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Are integrated livestock disease-management practices complements or substitutes? The case of AAT control in rural Ethiopia

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Abstract

Livestock, particularly cattle, are an integral part of livelihoods in rural sub-Saharan Africa. However, diseases such as African animal trypanosomosis (AAT) have limited the potential of this important sector in the rural household economy. Using a representative sample of small-scale cattle farmers, this study investigates the adoption of modern AAT-management technologies in rural Ethiopia. Specifically, this study investigates the adoption of so-called 'best-bet technologies' (BBTs), recommended by veterinary experts as complementary measures to manage AAT. The results show that the multiple adoption of BBTs was low. In addition, BBTs were adopted as substitutes, and not as complements as suggested by veterinary experts. The results suggest budgetary constraints are proxied by wealth, and information asymmetry explains the substitution effects. The training and re-education of veterinary personnel, as well as programmes and interventions that would improve access to livestock-management inputs, should be pursued vigorously by policy makers to increase the adoption of modern AAT-management technologies to improve cattle productivity.

Key words: livestock; adoption; multivariate probit; trypanosomosis; welfare; Ethiopia

1. Introduction

Livestock remains an important livelihood strategy for households in rural sub-Saharan Africa (SSA), especially in conjunction with crop production (Gelan *et al*. 2012; Leta *et al*. 2016; Abro *et al*. 2021). Livestock productivity in the region, however, is growing slower than expected as a result of the negative effects of pests and diseases, and the use of obsolete inputs and technologies. This low productivity has consequences for the wellbeing of these households, where keeping livestock remains an integral part of their livelihoods. One of the worst diseases that has severely affected the development of livestock, particularly the cattle sector in rural SSA, is African animal trypanosomosis (AAT). The disease causes both direct and indirect economic and welfare losses to cattle-dependent households, especially resource-constrained small-scale cattle-farming households. Conservatively, the incidence of AAT causes estimated losses in production of $1 billion to $1.2 billion and losses through treatment costs of $4 billion to $4.75 billion USD per annum in SSA (FAO 2019). This means that the control of AAT can directly enhance productivity in the AAT prevalence belt by approximately one billion USD,[1] with indirect savings of four billion USD annually. For example, a recent study by Leta *et al*. (2016) found that an estimated $50 million USD direct additional benefits can be realised from livestock production in Ethiopia through efficient AAT control.

However, although significant efforts have been made to control or even eradicate AAT, the incidence and prevalence remain high in the cattle-producing areas of SSA, contributing to poverty and food

[1] United Stated Dollars (USD)

insecurity (Clausen *et al*. 2010; Scoones 2014; Abro *et al*. 2021). The use of trypanocide has remained the most common and popular method, although overreliance on its use has given rise to a new problem, trypanocide resistance, in the fight against AAT (Mulandane *et al*. 2017). This has reduced the appeal and acceptability of the methods among small-scale cattle farmers. In addition, issues of fake and counterfeit trypanocidal drugs have made them less effective. Although other technologies, such as vector control and the use of trypanotolerant cattle breeds, are promising AAT prophylactic technologies, their use as standalone technologies seems less sustainable because of costs (Vreysen *et al*. 2013; Shaw *et al*. 2017; Bengaly *et al*. 2018). Emphasis has therefore shifted to promoting an integrated approach to the management and control of AAT. This includes the integrated use of tested prophylactic methods, such as tsetse control or suppression, good health-enhancing packages like deworming and feed supplementation, and therapeutic technologies and trypanocide drugs in an integrated manner (Holmes 1997; Clausen *et al*. 2010; Mungube *et al*. 2012). Since the tsetse fly is the only means of trypanosome transmission, its control is strategic for reducing AAT prevalence and incidence. Studies show that the method is highly effective in controlling AAT (Bauer *et al*. 1999; Vale & Torr 2005). The objective is to improve the health condition and immunological competence of the cattle to fight AAT infections and reduce the need for trypanocide treatment in the herd in the long term. This strategy offers two potential benefits to small-scale cattle farmers. First, a regulated and judicious use of trypanocide will reduce the growing trend for trypanocide resistance trend with log-term economic benefits in terms of reduced overhead treatment costs. Second, reduced disease and pest incidence improves productivity, with direct implications for a larger disposable household income from farm and livestock output sales. Notwithstanding these potential benefits, however, the use of integrated AAT control technologies, so-called ‘best-bet technologies (BBTs)’, remains low across SSA (Clausen *et al*. 2012; Mungube *et al*. 2012; Grace *et al*. 2008). The empirical question then is, why? Contributing to answering this question was the goal of this study. Specifically, understanding which of the BBTs were adopted more often and what trend such adoptions follow, i.e. whether they are complements or substitutes, and what drives such synergies. The correlation, if any, between productivity and BBT adoption was analysed.

Empirically, the contribution of this study is twofold. First, it provides evidence of the adoption behaviour of small-scale cattle farmers using a mix of disease-control technologies. Second, it provides evidence of the role of policy-relevant variables such as agricultural services and farmer education in livestock technology adoption. With an increase in adverse weather events having direct consequences for crop production in sub-Saharan Africa, a strong and resilient livestock (cattle) sector is an important and viable pathway for building rural resilience in the absence of or with limited formal coping instruments. Moreover, empirical evidence shows that livestock productivity had more disproportionate welfare effects in favour of small-scale households in SSA. The results of this study are therefore both important and timely to modernise and improve small-scale livestock production, particularly of cattle, in SSA to enhance welfare outcomes.

The rest of the study proceeds as follows: Section 2 presents the state of AAT in Ethiopia and the study area. Section 3 outlines the conceptual and empirical frameworks. The study area and data are presented in Section 4. Section 5 presents the results and discussion, while Section 6 summarises and concludes the paper.

2. AAT incidence and management in Ethiopia

African animal trypanosomosis, AAT for short, is an important zoonotic cattle disease transmitted cyclically by the tsetse fly, Glossina *spp*. (*tabanus* and *stomoxys*). AAT affects most livestock, such as goats, camels, cattle and sheep, yet significant economic losses are found in cattle (Steverding 2008; Degneh *et al*. 2017). While acute cases are fatal, most cases remain chronic, causing loss of appetite, prolonged diarrhoea, weight loss, and loss of physical condition (Simarro *et al*. 2010). Ethiopia is a tsetse fly and AAT hotspot in sub-Saharan Africa, and this has raised havoc in relation to the country's cattle productivity. A tsetse fly mapping showed that 15% of productive arable land in Ethiopia, covering 220 000 km² and approximately 70% of cattle, were exposed to tsetse flies (Cecchi *et al*. 2014). This has direct and indirect consequences for crop and livestock intensification in rural Ethiopia, with long-term effects on food security and nutrition outcomes for an already vulnerable population (Bekele *et al*. 2010; Shaw *et al*. 2015). In addition, direct AAT incidence induces significant income losses through morbidity and mortality, as well as lowered productivity of cattle.

