition to more efficient and environmentally friendly production practices. Technology and better management of animal health could help increase productivity, reduce the environmental footprint, and improve smallholder livelihoods. Herrero et al., (2016) show how the wider adoption of available technologies in livestock could be important for reducing GHG emissions. Herd health management – a preventive approach to animal health management – is one such technique that can translate into sustainable livestock intensification (Magnusson et al., 2021).

Herd health management is an important intervention being incorporated into the low-emission development (LED) agenda in livestock development planning in the Global South (Crane et al., 2020). The main broad pillars of herd health include preventive animal health, holistic nutrition, and better reproductive management (LeBlanc et al., 2006). For some of the practices such as routine vaccination of animals and the use of artificial insemination (AI), adoption remains low (Enahoro et al., 2021; Omondi et al., 2017). For those widely adopted such as deworming and routine spraying, utilization is uneven with farmers only responding to signs of infestation (Ericksen & Crane, 2018). This is linked to limited access to information about the practices, liquidity constraints, and in some cases high costs as in the case of routine vaccination (Marsh et al., 2016; Omondi et al., 2022; Railey et al., 2018). These inconsistencies in the adoption and utilization of important technologies are likely to exacerbate the risk of low levels of animal productivity and consequently farm incomes. Studies show disease risks such as those from East Coast Fever (ECF) can cause losses in productivity of cattle of improved breeds due to morbidity and high mortality rates of up to 80% (Gachohi et al., 2012).

1.1 Problem Statement and Objectives

Many technical innovations aiming to increase livestock productivity and improve the livelihoods of farmers have been promoted over the past in various developmental settings. Most of these innovations have been thoroughly tested and adapted, demonstrating efficacy and profitability (Babo Martins et al., 2010; Jensen et al., 2017; Omondi et al., 2017; Perry, 2016; Rao et al., 2019). Nevertheless, adoption has regularly not achieved the expected levels, especially in the small farm sector. Even with regular income from milk sales, demand formation and limited liquidity continue to constrain farmers from investing in profitable preventive animal healthcare such as vaccines (Teufel et al., 2021). Studies on innovative approaches to overcome adoption constraints hardly exist. Moreover, studies on the implications of these technologies are much less analyzed in livestock than in crops and agronomic technologies. Therefore, this dissertation aims to fill these gaps in the literature on the provision and utilization of animal health services in three stylized essays.

In the first essay, we address typical liquidity and technical barriers to accessing animal health services (Aina et al., 2018; Marsh et al., 2016). Here we use a vaccine against ECF – a veterinary service emblematic of valuable technologies with low adoption. We assess how leveraging vaccine provision through coordination between dairy cooperatives and vaccinators can boost uptake. Aggregation of farmers overcomes technical barriers in reaching out to widely dispersed farms (Brown et al., 2021). Moreover, dairy cooperatives could also offer additional institutional innovations such as check-off payment systems for veterinary services overcoming liquidity constraints (Nhantumbo et al., 2016; Rao et al., 2019). To this end, the extent to which these institutional innovations could boost adoption is yet to be analyzed in the literature. Therefore, analyzing how cooperative societies could improve the provision of animal health services is important for policy design in the Global South.

Similar to climate-smart agricultural technologies, research on animal health management has focused on productivity outcomes (Notenbaert et al., 2017; Thornton et al., 2018). But so far, the social and environmental implications of such interventions are yet to be analyzed. Studying the adoption patterns and the implications of these interventions beyond productivity gains will provide a more nuanced understanding of the synergies and trade-offs between economic, environmental, and social targets of LED interventions, providing a way forward to better design policy to support further scaling.

Literature focusing on reducing emissions in the livestock sector suggests accounting for social outcomes that come with changes in technical practices (Crane et al., 2020; Ericksen & Crane, 2018; Fischer et al., 2018). Livestock provides avenues for gender equality and women's empowerment (Baltenweck et al., 2024). Consequently, adoption of herd health management practices may result in higher capital intensity of production including additional labor demand. Yet, social indicators are seldom considered, more so in quantitative studies (Parlasca & Qaim, 2022). This underscores the need for a more holistic understanding of their implications. The second essay contributes to filling this dearth in literature by assessing how herd health management practices affect labor relations between men and women and their access and control over productive resources.

Vector control, an important herd health management practice reduces the risk of ECF disease that is spread by the tick *Rhipicephalus appendiculatus* - abundant in the Eastern, Central, and Southern Africa region (Gachohi et al., 2012; Githaka et al., 2022). Farmers use synthetic acaricides through weekly spraying of animals (Jumba et al., 2020). Similar to pesticide use in crops, acaricides are likely to have potential environmental and human health effects due to improper application practices by farmers (Meunier et al., 2024; Tran et al., 2023). Unlike in cropping systems, the assessment of these risks has received less attention in livestock. In the third essay, we evaluate the potential environmental and human health risks associated with improper acaricide application practices in dairy farms.

This dissertation, therefore, seeks to understand how institutional innovations can enhance the adoption and effective utilization of animal health services and their environmental and social implications. Specifically, we analyze:

1. How can dairy cooperative societies serve as effective platforms for improving the accessibility and affordability of animal health services for farmers?
2. What are the social implications of adopting herd health management practices among farmers, including labor allocation and women empowerment?
3. What are the environmental and human health risks and trade-offs associated with vector control practices in dairy systems?

1.2 Data and Study Context

Data for this study was collected from dairy farmers in several Counties in the Rift Valley, Mount Kenya, and Eastern regions of Kenya as shown in Figure 1.1. The Counties are representative of semi-intensive to extensive dairy production systems. The regions are characterized by low utilization of herd health practices such as vaccines yet face high disease risks such as a ECF (Karanja-Lumumba et al., 2015). The first essay is based on data collected from a larger project by the International Livestock Research Institute and the University of California Santa Cruz (UCSC). The study used a randomized control trial (RCT) to test an ECF vaccine aggregation model with Kenyan dairy cooperatives and vaccinators. The total sample size for the larger project was 1,050 randomly selected farmers. We then selected a sub-sample of 625 farmers who participated in a choice experiment designed to analyze farmers' preferences for ECF vaccination options provided through cooperative societies. The survey was conducted between October and December 2021. The author was involved in the planning and implementation of the survey and RCT and was responsible for the design of the choice experiment.

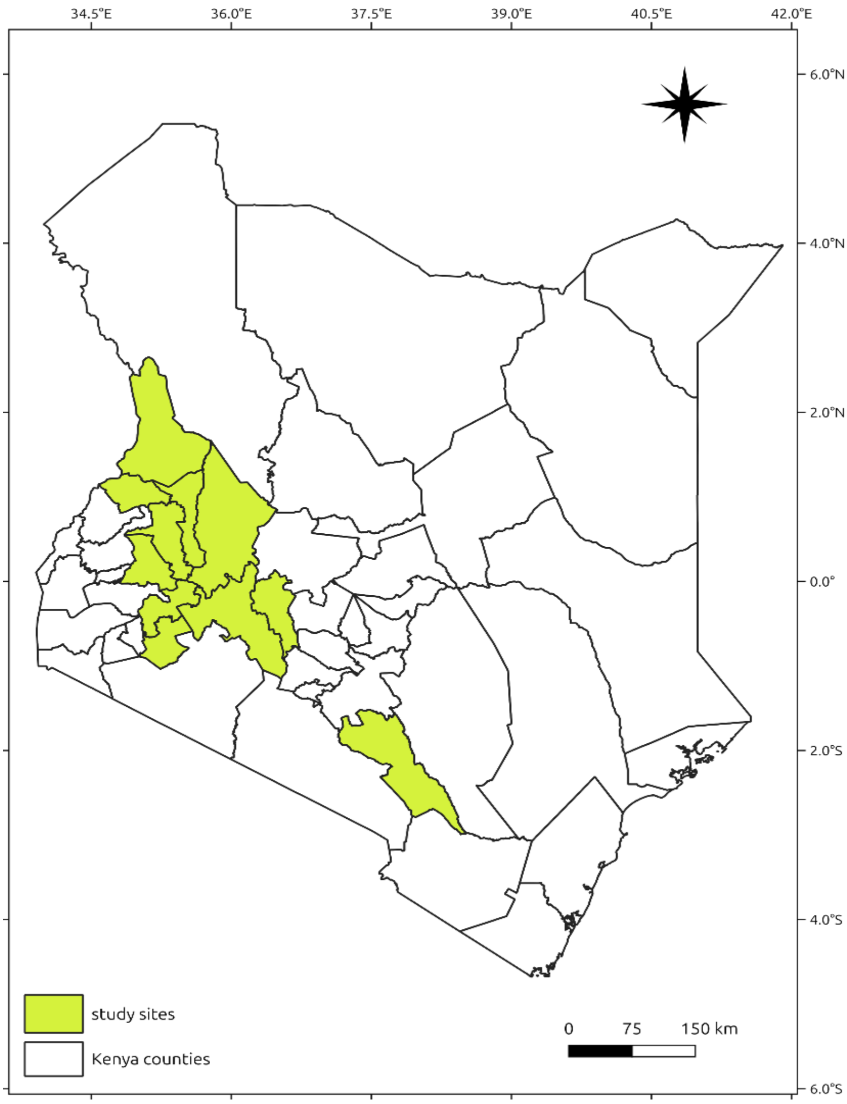

Figure 1.1: Map of selected study sites in Kenya

The second and third essays are based on data collected within the same region as part of the OneCGIAR initiative in Kenya on Sustainable Animal Productivity for Livelihoods, Nutrition, and Gender Inclusion (SAPLING[1]) led by ILRI. The data collection was conducted in October-November 2023. A total of 578 farmers were randomly selected in three Counties, namely, Elgeyo-Marakwet, Uasin-Gishu and Nandi.

[1] See for further details on SAPLING https://www.cgiar.org/initiative/sustainable-animal-productivity/

2 Farmer-Friendly Delivery of Veterinary Services: Experimental Insights from the Kenyan Dairy Sector*

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 Coast 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' heterogenous 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; East Coast Fever (ECF)

JEL: Q13; Q16; Q1

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The research idea was jointly developed by K.M., M.P., J.R. and M.Q. K.M. collected, analyzed, and interpreted the data, and wrote the first draft of the manuscript. All co-authors gave comments at various stages and approved the final version.

2.1 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 article, 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 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 our study, 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 client 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 article is organized as follows. Section 2.2 provides a brief background of veterinary services, dairy cooperatives, and input access among dairy farmers in Kenya. Section 2.3 describes the study area, data, and estimation strategy. Section 2.4 presents the empirical results and discussion. We conclude and give policy implications of our findings in section 5.

2.2 Veterinary Services, 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, 2012b; 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 animal health services through cooperatives reduces transaction costs and improves the flow of information among farmers. Moreover, it can help address farmers' liquidity constraints through a "check-off system", where farmers pay for the services rendered 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.

2.3 Materials and Methods

2.3.1 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 eleven 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 for our study was randomly selected jointly with the larger ILRI and UCSC 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. Several of these cooperatives were inactive, meaning that they still existed on paper but had ceased collective dairy activities. These inactive cooperatives were excluded. From the others, we obtained information on the number and size of cooperative sub-units, referring to the milk collection points that the cooperative transporters regularly access. As the cooperatives differ considerably in terms of size and geographical spread, we used these sub-units for further sampling to facilitate the fieldwork logistics. From 361 cooperative sub-units, we randomly sampled 210; then, in each sub-unit we randomly selected five farmers, resulting in a total of 1050 dairy farmers for the baseline survey.[1] For our choice experiment, we randomly selected 625 farmers from the baseline sample. The choice experiment was conducted together with the baseline survey between October and December 2021. The sample is considered representative of member farmers in dairy cooperatives in the eleven Kenyan counties.

2.3.2 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.

[1] The larger project by ILRI and UCSC involves a randomized controlled trial (RCT) with three treatment arms. Power calculations for this RCT suggested that 70 sub-units per treatment arm with five farmers each would suffice for efficient analysis. For our choice experiment, we do not use different treatment arms.

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 for insurance premiums, 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 2.1.

Table 2.1: 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	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 including service fee for the veterinarian/health worker (KES)	1	KES 500	Numerical
	2	KES 800	Numerical
	3	KES 1000	Numerical
	4	KES 1200	Numerical

Notes: KES, Kenyan Shillings. Exchange rate at time of survey 1 US $ = 110 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 36 choice sets that were randomly blocked into six 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 2.1.

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 given a brief description of the ECF vaccine, how the vaccinations are conducted at present, and the effectiveness of the vaccine.

