Essays on Livestock Technology, Diversification and Welfare Impact in sub–Saharan Africa

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ZUSAMMENFASSUNG

Die Tierproduktion bleibt ein kritischer Aspekt der ländlichen Lebensgrundlagen, die vor allem den Armen in den Entwicklungsländern unterschiedliche Zwecke erfüllen. Eine verbesserte Produktivität der Tiere hat somit das Potenzial, das Wachstum nachhaltig zu stimulieren und gleichzeitig den Wohlstand zu stärken und zu verbessern. Dies ist besonders kritisch in Subsahara-Afrika (SSA) angesichts unvollkommener Input- und Output Märkte, fehlender Kredit- und Versicherungsmärkte sowie begrenzter Beschäftigungsmöglichkeiten außerhalb der Landwirtschaft. Die Produktivität der Tiere wird jedoch durch das Auftreten von Krankheiten und den Einsatz veralteter Technologien eingeschränkt. Studien zeigen jedoch, dass Tiere der Armen aufgrund unzureichender Investitionen in gesundheitsfördernde Techniken und Technologien anfälliger für Krankheiten sind.

Diese Arbeit zielt darauf ab, zu einem besseren Verständnis des Adoptionsverhaltens moderner Nutztierinterventionen und ihrer Auswirkungen auf das Wohlergehen der Haushalte in SSA beizutragen. Konkret geht es in der Arbeit darum, zu untersuchen: (1) die Triebkräfte für die Einführung der so genannten "best-bet" Management-Technologien gegen die Afrikanischen Tier-Trypanosomose (AAT) - und ihre Auswirkungen auf die Ernährungssicherheit in Haushalten; (2) die Beziehung zwischen Management-Praktiken wie Entwurmung, Vektorkontrolle, Veterinärbehandlung und Nahrungsergänzungsmitteln. Konkret untersucht das Papier, ob diese Praktiken als Ergänzung oder Ersatz übernommen werden und welche Faktoren ihre Annahme antreiben; 3) die Erträge aus Maßnahmen zur Bekämpfung von Tierseuchen, die insbesondere Maßnahmen zur Steigerung der Tierproduktivität und der Armut und Vulnerabilität der Haushalte verbinden, und (4) die Rolle der Diversifizierung der Haushalte in Bezug auf die pflanzliche und tierische Erzeugung bei der Anpassung an Klimaveränderungen.

Die Daten für diese Arbeit stammen von Kleinviehhaltern in den Regionen Kara und Savana in Togo und der Southern Nations Nationalities and People Region (SNNPR) in Äthiopien. Die Auswahl der Befragten erfolgte durch mehrstufige Stichprobenverfahren, um angesichts der geografisch-diversen Untersuchungsregion eine gleich hohe Wahrscheinlichkeit der Auswahl zu gewährleisten. In Togo wurden zwei Datenwellen gesammelt, während in Äthiopien eine Welle gesammelt wurde. Im Jahr 2013 wurden insgesamt 486 bzw. 492 Haushalte aus Togo und Äthiopien befragt. Im Jahr 2016 wurde in Togo eine Folgebefragung unter den gleichen Haushalten durchgeführt, die 2013 befragt wurden. Aufgrund einer Fluktuation von 6% umfasste die Folgeerhebung jedoch 443 Haushalte. Ein umfassender Datensatz, der aus

sozioökonomischen Informationen der Haushalte besteht und alle Arten von einkommensschaffenden Tätigkeiten wie Selbständigkeit, außerbetriebliche Beschäftigung und andere in diesem Zeitraum ausgeübte Lohnarbeit umfasst. Bemerkenswert sind die Informationen über die Rinderproduktion wie Herdenzusammensetzung, Krankheits- und Schädlingsinzidenz und Gesundheitsmanagement. Es wurden Haushaltsrisiken und -schocks sowie Indikatoren für Vermögen, Konsum und Ernährungssicherheit erhoben. Zusätzlich zu den Daten auf Haushaltsebene wurden 2013 durch Interviews mit Interessengruppen Informationen auf Dorfebene wie Krankheitsschwere und -häufigkeit, Arzneimittelresistenz und Institutionen und Infrastruktur gesammelt.

Verschiedene methodische Ansätze wurden verwendet, um die Daten in dieser Arbeit zu analysieren. Im ersten Beitrag bildet die Theorie der Maximierung der Haushaltsnutzen unter Risiken und unvollkommenen Märkten die Grundlage für die empirische Schätzung der Adoptionsentscheidung über den rationalen Medikamenteneinsatz und dessen Auswirkungen auf die Ernährungssicherheit. Ein binäres Logit-Modell wird verwendet, um die Faktoren zu schätzen, die die Akzeptanz beeinflussen, während das Propensity Score Matching (PSM) verwendet wird, um die Auswirkungen auf die Ergebnisse der Ernährungssicherheit zu bestimmen. Im zweiten Beitrag wird die Einführung mehrerer Disease-Management-Praktiken als Funktion der Krankheitsbelastung (Risiken) in einer Rinderherde modelliert. Dies geschieht empirisch durch ein multivariates Maximum-Likelihood-Schätzverfahren. Im dritten Papier, unter Berücksichtigung der unvollständigen Randomisierung der Behandlung und mögliche endogene Heterogenitätseffekte, eine Reihe von quasi-experimentellen Identifikationsstrategien, wurden implementiert, um die kausale Beziehung zwischen den Interventionen und Haushaltshilfe festzustellen..

Die Umsetzung der verschiedenen Strategien kontrolliert mögliche empirische Fallstricke, wie der Selbstauswahl und unbeobachteter Heterogenität, die die Ergebnisse verzerren würden. Im vierten Papier zur Diversifizierung der Lebensgrundlagen wird davon ausgegangen, dass die Haushalte bei Vorliegen von Klimaschwankungen mit fehlenden oder unvollkommenen Kredit- und Versicherungsmärkten eine Kombination von Lebensgrundlagenstrategien wählen, um den zukünftigen Wohlstand zu maximieren und die aktuellen Ergebnisse vor negativen Wetterereignissen zu schützen. Die Entscheidung über den Portfoliomix basiert im Wesentlichen auf zwei Motivationen - Überleben oder Chancensuche. Die empirische Schätzung erlaubt es, das übergeordnete Motiv der Diversifizierung der Haushalte zu bestimmen. Da die verschiedenen Diversifikationsentscheidungen korreliert sein können, modellieren wir gemeinsam die Determinanten der Diversifikation unter Verwendung der Seemingly Unrelated Regression (SUR) mit Mundlak-Korrekturfaktor, um mögliche Endogenitätsprobleme zu berücksichtigen, die sich aus unbeobachteter Heterogenität ergeben. Korrelierte Zufallseffektabschätzungen, die mit den Annahmen Probit und Generalized Least Square (GLS) ausgestattet sind, werden verwendet, um die Auswirkungen der Diversifizierung auf Armut und Konsumergebnisse abzuschätzen, bzw. mit einer inhärenten unbeobachteten Endogenitätsverzerrung, die durch den Mundlak-Korrekturfaktor berücksichtigt wird.