Although the prevalence of AAT in Ethiopia is generally high, the Southern Nations, Nationalities, and People's Region (SNNPR) remains one region with a high prevalence rate because of its geographical location, making it a flourishing habitat for tsetse fly infestation. This leaves households, particularly cattle farmers, in the region vulnerable to the effects of the disease. For example, aside from the high exposure to AAT, households in the SNNPR region are largely small-scale farmers, with livestock farming, especially cattle, being one of the most important income support systems for their livelihoods (Abebe *et al*. 2004; Carter *et al*. 2007; Leta *et al*. 2016; Sheferaw *et al*. 2016). Controlling AAT is a potential welfare improvement channel, with direct implications for food production and income generation.

A number of technologies are available to local cattle farmers to control and manage AAT, including trypanocidal drugs, trypanotolerant cattle breeds, vector (tsetse) control technologies, and improved husbandry practices (feeding). Although considerable progress has been made in using these technologies to fight AAT, inefficiencies, mixed with low adoption, have affected total control and even eroded previous gains in the control of AAT. For example, while the use of trypanocides remains popular, trypanocide misuse and efficacy issues resulting in AAT-resistant strains have made it less effective in recent times. This is particularly true for the SNNPR, where approximately 90% of all cattle have shown traits of trypanocide resistance (Moti *et al*. 2012). Vector control technologies and trypanotolerant breeds, however, are limited in use and scope because of long-term sustainability issues. In addition, the migratory tendencies of tsetse flies make controlling them by employing locational technologies ineffective because of perennial reinvasion from other hotspots that may not be sprayed. Furthermore, vector control technologies are often criticised for their negative spill-over effects on biodiversity and water bodies, with consequences for human health. Perceived low productivity (low milk), initial investment cost and non-adaptability, in addition to small physical size, are reasons that have generally affected their wide-scale adoption by small-scale farmers in SSA as a whole, and in Ethiopia (Bauer *et al*. 1999; Clausen *et al*. 2010).

As a result of these challenges in conventional standalone AAT control methods, there is a concerted effort to shift from these single-component technologies to a more integrated approach that combines a number of effective therapeutic and prophylactic technologies. Such integrated AAT control technology must be sustainable in the long term and environmentally friendly, with minimal to no adverse effects on biodiversity, and should proactively reduce trypanocide use to address trypanocide resistance. AAT control in Ethiopia, especially along the southern rift valley of the SNNPR, has benefitted from the dissemination of these integrated technologies since the late 1990s (Alemu *et al*. 2007). However, epidemiological data has not shown a corresponding reduction in AAT prevalence to date (Cecchi *et al*. 2014). The low rate of technology adoption and improper implementation of technologies by farmers have been singled out as key reasons for the continued trajectory of AAT prevalence and trypanocide resistance in the region. Assessing the adoption behaviour of farmers is an important resource in combating AAT, with far-reaching policy implications for modernising and improving the productivity of small-scale cattle farmers in Ethiopia in particular, and SSA in general, where the disease remains a major livestock productivity constraint.

3. Study area and data description

3.1 Data source and study area

The data for this study was obtained from the Trypanosomosis Rational Chemotherapy (TRYRAC) project in the Southern Nations, Nationalities, and People's Region (SNNPR) of Ethiopia in 2012. The project involved 500 small-scale cattle farming households across 20 villages in three woredas (districts), viz. Cheha, Abeshege, and Enemor and Eaner woredas.[2] A multistage sampling procedure was used to select districts, villages and respondent households. In the first stage, districts were purposely selected based on the availability of small-scale cattle farmers, AAT prevalence, and incidences of drug resistance using national epidemiological data. Based on the size and population of the district, a total of 20 villages were then randomly drawn across the three districts. In the final stage, a comprehensive list of all cattle farmers was compiled, together with the district agricultural office, village veterinary officers and village heads to form the sampling frame. Survey respondents were then randomly selected from the list of farmers (approximately 18 to 27 households per village). Due to incomplete responses and missing data, the final sample used in the study comprised 482 households. Figure 1 shows the study districts and villages.

The study area covers approximately 15% of the total land mass of Ethiopia and is characterised by small-scale agriculture producing staple food crops (e.g. maize, rice, sorghum, teff, coffee and some vegetables) and mixed livestock farming. The region is home to some of the poorest households, and approximately 21% of the total number of cattle kept in Ethiopia (Degu 2012; Chanie *et al*. 2013). Cattle farming is an important livelihood support system for a vast majority of households in the region – providing animal-derived power for land preparation and the transportation of farm produce, in addition to some off-farm income. A report on livelihoods in Ethiopia shows that cattle farming is a critical resource for meeting food security and nutrition diversity in SNNPR (Butterworth et al. 2009).

Data collection took place between January and March 2013.[3] All recall data was restricted to 12 months before the survey date. The questionnaire included a knowledge, attitude and practices (KAP) section, which was a set of standard questions adapted to AAT that intend to capture the respondent's knowledge of diagnoses, causes, morbidity, mortality, treatment and prevention of AAT. A comprehensive household questionnaire was developed in conjunction with livestock health scientists, input sellers, cattle farmers and village leaders. To minimise accidental and unintended ambiguity bias during data collection, the questionnaire was translated into the local Amharic language of the SNNPR people. Trained university students familiar with the setting in the study area and supervised by researchers from Leibniz University collected the data. The questionnaire was administered to the household head, who in most cases also owned and made important agricultural (cattle) production decisions. In some cases, information on consumption expenditure was provided by the spouse. Data collected comprised detailed information on household characteristics, crop and livestock production (input and output), respondents' knowledge, attitudes and practices relating to AAT management, participation in off-farm activities, and other socioeconomic and village characteristics such as infrastructure and institutions, e.g. credit, agricultural offices and roads. Given the homogenous nature of small-scale cattle farmers in their adoption and use of technology to manage disease in their herd, this study presents insightful findings, with important policy implications for managing AAT in SSA.

[2] Six villages were sampled in Cheha and Abeshege districts, and eight villages were selected and sampled in the Abeshege, and Enemor and Eaner districts. In total, 135, 110 and 237 households were sampled in each district respectively.

[3] Although the data used for this paper was collected in 2013, the results remain relevant because, to the best of my knowledge, not much has changed in terms of AAT management or livestock farming practices in the study area to invalidate the data.