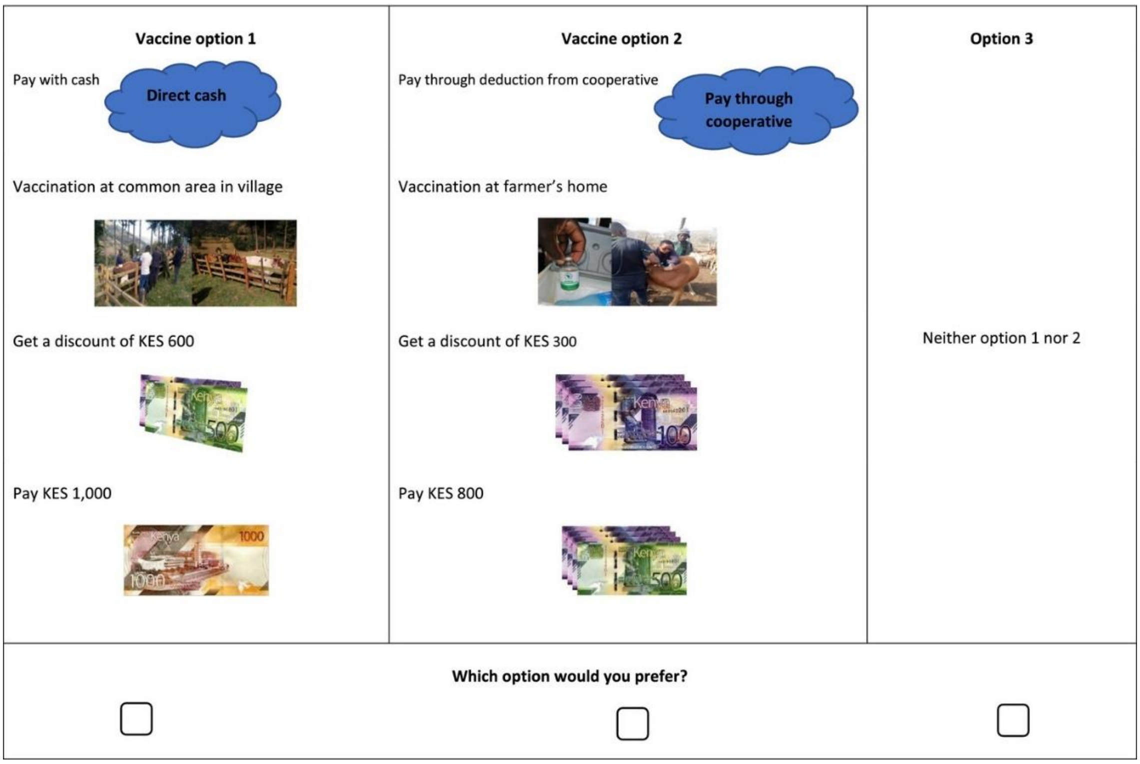

Figure 2.1: Sample of choice card

2.3.3 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:

$$U_{ijk} = \beta_i x_{ijk} + \varepsilon_{ijk,} \tag{2.1}$$

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, and ε_{ijk} is a stochastic error 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:

$$L_{iCk}(\beta_i) = \frac{e^{\beta_i x_{iCk}}}{\sum_{j=1}^{i} e^{\beta_i x_{ijk}}} \tag{2.2}$$

Equation (2.2) 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 (2.2) over all possible values of β, we can express the probability in a mixed logit as follows:

$$P_{iCk}(\theta) = \int L_{iCk}(\beta_i) f(\beta_i|\theta)\, d\beta_i \tag{2.3}$$

Assuming β is normally distributed and there is no closed form of the integral in equation (2.3), 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). The 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):

$$WTP_i = -\frac{\beta_i}{\beta_{price}} \tag{2.4}$$

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:

$$P(iCk\,|d|) = \prod_{k=1}^{K} \frac{\exp(\beta_d x_{iCk})}{\sum_{j=1}^{J} \exp(\beta_d x_{njk})} \tag{2.5}$$

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:

$$P(d) = \frac{\exp(\theta'_d z_k)}{\sum_{d=1}^{D} \exp(\theta'_d z_k)}, \qquad \theta'_d = 0 \tag{2.6}$$

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).

2.4 Results and Discussion

2.4.1 Descriptive Results

Table 2.2 shows household and farm characteristics of dairy farmers sampled for the survey and choice experiment. Household heads are largely men. The long average experience in dairy farming of 20 years 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 2.2: 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[2] 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 2.2 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-

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

reported disease incidences are shown in Panel A of Figure 2.2. 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.

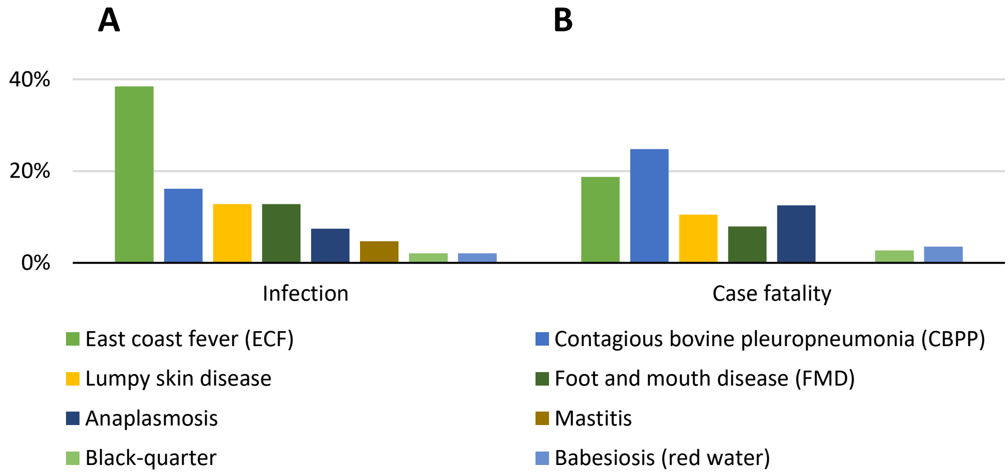

Figure 2.2: Reported incidence and case fatality of livestock diseases affecting dairy farmers in Kenya

In the survey, we also asked about farmers' knowledge of ECF and the vaccine as a preventive measure. Table 2.3 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).

Table 2.3: 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 more farmers do not choose to vaccinate their livestock. In Figure 2.3, 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.

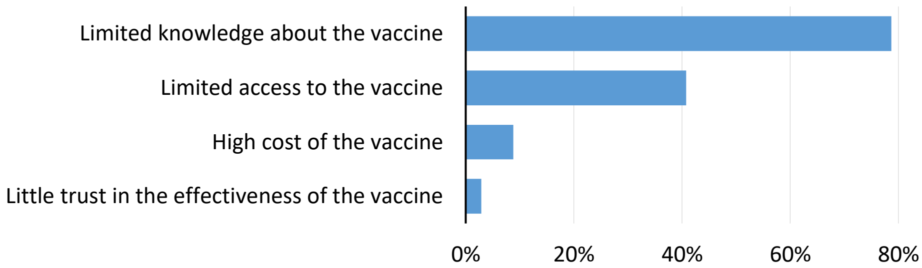

Figure 2.3: Reported reasons for non-adoption of ECF vaccine among dairy farmers in Kenya. *Multiple answers were possible. N= 559*

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 a cost-benefit analysis, we find that the net present value of vaccine adoption is positive and actually quite high at around $205 (Table A7.1 in the appendices). 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.

2.4.2 Results and Discussion of the Choice Experiment

We report simulated maximum likelihood estimates for the ML model (using 500 Halton draws) in Table 2.4. 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 A7.2 in the appendices).

Table 2.4: Simulated maximum likelihood estimates from the mixed logit model

Vaccine trait	Mean coefficient	Derived SD coefficient
Non-random parameters in the utility function		
ASC	-6.66*** (0.38)	
Price of the vaccine	-6.12*** (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 (χ^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. SD, standard deviation. ASC, alternative specific constant.*

The price coefficient in Table 2.4 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 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 observe a positive preference for a discount of KES 600 on the insurance premium against mortality. This coefficient is only marginally significant, whereas the coefficient for the KES 300 discount is statistically insignificant. These results suggest that farmers have limited interest in livestock insurance, such that a small discount on the insurance premium would hardly change their valuation of the vaccination package. Indeed, the uptake of livestock insurance is very low among Kenyan dairy farmers, mainly due to limited information and experience and high premium costs. Livestock insurers often charge 4% of the estimated value of animals per annum. More generally, the uptake of private agricultural insurance by farmers in Kenya is fairly low (Clarke, 2016; Kramer et al., 2023; Shee et al., 2021).

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 coefficient estimates in the base model in Table 2.5. 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 2.5: Marginal willingness to pay estimates for ECF vaccine attributes from 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 marginal rates 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 2.4, 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. Starting with a model with one class, we increased the number of classes until model convergence was no longer achieved. A solution was reached with a two-class model, which was empirically and conceptually valid (Table A7.3 in the appendices). 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 2.6. While many of the differences are relatively small in magnitude, several are statistically significant. 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 2.6: 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)	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: ***, **, and * represent statistical significance at 1%, 5%, and 10% levels, respectively. Standard deviations in parentheses. p-values for t-tests and Chi² tests. TLU, tropical livestock unit*

These differences between the two classes can explain some of the results of the latent class analysis in Table 2.7. 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 2.7: 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.

2.5 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.

3 Healthier Herds, Heavier Workloads? The Gendered Time and Resource Implications of Herd Health Management in Kenyan Dairy Systems*

Abstract

Strategies for sustainable intensification of livestock are critical for food system transformation. In dairying systems, herd health management is among such strategies. While adoption patterns and productivity gains have been analyzed in previous studies, the social implications are still not well understood. This paper provides insights into the relationship between herd health management and intra-household labor demand as well as women's empowerment. We test the hypotheses that the adoption of herd health management practices increases intra-household labor demand among male and female household members and, thereby, affects women's empowerment. We use primary data from smallholder dairy farmers in Kenya on time use, women's participation in decision-making and livestock asset ownership, adoption status of important herd health management practices, as well as household demographic characteristics. We apply censored regression and multinomial logit regression models to test our hypotheses. The results show that adopting herd health management practices is associated with more labor demand in dairy production for both men and women. The magnitude of the change differs across production systems but is always higher for men. Additionally, herd health management practices are negatively associated with different aspects of women's empowerment including women's livestock asset ownership and control over income from dairy. The study underscores the importance for gender-sensitivity in the sustainable intensification of livestock production in the Global South.

Keywords: Herd health management; gender; labor demand; dairying; Greenhouse gases (GHGs)

JEL: C31; D13; O12; O33; Q16; Q18

* This paper has been co-authored with Martin Parlasca and James Rao. The research idea was jointly developed by K.M., M.P., and J.R. K.M. collected, analyzed, and interpreted the data, and wrote the first draft of the manuscript. All co-authors gave comments at various stages and approved the final version.

3.1 Introduction

In order to nourish a growing population while staying within planetary boundaries, the livestock sector needs to become more sustainable. Improvements in animal health represent a promising strategy for reducing the environmental footprint of livestock production while simultaneously increasing productivity. The productivity gains of improved animal health present opportunities to reduce emission intensity, especially in the Global South where the emission intensities of livestock production are comparatively high, while expenditures for herd health have, thus far, remained relatively low (FAO, 2023; Herrero et al., 2013; Özkan et al., 2022). Herd health management, which encompasses a preventive approach to livestock disease management, holistic nutrition, and enhanced reproductive management (LeBlanc et al., 2006; Magnusson et al., 2021), has, therefore, been incorporated into the low-emission development agenda in livestock development planning in the Global South (Crane et al., 2020; Ericksen & Crane, 2018).

Research on the implications of herd health management tends to focus on productivity outcomes (Notenbaert et al., 2017; Thornton et al., 2018), while social indicators are rarely considered, especially in quantitative analyses (Parlasca & Qaim, 2022). However, livestock represents a crucial element in many people's lives, especially women in the Global South, offering avenues for gender equality and women's empowerment (Baltenweck et al., 2024). Changes in farming practices, such as the adoption of herd health management activities, may result in an increased time burden for the household and imply a higher capital intensity of production, both of which have the potential to challenge the pathways for female empowerment. Innovations in livestock production systems must, therefore, also be assessed from gender perspectives to achieve a more holistic understanding of their sustainability.

Against this background, this article addresses the question of how activities related to herd health management affect female and male dairy farmers in Kenya with regards to their time devoted to agricultural activities and their access and control over productive resources. Using primary data collected in Kenya in 2023, we first investigate the relationship between different herd health management practices and men's and women's time use related to farming. Given that herd health management may influence the relative involvement of women in the households' livestock husbandry activities, we also analyze if the adoption of herd health management practices can be associated with women's involvement in different agricultural decisions as well as their asset ownership. As labor requirements and gender roles often depend on where and how animals are kept, we also address possible heterogeneity across common production systems.

Our study aims to add to the literature on animal health provision in the Global South, as well as to the literature on gendered implications of emission-efficient agricultural development. While previous research shows that the distribution of costs and benefits of innovations related to low-emission development can be systematically different between men and women (Basu et al., 2019; Basu & Galiè, 2021; Doss & Quisumbing, 2020; Ndiritu et al., 2014; Quisumbing et al., 2015), these results have so far largely been based on qualitative assessments. Previous quantitative research on herd health management practices tends to focus on drivers of adoption or milk yields effects (Kebebe, 2017; Korir et al., 2023; Ries et al., 2022; Wairimu et al., 2022; Weyori, 2021), but rarely considers social dimensions. The article closest to our study is Lenjiso, (2019), who finds that the adoption of improved fodder technology, which is one of many aspects related to herd health management, can be associated with a higher amount of time women spent on dairy farming in Ethiopia. We extend this literature by analyzing the adoption of multiple herd health management practices, some of which are relatively time-intensive, some of which are capital-intensive, under different production systems and their implications on time allocation as well as on women's control over productive resources.

The rest of the paper is organized as follows. Section 3.2 provides a background of the dairy sector in Kenya and a brief conceptual framework. Section 3.3 outlines the study context, the sampling procedure, the measurement of key variables, and an econometric framework for our analysis. Section 3.4 presents the results and discussions. In section 3.5, we conclude with the key findings of the study.

3.2 Conceptual Framework

Livestock play important roles as sources of income, storage of wealth, and sources of food and nutritional security for many rural farming households in Sub-Saharan Africa (Baltenweck et al., 2020; Clay & Yurco, 2020). In Kenya, the dairy sub-sector accounts for 8% of the national gross domestic product (GDP) and 14% of the agricultural GDP (Ericksen & Crane, 2018; Odero-Waitituh, 2017; Okello et al., 2021). The dairy sector in Kenya is considered among the largest in Sub-Saharan Africa (Omondi et al., 2017; World Bank, 2013), while smallholder farmers owning two to three cows account for around 80% of national dairy production (Basu & Galiè, 2021; Ngeno, 2018).