Die Ergebnisse dieser Arbeit tragen in vielfältiger Weise zur empirischen Literatur bei. Erstens zeigt die Abschätzung der Faktoren und Auswirkungen der Technologieeinführung auf die Ernährungssicherheit, dass der Zugang zu Informationen und Veterinärdiensten, die Verbesserung des Wissens und der Zugang zu Medikamenten entscheidend für die Adoptionsentscheidung über verbesserte Disease-Management-Praktiken sind. Die Auswirkungen der Adoption sind im Allgemeinen positiv. So zeigen die Ergebnisse beispielsweise, dass Landwirte, die verbesserte Praktiken anwenden, eine höhere Produktivität der Tiere und einen höheren Pro-Kopf-Verbrauch aufweisen. Die Verbesserung der Gesundheit der Tiere durch die Einführung wissensintensiver integrierter Bekämpfungsmaßnahmen ist ein vielversprechender Weg, um die Lebensgrundlagen und die Ernährungssicherheit kleiner, von Rindern abhängiger Haushalte in Afrika südlich der Sahara zu verbessern. Dennoch ist die Akzeptanz verbesserter Disease-Management-Praktiken bei den Rinderzüchtern nach wie vor gering. Strategien, die das lokale Veterinärpersonal in die Verbreitung von Technologien und Inputs einbeziehen, sollten in Betracht gezogen werden, um die Adoptionsrate zu fördern.

Zweitens zeigt die Untersuchung der Einführung von veschiedenen best bet AAT Management Praktiken unter Verwendung der Daten von Kleinbauern in Äthiopien, dass diese Praktiken nicht komplementär, sondern substitutiv sind. Dies ist auf Ressourcen- und Haushaltsengpässe bei diesen Landwirten zurückzuführen. Auch das beobachtete geringe Wissen über das Management von AAT bei den Befragten erklärt den beobachteten Substitutionseffekt. Die Landwirte übernahmen und wandten meist eine Technologie an, nämliche die Verabreichung von Trypanozidmedikamenten - die beliebteste Praxis mit wenig oder gar keiner Investition in Entwurmung oder Schädlingsbekämpfung. Das Ergebnis verdeutlicht die Notwendigkeit eines gezielten Erweiterungsansatzes, um die Art und Weise, wie diese Technologie verbreitet wird, neu zu definieren. Es zeigt ferner, dass die Anwendung traditioneller Methoden zur Verbreitung dieser Praktiken die gleichzeitige Einführung von Agrartechnologien bei den Nutztierhaltern behindern könnte.

Drittens zeigt die Messung der Auswirkungen des gezielten AAT-Kontrollinterventionsprogramms mit Hilfe des Paneldatensatzes aus Togo im Allgemeinen positive Ergebnisse für die teilnehmenden Landwirte. Die Ergebnisse zeigen zum Beispiel, dass die Teilnehmer ihre Kenntnisse und Praktiken in Bezug auf die Diagnose und das Management von Tierkrankheiten im Allgemeinen und AAT im Besonderen verbessert haben. Darüber hinaus verzeichneten die Tiere der Programmteilnehmer eine höhere Produktivität, gemessen an der Milchleistung, und reduzierte Krankheitsinfektionen. Höhere Tierproduktivität und geringere Krankheitsinfektionen führten zu einem zusätzlichen Einkommen, das den Pro-Kopf-Konsum deutlich steigerte und die Armut verringerte. Die Ergebnisse zeigen, dass Interventionen, die auf die Viehbewirtschaftung von Kleinbauern in SSA abzielen, zu positiven Ergebnissen bei der Existenzsicherung führen können.

Schließlich zeigen die Ergebnisse, dass die Portfoliodiversifikation im ländlichen Togo im Allgemeinen von Vermögensvariablen getrieben wird, wenn man sich die Triebkräfteder Diversifikation zuwendet und wie die Diversifikation den Haushalten hilft, mit den Auswirkungen der Klimaschwankungen umzugehen. Außerdem zeigen die Ergebnisse einen negativen Zusammenhang zwischen der Diversifizierung der Haushalte und den Klimaschwankungen. Im Hinblick auf die Auswirkungen auf das Wohlergehen deuten die Ergebnisse darauf hin, dass die Diversifizierung der Nutztiere das Potenzial hat, das Wohlergehen eines Haushalts zu verbessern und auch die negativen Auswirkungen der Klimaschwankungen abzumildern. Die Institutionen scheinen die Diversifizierung von Nutzpflanzen und Nutztieren zu unterstützen und tragen auch zur Verringerung der Armut bei. Die derzeitige Einrichtung von Institutionen ist jedoch nicht wirksam, um negative Auswirkungen eines zunehmend risikoreichen Umfelds abzumildern. Die Ergebnisse zeigen, dass es notwendig ist, die Kredit-, Landwirtschafts- und Marktinstitutionen als mögliche politische Ziele für die Förderung der Diversifizierung der Lebensgrundlagen als Bewältigungsstrategie für Gebiete zu stärken, die negativen Auswirkungen der Klimaschwankungen und fehlenden oder unvollkommenen Märkten ausgesetzt sind.

Schlüsselwörter: Adoption, Auswirkungen, Viehbestand, Diversifizierung, Anfälligkeit, Klimaschwankungen, Togo, Äthiopien.

ABSTRACT

Livestock production remains a critical aspect of rural livelihoods serving different purposes especially for the poor in developing countries. Enhanced livestock productivity thus has the potential to stimulate growth in a sustainable way and also to strengthen and improve welfare. This is especially critical in sub-Saharan Africa (SSA) in the face of imperfect input and output markets, missing credit and insurance markets, as well as limited off-farm employment opportunities. However, livestock productivity is constrained by the incidence of diseases and the use of obsolete technologies. Yet, studies show that livestock of the poor are more vulnerable to diseases because of inadequate investments in health improving techniques and technologies approaches.

This thesis aims to contribute to an improved understanding of the adoption behavior of modern livestock interventions and their impact on household welfare in SSA. Specifically, the thesis sets out to investigate: (1) the drivers of adopting the so called "best–bet" African Animal Trypanosomosis (AAT) management technologies and its impact on household food security; (2) the relationship between disease management practices such as deworming, vector control, veterinary treatment, and feed supplements. Specifically, the thesis investigates if these practices are adopted as complements or substitutes and what factors drive their adoption; 3) the returns to livestock disease control interventions especially linking interventions to animal productivity and household vulnerability and poverty and (4) the role of household diversification with respect to crop and livestock production in adapting to climate variability.