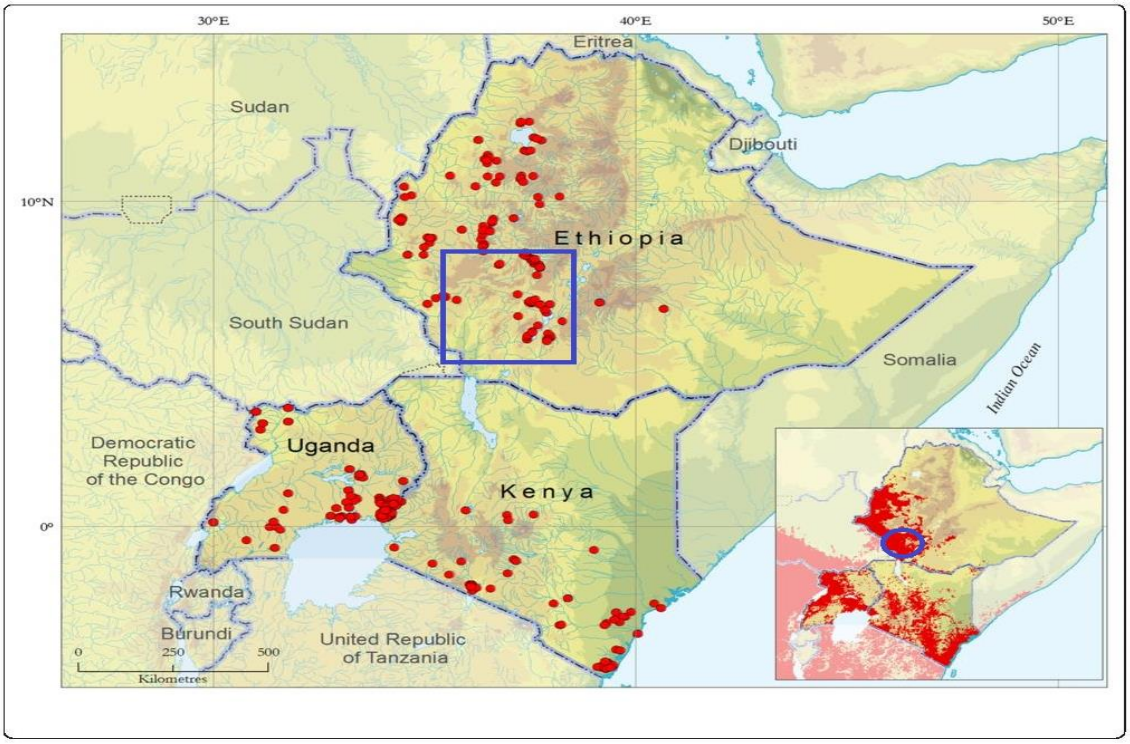

Figure 1: Map of Ethiopia showing the study area (violet outline) and AAT prevalence (dotted in red)
Source: Adapted from Cacchi et al. (2014)

3.2 Description of data

Table 1 presents selected characteristics of the respondents. The majority of respondents (94%) were male, which is an indication of gender disparity in ownership of livestock assets – cattle – in Ethiopia. On average, the respondents were 47 years old, had three years of formal school education, owned 0.65 ha of crop land and at least two head of cattle. In terms of social capita proxied as a farmer association, 89% of all respondents reported membership in at least one agriculture-related association. On the epidemiological level, the data shows that AAT prevalence remained very high in the study area, with 99% of respondents reporting AAT incidence in their herd within the preceding 12 months. The knowledge variable that captured how well the respondents understood the causes, diagnosis and treatment of AAT showed that they were well informed. For example, 91% of the respondents correctly identified the cause, transmission and symptoms of AAT. The relatively high knowledge of the respondents could be attributed to the efforts of the Ethiopian government, Pan-African Tsetse Eradication Campaign and the international Atomic Energy Agency[4] in the study region (Leta *et al*. 2016). Trypanocide resistance was found to be high in the sampled cattle, with approximately 33% of cattle showing strains of trypanosomes resistant to trypanocide treatment. The full list of variables and a summary description is presented in Table 1.

Since not all the respondents adopted the BBTs, adopters were compared with nonadopters in terms of their observed characteristics. For the purposes of this study and analysis, a BBT adopter was a cattle farmer who had adopted at least one BBT in managing AAT, and a nonadopter was one who was using none of the BBTs on his farm. From Table 1, the data show that adopters and nonadopters

[4] The Ethiopian Government, Pan-African Tsetse Eradication Campaign (PATEC) and the International Atomic Energy Agency (IAEA) have developed and implemented a number of projects and programmes in the SNNPR region of Ethiopia to suppress the tsetse population. Of particular mention is the sterile insect technique (SIT) project collaboratively implemented in the region to eradicate and reduce tsetse populations. Furthermore, a settlement programme undertaken by the Ethiopian government destroyed the tsetse habitat in the SNNPR region.

do not differ significantly in demographic characteristics. However, adopters were significantly younger (46 years), had a higher per capita income and were more knowledgeable in terms of understanding AAT, as their knowledge score was significantly higher than that of nonadopters. In addition, adopters reported a higher AAT prevalence and trypanocide resistance than nonadopters.

Table 1: Household characteristics of respondents

Variable	**Full sample**		**Non-adopters**		**Adopters**		
Household characteristics	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	**P value**
Age of household head	47	13.41	50	11.9	46	13.43	0.005**
Gender household head (1 = male)	0.94	0.24	0.92	0.26	0.93	0.24	0.722
Household size	6.60	2.39	6.60	2.72	6.6	2.35	0.996
Dependency ratio	0.88	0.75	0.83	0.75	0.90	0.76	0.500
Formal education of household head (1 = yes)	0.88	0.75	0.48	0.50	0.51	0.50	0.495
Household head education (years)	3.02	3.71	2.7	3.60	3	3.68	0.428
Farmer group membership (1 = yes)	0.89	0.31	0.86	0.34	0.90	0.30	0.360
Owns TV/radio (yes = 1)	0.38	0.49	0.22	0.42	0.40	0.49	0.17**
Owns knapsack (yes = 1)	0.41	0.49	0.24	0.43	0.43	0.50	0.18**
Wealth index	8.02	0.03	7.97	0.06	8.04	0.04	0.07
Income per capita (PPP$)	590.3	2 107	382	532	647	2 358	0.044*
Farm characteristics							
Own land (1 = yes)	0.99	0.10	0.97	0.16	0.99	0.10	0.166
Crop shock (yes = 1)	0.63	0.02	0.55	0.50	0.64	0.48	0.10
Land size (ha)	0.66	1.95	0.98	2.65	0.54	1.64	0.107
Number of plots of land	1.88	1.50	2	1.78	1.81	1.37	0.100
Herd size	1.77	1.20	1.61	1.12	1.50	1.20	0.320
AAT information							
Reported AAT in past 12 months (1 = yes)	0.99	0.06	0.89	0.31	0.97	0.16	0.001***
Knows cause of AAT (1 = yes)	0.91	0.35	0.71	0.45	0.90	0.30	0.000***
Drug resistance observed (1 = yes)	0.33	0.47	0.16	0.37	0.38	0.48	0.000***
AAT livestock death (1 = yes)	0.56	1.75	0.30	0.26	0.21	0.11	0.396
Households reporting cattle death (%)	52.16	50.0	56.7	49.7	50.9	50.0	0.2928
Kraal[5] close to watershed (yes = 1)	0.39	0.49	0.45	0.50	0.38	0.48	-0.07
Number of observations	486		53		433		

Note: *** p < 0.01, ** p < 0.05, * p < 0.1 level of significance; SD: standard deviation; hh: household head; ha: hectare.
Source: Author's own calculation

The main observation from Table 1 in terms of the adoption of BBTs is that there is a suggestive correlation between AAT prevalence, trypanocide resistance and respondent wealth and BBT adoption. However, proper econometric estimation controlling for all confounding variables would need to be undertaken before drawing any conclusions. This is done in the subsequent sections.

To understand the role of cattle in the livelihood of the respondents, Table 2 shows the production and use of different cattle products (draught power, milk, manure and transport) by respondents in the SNNPR. Table 2 shows that the majority of products are consumed at home, with a small fraction sold locally. Although absolute sales volumes from Table 2 seem small, these sales provide important income sources for households with limited income diversity. Livestock income is shown in the literature to be an important source of liquidity for most rural household in SSA in the absence of well-developed and integrated markets. Similarly, livestock income plays an important buffer function against consumption shortfalls for rural agricultural households due to shocks and disruptions to traditional income sources, which are usually limited to on-farm activities such as crop production (Fafchamps *et al*. 1998; Herrero *et al*. 2012; Leta *et al*. 2016).