Despite the importance of dairy production in Kenya and many other countries in sub-Saharan Africa, the adoption of herd health practices often remains low (Gertzell et al., 2021). The main broad pillars of herd health include preventive animal health, holistic nutrition, and better reproductive management (LeBlanc et al., 2006). For some of the practices such as routine vaccination and the use of artificial insemination, adoption remains relatively low (Omondi et al., 2017; Teufel et al., 2021). Some practices are already adopted much more widely, including deworming and routine spraying. However, even for those activities, utilization remains below optimum levels and farmers often only respond *ex-post* to signs of infestation (Ericksen & Crane, 2018). Barriers to adoption are linked to limited access to information about the practices, liquidity constraints, and in some cases high costs (Maina et al., 2024; Marsh et al., 2016; Omondi et al., 2022; Railey et al., 2018).

Herd health management can increase yields, income, and GHG emission efficiency, but its implementation may also have social implications for the household. In the context of our study, we expect the adoption of productivity-enhancing technologies around herd health management to influence farmers’ time use. Based on the household production function framework proposed by Udry, (1996), we assume that households maximize their labor utility by allocating their labor resources to both agricultural and non-agricultural activities subject to their current level of technology and resource constraints. A shift in the technology function would, therefore, cause households to reallocate their labor supply.

However, whether these technologies increase or decrease the time spent on farming activities most likely depends on the specific technology and the households' livestock production systems. While some herd health management practices, such as routine vaccinations, are not labor intensive *per se*, they have been shown to generally improve the health of animals, averting livestock death and resulting in larger herd sizes (Jumba et al., 2020). Moreover, some practices, such as better reproductive management through artificial insemination, lead to a higher proportion of improved breeds which demand new management skills among farmers, which, again, may increase time burden for farmers (Omondi et al., 2022; Quisumbing et al., 2015).

Changes in time use may be different for female and male household members due to the distinct roles and responsibilities of women and men in the study area. Women typically participate more in husbandry practices such as feeding and milking, whilst men are typically more involved in the delivery of milk, engagement in the cooperatives and hub services, purchase of inputs such as feed supplements and medicine, and collection of payments (Hovorka, 2012; Kristjanson et al., 2010; Njuki & Sanginga, 2013; Tavenner & Crane, 2018). Given these gendered roles in dairy farming, we analyze time burdens associated with the adoption of different herd health management practices for women and men separately.

Therefore, our first hypotheses are:

H1a: The adoption of herd health management practices is positively associated with time spent on agricultural activities by female household members.

H1b: The adoption of herd health management practices is positively associated with time spent on agricultural activities by male household members.

Data on specific time requirements for different aspects of herd health management practices and under different production systems are very scarce. In Kenya, dairy production is primarily classified into three systems, namely open grazing systems, semi-intensive, and intensive systems (Benard, 2016). Intensive systems are characterized by the adoption of high-yielding breeds that are zero-grazed mainly in regions with small-landholding and high population density and peri-urban areas. Semi-intensive systems are characterized by relatively lower adoption of high-yielding breeds with farmers practicing semi-confined systems that combine grazing and stall feeding on largely unimproved fodder (Lukuyu et al., 2018). It is likely that in open grazing farming systems, most herd health management practices take significantly more time compared to confined and semi-confined systems due to the additional time requirements needed for outreach, gathering animals, and possibly animal transport. It is also likely that, if herd health increases productivity, intensity is also raised in some husbandry practices such as feeding, where recommendations on holistic nutrition may require better processing of forages. In such cases, herd health may lead to more demand on women's time in confined/ semi-confined systems than in grazing systems. The effect may be indeterminate and context-specific. We, therefore, test what is applicable in the context of our study.

Our second hypotheses, which due to the scarcity of empirical literature on this topic are rather explorative, state:

H2a. For men, the additional time requirements of herd health management practices are larger under open grazing farming systems compared to confined and semi-confined systems.

H2b: For women, the additional time requirements of herd health management practices are smaller under open grazing farming systems compared to confined and semi-confined systems.

The adoption of herd health management may also influence women's access to and control over livestock. Based on the existing literature, we propose two main channels. The first channel directly relates to time and financial resources spent on agricultural activities. When men invest more time and money in dairy farming, e.g. by purchasing veterinary inputs or carrying out activities around herd health management, men's involvement in dairy farming increases and so may their determination to influence household decisions on these matters (Grassi et al., 2015; Tavenner et al., 2019). Women may also invest more time in agriculture, but research shows that this often fails to translate into higher female empowerment (Khed & Krishna, 2023). Women rather experience a reduction in leisure time, further exacerbating issues of time poverty.

The second channel is commercialization and increased milk sales. Beyond time investments by men, the adoption of herd health management may also increase productivity and higher milk sales. Research from both livestock and arable farming suggests that increases in sales often reduce female control over decisions related to sales of output (Fischer & Qaim, 2012b). Commercialization in dairy farming, for example, has caused an uneven distribution of labor and control in Rwanda (Clay et al., 2020).

However, context-specific gender norms are important. In the study region, evening milk, for example, is usually either consumed by the household or sold to informal markets such as neighbors – a decision usually made by women. Yet, if production or sales increase substantially, the control over this decision may shift towards men (Tavenner et al., 2019). This is in line with the general finding that control of smaller and lesser-valued crop and livestock products is relatively often left to women, but when stakes increase, men tend to become more involved in these types of decisions (Chege et al., 2015; Fischer & Qaim, 2012a). For the specific case of herd health management practices, gender implications are not yet well understood.

Therefore, we further hypothesize:

H3a: The adoption of herd health management practices is negatively associated with women's control and access to household livestock assets.

H3a: The adoption of herd health management practices is negatively associated with women's decision-making power related to dairy farming.

3.3 Materials and Methods

3.3.1 Study Area and Sampling

To analyze adoption and social implications of herd health practices, we conducted a household survey in Elgeyo Marakwet, Uasing Gishu and Nandi Counties representing semi-intensive dairy systems in Kenya. The study sites also form part of a larger project led by the International Livestock Research Institute (ILRI) within the OneCGIAR initiative on Sustainable Animal Productivity for Livelihoods, Nutrition, and Gender Inclusion (SAPLING) in Kenya. We followed a multistage sampling technique to select farmers for the survey that was conducted in October-November 2023.

In the first stage, we purposively selected 5 dairy cooperatives with active membership (Lessos, Lelelchego, Tarakwo, Ainabkoi and Chepkorio). Second, we determined eligible milk collection clusters with a minimum of 20 farmers, which is the least sample size that can allow random replacement in case selected farmers become unavailable and randomly selected 64 milk collection clusters. Third, using proportionate random sampling, we randomly selected 49 routes and subsequently randomly sampled 578 dairy farmers. Figure 3.1 shows a map of the sampled area, and a detailed sample distribution is provided in the appendices (see Table A7.4). Data were collected through face-to-face interviews with the household head and the spouse to ensure questions regarding labor participation and decision-making were fully answered.

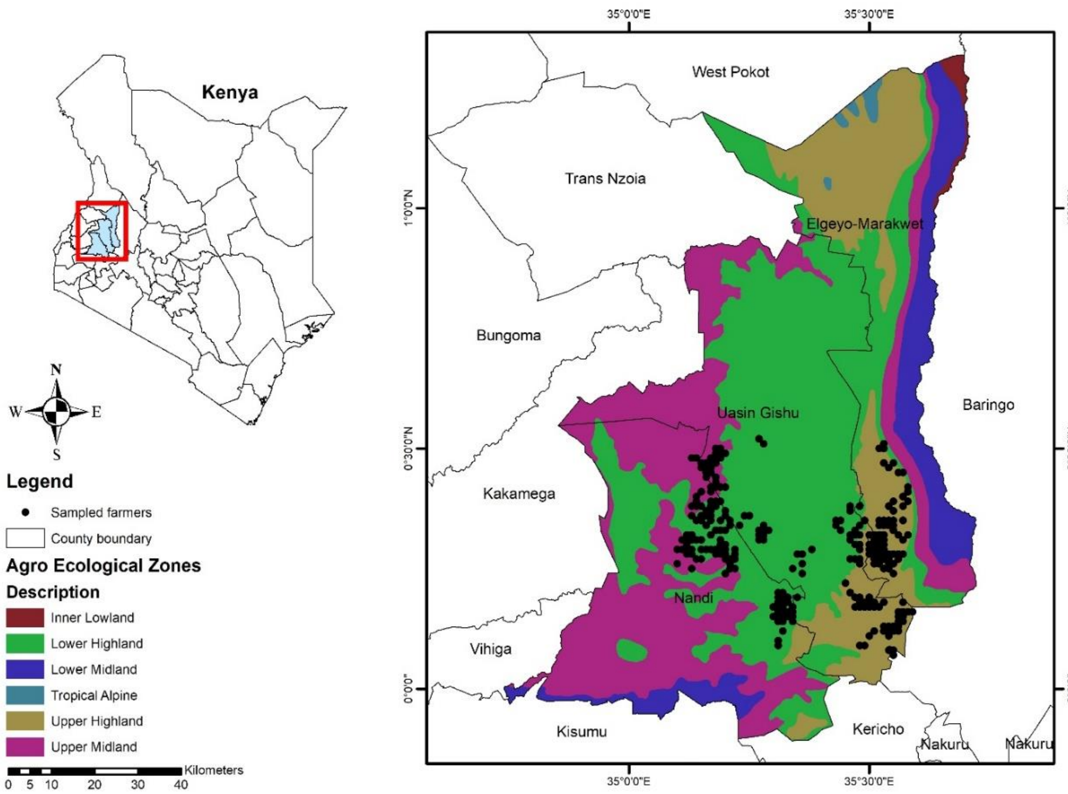

Figure 3.1: Map of the sampled area

3.3.2 Definition and Measurement of Key Variables

For herd health management practices, we collected data on several different practices based on literature (Derks et al., 2014; Ericksen & Crane, 2018; Green et al., 2012; Hall et al., 2004; Skjølstrup et al., 2021). Farmers' use of commercial dairy meals and mineral blocks relates to the pillar of holistic nutrition. The use of artificial insemination reflects better reproductive management. We also include practices related to preventive animal health, namely deworming using anthelmintics, tick control through spraying, and routine vaccination against notifiable[1] and non-notifiable[2] diseases prevalent in the region. For the main analysis, we focus on the extent of adoption, which we measure as the number of herd health management practices adopted by the household. This

[1] Notifiable diseases refer to zoonotic diseases whose vaccination is provided for free or for a subsidized cost by the government e.g. Rift Valley Fever (RVF), Foot and Mouth (FMD) and Anthrax.

[2] Non-notifiable diseases include tick-borne diseases such as East Coast Fever (ECF).

indicator ranges from zero (no practices adopted) to five (all practices adopted), but we also analyze individual practices.

Data on labor use in dairy production covers family labor in dairy-related activities measured by average weekly hours spent per person, captured for both primary adult male and female household members who contributed to family labor in the last 12 months preceding the survey. Labor data encompass participation in different activities including, the collection of manure, grazing, crop production, feeding (collection and preparation), on-farm fodder production, milking, and cleaning of animal sheds. Children in the study area are typically engaged in schooling activities so that active child labor is rare.

For women's decision-making and control, we adapt measures of decision-making and control over resources from the Women Empowerment in Livestock Index (WELI) tool[3] developed by Galiè et al., (2019). We evaluate women's decision-making in production decisions and on use of income. Specifically, we collect data on decisions regarding dairy production (e.g. decision on livestock breeds, animal treatment, growing of fodder), and decisions on the use of income received from the sale of livestock, and sale of milk (morning and evening). Decisions are categorized to be made by either the woman alone, or jointly by the woman and man, or by the man alone. We also measured livestock asset ownership by women (owned both individually and jointly). This is quantified as the number of livestock, measured in Tropical Livestock Units (TLUs), owned by the women divided by the total amount of livestock owned by the household.

3.3.3 Estimation Strategy

To test hypotheses 1a and 1b, we first analyze the association between the adoption of herd health management practices and time used for farming by women and men. Given

[3] See Table A7.5 in the appendices.

that time spent on farming is left-censored at zero, our analysis is based on the following Tobit model (Tobin, 1958), which we estimate separately for men and for women:

$$y_i^* = \beta\left(\sum_{t=1}^{5} t_i\right) + X_i\omega_i + \varepsilon_i, \text{with}$$

$$y_i = max(y_i^*, L)\begin{cases} y_i = y_i^* if \;\; y_i^* > \; L \\ \vdots \quad \vdots \quad \vdots \\ y_i = L \; if \; y_i^* \leq \; L \end{cases} \quad where\ L\ is\ a\ lower\ threshold\ for\ y \tag{3.1}$$

where y_i^* is the observed weekly labor hours spent by female or male household members in dairy production activities for household i. The extent of adoption is measured as the sum of the adoption dummies of five specific herd health management practices t_i. Our main coefficient of interest for hypotheses 1a and 1b is β.

Given that the adoption of herd health management practices is not random, we adjust for a range of household and farm characteristics captured by the vector X_i. These variables include gender, age, and dairy farming experience of the household head, herd size, a dummy indicating whether dairy farming is the households' main occupation, a categorical variable for the production system, the household size, and a dummy indicating whether or not households hired labor for their dairy farming operations. We estimate robust error terms denoted by ε_i.

Despite controlling for a range of socio-economic control variables, we cannot rule out potential bias resulting from unobserved heterogeneity. We aim to grasp a better understanding of the importance of the inclusion and exclusion of control variables, by estimating specification curves for the coefficient β (Simonsohn et al., 2015). In particular, we plot point estimates and confidence intervals for all possible combinations of control variables, with the exception of the dummy for hired labor, which is always included due to the strong link to farmers' time use. Still, it is important to mention that the coefficients estimated in equation 3.1 represent conditional associations and should not be interpreted as causal estimates.