The data for this thesis comes from small scale cattle farmers in the Kara and Savana regions of Togo and the Southern Nations Nationalities and People Region (SNNPR) of Ethiopia. Selection of respondents involved multi stage random sampling procedures to ensure equal probability of being selected given the geographically dispersed nature of the study region. Two waves of data were collected in Togo while one wave has been collected in Ethiopia. In 2013, a total of 486 and 492 households from Togo and Ethiopia respectively were interviewed. In 2016, a follow up survey was conducted in Togo involving the same households interviewed in 2013. A comprehensive data set consisting of household socio-economic information, involving all kinds of income generating activities such as self-employment, off-farm employment and other on-farm wage employments undertaken in the period. Noteworthy are the information on cattle production such as herd composition, disease and pest incidences, and health management. Household risks and shocks as well as assets, consumption and food security indicators have been collected. In addition to the household level data, village level

information such as disease severity and incidence, drug resistance and village level institutions and infrastructure have been collected through stakeholder interviews in 2013.

Different methodological approaches have been used to analyze the data in this thesis. In the first paper, the household utility maximization theory under risks and imperfect markets forms the basis for the empirical estimation of the household adoption decision and impact of rational drug use on food security. A binary logit model is used to estimate the factors influencing adoption while the Propensity Score Matching (PSM) is used to determine the impact on food security outcome. In the second paper, the adoption of multiple disease management practices is modelled as a function of disease load (risks exposed) in a cattle herd. This is done empirically through a multivariate maximum likelihood estimation procedure. In the third paper, considering the incomplete randomization of the treatment assignment and possible endogenous heterogeneity effects, a number of quasi–experimental identifications strategies, such as difference in difference, fixed effects and the fixed effects instrumental variable, have been implemented to determine the causal relationship between the interventions and household welfare.

The implementation of the multiple strategies controls for potential confounding issues of self-selection and unobserved heterogeneity that would bias results. In the fourth paper on livelihood diversification, it is assumed that in the presence of climate variability with missing or imperfect credit and insurance markets households choose a combination of livelihood strategies to maximize future welfare as well as protecting current outcomes against adverse weather events. The portfolio mix decision is based cardinally on two motivations – survival or opportunity seeking. The empirical estimation allows determining the overriding motive by households to diversify. Different diversification decisions may be correlated therefore the determinants of diversification are jointly estimated using the Seemingly Unrelated Regression (SUR) with Mundlak correction factor to account for possible endogeneity issues arising from unobserved heterogeneity. Correlated random effects estimation fitted with logit and Generalized Least Square (GLS) assumptions are used to estimate impact of diversification on poverty and consumption outcomes respectively with inherent unobserved endogeneity bias taken care for by the Mundlak correction factor.

The results from this thesis contribute to the empirical literature in a number of ways. First, the estimation of drivers and impacts of technology adoption on food security shows that access to information and veterinary services, improved knowledge, and access to disease inputs are critical to the adoption decision of improved disease management practices. Adoption impacts are generally positive. For example, results show that farmers who adopt improved practices have higher livestock productivity and higher consumption per capita. Improving livestock health by introducing knowledge-intensive integrated control measures is a promising way to enhance livelihoods and to improve food security of small-scale cattle dependent households in sub-Saharan Africa. Nonetheless, adoption of improved disease management practices remains low among cattle farmers. Policies that involve local veterinary personnel in the dissemination of technologies and inputs should be considered to stimulate adoption.

Second, investigating the adoption of multiple best bet AAT management practices using the data from small scale farmers in Ethiopia shows that these practices are not complementary, but substitutional. The study finds this to be as a result of resource and budgetary constraints. Also, the observed low knowledge of the management of AAT amongst respondents explains the observed substitutional effect. Farmers mostly adopted and applied one technology – trypanocidal drugs– the most popular practice with little or no investment in deworming or pest control. The result highlights the need for targeted extension approach to redefine how such technology is disseminating. It further shows that the use of traditional extension methods to disseminate these practices could be hampering the simultaneous adoption of farm technology among livestock farmers.

Third, measuring the impacts of the targeted AAT control intervention program using the panel data set from Togo generally shows positive outcomes for participating farmers. For example, the results show that participants improved their knowledge and practices in relation to diagnosing and management of livestock diseases in general and AAT in particular. Furthermore, the animals of program participants recorded higher productivity measured in milk output and reduced disease infections which are both direct benefits of the program intervention. Higher animal productivity and lower disease infections resulted in additional income that significantly increased per capita consumption and decrease poverty headcount, i.e., two important welfare indicators in rural SSA. The results show that interventions targeted at managing livestock of small scale cattle producers in SSA can lead to positive livelihoods outcomes.

Finally, turning to drivers of diversification and how diversification helps households cope with climate variability effects, the results show that portfolio diversification in rural Togo is generally driven by wealth variables. Also, the results show a negative correlation between household diversification and climate variability. In terms of welfare implications, the results indicate that livestock diversification has the potential to improve a household’s welfare and

also mitigate adverse effects of climate variability. Institutions seem to be supportive in crop and livestock diversification and also contribute to decreases in poverty. However, the current set up of institutions is not effective to mitigate negative effects from an increasingly risky environment. The results point to the necessity of strengthening credit, agricultural and market institutions as possible policy targets for stimulating livelihood diversification as a coping strategy for areas exposed to negative effects of climate variability and with missing or imperfect markets.

Keywords: Adoption, impact, livestock, diversification, vulnerability, climate variability, Togo, Ethiopia.

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LIST OF ABBREVIATIONS

AAT	African Animal Trypanosomosis
AES	Adult Equivalent Scale
ARC2	African Climatology Version2
ARD	Agricultural Research and Development
ATE	Average Treatment Effect
ATT	Average Treatment effect on Treated
BBP	Best Bet Practice
CIA	Central Intelligence Agency
CoV	Coefficient of Variation
CRE	Correlated Random Effects
DIM	Diminazene
ECOWAS	Economic Community of West African States
ETHB	Ethiopian Birr
EU	European Union
FAO	Food and Agricultural Organization
FCFA	Franc Communauté Françaises d'Afrique
FGLS	Feasible Generalized Least Squares
GDP	Gross Domestic Product
GLS	Generalized Least Squares
GR	Green Revolution
HH	House Hold
i.i.d	Independent and Identically Distributed

IMF	International Monetary Fund
ISM	Isometamidium
KAP	Knowledge Attitudes and Practices
Km^2	Kilometer square
LID	Livestock in Development
mm	Millimeter
MVP	Multivariate Probit
NNM	Nearest Neighbor Matching
NOAA	National Oceanic and Atmospheric Administration
PPP	Purchasing power parity
PSM	Propensity score matching
RDU	Rational Drug Use
SD	Standard Deviation
SNNPR	Southern Nationals Nationalities and People Region
SSA	sub-Saharan Africa
SUR	Seemingly Unrelated Regression
TLU	Tropical Livestock Unit
TRYRAC	Trypanosomosis Rational Chemotherapy
US	United States
US$	United State Dollar
WHO	World Health Organization