[5] A traditional enclosure for housing cattle in sub-Saharan Africa.

Table 2: Cattle products and use by households in 2013

Type of product	Units	Mean output per annum	Usage (%)	
			Home	Sold
Traction	Hectares (ha)	45.7	96	4
Transport	Hours (hrs)	347	96	4
Milk	Litres (l)	116.9	94	6
Manure	Kilograms (kg)	49.8	98	2
Meat	Kilograms (kg)	60	82	18

Note: HH, household
Source: Author's own calculation

As discussed earlier, the BBT integrated approach includes rational drug use[6] (RDU), i.e. supervised trypanocide use on need-to-use basis, feed supplements with good husbandry routines, regular deworming, and vector control technologies such as traps and insecticide sprays or pour-ons (Clausen *et al*. 2010; Leta *et al*. 2016). Table 3 presents the adoption outcome of the different practices outlined under the BBT approach. A large proportion, representing 89% of respondents, adopted at least one type of BBT. Table 3 suggests that respondents were aware of the effects of AAT and made an effort to mitigate the negative effects on their herds. In addition, this high adoption rate may likely be explained by the continuous interventions of government and development partners in creating awareness of BBTs to manage AAT (Degu 2012; Shaw *et al*. 2015; Leta *et al*. 2016). A closer look at Table 3 reveals that, although the adoption of improved BBTs by respondents on the basis of absolute numbers was high, these practices were not being adopted simultaneously, as is implied by the integrated BBT approach.

Table 3: Intensity of adoption

No. of BBTs adopted	Households	Percentage
0	53	11
1	223	46
2	210	43
> 2	0	0
No. of observations	486	100

Source: Author's own calculation

Issues of observed inefficiencies of single-dose practices as stand-alone AAT management regimes make the low multiple adoption of BBTs problematic, as shown in Table 3. This is particularly so given the rising incidence of resistant AAT strains. Table 4 shows the adoption of particular BBTs. The results in Table 4 show that RDU and feed supplements were widely adopted technologies (60% and 45% respondents respectively). Deworming was the least popular among the respondents; 5% of respondents dewormed cattle in the 12 months preceding the survey period.

Table 4: Distribution of adoption of best-bet practices by respondents

Best-bet technologies (BBTs)	Frequency	Percentage of HHs
RDU	290	59.67
Regular deworming	25	5.14
Feed supplements	220	45.27
Vector control (traps & insecticides)	108	22.22

Note: HH: household
Source: Author's own calculation

Since the main objective for promoting and disseminating BBTs was to improve cattle productivity through its effect as a damage-control input for AAT and other coinfections, a simple correlation was presented between these damage-control inputs and different cattle outputs. Using milk production

[6] Isometamidium (ISMM) and diminazen (DIM) are the two most effective and most widely available trypanocides for treating AAT.

as a measure of cattle productivity, Figures 2 to 5 show a positive association of BBT adoption and milk output. The overall observation was that milk output for adopters of all BBTs (except deworming, Figure 3) held first-order stochastic dominance over nonadopters. This result suggests that BBT adoption was correlated with higher productivity. However, this result should be interpreted with caution, as no causal inference can be concluded from these correlation results.[7]