In the analysis of time use, we also consider a model where each herd health management practice is included as a separate treatment variable. This allows insights into time burdens associated with specific practices. The respective model is:

$$y_i^* = \gamma_i p_i + X_i\omega_i + \epsilon_i, \text{with}$$

$$y_i = max(y_i^*, L)\begin{cases} y_i = y_i^* if \;\; y_i^* > \; L \\ \;\;\vdots \quad \vdots \quad \vdots \\ y_i = L \; if \; y_i^* \leq \; L \end{cases} \tag{3.2}$$

where γ_i is a vector of coefficients associated with each of the five practices p_i.

To test hypotheses 2a and 2b, we estimate the following tobit model:

$$y_i^* = \beta\left(\sum\nolimits_{t=1}^{5} t_i \times G_i\right) + X_i\omega_i + \epsilon_i, \text{with}$$

$$y_i = max(y_i^*, L)\begin{cases} y_i = y_i^* if \;\; y_i^* > \; L \\ \;\;\vdots \quad \vdots \quad \vdots \\ y_i = L \; if \; y_i^* \leq L \end{cases} \tag{3.3}$$

Here, we estimate β that captures the interaction term between herd health management practices (t_i) and management system (G_i), again adjusting for the same control variables as in equations 3.1 and 3.2.

To test hypotheses 3a and 3b, we estimate a multinomial logit model following McFadden, (1973) for each of the gender-related outcome variables discussed in the previous section:

$$D_{ij}^* = t_i\beta_i + X_i\omega_i + \varepsilon_i \tag{3.4}$$

where D_{ij}^* are gender-related outcomes on asset ownership and involvement in management decisions and control of income discussed in detail in the previous section. D_{ij}^* is measured as a categorical variable capturing decisions by men alone, women alone, and joint ($j = 1, 2, 3$). We then estimate the probability of the effect of adopting HHPs (β_i) on D_{ij}^* by maximum likelihood and obtain consistent estimates as:

$$P_{ij} = \Pr(\beta_i, \omega_i < 0 | t_i, X_i) = \frac{\exp\,(t_i\beta_j, X_i\omega_j)}{\sum_{n\neq 1}^{j} \exp\,(t_i\beta_n, X_i\omega_n)} \quad j = 1{,}2{,}3 \tag{3.5}$$

Again, these results do not represent causal estimates, but rather conditional associations.

3.4 Empirical Results

3.4.1 Descriptive Statistics

Descriptive statistics of the sampled households are presented in Table 3.1.

Table 3.1: Descriptive statistics of sampled farmers

Variables	Mean	Std dev
Male household head (male = 1)	0.79	
Age of household head (years)	53.53	14.19
Education of household head (years of schooling completed)	13.03	4.41
Dairy farming experience (years)	21.20	14.27
Household head main occupation (farming = 1)	0.74	
Household size (count)	5.33	1.99
Livestock ownership (TLU)	4.89	3.85
Grazing system (yes = 1)	0.38	
Wealth index	59.76	12.89
Hired labor (yes = 1)	0.42	
Individual HH practice		
Deworming	1.00	
Routine vaccination	0.28	
Tick control	0.74	
Holistic nutrition (commercial dairy meal/mineral blocks)	0.95	
Artificial insemination (AI)	0.40	
Adoption intensities of HH practices		
One practice	0.01	
Two practices	0.16	
Three practices	0.39	
Four practices	0.36	
Five practices	0.08	

Notes: N = 578. TLU = tropical livestock units with conversion factors based on Njuki et al., (2011) for Sub-Saharan Africa. Herd health (HH)

The majority of sampled households are headed by men who practice farming as their main occupation, owning an average herd size of 5 tropical livestock units (TLU) with 38% under grazing type of production systems. We also find that farmers adopt practices related to holistic nutrition, deworming, and tick control. However, routine vaccination and artificial insemination have a lower rate of utilization. Similarly, a majority of farmers adopt between 3-4 practices and seldom observe the adoption of one practice.

3.4.2 Associations Between the Adoption of Herd Health Practices and Time Allocation

Table 3.2 presents the regression estimates on the association between the adoption of HHPs and time allocation to dairy-related production activities for both primary adult male and female household members. We find that the adoption of herd health management practices is associated with an increase in the time spent on livestock activities for both men and women. Each additional practice is associated with more than 3 hours additional workload per week for women (column (1)) and 8 hours per week for men (column (3).

Moreover, even when we look at specific practices, we find statistically significant and positive associations for most practices on time use for both men and women. The magnitudes of the coefficients are particularly large for practices related to improved nutrition. One exception is artificial insemination, which is associated with fewer hours spent on farming for women. This may be explained by the fact that AI is less labor-intensive compared to the use of bulls for insemination, which requires more time in handling animals.

Table 3.2:Regression estimates on the association between herd health management practices and intra-household labor demand

	Female members		Male members	
	(1)	(2)	(3)	(4)
Number of practices adopted	3.45**		8.00***	
	(1.44)		(2.25)	
Individual practices				
Deworming		2.82		-10.72
		(15.52)		(22.66)
Routine vaccination		7.92***		11.15***
		(2.68)		(4.34)
Tick control		7.23**		11.01**
		(3.09)		(4.70)
Artificial insemination (AI)		-5.23**		1.87
		(2.71)		(4.32)
Holistic nutrition (commercial dairy meal/mineral blocks)		16.08**		16.16*
		(6.76)		(9.20)
Household controls				
Male household head (male = 1)	0.12	0.88	27.88***	28.22***
	(3.28)	(3.26)	(5.76)	(5.77)
Age of household head (years)	-0.16	-0.15	-0.64***	-0.63***
	(0.15)	(0.15)	(0.23)	(0.23)
Dairy farming experience (years)	0.06	0.08	0.43**	0.43**
	(0.15)	(0.15)	(0.22)	(0.22)
Household head main occupation (farming = 1)	-3.82	-5.31*	12.13***	10.98**
	(3.11)	(3.10)	(4.50)	(4.53)
Household size (count)	0.05	0.02	-0.78	-0.79
	(0.75)	(0.74)	(1.11)	(1.10)
Livestock ownership (TLU)	-0.46	-0.46	-0.47	-0.46
	(0.36)	(0.36)	(0.55)	(0.55)
Wealth index	-0.38***	-0.31***	-0.60***	-0.56***
	(0.13)	(0.13)	(0.19)	(0.19)
Grazing system (yes = 1)	-6.60***	-8.25***	-9.71**	-11.11***
	(2.67)	(2.70)	(4.11)	(4.20)
Hired labor (yes = 1)	-5.58*	-5.41*	-5.76	-5.58
	(2.98)	(2.92)	(4.52)	(4.50)
Pseudo R^2	0.01	0.02	0.02	0.03

*Notes: N = 578. Regression coefficients are shown with robust standard errors in parentheses. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

To analyze the potential sensitivity of the coefficients in column 1 and 3 to omitted variables, we present specification curves for the coefficients in Figure 3.2.

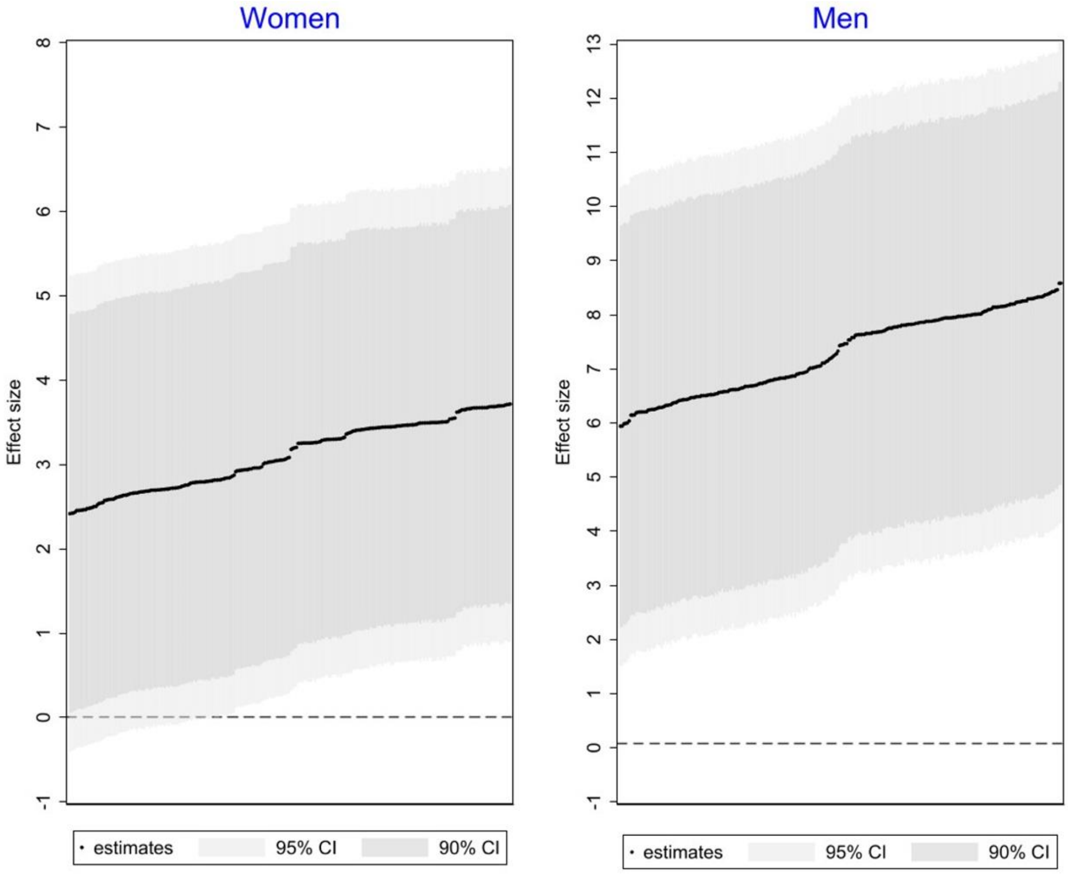

Figure 3.2: Specification curve on the effect of herd health practices on time use for men and women

Our coefficient point estimates are rather stable. For all 256 possible combinations of control variables, the coefficient for female time use is statistically significant at least at a 10% level and the coefficient for male time use is statistically significant at a 5% level. We, therefore, find empirical support for both Hypothesis 1a and 1b.

To test our second hypothesis, we compare if the relationship between time use and herd health management practices differ across production systems (eq. 3.3) (grazing vs confined/ semi-confined systems). Regression results are shown in Table 3.3.

Table 3.3: Associations between herd health management practices and intra-household labor demand by livestock management system

	Female members	Male members
	(1)	(2)
Number of practices adopted	4.21***	9.16***
	(1.45)	(2.27)
Number of practices adopted X grazing system	-1.71**	-2.77**
	(0.75)	(1.16)
Household controls	Yes	Yes
Pseudo R^2	0.01	0.03

*Notes: N = 578. Regression coefficients are shown with robust standard errors in parentheses. Household controls are gender, age, dairy experience, main occupation of the household head, household size, livestock management system (free-grazing or zero-grazing), herd size (TLU), wealth index, and use of hired labor. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

We find that in grazing systems, the increase in labor hours associated with the adoption of HHPs is lower compared to confined systems. This holds for both women and men. The results contradict the second hypothesis that the additional time requirements for men would be larger under open grazing systems. On the contrary, the findings support our hypothesis that the additional time requirements are smaller for women in open grazing systems. Still, the fact that the increase in labor demand for women is weaker in grazing systems is not implausible. In confined systems, it is likely that the intensity of some practices such as feeding may require more processes such as preparation compared to grazing systems. This is a particular concern for women since animals are closer home and women are likely to have added responsibilities to their other domestic roles in the homestead. We also find household labor participation in different husbandry practices increases in confined systems compared to grazing systems (see Table A7.3 in the appendices).

3.4.3 Associations Between the Adoption of Herd Health Practices and Intra-Household Decision-Making and Control

Table 3.4 shows regression coefficient estimates for variables measuring intra-household decision-making and control over resources following equations 3.4 and 3.5. For livestock asset ownership, we find a negative relationship between the adoption of

HHPs and individual livestock asset ownership by women. Thus, the relative probability of men owning livestock assets is double (2.03)[4] that of women as households adopt more HHPs. On the contrary, although not significant, we observe a positive relationship for joint ownership between women and their spouses. This similar pattern is also observed in dairy production decisions as the intensity of adopting HHPs increases.

Table 3.4: Multinomial regression estimates on the association between herd health management practices and intra-household participation in decision-making and control

	Livestock asset ownership	Decision on			
		dairy production activities	income from sale of livestock	income from sale of milk (morning)	income from sale of milk (evening)
	(1)	(2)	(3)	(4)	(5)
Base = men alone					
Joint	0.17	0.16	-0.05	-0.29**	-0.73**
	(0.11)	(0.12)	(0.14)	(0.13)	(0.30)
Women alone	-0.71***	-0.32	-0.69***	-0.52***	-0.72**
	(0.23)	(0.22)	(0.25)	(0.17)	(0.35)
Household controls	Yes	Yes	Yes	Yes	Yes
Chi2 (20)	161.92***	197.41***	110.54***	153.09***	48.65***
Pseudo R^2	0.27	0.29	0.13	0.18	0.05

*Notes: N = 578. Regression coefficients are shown with robust standard errors in parentheses. Household controls are gender, age, dairy experience, main occupation of the household head, household size, livestock management system (free-grazing or zero-grazing), herd size (TLU), wealth index, use of hired labor. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

For decisions regarding income from the sale of livestock and milk (both morning and evening), there is a negative relationship between the involvement of women in decision-making and the adoption of HHPs. This also includes their participation in joint decision-making with their spouses. Interestingly, milk produced in the evening is usually consumed at home or sold to neighbors - a decision taken by women. It is possible that men finance the HHPs and would therefore like to recoup their invested finances, hence the growing role in decisions over dairy income with increasing adoption of HHPs. Thus, men are likely to take control over income from the

[4] Computed by taking the exponent of the coefficient.

sales (Tavenner et al., 2019). The results are comparable even when we control for time use and the level of milk production (see Table A7.7 in the appendices). We find that time use is often statistically significant and with the expected sign, but we do not see strong mediation effects.