CHAPTER 1: INTRODUCTION

1.1. Motivation

Agricultural production in sub-Saharan Africa (SSA) is the backbone of economic growth, poverty reduction and food security. This is evident in the increasing contribution of the sector to national economy and household's livelihoods. The agricultural sector employs up to approximately 80 % of the workforce in SSA contributing between 25 % and 60 % of national GDP (FAO, 2012; World Bank, 2016). Whereas crop production is the most important sub-sector, declining soil fertility, climate change and its attendant shocks calls for diversifying and strengthening other sectors such as the livestock sub-sector as a means of supporting and expanding the growth of livelihoods horizontally. Severally studies show that agricultural led growth especially livestock has the potential for sustainable, inclusive and participatory growth for rural economies (FAO, 2010; Delgado et al., 1998; Christiaensen et al., 2011; Ravallion et al., 2007). For the rural poor, livestock in particular is a critical component for a sustainable growth pathway both in terms of enhancing crop production and increasing income (Ellis and Freeman, 2004; LID, 2004; Flintan, 2008). Similarly, the empirical literature show that livestock ownership is an important input for crop intensification, enhances livelihood diversification, provides buffer for crop failure risks and smoothens income especially where markets remain ineffective and natural shocks are prevalent (Fafchamps et al., 1998; Otte and Knips, 2005; Chamberlin et al., 2014; Dillon and Barret, 2014; Bhende and Venkataram, 1994; Kristjanson et al., 2010). As Otte and Knips (2005) put it, "livestock and livestock products are the "cash crop" of the small scale farmer in SSA".

However, the livestock sector as a whole especially the cattle sub-sector in SSA is characterized by low productivity. The reasons for this includes low investments, obsolete production practices, lack of adoption of modern and improved technologies and the effect of diseases and pests (Fitzpatrick, 2013; Otte and Knips, 2005; FAO, 2012). In cattle production, disease is the most important constraint with wide ranging economic consequences for the household and national economy. In SSA, the African Animal Trypanosomosis (AAT) is the most important economic disease with about 70% to 100% of cattle being at risks resulting in direct and indirect consequences for cattle productivity (Herrero et al., 2010; Turner et al., 2014; Herrero et al., 2013). Directly, it causes animal mortality, reduced milk production, lower calving rates, higher frequency of abortions and higher production costs - reducing income and profits. Indirectly, AAT affects crop production through reduced availability of draft animals affecting crucial farm activities as well as the type of crops to cultivate (Holt et al., 2016: Swallow, 2000). Given the critical role of livestock and livestock products in supporting livelihoods of rural SSA households, livestock losses can have economy-wide effects increasing vulnerability to poverty. In this regard, a proper management and control of AAT can have positive multiplier effects on household income and crop production with downstream effects on non-livestock farmers. This can further stimulate economic growth in the local rural economy. The critical question thus is: why are livestock farmers in SSA not investing in controlling AAT?

For example, the adoption of modern AAT management practices in livestock production is low among small scale farmers in SSA (Liebenehm et al., 2011; Grace et al., 2008). The result is that most technical innovations, such as the integrated disease management concept, have not benefited livestock producers. On the other hand, so far there are only few impact studies that use rigorous econometric estimation approaches to investigate the effects of livestock sector interventions on household welfare (Gelan et al., 2012; Bennett 2003; Fitzpatrick 2013). The difficulty to monetize outputs of livestock, the high data requirements and the multidimensional and complex cause and effect relationship between any intervention and its outcomes and impact are some of the reasons for this gap (Pica-Ciamarra et al., 2015; Barret, 2010).

This thesis aims to fill some of these gaps using data from the Trypanosomosis Rational Chemotherapy (TRYRAC) project of the European Commission in SSA. In terms of contribution to the literature, it has two major contributions. First, it sheds more light on the impact of technology interventions in livestock production and second, it exploits new growth options that can be pursued by small scale livestock farmers in SSA to increase their welfare in an environment increasingly exposed to the risks of climate change.

1.2. Main Objective

The central objective of this thesis is to investigate the impact of livestock disease management technologies in improving livelihoods of small scale cattle farmers in sub-Saharan Africa. To achieve this objective, four specific research questions have been formulated as follows:

1. What factors drive adoption of improved livestock disease control practices among small scale cattle farmers in sub-Saharan Africa?
2. What is the role of livestock disease management on household food security and poverty among small scale livestock farmers?

3. What is the impact of livestock disease control interventions on household welfare and vulnerability to poverty?
4. What is the role of livestock and other portfolio diversification in coping with weather variability shocks?

1.3. Methodologies

The thesis is structured such that it contains four thematic papers with each paper answering one of the four specific research question formulated above. The four papers employ different theoretical models and empirical methodologies. In this section, an overview of each methodological approach is briefly introduced.

In the **first paper**, following the household discounted utility maximization theory under imperfect markets and credit and labor constraints to model the adoption of a technology called “rational drug use” (RDU) among small-scale cattle farmers in Togo. In this paper, the estimation goes beyond measures of livestock productivity which hitherto have been applied in most livestock impact studies. As empirical method, a combination of logistic regression and propensity score matching (PSM) to compare the welfare outcome of adopters and non-adopters of RDU has been implemented. PSM has been applied because of the absence of time series data and the lack of good instrumental variables. To overcome some of its limitations, the study follows the empirical literature (Jalan and Ravallion, 2003; Rosenbaum, 2002; Ali and Abdulai, 2010; Smith and Todd, 2003; Caliendo and Kopeinig, 2008) and test the sensitivity of results to hidden bias. Specifically, the Rosenbaum bounds test, covariate balancing test and the comparison of pseudo-R^2 of matched households before and after matching have been applied. Also, based on literature of technology adoption and many exogenous variables have been included in estimating the propensity score used in the matching procedure. Respondents are then matched using the nearest neighbor and propensity score algorithms. The corresponding estimation procedure was implemented through the **teffects** program in STATA 14.

In the **second paper,** the McInerney (1996) model of livestock disease management decisions is extended to model the decision to adopt best bet practices (BBPs) for the control and management of AAT. The adoption decision is modelled based on expected utility maximization theory in the presence of risks. It is assumed that, the number of BBPs adopted is a function of AAT risks both past and present and utility is maximized by reducing productivity loses caused by AAT. To understand the interdependence of the practices, we empirically estimate the adoption decision employing a multivariate probit model, allowing the error term for each decision to correlate and thus allowing simultaneous estimation. Our estimation procedure allows us to explicitly determine the complementary or substitutive effects of the components within the technology bundle. The empirical estimation procedure has been implemented as a maximum simulated likelihood estimation running the **mvprobit** SSC file in STATA 14.