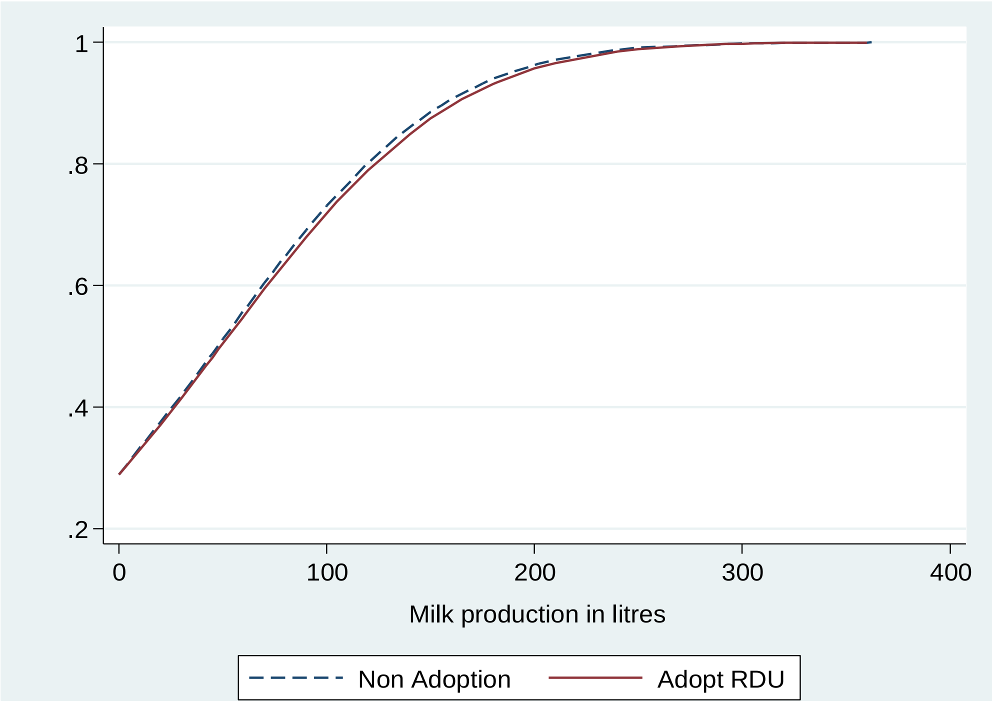

Figure 2: RDU adoption and milk production in litres

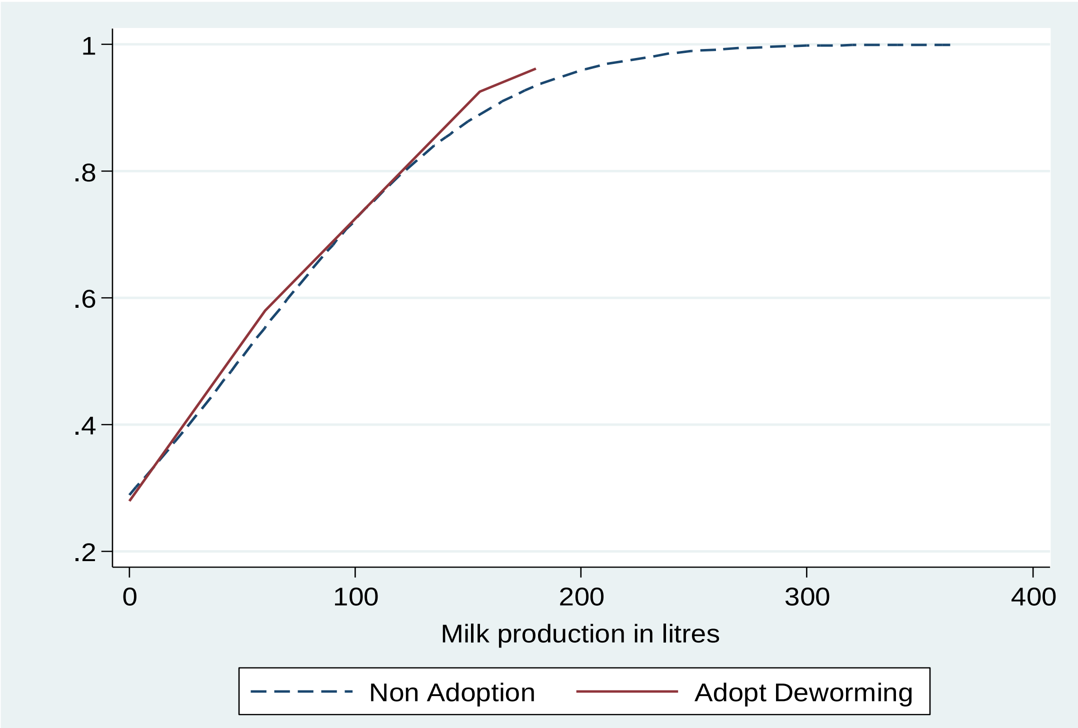

Figure 3: Deworming and milk production in litres

[7] Actual impact or causality studies require the use of methods that net out effects of technology controlling for selection and other unobserved heterogeneity. This was beyond the scope of the current study.

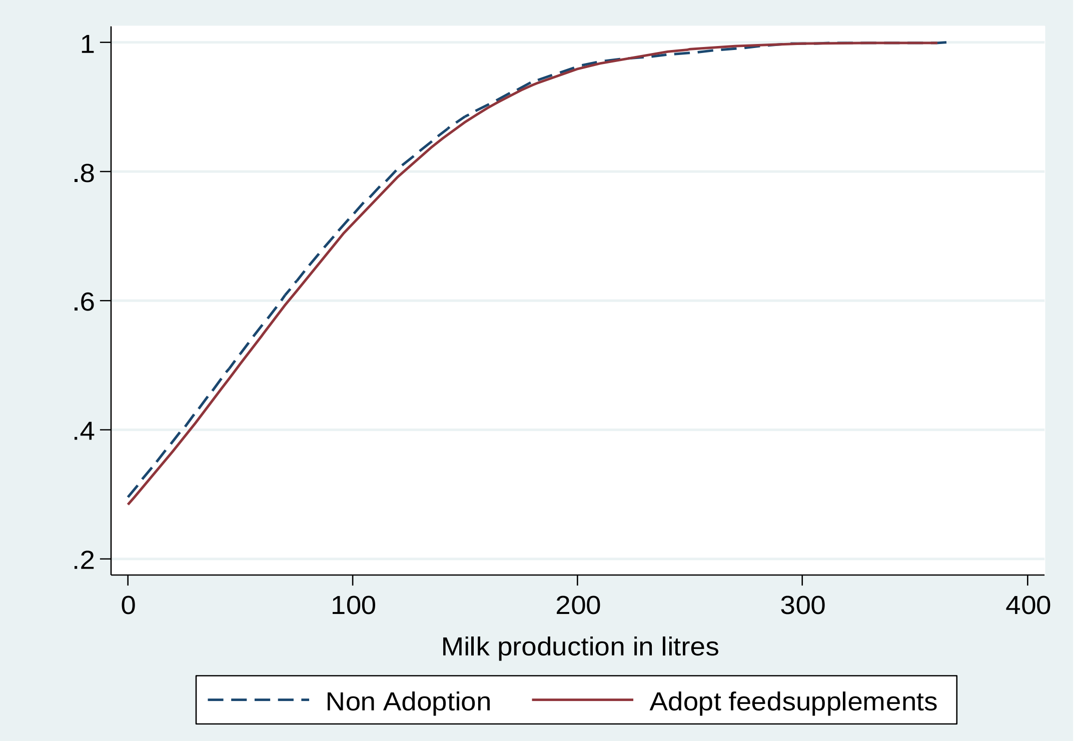

Figure 4: Feed supplement adoption and milk output in litres

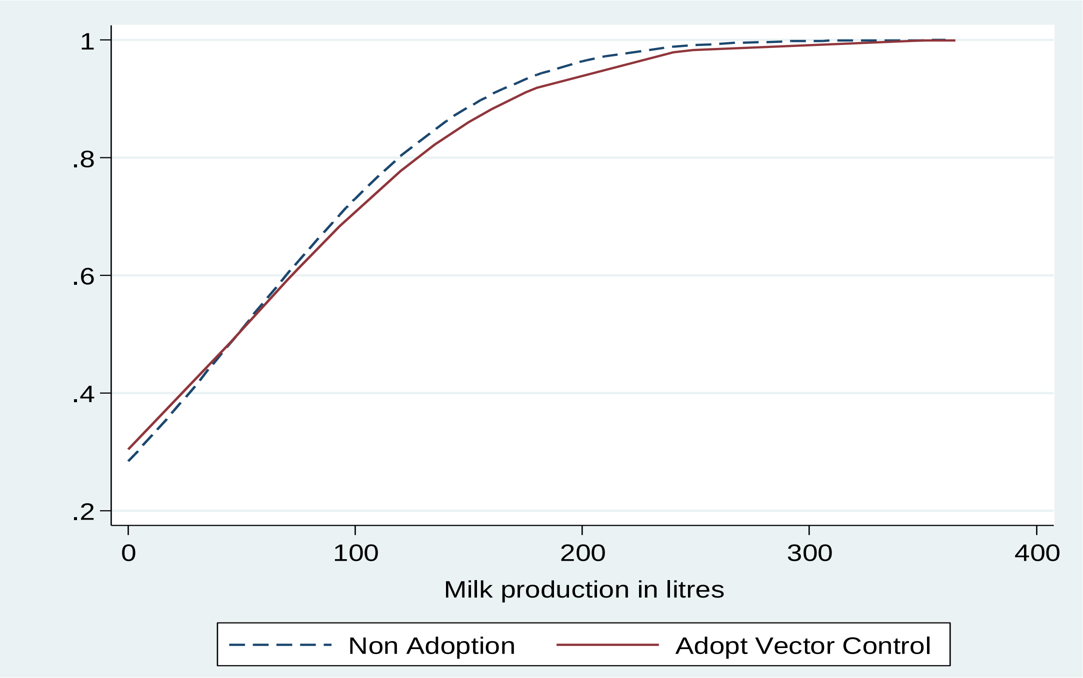

Figure 5: Vector control and milk output in litres

4. The adoption estimation

4.1 Theoretical framework

The adoption decision was modelled as a discounted expected utility-maximisation objective taking into account the risk attitudes and perceptions of the household. Cattle farmers were assumed to be rational economic agents who seek to mitigate the AAT risk in their herd by choosing a combination of improved technologies with the highest animal productivity gains. These technologies act as damage control inputs, so they will only improve productivity by reducing the negative effect of AAT on the herd. The BBTs were a mix of practices that can be adopted simultaneously to prevent or treat AAT infections with positive long-term productivity returns. Depending on the respondent's knowledge (information), resource endowments and risk behaviour, utility captured as profits can be achieved through the partial adoption of k BBTs, where k = 1, 2, 3..., n. Following an earlier disease control framework developed by McInerney (1996) and Gramig *et al*. (2010), the expected profit function is given as follows:

$$\pi = P_Q Q(R,\ K,\ D) - P_V V_P = P_Q\{Q_0[1 - F(D(V_P))]\} - P_V V_P, \qquad (1)$$

where P_Q is the price of input Q, and the input Q is a function of variable inputs R, fixed inputs K and disease load D. Disease load is $D(V_P, R)$, such that (R) are variable inputs and V_P is a $W\times 1$ vector of AAT management inputs. P_V is a $W\times 1$ vector of input prices that corresponds to V_P. If V_P is denoted as $k \in [0,\ \infty]$, such that k is a positive integer count of BBTs – a list of mutually exclusive technologies such that the adoption of one does not exclude the adoption of another, as long as doing so will increase the marginal utility of adoption. Based on Equation (1), $k > 0$ will be observed if the utility for adoption is greater than non-adoption, i.e. $\pi_k^A > \pi_k^{NA}$, where π_k^A and π_k^{NA} are the utility of adoption and non-adoption of k practices respectively. Rearranging Equation (1) gives:

$$P_Q Q_0[F(D(0)) - F(D(k))] > P_k \qquad \forall k > 0 \qquad (2)$$

At this stage, it was assumed that farmers were already aware of the effectiveness of k in Equation (2), which is given as $\mathrm{F}(\mathrm{D}(k))$. From the foregoing framework, the empirical adoption decision should be preceded by a determination of the link between BBTs and AAT management. However, in this analysis, the adoption decision was directly estimated because the BBTs considered in this study were positively correlated with AAT prevention and treatment (Clausen *et al*. 2010; Mungube *et al*. 2012). In the next section, the empirical estimation strategy is outlined.

4.2 The empirical model

Since the BBTs considered in this study were assumed not to be independent of each other, analysing their adoption through a discrete choice model without accounting for possible error correlation would lead to bias and inefficient results. To control for potential bias resulting from the complementarity and substitutability of technologies and the unobserved respondent-specific effects, the recent works of Kassie *et al*. (2015), Wainaina *et al*. (2016) and Muriithi *et al*. (2018) implement a multivariate probit (MVP) model that relaxes the assumption of no correlation of error terms by simultaneously estimating the different best-bet technologies as a function of a set of covariates, thus allowing the error terms to be correlated. In this regard, the MVP produces coefficients that remain robust, unbiased and efficient (Greene 2012; Yegbemey *et al*. 2013).

The adoption decision of the n^{th} BBTs of the i^{th} farmer is given as follows:

$\mathrm{Y}_{ik}^* = \pi_k^A > \pi_k^{NA} > 0$, where Y_{ik}^* is a latent variable and gives the expected utility of adopting (k) technology, (π_k^A), compared to non-adoption (π_k^{NA}).

Since Y_{ik}^*, is a latent variable, the empirical form is estimated is a binary variable given as follows:

$$Y_{ik} = \beta \mathrm{X}_i + \varepsilon, \qquad (3)$$

where $Y_{ik} = \begin{cases} 1 & \text{if } Y_{ik}^{*} > 0 \\ 0 & \text{otherwise} \end{cases}$ and X represent various demographic-, technology- and village-level characteristics that influence the adoption decision; ε is a stochastic error term. Equation (3) consists of four separate binary choice equations that are simultaneously estimated and specified as follows:

$$Y_{i1} = \beta X_{i1} + \varepsilon_1, \text{ for } k = \text{RDU} \tag{4}$$

$$Y_{i2} = \beta X_{i2} + \varepsilon_2, \text{ for } k = \text{Vector control} \tag{5}$$

$$Y_{i3} = \beta X_{i3} + \varepsilon_3, \text{ for } k = \text{Feed supplements} \tag{6}$$

$$Y_{i4} = \beta X_{i4} + \varepsilon_4, \text{ for } k = \text{Deworming} \tag{7}$$

The error terms $(\varepsilon_1, \varepsilon_2, \varepsilon_3 \text{ and } \varepsilon_4)$ jointly follow a multivariate normal distribution with a zero conditional mean and variance normalised to unity, $E[\varepsilon_1] = E[\varepsilon_2] = E[\varepsilon_3] = E[\varepsilon_4] = (0, \Omega)$, a symmetric covariance matrix Ω, given by:

$$\begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 \end{bmatrix} \tag{8}$$

with the leading diagonal of the matrix having a value of 1, while the off-diagonal covariance matrix represents the unobservable correlations between the BBTs to be estimated.

The correlation of the error term answers the critical question of this study. Therefore, were BBTs adopted as complements or substitutes? Based on the sign of the correlation coefficient, the complementarity or substitutability relationship was defined. For example, if a substitution effect existed, the probability of adopting each additional BBT decreased after the first practice, showing a negative sign in the correlation coefficient. The reverse explanation holds true if practices were complementary.

4.3 Variables included in the adoption model

A number of factors encompassing socioeconomic characteristics and farm-, institutional- and village-level institutions determine technology adoption. Household characteristics such as age, education, family size and gender of household head may affect the decision of the household to adopt the BBTs. For example, the age of the farmer is associated with risk behaviour, and younger farmers are usually risk lovers, making them more likely to adopt new technologies than older farmers (Ward *et al*. 2008; Asfaw *et al*. 2012). However, when the technology is laborious, older farmers may be less willing to adopt as a result of a shorter planning horizon and labour requirements. The effect of age is therefore not expected only in one direction. Household size is a proxy for labour availability and determines the labour allocation possibility of a household. A number of studies show that household labour is positive and significantly associated with technology adoption, especially for technology that requires additional labour resources to be implemented (Doss 2006; Kassie *et al*. 2013; Khonje *et al*. 2018). BBT adoption is expected to increase with household size.

Other household-specific variables that are expected to determine the adoption of BBTs include access to information, education, gender of the household head, and wealth proxied by ownership of different productive assets (Abdulai *et al*. 2008; Kassie *et al*. 2018; Khonje *et al*. 2018). Ward *et al*. (2008) found that the effect of formal education on farm technology was not straightforward. For example, higher education attainment may be a disincentive for farm technology adoption by increasing off-farm employment. This is particularly true for SSA, where labour markets are less integrated and marginal returns to labour for off-farm activities could be disproportionately high. However, education has also been found to increase the assimilation of potential benefits of the technology by the respondent, thereby positively driving adoption. Other variables controlled in the estimation include cattle herd characteristics, such as AAT morbidity and mortality. Chi *et al*. (2002) found that livestock farmers who previously reported disease incidence on their farms were more likely to invest in disease management. The expectation is that respondents who report high AAT morbidity and mortality would prioritise BBT adoption to minimise future losses.