3.5 Conclusion

In this study, we evaluated the social impacts of adopting herd health practices in dairying systems in Kenya. We specified five practices namely, deworming, tick control, routine vaccination, holistic nutrition (use of mineral blocks/commercial dairy meal), and artificial insemination to understand the social implications at the household level. Our findings reveal that the adoption of HHPs are associated with higher demand for family labor for both men and women, potentially increasing issues around women's time poverty. This is consistent with prior studies on multiple agricultural technology adoption and labor demand (Addison et al., 2020; Lenjiso et al., 2016; Mwambi et al., 2021; Teklewold et al., 2013).

Given the role that women play in livestock production in the study context, the adoption of HHPs is associated with more labor burden on women through labor reallocation. Further, our heterogenous analysis shows that the association between HHPS and women's time use is stronger in confined/semi-confined production systems. However, at higher intensification/commercialization levels, households can afford external labor, leading to more time saving for women as in the case of dairying intensification and child nutrition in Kenya (Njuki et al., 2016). Therefore, of policy concern, is the effect of initial intensification on changes to roles and responsibilities between men and women.

In terms of decision and control over resources, we find that the adoption of HHPs associated with a reduction in individual ownership of livestock assets by women. We also find that the adoption of HHPs is associated with reduced women's control over income from the sale of livestock and milk. Therefore, as dairy production becomes more commercialized – herein increased investments in intensification practices such as HHPs, women are likely to be pushed out of the enterprise to other farm enterprises that may not be as lucrative to the men as dairy. Similar findings have also been observed in other studies where men increase their control over incomes when production intensities and sales increase (Njuki & Sanginga, 2013; Price et al., 2018). Thus, further scaling of herd health management practices may contribute to the disempowerment of women, negating gains already made in the dairy sector.

It is important to note a few limitations in this study. First, our study does not have comprehensive time-use data that captures other economic and social activities. Second, our study relies on observational data and cannot fully account for all possible sources of heterogeneity. Additionally, the outcome variables are based on recall data which can be biased due to measurement error (Abay et al., 2021).

Based on the observed associations, this study cautiously suggest policy implications for targeting support and investment in scaling herd health management practices. First, the negative relationship between HHPs and women's time poverty underscores the potential need for nuanced policy support that considers women's access to institutional services, such as extension services, across different dairy production systems. Increased labor participation by women may require complementary interventions aimed at improving their access to knowledge on new technology – an area that is often underdeveloped in practice (Grassi et al., 2015). This could include both strengthening existing extension service delivery models as well as exploring alternative approaches, such as leveraging information communication technology and mobile phone services. In Kenya, for example, the growth in mobile phones adoption, supported by improved infrastructure and internet access may provide a promising avenue for extending such services.

Second, the association between HHPs and women's livestock asset ownership and their participation in decisions over dairy income suggests the potential benefits of strategies aimed at transforming gender norms. Future efforts to scale HHPs could consider incorporating interventions that support the transformation of gender norms, which may help address the unequal distribution of labor and responsibilities between men and women. For example, encouraging the active membership and participation of women in dairy cooperatives could help foster more equitable sharing of the workload, livestock resources, and income, even as HHP adoption expands.

4 From Protection to Pollution: Examining Environmental and Human Health Risks of Acaricide Use in Dairy Farming in Kenya[*]

Abstract

Sustainable intensification of livestock production relies critically on effective disease management, yet the environmental implications of current practices remain poorly understood. We examine how acaricide use in tick control in Kenya's dairy sector affects environmental and human health risks. Using original survey data from dairy farmers and a two-stage least square (2SLS) approach, we find that farmers' adaptation to perceived ineffective tick treatment leads to potentially harmful practices. Twenty percent of farmers improperly rotate acaricides, while 66% under-apply recommended doses. Despite 65% using protective gear, 29% report adverse health effects. Our estimates show that improper acaricide group rotation increases the environmental and human health risks by 35%. These findings highlight important trade-offs between animal health management and environmental and human health objectives, suggesting a need to reform current disease prevention approaches to balance productivity gains with environmental sustainability in developing countries.

Keywords: Acaricide rotation; environmental impact quotient (EIQ); human health; pesticides

JEL: I15, O13, O33, Q12, Q18

[*] This paper has been co-authored with Martin Parlasca and James Rao. The research idea was jointly developed by K.M., M.P., and J.R. K.M. collected, analyzed, and interpreted the data, and wrote the first draft of the manuscript. All co-authors gave comments at various stages and approved the final version.

4.1 Introduction

Chemical pesticides remain integral to modern agricultural production, offering critical benefits in crop protection and livestock disease management. In developing countries, where agricultural productivity gains are central to economic transformation, the continued use of pesticides has raised mounting concerns about environmental degradation, biodiversity loss, and human health risks from chemical exposure (Meunier et al., 2024; Schreinemachers et al., 2020; Tran et al., 2023). These environmental and human health trade-offs are salient in livestock systems, where farmers regularly apply synthetic acaricides to control ticks.

In Sub-Saharan Africa (SSA), where tick-borne diseases like East Coast Fever (ECF) have been shown to cause considerable losses in productivity due to morbidity and mortality (Maina et al., 2024; Teufel et al., 2021), weekly chemical treatments through spraying or dipping animals have become standard practice (Nagagi et al., 2020). Yet, the effectiveness of these chemical controls is increasingly compromised by growing tick resistance linked to the frequency of acaricide change, herein referred to as acaricide active ingredient group rotation. Failure to adhere to recommended acaricide rotation practices has been shown to increase tick resistance over time (Abbas et al., 2014; Thullner et al., 2007), often prompting farmers to adopt potentially harmful practices like increased application frequency or admixing of different chemical products to increase perceived effectiveness in tick control (Mutavi et al., 2021; Vudriko et al., 2018).

In this paper, we examine the environmental and human health implications of acaricide use in Kenya's dairy sector, where intensive tick control is critical for maintaining productive cattle herds. Using original survey data from 412 dairy farmers, we analyze current acaricide application practices and their association with environmental and health risks. Our results reveal that improper active ingredient rotation significantly increases environmental and human health risks – an incidence of improper active ingredient rotation in a farmer's annual rotation increases the environmental and human health risks, as measured by the environmental impact quotient (EIQ), by 35%.

Our analysis contributes to three strands of literature. First, we add to research on agricultural intensification, and environmental and human health in developing countries (Kim et al., 2017; Sheahan et al., 2017; Van Hoi et al., 2013). While extensive work has documented the environmental impacts of pesticide use in crop production, far less attention has been paid to livestock systems, despite their growing importance in agricultural transformation. Second, we contribute to studies examining farmer behavior around agricultural chemical use (Ghimire & Woodward, 2013; Schreinemachers et al., 2020; Zhang et al., 2015). Our findings highlight how information constraints and adaptation to treatment failure can lead to unintended environmentally damaging practices. Finally, we extend the literature on livestock health management in developing countries (Bishop et al., 2023; Marsh et al., 2016; Vudriko et al., 2018). While previous work has focused primarily on the technical aspects of tick resistance or farmer knowledge and attitudes, we provide novel evidence linking these practices to quantifiable environmental and health risks.

Our study also offers methodological innovations for analyzing environmental impacts in livestock systems. By adapting the environmental impact quotient (EIQ) framework – previously applied mainly to crop systems – we develop a quantitative assessment of environmental and human health risks from livestock disease management practices in a developing country context. This approach could prove valuable for future research examining environmental and human health trade-offs in livestock intensification.

The remainder of the paper is organized as follows. Section 4.2 provides background on acaricide use in Kenyan dairy systems. Section 4.3 describes our data and empirical strategy. Sections 4.4 and 4.5 present and discuss the results. Section 4.6 concludes with policy implications and directions for future research.

4.2 Acaricide Use in Livestock Production in Kenya

In Kenya, dairy production is primarily classified into three systems namely extensive grazing systems, semi-intensive, and intensive systems (Benard, 2016). Intensive systems are characterized by adopting high-yielding exotic breeds of cattle that are zero-grazed mainly in regions with small-landholding and high population density around Central Kenya and peri-urban areas of the capital Nairobi. Semi-intensive systems are characterized by low adoption of high-yielding breeds with farmers practicing semi-confined systems that combine grazing and stall feeding on largely unimproved fodder (Lukuyu et al., 2018). This forms part of the Western region in Kenya including the North Rift region. These production systems face challenges from tick infestation with the risk of cows of improved breeds being susceptible to ECF (Chepkwony et al., 2020).

Despite the existence of alternative vector control approaches, chemical control using acaricides remains the primary mode of tick control for most farmers (Muyobela et al., 2015; Vudriko et al., 2018). However, studies show current chemical tick control approaches have experienced increased incidences of acaricide resistance (Abbas et al., 2014; Githaka et al., 2022). This is further exacerbated by farmers' limited knowledge of proper acaricide application practices (Mutavi et al., 2021; Thullner et al., 2007). To successfully control ticks using acaricides, farmers are required to adhere to instructions on application rates per animal, a correct mixing ratio of acaricides and water, and recommended acaricide chemical group rotation – which involves changes in acaricides of different chemical groups based on active ingredients (AI) to avert tick resistance (De Meneghi et al., 2016).

Acaricide rotation is meant to reduce the development of tick resistance whereby farmers switch between different active ingredient groups over a specified interval (number of months). Despite no consensus on the optimal number of months to consider for acaricide group rotation (Githaka et al., 2022), studies show a 6 to 12 months interval – approximately 2 acaricide groups annually – to be an appropriate rotation period in African livestock systems (Bishop et al., 2023; Mutavi et al., 2021). However, what remains unknown is whether farmers adhere to these recommendations and how their practices affect the effectiveness of tick control.

Improper acaricide group rotation over time often leads to acaricide failure, prompting farmers to switch between acaricides at shorter intervals, increasing the number of acaricide products used (Rojas-Cabeza et al., 2025). Farmers may also engage in other unsafe acaricide application practices, such as applying increasingly higher chemical dosages beyond recommended rates or hazardous mixing of acaricides with other groups of pesticides (Githaka et al., 2022; Miyama et al., 2020). Thus, improper acaricide group rotation is likely to be correlated with an increased number of acaricides used by farmers. Consequently, this has potentially negative implications on the environment and human health risks due to contamination and exposure of soil, water, and animal products by chemical residues over time (Groot & van't Hooft, 2016; Laing et al., 2018; Rani et al., 2021).

However, these effects may be context-specific, and empirical literature in the context of livestock systems remains scarce. Therefore, our analysis is explorative and aims to investigate the association between improper acaricide group rotation practices and potential environmental and human health risks measured by EIQ.

4.3 Materials and Methods

4.3.1 Data

We conducted a farm household survey in Elgeyo Marakwet, Uasin Gishu, and Nandi Counties to understand acaricide use and its environmental implications. We followed a multistage sampling technique to select farmers. In the first stage, based on active membership, 5 dairy cooperatives (Ainabkoi, Chepkorio, Lessos, Lelelchego, and Tarakwo) were purposively selected. In the second stage, we randomly selected 64 milk collection clusters with a minimum of 20[1] farmers. The third stage involved a random selection of 49 clusters and 578 dairy farmers using proportionate random sampling with the spatial distribution shown in figure 4.1.

Face-to-face interviews were held in October-November 2023 with either the household head or the spouse. We find 71% of the sampled farmers use hand spraying

[1] This is the least number of sample size per cluster that can allow random replacements.

as their main method for tick control compared to 29% who use dipping (both private and public) as the main method for tick control. For our analysis, we focus on farmers who use hand-spraying as their main method for tick control further reducing our final sample to 412 dairy farmers. This was informed by two main reasons. First, from an analytical perspective, it is difficult to quantify the parameters we use in estimating the EIQ from acaricides used in cattle dips. Second, farmers may lack completeness of data relating to the type of acaricide used in the cattle dip and the amounts applied.