Given the central theme of impact of technology adoption on AAT management, **the third paper** investigates the impact of the TRYRAC intervention program by veterinary extension services on the welfare of small holder farmers. Rigorous impact estimation requires that the impact pathway is established which attributes the intervention with output and welfare. In this paper we link veterinary interventions to cattle productivity increase and welfare outcomes at the household level. The actual empirical estimation procedure follows a three-step process. First, estimate the impact of the interventions on farmer AAT knowledge. Second, investigate the impact of enhanced knowledge on the adoption of modern disease management practices. Third, estimate the impact of TRYRAC interventions on income, consumption per capita and probability of falling below the national poverty line, i.e., following the approach of Chaudhuri, (2003) and Hoddinott and Quisumbing (2003) to estimate the impact of TRYRAC interventions on vulnerability to poverty. In practice, the full maximum likelihood estimations were implemented using three models, namely difference-in-difference, fixed effects and instrumental variable fixed effects methods using STATA 14. Methodological, our estimation procedures deal with program endogeneity and self-selection bias issues under different assumptions.

The **fourth paper** investigates households' diversification decision and the role of climate change. The paper employs the inseparable agricultural household model in the presence of risks and market imperfections to model the diversification choices of households to maximize utility under a set of constraints and endowments. Using the Gini-Simpson index, first, the diversification level of households in terms of crop, livestock and income portfolios is estimated. Implementing a group of linear regression models simultaneously through the seemingly unrelated regression (SUR) (Zellner, 1962) the paper investigate factors that drive diversification decisions focusing on "pull" and "push" factors with special attention on the role of rainfall variability which is captured as long term rainfall coefficient of variation (CoV) and lagged season rainfall anomaly from the long term average. Potential endogeneity of the estimation is accounted for through correlated random effects with Mundlak correction terms (Wooldridge, 2010; Wen and Maani, 2018). The role of rainfall variability and portfolio diversification on household poverty and consumption outcomes is also estimated through a generalized least square model accounting for potential endogeneity of the diversification variable is implemented. In this way, the estimation is able to take into consideration the mitigation effect of diversification in cushioning households against the negative effects of weather variability shocks. This is achieved by interacting observed household diversification outcome with the long term coefficient of variation (CoV). The resulting estimation is done in STATA 14 implementing SUR and CRE-with Mundlak corrections.

1.4. Study areas

In this section a brief description of the two study countries Ethiopia and Togo where the data has been collected and used for the papers in this thesis is presented.

1.4.1. Ethiopia

In Ethiopia this study has been conducted in the Southern Nationals Nationalities and People's Region (SNNPR) in the South-western part of the country.

Ethiopia is a landlocked country and covers a land mass of 1,126,829 Km^2 located at the horn of Africa between latitudes 3°N and 15°N, and longitudes 33°E and 48°E. Ethiopia has a population of about 102 million, majority of who are engaged by the small scale Agricultural sector. In terms of administration, Ethiopia is divided into 9 administrative regions (World Factbook, 2017). The SNNPR covers approximately 10% of the total land mass of Ethiopia and shares border with Kenya to the south, Republic of Sudan to the south-west, the state of Gambella's People's in the North-west, and the state of Oromiya in the north and East (RiPPLE, 2009). The SNNPR is one of the poorest regions in Ethiopia with about 21% of the total cattle population in Ethiopia (Degu, 2012; Chanie et al., 2013). Agricultural production is one of the most important economic activities undertaken by the households in the region and is characterized by staple crops. The most important crops include cereals (maize, rice, teff, and sorghum), legumes, oilseed, vegetables and some cash crops such as coffee. Aside crop production, livestock production anchors livelihoods in the region providing draft power for crop production and also a source of cash income to enable households to purchase grains for human consumption (Chanie et al., 2013; RIPPLE, 2009).

The contribution of Agriculture to Ethiopia's GDP is about 46% and approximately 85% of the labor force is employed in agriculture (World Factbook, 2017). Ethiopia has the largest livestock population in Africa with over 133 million cattle heads contributing to different aspects of household economy. Rural Ethiopia is constrained in terms of access to formal employment opportunities therefore making the agricultural sector an important income source to these rural dwellers (Degu, 2012; World Factbook, 2017). Incidence of AAT is high among livestock keepers in the SNNPR and accounts for a major loss in cattle output in the region. The location of the region close to the Ghibe rift river provides a good habitat for tsetse fly the main vector responsible for the mechanical transmission of the disease (Miruk et al., 2008; Shaw et al., 2015). Accordingly, tsetse infects about 220,00km^2 of fertile land in the region of the SNNPR (Cecchi et al., 2015; Chanie et al., 2013) making AAT the most important economic disease constraining livestock sector productivity and growth in the region.