Based on previous technology adoption literature, other farm-level variables such as herd size and cattle species, along with the composition of other livestock given in terms of tropical livestock units (TLU), were controlled to address farm-level heterogeneities (Abdulai *et al*. 2008; Taye *et al*. 2012; Kassie et al. 2018). Wealth is expected to have a positive correlation with BBT adoption. A wealth index that was constructed from the respondent's productive assets (without livestock assets) was also included in the empirical estimation. A list of variables that also captures respondents' knowledge in relation to AAT was controlled for. Given that potential information asymmetry results in misconceptions about AAT (Weyori *et al*. 2019), a knowledge index variable capturing respondent knowledge of AAT diagnosis, treatment and prevention strategies was calculated and included in the estimation. The expectation is that a higher knowledge score will increase BBT adoption. To address possible geographical and spatial heterogeneities, district fixed effects were included.

5. Econometric results and discussion

Table 5 reports the results of the multivariate probit (MVP) estimation. Before discussing the main econometric results, the goodness of fit of the MVP model is assessed. Wald's test of the hypothesis that all regression coefficients are jointly equal to zero is rejected, (101) = 475.63, P = 0.000. The likelihood ratio test (Chi² (6) = 128.594, P < 0.000) of independence of the error terms is strongly rejected. This means that the adoption of BBTs was not mutually independent, therefore supporting MVP as a model of choice to model the adoption decision.[8]

For the main regression coefficients regarding the determinants of BBT adoption, the results show that different individual-, household- and village-level characteristics drive the individual's decision. In agreement with studies that found an association between age and farm technology adoption, the MVP results in Table 5 show that the respondents' age was positive and significantly associated with RDU adoption, indicating that older farmers, who were more likely to also have more years of experience in livestock farming, were more likely to adopt RDU. Although contrasting with the findings of Doss (2006), Asfaw *et al*. (2012) and Kassie *et al*. (2018), this result may suggest that older farmers were somehow likely to experience the negative effects of AAT, and therefore likely to rely on a veterinarian rather than other methods. Formal education was significantly associated with RDU, but was negatively associated with vector control, deworming and feed supplement technologies.

[8] A binary correlation of the error terms of the four adoption equations shows statistical significance for two of the errors (rho21 & rho42), which indicates a significant correlation between the estimated equations. The covariance of the error terms of all equations estimated is attached in an appendix as Table A1.

Table 5: Estimates of the multivariate probit model of BBT adoption

	Dependent variables			
Explanatory variables	**RDU**	**Vector control**	**Deworming**	**Feed supplement**
Age of household head (years)	0.011(0.006)*	-0.010(0.006)	-0.010(0.010)	-0.006(0.005)
Gender of household head (male = 1)	-0.108 (0.265)	0.041(0.281)	0.201(0.354)	0.398(0.258)
Dependency ratio	-0.046(0.085)	0.034(0.096)	0.122(0.197)	-0.016(0.093)
Household size	0.002(0.026)	0.005(0.028)	0.100(0.045)**	-0.008(0.031)
Formal education (yes = 1)	0.435(0.139)**	-0.306(0.146)*	-0.764(0.236)**	-0.330(0.156)*
Land size (log)	-0.024(0.034)	-0.022(0.039)	-0.370(0.364)	-0.049(0.035)
Social network (yes = 1)	-0.172(0.135)	0.011(0.141)	-0.398(0.221)	0.174(0.146)
Herd size	0.151(0.049)**	-0.075(0.055)	-0.006(0.068)	-0.015(0.146)
Owns calves dummy (yes = 1)	0.230(0.194)	-0.263(0.187)	-0.573(0.268)*	0.170(0.205)
Other livestock (TLU)	-0.172(0.167)	0.165(0.179)	-0.470(0.288)	-0.254(0.181)
Wealth index	-0.093(0.856)	0.221(0.104)*	-0.043(0.178)	0.064(0.102)
Owns TV/radio (yes = 1)	-0.184(0.146)	0.760(0.162)***	0.120(0.252)	-0.082(0.169)
Owns knapsack (yes = 1)		0.243(0.116)*		
Trypanocides from open market (yes = 1)	0.813(0.63)***	-1.062(0.250)***	-0.68(0.257)	-1.132(0.193)***
Knows cause of AAT (yes = 1)	-0.275(0.191)*	0.463(0.140)**	0.187(0.366)	-0.026(0.193)
Veterinary contact (yes = 1)	0.402(0.134)**	-0.042(0.140)	-0.410 (0.217)*	1.011(0.143)***
Crop shock (yes = 1)	0.061(0.132)	0.284(0.140)*	-0.846(0.216)***	0.095(0.146)
AAT death in last 12 months (yes = 1)	0.610 (0.123)	0.214(0.136)	-0.079(0.204)	-0.024(0.135)
Kraal close to watershed (yes = 1)	0.777 (0.151)	0.465(0.168)**	-0.299(0.242)	0.055 (0.173)
District dummy				
Cheha District	0.180(0.172)	-0.213(0.187)	-1.022(0.380)**	0.582(0.195)**
Enemor and Eaner District	0.269(0.162)*	-0.317(0.182)	-0.887(0.289)**	-0.220(0.173)
Constant	-0.570(0.832)	-2.715(0.966)***	0.053(1.143)	-0.623(0.989)
Log pseudo likelihood	-766.1970			
Model chi² (81)	326.17			
Observations	**482**			

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$ level of significance; Tropical livestock unit (TLU); Robust standard errors in parentheses. Source: Author's own calculations

This mixed result suggests the workings of a substitution effect, whereby the different technologies compete for the scarce resources of the cattle farmer. Therefore, educated farmers who are able to assess the returns of the different technologies will allocate resources to RDU for direct suppression of AAT in the herd. Another explanation is the likely existence of information asymmetry and/or a lack of full information on the direct or indirect effects of the other technologies in AAT management.

Consistent with the literature on farm technology adoption (Teklewold *et al*. 2013, Manda *et al*. 2018), wealth variables proxied by herd size and wealth index were found to be positively correlated with BBT adoption. Larger herd size was found to be positively associated with RDU adoption. This may be explained by the wealth effects of overcoming liquidity constraints to purchasing medications or paying for veterinary services. In addition, given the likely devastating effect of AAT, owners of large herds lose more when their animals are affected by AAT and therefore adopt the RDU as a mitigating strategy. Access to information proxied by ownership of television/radio sets positively increased BBT adoption, especially vector control technologies, with no effect for the others. This finding can be explained by the lack of active advertisement of or information on livestock technologies, especially AAT management, in the formal media landscape in SSA, especially in rural Ethiopia. During the survey, an interaction with input sellers showed that input sellers do not advertise AAT-related control inputs in the media. This was further confirmed when a vast majority of farmers interviewed were not aware of the potential positive correlation between these technologies and AAT control. Owning a knapsack, an important implement for applying vector control inputs, was found to be positively associated with vector control adoption.

In terms of AAT and farm characteristics, the respondents' knowledge of the cause of AAT was positively associated with BBT adoption, particularly that of vector control technology. The results show that respondents who correctly identified the tsetse fly as the cause of AAT were more likely to adopt vector control. This is consistent with the findings of Liebenehm *et al*. (2011) in Mali and Burkina Faso. A reverse effect is found for RDU adoption, a possible indication of misinformation and/or information asymmetry. A binary kraal location, i.e. whether the kraal was near a watershed or not, shows that farmers who had their kraals close to watersheds were more likely to adopt vector control technologies yet had no effect on adopting the technologies. A lagged shock to crop production increased the adoption of BBTs, particularly vector control, while it reduced the likelihood of adopting deworming. The positive correlation of crop shock with vector control adoption can be explained by the overlap function of pesticides in both crop and livestock production. This reduces the initial costs associated with vector control technology. Input cost constraints were usually one reason associated with the non-adoption of farm technologies. Given the competing nature of the BBTs, small-scale cattle farmers – being resource constrained – allocate scarce inputs to practices from which they expect the highest utility. This economic decision explains the opposite effect of shock on vector control technologies and deworming.