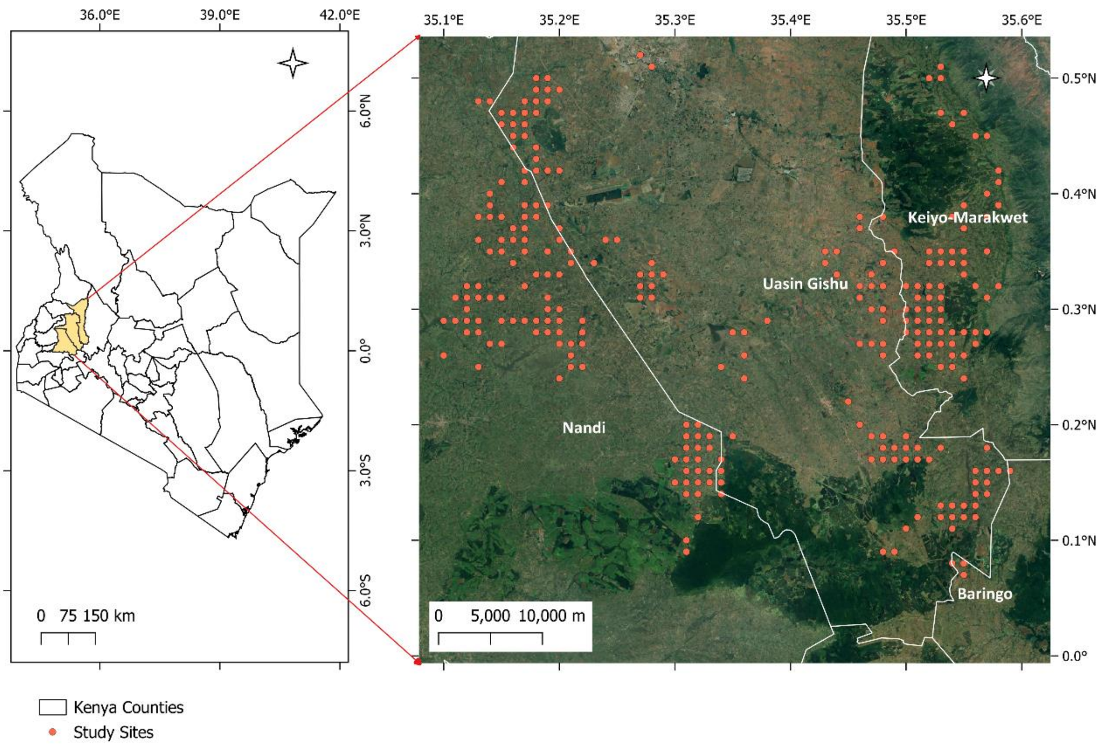

Figure 4.1: Map of the sampled area

Table 4.1 presents summary statistics of sampled households. Most sampled households are male-headed with an average of 21 years of dairy farming experience.

Table 4.1: Descriptive statistics of sampled farmers

Variables	Mean	Std dev
Male household head (male = 1)	0.80	
Dairy farming experience (years)	21.08	14.00
Household head main occupation (farming = 1)	0.75	
Grazing system (yes = 1)	0.35	
Livestock ownership (TLU)	4.95	3.87
Log annual household expenditure (KES)	12.45	1.21
Number of extension visits (annually)	4.37	14.01
Distance to nearest vet shop (kilometers)	2.74	1.85

Notes: N = 412. TLU = tropical livestock units with conversion factors based on (Njuki et al., 2011) for Sub-Saharan Africa.

The household heads mainly practice farming as their main occupation (75%). The average herd size for dairy cattle is about 5 tropical livestock units (TLU), translating to farmers keeping an average of 5 heads of cattle. However, only 35% of the farms practice grazing systems implying a higher proportion of farms under zero-grazed intensive production systems.

4.3.2 Measuring the Effects of Acaricide Use on the Environment and Human Health Risks

Assessing the changes in the frequency of application of acaricide or application rates per animal due to changes in the incidence of improper acaricide group rotation can be useful indicators of reduced risks to the environment and human health. However, this approach does not consider differences in specific acaricides used by farmers that may have varying environmental and human health risks. Chemical pesticide products differ in terms of toxicity levels and persistence (Kouser & Qaim, 2013). To overcome this challenge, we used the environmental impact quotient (EIQ) developed by Kovach et al., (1992) to measure the environmental and human health risks associated with acaricide use. This approach relies on toxicological information on different chemical products to give a single numerical indicator of the risks to farmer workers, consumers, and the environment (Eshenaur et al., 2015)[2]. Despite criticism of the use of arbitrary weights, EIQ proves useful as a proxy to comprehensively measure environmental and human health risks in the absence of alternatives. It has been used in different contexts to estimate the effects of pesticides in cropping systems (Kouser & Qaim, 2013; Midingoyi et al., 2019; Oliver et al., 2016; Schreinemachers et al., 2011).

We first extract data on active ingredients (AI) for each acaricide product used by farmers and further collate the EIQ values for each of the AI from Cornell University College of Agriculture and Life Sciences[3] database. We present EIQ values for different acaricides being used by farmers in Tables A7.8 and A7.9 in the appendices. Following Kouser & Qaim, (2013) and Eshenaur et al., (2015) we make a slight alteration to EIQ field use computation that allows for comparisons. The EIQ field use is given by:

$$EIQ\ field\ use = EIQ\ \times\ \%\ active\ ingredient \times frequency\ of\ application \times dose\ or\ application\ rate \tag{4.1}$$

Application rate/dose in cropping systems is given by litres/ha or kg/ha, in our case we consider liters per animal as a measure in acaricide application (Mutavi et al., 2021).

4.3.3 Estimation Strategy

We set out to estimate the relationship between improper acaricide group rotation and environmental and human health risks using the following specification:

$$Y_i = \beta_0 + \beta_1 R_i + \beta_2 X_i + \varepsilon_i \tag{4.2}$$

[2] See Kovach et al., (1992) for detailed computation of EIQ

[3] https://cals.cornell.edu/new-york-state-integrated-pest-management/risk-assessment/eiq/eiq-pesticide-values

where Y_i represents EIQ for household i, capturing the environmental and human health effects of acaricide use, R_i is a dummy variable measuring improper acaricide group rotation. X_i is a vector household socio-demographic characteristics, and ε_i is the error term. The parameter of interest, β_1, captures the marginal effect of acaricide usage on environmental and health risks.

While equation (4.2) provides a baseline relationship, OLS estimation likely yields biased estimates of β_1 due to endogenous selection in acaricide usage. Farmers' decisions regarding the frequency and type of acaricides are potentially correlated with unobservable characteristics such as managerial ability, risk preferences, and access to institutional resources. For instance, more skilled farmers might optimize their acaricide rotation strategies while simultaneously implementing other practices that affect environmental outcomes. Similarly, risk-averse farmers may both over-apply acaricides and take other precautionary measures that influence the EIQ. These selection issues could bias our OLS estimates in either direction.

To address these endogeneity concerns, we depict this as a causal chain and employ a two-stage least square (2SLS) approach. We instrument the total number of acaricide products used using the incidence of improper acaricide group rotation. The validity of our identification strategy rests on two key conditions. First, regarding relevance assumption, improper acaricide group rotation should strongly predict overall acaricide usage – the total number of acaricide products farmers use. The first-stage results in Table 4.6 confirm this relationship, with an *F*-statistic of 19.09, well above the Stock and Yogo, (2002) threshold of 10 for weak instrument concerns.

Second, our exclusion assumption requires that improper acaricide group rotation affects environmental impact only through its influence on the total number of acaricides used. While this assumption is inherently untestable (Angrist & Pischke, 2009), we argue for its plausibility based on the institutional context of acaricide purchases. Most farmers lack detailed knowledge of active ingredients when making purchasing decisions, effectively randomizing the proper/improper nature of their rotation sequences. This information gap creates quasi-random variation in rotation quality that is plausibly exogenous to unobserved determinants of environmental impact.

In addition, we also perform sensitivity analysis for the 2SLS estimation using the kinky least squares (KLS) regression. Kinky least squares (KLS) is an instrument-free model that overcomes challenges associated with IV approaches (Kripfganz & Kiviet, 2021). The graphical outputs from the approach allow us to compare the confidence intervals for both KLS and IV, providing insights into the strength of our instrument. Weak instruments are associated with wider confidence intervals from the IV approach compared to the Kinky approach (Tabe-Ojong, 2024).

We proceed with the 2SLS strategy as follows:

$$First\ stage: R_i = \beta_0 + \beta_1 S_i + \beta_2 X_i + \varepsilon_i \quad (4.3)$$

$$Second\ stage: Y_i = \beta_0 + \sigma_i \hat{R}_i + \beta_2 X_i + \varepsilon_i \quad (4.4)$$

where S_i in the first stage measures the effect of improper acaricide group rotation in household i's acaricide rotation sequence on the number of acaricide products used, and $\hat{R}_i$ in the second stage represents the predicted values from the first stage. The controls, X_i are as defined in Equation 4.2.

4.4 Empirical Results and Discussion

4.4.1 Acaricides Used in Dairy Farms in Kenya

Figure 4.2 and Table 4.2 summarize the different acaricide groups and products used in the control of ticks by sampled farmers. On average farmers apply acaricides three times a month, translating to a seven-day-interval between sprays on average. Farmers use a particular acaricide product for six months before switching to a different acaricide group. This means that, on average, farmers use two different acaricides annually.

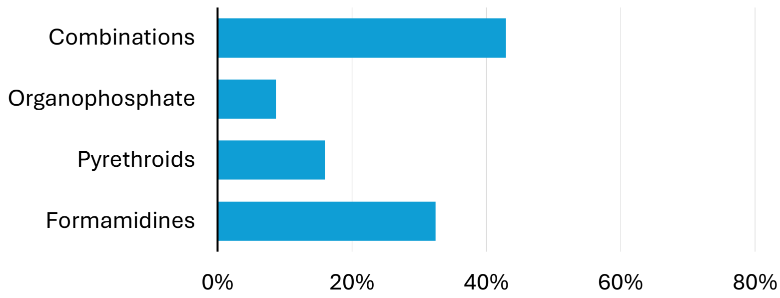

Figure 4.2: Acaricide groups used by dairy farmers. *Multiple answers were possible. N = 412*

We find a significant inverse correlation (-0.35) between the duration of acaricide use and the frequency of its monthly application. This suggests that when farmers use an acaricide product for a longer duration, they tend to spray less frequently each month. A plausible explanation is that more effective acaricides provide better tick control, reducing the need for frequent spraying (i.e. every seven days). In contrast, when acaricides are less effective, farmers may need to apply them more often or switch to different products to achieve better results. Most farmers use acaricides with combined active ingredient, mainly a combination of cypermethrin and chlorpyrifos (Table 4.2). They also use acaricide products in the formamidines group where the main AI is *amitraz*. We also observe cases of farmers using other chemicals classified as pyrethroids to control ticks, for example, Duduthrin® and Cypertex products are mainly used to control crop pests such as aphids and armyworms in crops. Further qualitative probing from farmers on the use of crop pesticides indicates that the effectiveness is perceived to be higher in tick control than the available acaricides classes in the region.

Based on the World Health Organization (WHO), (2020) hazard classification of pesticides, most of the acaricides in use are classified as moderately hazardous (II) except for Steladone which is classified as highly hazardous (1b) (Table 4.2).

Table 4.2: Common acaricides used by farmers for tick control

Acaricide group	Active ingredient (AI)	% for each active ingredient	Trade name	Number of households using	Number of applications per month in the last one year	Number of months used in the last one year	WHO hazard classification
Formamidines	Amitraz 12.5%	32.07	Actraz®	3	2.33 (1.53)	3.67 (2.08)	II
			Almatix®	13	2.69 (1.18)	5 (3.37)	II
			ByeBye®	2	1.5 (0.71)	4 (2.83)	II
			Norotraz®	40	3.1 (1.15)	5.42 (3.43)	II
			Taktic®	13	2.69 (1.25)	4.77 (2.71)	II
			Tikfix®	14	2.71 (1.33)	5.07 (3.81)	II
			Triatix®	216	2.79 (1.21)	6.38 (3.49)	II
			Twigatraz®	3	3 (1.73)	8 (3.46)	II
Pyrethroids	Alpha-cypermethrin	4.22	Cypertix	38	3.18 (1.18)	4.76 (3.13)	II
			Daltix	1	2	4	II
			Eliminator	1	4	6	II
	Lambda-cyhalothrin	0.11	[a]Duduthrin®	1	2	12	II
	Cyhalothrin 5%	4.11	Grenade	39	2.90 (1.17)	4.74 (2.37)	II
	Cypermethrin	1.48	[b]Cypertex	1	4	2	II
			Ectomin	13	2.54 (1.33)	5.15 (3.56)	II
	Deltamethrin	6.43	Delete	61	2.67 (1.47)	5.77 (3.70)	II
Organophosphate	Chlorfenvinphos	8.76	Steladone	83	3.07 (1.18)	5.14 (3.17)	Ib

Table 4.2 (continued)

Acaricide group	Active ingredient (AI)	% for each active ingredient	Trade name	Number of households using	Number of applications per month in the last one year	Number of months used in the last one year	WHO hazard classification
Combination	Chlorpyrifos 50% + Cypermethrin 5%	40.51	Cyperdip®	11	3	6	II
			Dabotik®	8	2.29 (1.25)	7.86 (4.01)	II
			DuoDip®	334	2.84 (1.27)	7.19 (3.52)	II
			Pyrotix®	1	4	2	II
			Sidai Ultradip®	18	3.06 (1.30)	4.82 (2.96)	II
			TikDip®	9	2.78 (1.48)	6.67 (4.09)	II
			Ultradip®	3	1.67 (0.58)	6.33 (4.93)	II
	Cypermethrin + Chlorpyrifos + Piperonyl butoxide + Citronell	2.32	Vectoclor®	22	3.04 (1.76)	6.86 (3.73)	II

Notes: Standard deviations in parentheses. a = insecticide being used in tick control; b= crop pesticides being used in tick control; World Health Organization (WHO) pesticide hazard classification of pesticide active ingredient: Ib = highly hazardous, II = moderately hazardous, III = slightly hazardous, U= unlikely.

4.4.2 Acaricides Application Practices and Potential Human Health Risks

Table 4.3 summarizes acaricide application practices among sampled farmers. We find that 20% of farmers improperly rotate their acaricides. This involves switching acaricides within the same acaricide group and is likely to cause the build-up of tick resistance over time (De Meneghi et al., 2016).