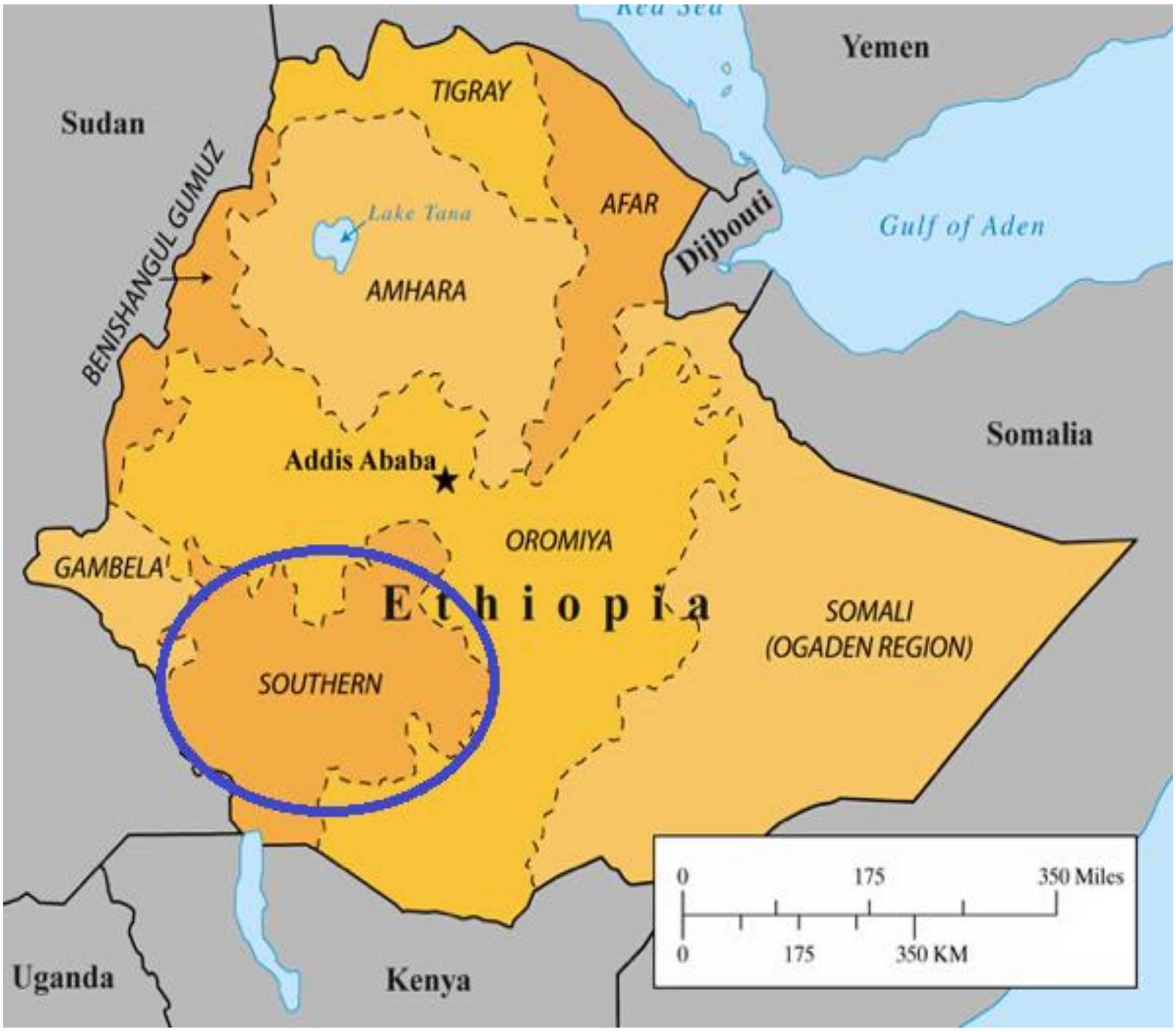

Figure 1.1 Map of Ethiopia showing the study area

Source: Own illustration based on Google Maps

1.4.2. Togo

In Togo the study areas were Kara and Savana in the northern most part of Togo. The Republic of Togo is a small country on the west coast of Africa on the Latitude 6°N – 11° N and longitude 0°E – 1°50°E and covers a land mass of 57,000 km^2. Togo has an estimated population of 7.6 million in habitants (World Population Prospects, 2017). Administrative Togo is divided into 5 regions. Like most developing countries in SSA, Agriculture is the backbone of the economy of Togo employing nearly 50% of the national workforce and contributes approximately 28% of GDP. Agriculture in Togo is characterized by small scale staple crop (maize, rice, sorghum, legumes, and vegetables) and livestock (goats, sheep, pigs and cattle) production. The country also has thriving cotton, cocoa and coffee sectors (World Factbook, 2017).

In Togo, the Kara and Savana regions are the most important livestock production regions with about 55 – 65% of the total national cattle production (Talakai et al., 2014; FAO 2016). Households largely depend on rainfed agriculture to meet their food production needs. Staple crops such as maize, sorghum, cassava and yam, legumes such as beans and groundnuts and vegetables remain the most important agricultural activity for households. Some pockets of cocoa and coffee production are also found in these regions but these play a minor role. In addition to crops, livestock production is also an important component of these households contributing about 20% of the rural economy (Domingo, 2000). With increasing negative effects of weather variability resulting in erratic rainfall patterns coupled with declining soil fertility, livestock keeping has become increasingly important to the livelihoods of many households in the region due to its consumption and income smoothing effects (Kazianga and Udry, 2006; IMF, 2014). Poverty is widespread in Togo with a national poverty headcount of over 60% with figures in rural poverty rising up to about 80% especially in the Savana and Kara regions (World Bank, 2016).

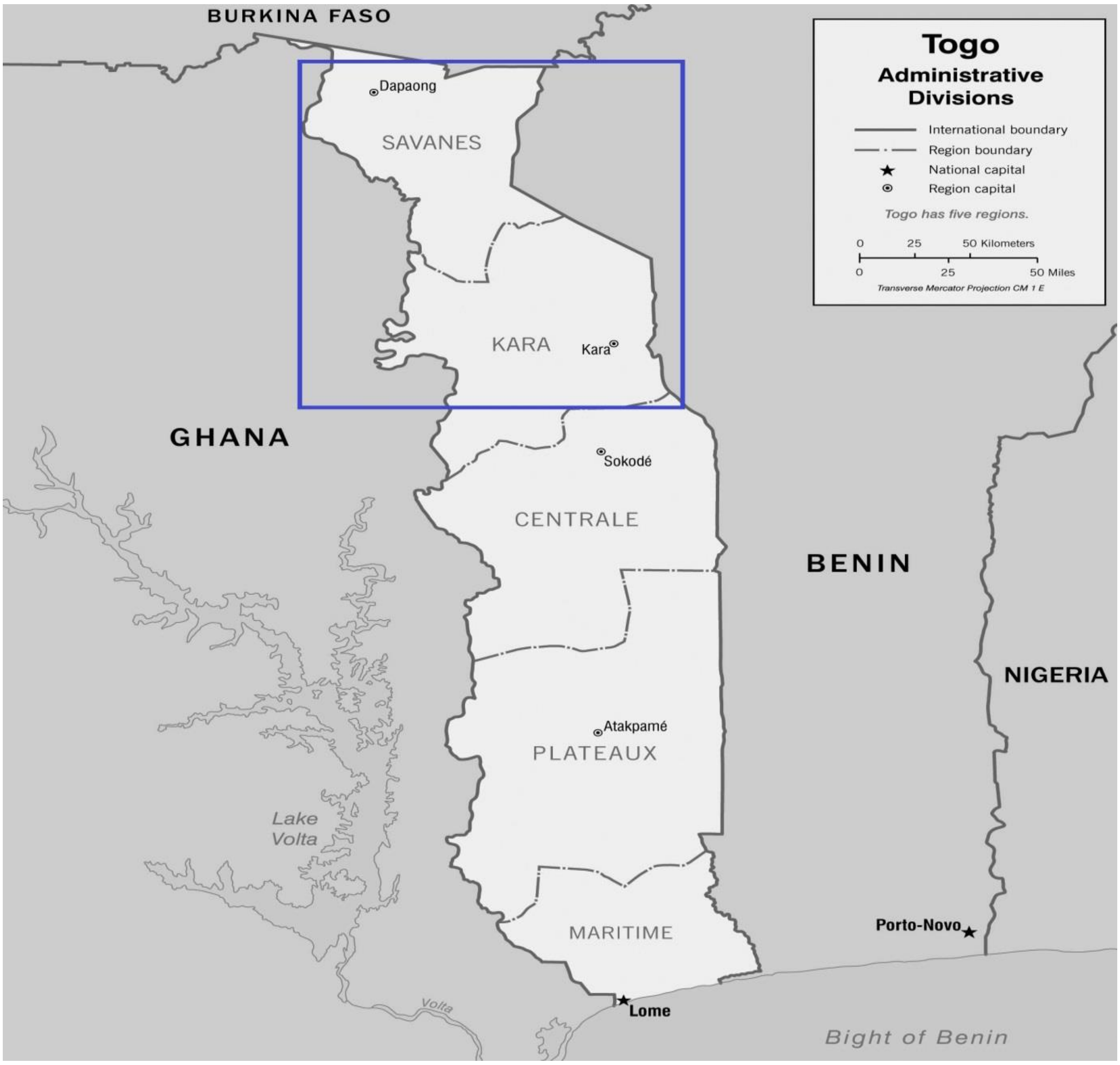

Figure 1.2 Map of Togo showing study area
Source: Own illustration based on Google Maps