The quality of access to farm inputs is important for adopting technologies that require the use of external inputs for successful implementation. A binary variable for access to trypanocide was proxied by the source of the trypanocide purchase, i.e. the open market. The variable was found to have a mixed effect on BBT adoption. Buying AAT inputs from the local village market was positively and significantly associated with RDU adoption. It was also negatively associated with vector control and feed supplement adoption. Access to veterinary services was found to have a mixed effect on BBTs. However, receiving at least one veterinary visit in the last six months increased the likelihood of adopting RDU and feed supplements, which is consistent with the finding of Degu (2012). Consequently, access to veterinary services reduces the likelihood of adopting deworming technology. The mixed results from access to veterinary services presents an opportunity to provide resources to and strengthen veterinary and other agricultural services in the livestock context. This will ensure that these institutions are properly resourced and visible, which will stimulate livestock technology adoption in general and AAT management in particular. Livestock extension personnel are a critical bridge for livestock technology dissemination and adoption in Ethiopia. This is because of the low level of formal education among most livestock farmers and the lack of formal information delivery systems for livestock disease management. This is especially important, as only a fraction of the respondents accessed veterinary services within the period of the study. Controlling for district fixed effects shows that adoption varied across the three districts, an indication that district infrastructure and institutions, as well as geographical characteristics, play a role in adoption. Respondents in Enemor and Eaner districts were more likely to adopt RDU and feed supplements than those in Abeshege, the reference district. However, deworming was more likely to be adopted in the Cheha and Enemor and Eaner districts than in the Abeshege District. The district effect – aside from suggesting the role of locational characteristics such as infrastructure – also shows the specific role of the Ghibe River as an important tsetse habitat that lies close to the study districts.

Given the apparently low multiple adoption of the BBTs, as shown in Table 3, a simple pairwise correlation analysis was performed to fully understand the type of relationship existing between the different practices. This is presented in Table 6. The Spearman correlation matrix shows that the relationship between most BBTs was negative (substitutes), except for that between vector control (tsetse control) and RDU. The observed negative correlation was counterintuitive because veterinary and epidemiological data on managing AAT show that the effectiveness of these so-called BBTs are maximised when adopted as complements in an integrated manner. A number of reasons were adduced for the negative correlation observed. First, there was a lack of or inadequate extension education accompanying the dissemination of best-bet technology in the region. Second, possible resource constraints prevent respondents from adopting multiple BBTs, although they may know of the potential benefits of adopting these technologies as complements. However, the positive correlation between RDU and vector control technologies may be explained by the positive spill-over effect of veterinary personnel administering RDU to respondents. For example, personnel administering trypanocides could either treat animals against tsetse flies and other insect vectors in the herd, or offer advice to the households they visit.

Table 6: Complementarity or substitutability of best-bet technologies

	RDU	Feed supplements	Regular deworming	Vector control
RDU	1			
Feed supplements	-0.070***	1		
Regular deworming	-0. 112***	-0.070***	1	
Vector control	0.137***	-0.490***	-0.125***	1

Note: *** = Significance at the 1% level
Source: Author's own calculation

6. Summary and implications

Using comprehensive household, village and livestock epidemiological data, this study investigated the adoption of four veterinary-recommended integrated AAT control strategies, referred to as best-bet technologies (BBTs), in Ethiopia. Specifically, the study investigated the adoption of rational drug use, vector control technologies, regular deworming and feed supplements as a group of technologies that show promise for AAT management and reduce the surging trypanocide resistance menace in SSA. Aside from investigating what drives the adoption of these technologies, the analysis also examined how these BBTs were related, i.e. whether they were complements or substitutes.

The results of the study show that, although livestock farming, and in particularly cattle farming, is an important livelihood strategy, it continues to suffer low productivity because of AAT effects. Despite the negative AAT effect, however, the adoption and use of multiple technologies or practices recommended by veterinary experts to manage the disease is low among small-scale cattle farmers in Ethiopia. A vast majority of cattle farmers adopt and depend on trypanocides to manage AAT, a possible reason for the rising trypanocide resistance in the region. Prophylactic technologies are adopted the least in the management of AAT. One important result from this study is the strong negative correlation (substitution effect) between the best-bet technologies, in contrast to the existing AAT management literature. This finding provides important insights for formulating and designing extension policies to promote BBTs as complements in the management of livestock disease. Such policies would make farmers maximise the benefits of these technologies for long-term productivity outcomes. In terms of drivers of BBT adoption, a number of important household-, herd- and district-level characteristics have been shown to have heterogeneous effects on the different technologies. Specifically, the education of the household head, access to information, and wealth are important determinants of BBT adoption. The results further show that access to agricultural institutions such as veterinary services drive adoption. These findings open up possible channels for policy entry to stimulate livestock technology adoption. For example, the positive correlation between veterinary service and BBT adoption highlights the importance of resourcing and improving the accessibility of rural agricultural services to enhance efficiency in service delivery. Furthermore, the results further suggest that in the context of the study area, multiple adoption of BBTs increased with integration of markets and participation of rural institutions.

The results of this study have important implications for cattle production in the context of the study area and small-scale cattle producers in SSA. First, to reduce the burden of AAT and improve cattle productivity, enhanced training and re-education of veterinary personnel should be pursued vigorously to tackle issues of information asymmetry so as to improve the uptake of technologies. Second, retooling and redesigning extension messages to internalise the benefits of the adoption of multiple BBTs should be supported. Third, programmes and interventions that improve access to information and livestock disease inputs, such as subsidy payments targeted for deworming, vector control technologies and feed supplement inputs, should be considered and deliberately pursued as a way to stimulate the adoption of these technologies in an integrated manner. Finally, targeted, regular disease sensitisation outreach at the community level should be pursued to increase awareness of both primary and secondary prophylaxis in livestock disease management. These policies, together with measures that holistically improve infrastructure to modernise livestock production systems, can significantly propel the needed growth in the livestock sector. This will greatly increase food security and will have the potential to reduce the poverty of livestock-dependent households in rural SSA regions.

Although the results suggest a positive link between BBTs and increased productivity, further research employing appropriate econometric methods should be conducted to determine the influence of adopting these practices on the wellbeing of small-scale cattle-producing households.

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Appendix

Table A1: Covariance of the error terms and likelihood ratio test

rho	Coefficient	Standard error	P > |z|
rho21	-0.78	0.05	0.000
rho31	0.06	0.09	0.526
rho41	0.06	0.09	0.485
rho32	0.00	0.08	0.970
rho42	-0.55	0.13	0.000
rho43	-0.08	0.12	0.477

Likelihood ratio test of: rho21 = rho31 = rho41 = rho32 = rho42 = rho43 = 0
Chi^2 (6) = 128.594; P > chi^2 = 0.0000
Source: Author's own calculation