Table 4.3: Acaricide application practice among farmers

	Percentage
Acaracide AI group rotation	
Incidence of improper acaricide rotation (1 = yes)	20.39
Acaracide usage based on application rate per animal (recommended 5 litres of diluted solution per animal	
Under application	65.67
Recommended application	14.48
Over application	19.85

Notes: N= 412

Additionally, 66% of farmers tend to under-apply acaricides on animals and are likely to increase the risk of tick infestation and acaricide failure (Githaka et al., 2022; Muyobela et al., 2015). The recommended application rate of a diluted acaricide solution is 5 liters per animal per spray (Mutavi et al., 2021). About 20% of farmers apply acaricides above the optimum recommended levels and only 14% of farmers applying the recommended level.

Table 4.4 summarizes acaricide measurement practices among farmers. On average, most farmers use measuring cylinders to achieve the correct acaricide dilution ratio. Most acaricides are sold with calibrated measuring cylinders and the dilution ratio is provided on the packaging. We do not observe differences in proportions between farmers who follow proper acaricide class rotation and those who follow otherwise. This in part shows that most farmers have some level of knowledge on dilution ratio and can follow manufacturer’s instructions.

Table 4.4: Acaricide measurement practices among farmers

	Percentage
Measurement practices	
Measuring cylinder	86.17
Bottle top	12.14
Use of eyes to estimate	1.70

Notes: N= 412.

However, we observe some farmers using bottle tops to estimate the acaricide dilution ratio. Most times farmers use the bottle tops of the acaricide product, thereby relying on an estimate as opposed to measuring the exact dilution ratio. While this may be considered a bad practice, qualitative insights from the farmers show that with sufficient experience, one can measure accurately recommended amounts similar to using calibrated cylinders.

We present results on acaricide handling and safety practices in figure 4.3. We find that 65% of farmers use some form of protective gear when applying acaricides. This implies that farmers are aware of human health risks associated with acaricide use and follow recommendations to reduce exposure. The personal protective materials include boots, overalls, nose masks, gloves, and goggles to prevent adverse effects from exposure to acaricides.

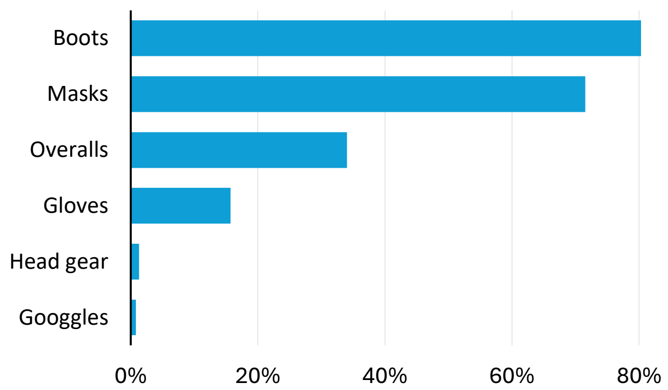

Figure 4.3: Use of protective gear in the application of acaricides. *Multiple answers were possible. N = 412*

Despite farmers using some form of protective material, we find reported cases of adverse effects from acaricides (29%), as shown in Table 4.5.

Table 4.5: Reported cases of adverse effects of acaricide after application and symptoms

	Percentage
Adverse effects from acaricide use	
Incidence of adverse effects from acaricide use (yes = 1)	29
Household members affected	
HH head	53
Spouse	19
Child	22
Farm worker	6
Type of symptoms (symptoms consistent with intoxication)	
Headache	30
Sneezing	24
Irritation in the eyes	26
Dizziness	23
Nausea	23
Shortness of breath	6
Skin irritation	23
Fatigue	2.89

Notes: N= 412. Multiple answers were possible

Adverse effects from acaricide were mainly experienced by the household head with symptoms including headaches, irritation in the eyes, sneezing, dizziness, nausea, and irritation of the skin. These symptoms are consistent with the level of exposure, especially among the farmers who do not use any form of protective gear.

4.4.3 Regression Results

Table 4.6 presents the first-stage regression results, examining the relationship between improper acaricide group rotation and the total number of acaricide products used. The estimates reveal a strong and statistically significant relationship supporting the relevance condition of our identification strategy.

Table 4.6: First-stage regression results on improper acaricide rotation and the number of acaricides used annually

	Number of acaricides used annually	
	(1)	(2)
Incidence of improper acaricide rotation (yes = 1)	0.21**	1.34***
	(0.07)	(0.11)
Constant	7.12***	1.74***
	(0.18)	(0.42)
Controls	No	Yes
R-squared	0.07	0.32
Observations	412	412
F-Statistic	8.27	19.09

*Notes: Coefficients are shown with robust standard errors in parentheses. Controls include gender, dairy farming experience, main occupation of the household head, livestock management system, herd size (TLU), household expenditure, number of extension visits annually, use of protective gear when spraying, and distance to a veterinary shop. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

Column (1) presents the baseline specification without controls, while Column (2) includes our full set of household and farm-level controls. The coefficient on improper rotation increases substantially from 0.21 to 1.34 ($p < 0.01$) when including controls, suggesting that observable characteristics play an important role in mediating the relationship between rotation practices and overall acaricide use. This finding indicates that farmers who improperly rotate active ingredients use, on average, 1.34 more acaricide products annually compared to those who follow proper acaricide rotation protocols.

The magnitude of this effect is economically significant, representing approximately 67% of the mean number of annual acaricides that farmers use in our sample. The positive coefficient aligns with our theoretical expectations: improper rotation practices likely lead to reduced acaricide treatment effectiveness, compelling farmers to increase the frequency of application or experiment with additional products to maintain tick control.

These first-stage results yield important implications for understanding farmer behavior and agricultural extension services. The strong positive relationship suggests that inadequate knowledge of active ingredients leads to inefficient pest management practices, resulting in increased chemical use. The substantial change in the coefficient magnitude when including controls indicates that socioeconomic and farm characteristics significantly influence acaricide management decisions.

Next, we present our main results examining the relationship between the total number of acaricide products and environmental and human health impact, as measured by the environmental impact quotient (EIQ) field use value in Table 4.7. We report both OLS and instrumental variable estimates, with the latter addressing potential endogeneity in farmers' acaricide rotation decisions.

Table 4.7: 2SLS estimates of the association between the number of acaricides used annually and annual EIQ field use

	Log annual EIQ field use	
	(1)	(2)
Number of acaricides used annually	0.29***	0.26***
	(0.05)	(0.08)
Constant	8.91***	8.95***
	(0.66)	(0.67)
Controls	Yes	Yes
R-squared	0.16	0.16
Observations	412	412

*Notes: Coefficients are shown with robust standard errors in parenthesis. Controls include gender, dairy farming experience, main occupation of the household head, livestock management system, herd size (TLU), household expenditure, number of extension visits annually, use of protective gear when spraying, and distance to a veterinary shop. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

The OLS estimates in column (1) indicate a significant positive association between acaricide usage and environmental and human health risks, with each additional acaricide product used associated with a 29% increase in the EIQ field use value ($p < 0.01$). Our preferred 2SLS specification in column (2), which instruments for improper rotation practices, yields a similar but slightly smaller coefficient of 0.26 ($p < 0.01$). This suggests that each additional acaricide product due to improper acaricide rotation increases the environmental and health risk indicator by 26%, holding other factors constant. Therefore, the incidence of improper acaricide group rotation is likely to increase the EIQ value by 35%[1]. The similarity between OLS and 2SLS estimates

[1] Computed by multiplying first-stage and second-stage coefficients (1.34 and 0.26, respectively)

suggests that selection bias may not be severely distorting the relationship between acaricide use and environmental human health impact in our context. Moreover, the similarity also suggests that observable characteristics might be useful in identifying farmers at higher risk of engaging in environmentally damaging pest management practices.

The magnitude of these effects is economically significant. Given the mean annual EIQ field use value in our sample of 256, this implies that each additional acaricide increases the potential environmental and human health risks by approximately 66.62 units annually. The persistence of this large effect in our 2SLS specification provides robust evidence that intensive acaricide rotation practices substantially amplify environmental and human health risks.

4.4.4 Robustness Checks

We perform robustness/ sensitivity checks on our 2SLS estimation using the Kinky Least Square regression. Here we compare the confidence intervals from the 2SLS approach and KLS to assess the weakness of our selected estimation. As shown in Figure 4.4, we find that the confidence intervals for our 2SLS approach are not wide validating our estimations. Additionally, we observe an overlap in the 2SLS and KLS estimation supporting the validity of our approach.

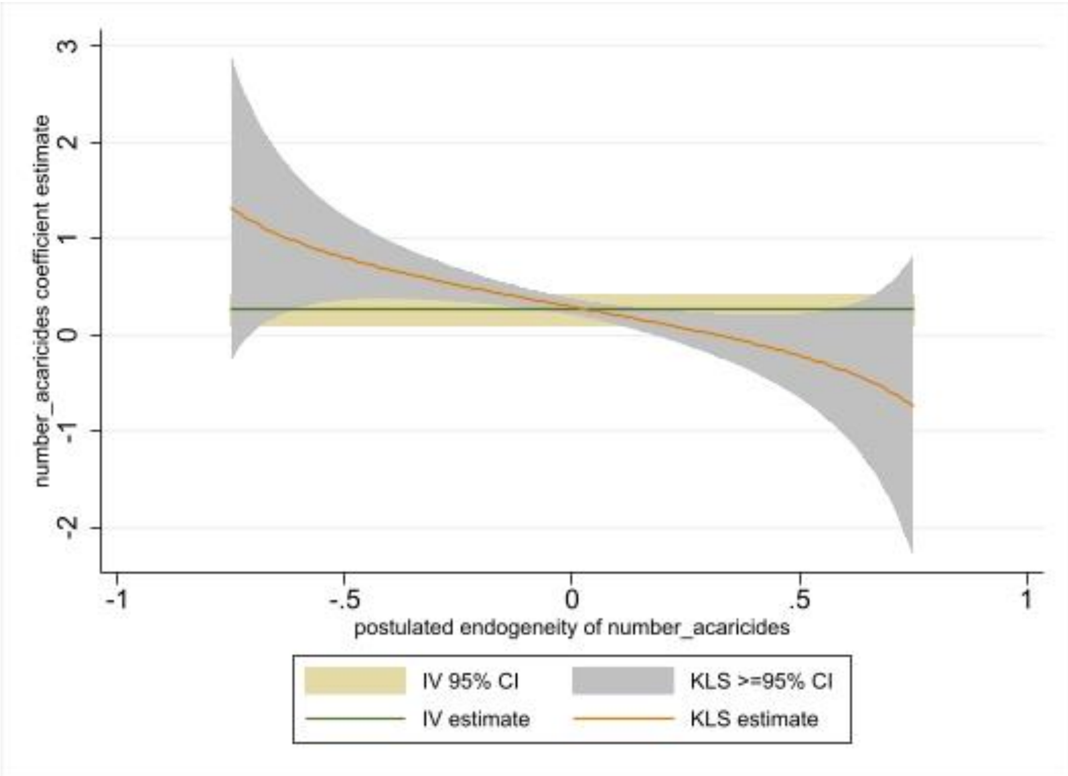

Figure 4.4: 2SLS and KLS coefficient estimates and confidence intervals

These observations imply that our estimates are unlikely biased. However, our study may not have adequately controlled some unobserved heterogeneity. Thus, we interpret our findings with caution.

4.5 Discussion

These findings illuminate several important mechanisms in the complex relationship between livestock health management and environmental and human health outcomes. First, they suggest a concerning feedback loop in tick control practices: as documented by Vudriko et al., (2018) in Uganda, improper rotation of acaricides often leads to tick resistance, compelling farmers to increase application frequency and switch to acaricides perceived to be more effective. Our results indicate that this adaptive behavior significantly amplifies potential environmental and human health risks. The magnitude of our estimates suggests that the environmental and human health costs of these adaptation strategies may be substantial and previously underappreciated in the literature.

Second, our findings highlight the environmental and human health implications of farmers' behavioral responses to perceived treatment inefficacy. Descriptive evidence as discussed earlier reveals that farmers often resort to potentially harmful practices such as admixing acaricides with other pesticides to enhance efficacy. Reconciling this descriptive evidence with 2SLS results suggests that these compensatory behaviors may be driving the environmental and human health impact beyond the direct effects of increased frequency in acaricide rotation. This points to an important interaction between farmers' technical knowledge, pest management decisions, and environmental outcomes. Altogether, the substantial environmental costs we document suggest that interventions targeting proper acaricide rotation practices could yield significant environmental and human health co-benefits alongside their primary goal of improving animal health.

4.6 Conclusion

This paper contributes to the growing literature on the environmental and human health implications of agricultural intensification in developing countries by examining acaricide use practices in dairy farming systems. While previous research has extensively documented the environmental impacts of pesticide use in crop production, our study provides novel evidence on the environmental and human health risks associated with chemical-based vector control in livestock systems, using Kenya's dairy sector as an empirical setting.

Our analysis reveals several important findings. Descriptively, we document widespread suboptimal acaricide practices: 20% of farmers engage in improper rotation of active ingredients, 66% under-apply acaricides relative to recommended application rates, and about 29% report adverse health effects despite 65% using protective gear. More concerning is the emergence of potentially hazardous adaptation strategies, including the use of crop pesticides for tick control and the admixing of different chemical products to enhance perceived efficacy. Our 2SLS estimation provides empirical evidence that improper acaricide rotation significantly amplifies environmental and human health risks with each additional acaricide product in a farmer's annual rotation increasing the environmental and human health risks by 26%.

These findings have important policy implications for animal health management in SSA and other developing countries. First, they highlight an urgent need to reform current approaches to animal disease control, balancing the economic imperatives of livestock productivity with environmental and public health considerations. Agricultural extension services should be strengthened to improve farmers' knowledge of proper acaricide rotation and application practices, particularly focusing on the risks of improper active ingredient rotation and chemical mixing. Second, our results suggest that policy interventions targeting agro-veterinary shops could be particularly effective, as these represent crucial last-mile information sources for farmers. However, this would require enhanced regulation of agro-veterinary services to ensure quality advice from trained professionals.