1.5. Data collection

The data used in this thesis comes from the Trypanosomosis Rational Chemotherapy (TRYRAC) project funded by the European Union Global Program on Agricultural Research and Development (ARD) that was implemented in three (3) sub-Saharan African countries (Ethiopia, Togo and Mozambique)[1]. An extensive household survey was conducted covering two waves 2013 and 2016[2]. The study covered mainly small scale cattle keeping households in

[1] Only data from Togo and Ethiopia has been used since no survey was conducted in Mozambique.

[2] The panel data is only available for Togo. No second survey was conducted in Ethiopia because project partners could not implement the interventions on time which caused a major disruption to the project calendar.

the two countries. Three tiers of data have been collected and used – household, village level and stakeholder data.

On the household level, a detailed survey instrument data was used to collect on demographic information and household characteristics as well detailed household economic data such as assets, consumption, on– and off–farm employment, farm production (both crop and livestock) including inputs used, outputs produced, usage of the output and prices of outputs and inputs. Specifically, additional information on cattle production relating to disease incidence of AAT, inputs used, regimes used to treat animals, herd structure and other information on herd dynamics were collected. In addition, information on general risk and time preference, shocks, and food security outcome of the household has been collected. In total 485 and 491 cattle keeping household heads were randomly selected from 20 villages each in Togo and Ethiopia respectively were interviewed during the baseline survey in 2013. During the follow-up survey (impact survey) the same households were surveyed again in 2016 in order to be able to measure impact. Table 1.1 gives the layout of the questionnaire and the different sections that have been captured.

The sampled households per villages and per country are presented in Table 1.2.

At the village level, data on infrastructure such as markets, agricultural office, credit institution, health, education and transportation facilities as well as number of herders in the village has been collected through village head or chief interviews.

Finally, epidemiological data such as trypanocide use, general inputs used by livestock farmers for treating disease and other infections, AAT prevalence at the village level, drug resistance outcome, morbidity and mortality of cattle in the study villages was collected as a secondary data from the TRYRAC project partners – Free University of Berlin (FUB) and Institute of Tropical Medicine (ITM-Antwerp) who conducted a detailed epidemiological study together with local veterinary personnel in 2012 in the study villages.

Table 1.1 Structure of the household questionnaire

Section	Topic	Description
1	Survey information	This section collects basic information of the respondent such name of village, name of respondent, relationship to household head, country code, date and time of the interview
2	Household membership details	Captures all members of the household, their demographic details and other related characteristics such as education and health outcomes.
3	Housing details	Details of the housing of the respondent such as size of compound, type of construction material and ownership status is given here.
4	Agricultural Section	▪ Household Farm size, crops grown and quantity harvested, usage of harvested crop ▪ Livestock kept, breed and composition of herd, outputs produced, usage of these products ▪ Input used for crop and livestock production
5	Knowledge attitudes and practices (KAP)	In this section we collect data on knowledge of the respondent on symptoms, causes, treatment and prevention of livestock disease especially AAT. Data on worm and other ecto parasites is collected in this section
6	Natural resources	Household extraction, sales and use of natural resources is collected in this section for the last 12 months
7	Off-employment	Off-farm employment history of all household members, wages earned and time in employment is recorded for the last 12 months
8	Non-farm self-employment	This section reports self-employment (non-farm) history of the household members within the period
9	Shocks	All shocks both positive and negative shocks experience by the household in the last 5years are reported in in this section. Duration and impact of shock as well as coping strategies of the household are given.
10	Risks	In this section, household risks and mitigation strategies are reported
11	Perception and preferences	In this section, using an experimental setup we collect the time risk preference of the respondent.
12	Borrowing	Data on all borrowing details is recorded. Loans taken (cash or valuables); when and where, reason for borrowing, repayments and outstanding payments
13	Savings	Saving details of the household-how much is saved, where they save, and form of savings etc.
14	Public transfers	Records of remittances and transfer payments the household received with the last 12 months
15	Household expenses	Total household expenditures on food, nonfood, transportation, education, health, social issues and any other item with the last 12 months
16	Household assets	All household assets and their estimated values using current depreciated prices
17	Food insecurity	Self-assessed food security outcomes of the household for the last 12 months
18	Interventions	Section added during the impact survey in 2016 to identify respondents that participated in the interventions and what programs interventions and how they received them.

Table 1.2 Sample villages and households used in the study

Togo		Ethiopia	
Name village	**Number of households**	**Name of village**	**Number of households**
Agbassa	24	Agerea	25
Bidjandè	25	Bida Tadelea Gote 9	25
Broukou	25	Egir Zizo	25
Délabre	25	Engudewea	24
Djapal	25	Gebeya Agerea	24
Faré	26	Gerenbo	24
Gando	22	Gibre Abare Gote 2	25
Kerkètè	22	Gibre Abare Gote 4	25
Koudjoudjou	22	Guantana	25
Koundoum	26	Gura Seratea	24
Koutchétchéou	24	Hole Gote1	25
Lopano	22	Hudad 4 (Miscreta)	24
Magnan	25	Jaju	24
M'boratchika	25	Lay Bora	25
Pangouda	25	Legischo	25
Politi	24	Semon Boleeta Gora Quaya	25
Sadori	25	Sileora	25
Tchoré	26	Teteona	25
Togué	24	Yaya Atena Hudad 4	24
Wakadè-Peulh	24	Yetenaqa	24
Total	**486**		**492**

Source: Authors' compilation

In the next section the results of the various papers are presented.

1.6. Results

In the **first paper**, we investigated the role of improved technology in the livestock sub-sector and food security of rural households. The paper explicitly links improved livestock management decisions to the household food security outcome. Results show that there are at least four channels through which livestock can help improve the food security status of livestock dependent households: (i) as a source of protein through milk and meat for improved nutritional outcomes, (ii) the supply of draft power and manure (Liu et al., 2010; Smith et al., 2013), (iii) as a direct source of income through the sales of livestock and livestock products and (Fafchamps et al., 1998; Amare et al., 2012) (iv) as an asset to smooth food consumption during adverse events (Barrett and Carter 2013; Kazianga and Udry, 2006; Fafchamps et al., 1998). We find that adoption of improved technology resulted in higher food consumption per capita by between 5 and 12%. The results also show that the adoption of modern technology reduces the likelihood of becoming food insecure by 13 to 18 percentage points.