Looking ahead, future research should explore several promising directions. Studies could evaluate the cost-effectiveness of alternative tick control strategies, including biological controls and vaccination programs, accounting for both productivity and environmental impacts. Additionally, research is needed to understand the long-term environmental accumulation of acaricide residues in different production systems and their implications for ecosystem health. Finally, given the role of information constraints in driving suboptimal practices, experimental studies could test different approaches to improving farmers' knowledge and adoption of safer acaricide management practices.

5 General Conclusion

5.1 Main Findings

We have examined how institutional innovations can enhance the adoption of animal health services – something which, to the best of our knowledge, had not been done before with a focus on vaccine provision. We have also analyzed the association between herd health management practices and household labor allocation and aspects of women empowerment, given that these gender dynamics may also influence adoption patterns. Lastly, we have assessed the effect of vector control practices using acaricides on potential environmental and human health risks, further adding insights to the literature on agricultural intensification and environmental tradeoffs.

In the first essay, we use a vaccine against East Coast Fever (ECF) to test how designing new institutional innovations can overcome adoption barriers. Using a choice experiment with 625 dairy farmers, we evaluate farmers' preferences for an alternative vaccine delivery that involves the coordination of vaccination through dairy cooperatives and vaccinators and the provision of flexible vaccine payment options involving checkoff. Our results show that farmers generally welcome institutional innovations that improve their access to veterinary services. However, the innovations, even in the provision of other animal health services, ought to be tailored to farmers' socio-economic conditions to enhance uptake.

The second essay evaluates the relationship between herd health management practices (HHPs), intra-household labor demand, and women empowerment. The findings show that adopting HHPs is associated with more labor demand for men and women and varies across production systems. We also find negative associations between HHPs and women empowerment domains, including access to and control of income from dairy. The findings underscore the need for gender sensitivity in scaling sustainable livestock intensification practices.

The last essay evaluates the environmental and human health risks associated with acaricide use practices. The results show suboptimal acaricide application practices among farmers. We also find incidences of adverse effects on human health due to exposure to chemicals. Empirical findings show a positive association between the increased frequency of acaricide rotation practices and potential environmental and human health risks measured by EIQ. The findings offer several policy implications for pesticide use in livestock systems.

5.2 Policy Implications

The findings from this dissertation underscore the complex interaction between institutional, social, and environmental dimensions in scaling animal health management practices, which have several implications for policy and practice. Several common issues emerge from the three essays. First, we find the need for more effective institutional innovations to overcome typical adoption barriers to effective veterinary services. Second, beyond productivity gains from better animal health management, we demonstrate how adopting herd health management practices can increase labor demand and potentially negate gains on women's empowerment. Lastly, the essays shows how beneficial vector control practices can have unintended environmental and human health consequences.

Producer organizations can play a more significant role in raising awareness and providing innovative and scalable solutions. The innovations need to be bundled with complementary support services, such as using new information and communication technologies that potentially ease logistical challenges and reduce transaction costs. Public policies must prioritize creating enabling environments that strengthen these organizations.

The second essay draws attention to the gendered impacts of herd health management practices (HHPs), particularly the exacerbation of women's time poverty. These findings point to the urgency of embedding gender-responsive strategies into institutional frameworks. For instance, tailored extension services leveraging ICT can improve women's access to timely and relevant information, mitigating existing barriers. Moreover, the persistent influence of restrictive gender norms on labor relations and responsibilities highlights the need for initiatives that actively challenge and transform these norms. Achieving equity in livestock production requires a dual focus on scaling innovations and addressing the underlying social structures constraining women's empowerment.

We find unintended consequences associated with acaricide use practices, highlighting the need to reduce reliance on harmful chemical pesticides. Advocating for alternative tick control strategies, such as integrated tick control and the use of biopesticides, would be important. Additionally, the private sector has an important role in fostering responsible chemical use practices. Ensuring that farmers receive accurate information at the point of input purchases is essential; thus, stricter regulation of agro-vet service providers would be required.

In conclusion, this dissertation advocates for a holistic and multidimensional approach to scaling animal health management practices—one that includes institutional innovations, advocates for gender equity, and is environmentally just. Thus, policymakers and stakeholders can foster sustainable, inclusive, and resilient livestock systems.

5.3 Limitations and Scope for Further Research

A few limitations of the research presented in this dissertation are worth mentioning and can be addressed in future research studies. In the first essay, we use a hypothetical choice experiment that may not perfectly reflect farmers' real-life choices. Further, the vaccine delivery options we analyze have yet to be implemented in practice, and thus, market data may not be available. Future research could build on this work by focusing on other underused technologies, including real market valuation approaches such as experimental auctions.

In the second study, our analysis is limited by a lack of comprehensive time-use data capturing other economic and social activities in a household. Consequently, in both the second and third essays, we rely on recall data, which can be biased by measurement error (Abay et al., 2021). Using cross-sectional data cannot account for all possible sources of heterogeneity; hence, our estimations remain associational. Future research could utilize panel data to re-estimate our findings even with preference studies deemed stable over time.

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7 Appendices

7.1 Chapter. 2 Appendix A7.1 to A7.3:

7.1.1 Cost-Benefit Analysis of ECF Vaccination

Table A7.1 Analysis of costs and benefits 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 (liters)	2,916.59		
Average annual milk loss due to ECF (liters)	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.

Additional explanation: Investment appraisal of livestock systems is often difficult to conduct given the distinct characteristics of livestock reproducing and the length of time taken to mature. Therefore, to appraise the costs/benefits 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 acaricide use. Second, we limit our assessment to cows of improved breeds because they are more susceptible to ECF infection compared to local breeds. Third, 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 204.84). 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.

7.1.2 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 A7.2: 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 (χ2 (5)) ***		
Halton draws	500		
Number of observations	3,750		

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

7.1.3 Determining the Number of Latent Classes

Table A7.3: 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	-	-	-	-	-	-

While models with 3 and 4 classes seem to be preferred (AIC and BIC decrease further), estimation beyond 2 classes is empirically unidentified in our dataset. The models with 3 and 4 classes overfit the data by generating classes that perfectly predict this choice pattern (when ASC is included). A model with 2 classes is therefore the best choice in our case.

7.2 Chapter. 3 Appendix A7.4 to A7.7:

7.2.1 Distribution of Sample Size

Table A7.4: Distribution of sampled households by County and gender of household head

County	**Number of households**		
	Gender of household head		**Total**
	Female-headed	**Male-headed**	
Uasin Gishu	30	119	149
Nandi	40	176	216
Elgeyo Marakwet	51	162	213
Total	121	457	578

7.2.2 Sample Questions on Decision-Making from WELI Tool by Galiè et al., (2019)

Table A7.5: Sample questions on decision-making adapted from WELI tool

Variable name	**Question**	**Variable definition**
Livestock asset ownership		
Share of assets owned by household members	Number of animals owned by1=Male; 2=Female; 3=Joint	Categorical variable is defined where 1 = women alone 2 = men alone and 3 = joint
Female involved in management decisions		
Livestock activities (categorical)	Who is involved in livestock management decisions including the type of breeds to keep, and breeding methods? (1=Male; 2=Female; 3=Both)	Categorical variable is defined where 1 = women alone 2 = men alone and 3 = joint
Female involved in income decisions and control		
Livestock income (categorical)	Who is involved in deciding on how the income generated from sale of livestock is used? (1=Male; 2=Female; 3=Joint)	Categorical variable is defined where 1 = women alone 2 = men alone and 3 = joint
Milk income morning (categorical)	Who is involved in deciding on how the income generated from sale of milk in the morning is used? (1=Male; 2=Female; 3=Joint)	Categorical variable is defined where 1 = women alone 2 = men alone and 3 = joint
Milk income evening (categorical)	Who is involved in deciding how the income generated from sale of milk in the evening is used? 1=Male; 2=Female; 3=Joint)	Categorical variable is defined where 1 = women alone 2 = men alone and 3 = joint

7.2.3 Time Allocation by Household Members on Different Animal Husbandry Practices by Livestock Management System

Table A7.6: Time allocation by household member on different animal husbandry practices by livestock management system

	Grazing system		Confined/Semi-confined system	
	Women	**Men**	**Women**	**Men**
Cleaning of animal shed/shelter	0.22	3.00	1.09	1.33
Collection of Farmyard Manure (FYM)	0	3.00	1.84	2.6
Feeding (+ collecting & preparation)	1.64	2.21	1.50	2.32
Fodder/feed production on farm	1.37	2.52	1.77	2.02
Grazing	1.75	2.60	1.92	2.54
Milking and milk processing	0.97	1.89	1.49	2.07
Providing water to the animals	1.48	2.14	1.61	2.05
Selling milk	1.19	2.29	1.17	2.24
Spraying	0	0	1.00	1.00

7.2.4 Assessment of the Association Between Herd Health Practices and Intra-Household Participation in Decision-Making While Controlling for the Level of Milk Production and Time Use

Table A7.7: Multinomial regression estimates on the association between herd health practices and intra-household participation in decision-making when controlling for level of milk production and time use

		Decision on			
	Livestock asset ownership	**dairy production activities**	**income from sale of livestock**	**income from sale of milk (morning)**	**income from sale of milk (evening)**
	(1)	(2)	(3)	(4)	(5)
Base = men alone					
Joint	0.23**	0.24**	-0.03	-0.33**	-0.69**
	(0.12)	(0.12)	(0.14)	(0.13)	(0.31)
Women alone	-0.65***	-0.24	-0.67***	-0.46***	-0.72**
	(0.24)	(0.21)	(0.25)	(0.17)	(0.36)
Women time use	Yes	Yes	Yes	Yes	Yes
Men time use	Yes	Yes	Yes	Yes	Yes
Level of milk production (daily)	Yes	Yes	Yes	Yes	Yes
Household controls	Yes	Yes	Yes	Yes	Yes
Chi2 (26)	172.58***	244.71***	139.47***	159.51***	66.86***
Pseudo R^2	0.29	0.32	0.16	0.18	0.07

*Notes: N = 578. Regression coefficients are shown with robust standard errors in parentheses. Household controls are gender, age, dairy experience, main occupation of the household head, household size, livestock management system (free-grazing or zero-grazing), herd size (TLU), wealth index, use of hired labor. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.*

7.3 Chapter. 4 Appendix A7.8 to A7.11:

7.3.1 Environmental Impact Quotient of Different Acaricide Products

Table A7.8: EIQ values for different acaricides by active ingredients

Active ingredient	EIQ farm worker	EIQ consumer	EIQ ecology	EIQ value
Amitraz 12.5%	27	2.5	46	25.17
Alpha-cypermethrin 10%	6	3	71	26.67
Lambdacyhalothrin 1.75%	13.11	4.99	114.04	44.05
Cyhalothrin 5%	20.7	3.45	108.35	44.17
Cypermethrin 10%	13.8	5.9	89.35	36.35
Deltamethrin 2.5%	18	2	65.15	28.38
Chlorfenvinphos 30%	65.55	7.66	93.53	55.58
Chlorpyrifos 50% + Cypermethrin 5%	-	-	-	-
Chlorpyrifos 50%	6	2	72.55	26.85
Cypermethrin 1.5% + Chlorpyrifos 2.5% + Piperonyl butoxide 1.5%+ Citronell 0.1%	-	-	-	-
Piperonyl butoxide 1.5%	10.35	4.15	62.82	25.77
Citronell 0.1%	NA	NA	NA	NA

Table A7.9: Mean EIQ field use by acaricide group

Acaricide group	Mean EIQ field use
Formamidines	36.09
Pyrethroids	23.23
Organophosphate	216.73
Combinations	178.04

7.3.2 2sls estimation

Table A7.10: First-stage coefficient estimates for the determinants of the number of acaricides used annually

Controls	Improper acaricide rotation
Male household head (male = 1)	0.02
	(0.11)
Dairy farming experience (years)	-0.01**
	(0.00)
Household head main occupation (farming = 1)	0.06
	(0.10)
Grazing system (yes = 1)	0.08
	(0.09)
Livestock ownership (TLU)	0.04***
	(0.03)
Log annual household expenditure (KES)	0.01
	(0.03)
Number of extension visits (annually)	0.00
	(0.00)
Use protective gear (yes = 1)	0.02
	(0.10)
Distance to nearest vet shop (kilometers)	0.00
	(0.02)
Constant	1.74***
	(0.42)
Instrument	
Incidence of improper acaricide rotation (yes = 1)	1.34***
	(0.12)
R-squared	0.32
F statistic	19.09
Observations	412

Notes: Regression coefficients are shown with robust standard errors in parenthesis. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.

Table A7.11: Second-stage coefficient estimates for the association between improper acaricide rotation and EIQ field use

Controls	**Log EIQ field use**
Number of acaricides used annually	0.26***
	(0.08)
Male household head (male = 1)	0.01
	(0.11)
Dairy farming experience (years)	-0.00
	(0.00)
Household head main occupation (farming = 1)	-0.15
	(0.10)
Grazing system (yes = 1)	-0.07
	(0.09)
Livestock ownership (TLU)	-0.06**
	(0.02)
Log annual household expenditure (KES)	-0.11**
	(0.05)
Number of extension visits (annually)	-0.01**
	(0.00)
Use protective gear (yes =1)	-0.15
	(0.10)
Distance to nearest vet shop (kilometers)	0.00
	(0.02)
Constant	8.95***
	(0.67)
Observations	412

Notes: Regression coefficients are shown with robust standard errors in parenthesis. Statistical significance at *p < 0.1, **p < 0.05, ***p < 0.01.