The **second paper**, investigated factors that drive adoption of multiple technology practices in the livestock sector in Ethiopia. The paper finds important and interesting results for policy formulation in regards to disease control and management. First, the paper demonstrates that the BBPs are not complementary as expected. We find that all the practices in the BBPs introduced to farmers were negatively correlated which is an indication of a substitution effect. In detail, results show that households on average adopted only one out of 4 available BBPs. This is an indication of low adoption rate of livestock technology in Ethiopia. Second, our results show that adoption of different BBPs is driven by different household-, institution- and district level characteristics. Specifically, we find that age and education of the household head, the number of plots, herd size, assets, access to media (owning a television), access to veterinary inputs and services, knowledge of the cause of AAT and the location of household enhance adoption.

The **third paper** investigated the impact of veterinary interventions on Togolese households using panel data. Results show that treated households scored higher in terms of their AAT knowledge scores– approximately 30% compared to non-participants. Also, we find that for every 10% increase in knowledge, TRYRAC participants adopted 3 more improved livestock husbandry practices resulting in a drop in AAT infections. As a consequence of the fewer AAT infections their cattle herds also recorded higher productivity (between 64–95% in terms of income) as compared to non-participants. Also, fewer infections translated into savings of veterinary costs of approximately US$3–5.5 per cattle head per annum, i.e., an annual saving of approximately US$27–50 per cattle herd, which is also equivalent to between 5.8 and 10% of the average annual household income per capita.

In terms of the household welfare outcome indicators, the results show that veterinary interventions significantly enhance small-holder welfare. In particular, the intervention triggered consumption increases between PPP$250 and PPP$290 while reducing poverty and vulnerability by 12% and 7%, respectively. These welfare impacts are related to improvements in animal health, which are likely to originate through improvements in farmers' knowledge and animal husbandry practices.

The **fourth paper** investigated the drivers of portfolio diversification in the context of "pull" and "push" factors (Ellis, 1998; Bryceson, 1999; Dimova and Sen, 2010; Martin and Lorenzen, 2016) in Togo. We focus on the role of climate variability on income, crop and livestock diversification. We expect the long term climate variability to push households into diversification as a mitigation strategy. However, the result show that long term climate variability reduces household diversification in general, which is contrary to most findings in region (Arslan et al., 2017; Asfaw et al., 2015). Our explanation of this phenomenon is that because of the dependence of majority of household on rainfed activities combined with imperfect or missing markets (labor, credit and insurance markets), household tend to reduce their risk exposure by reducing their portfolio investments to hedge current and future consumptions against possible weather related shocks. Our results also indicate that during periods of high rainfall variability, access to credit could stimulate the diversification. This finding could suggest that high initial capital requirements especially livestock diversification acts as a constraint to household diversification.

Investigating the role of climate variability on household welfare shows that it has a negative impact on current consumption outcomes and positive correlation with poverty headcount. This finding is consistent with other studies in the sub-Saharan Africa (Tesfeya and Assefa, 2010; Arslan et al., 2017; Asfaw et al., 2015). Household diversification, especially livestock diversification, however is able to mitigate the negative impact of climate variability on household welfare.

1.7. Conclusions, policy implications and future study

The conclusions presented here are based on the empirical findings of each paper. Based on each conclusion we draw policy implications for improving welfare in rural Africa.

The stand out conclusion from **the first paper** suggests that the adoption of improved technology is able to improve household welfare and food security outcomes. Improving livestock health by introducing knowledge-intensive integrated control measures is a promising way to enhance livelihoods and improving food security of small-scale cattle dependent households in sub-Saharan Africa. In this regards and given the spread in ownership of livestock especially among the poor in SSA, policy interventions targeted at stimulating productivity should be considered an important growth path for the marginalized rural households. For example, the policy that enhances the capacity and equips local livestock scientists like veterinary delivery service should be deliberately pursued to promote the development and dissemination of modern technologies to enhance productivity. This is especially important given the low productivity observed in the sub-Saharan African region in spite of the potential for growth. An enhanced public, private partnership may be an option to have more veterinary personnel trained and deployed in rural areas where traditional veterinary service numbers are low and inadequate.

From the results of **the second paper**, we conclude that adoption of multiple modern technologies remains low among livestock farmers. Furthermore, we conclude that assumed complementarity between these technologies makes the drawing up of inappropriate extension as well as dissemination strategies for technologies which explain the low penetration observed. We further conclude that wealth and access to information and relevant inputs drive adoption of livestock technology. Based on these conclusions, extension messages should be designed to bring the benefits of new technology that are adopted in full. Also, livestock disease control programs should target training of veterinary personnel and other stakeholders such as input dealers, herders, and para-veterinary to improve their understanding of modern livestock technologies and how farmers can maximize the returns through full adoption. Similarly, programs and interventions that improve access to information and inputs such as input subsidy payments targeted to trypanocides should be considered to stimulate BBPs adoption. Similarly, policies targeted to improve household asset base such as improved access to credit should be pursued as deliberate policy to improve BBP adoption.

However, in the absence of panel data the study could not investigate the returns to adopting different number of technologies. In this regards, a panel data set that covers a two-time period could test the returns to simultaneous technology adoption on livestock health and household welfare in particular.

The main conclusion from **the third paper** points to the important role of interventions targeted at improving the health of livestock, which leads to improved rural livelihoods in SSA. In this regards to scale up technology adoption, there should be increased farmer and local partner participation in the technology dissemination chain. Ownership of farm implements such as the animal-drawn implements should be encouraged among cattle farmers by removing bottlenecks and the bureaucracy in the access to credit. Farmers should also be assisted to form and operate animal-drawn machinery pool.

Although we find a positive effect, the spillover effect capturing the effects of the interventions on non-participating villages still remains unclear. Creating a longer time series data that consists of 3 waves and including more households in the nonparticipating villages would allow the adequate comparison of outcomes.

The **fourth paper** concludes that income diversification, especially off-farm income, remains low in the two northern regions of Togo. Crop and livestock production are the two most important contributors of household income in the study region contributing up to 100% of total disposal income. At the same time, climate variability is very high in the study region. However, households do not use portfolio diversification as a risks mitigation strategy against rainfall variability. Credit constraint limits portfolio diversification among households. While climate variability negatively affects households' welfare, livestock portfolio diversification improves household welfare. Therefore, policies that stimulate livestock diversification such as access to credit and access to services to improve livestock health and productivity should be considered by relevant institutions to improve household welfare and reduce the negative effect of climate variability.

1.8. Organization of the thesis

The rest of the thesis containing the three papers is organized as follows. Chapter 2 contains the first paper **"The impact of integrated livestock disease management for food security in Togo"**. Previous versions of this paper have been presented at the Tropentag – Berlin, Germany (16–18 September 2015), Global food security conference Göttingen, Germany (April 28–29, 2017) and Ausschuss für Entwicklungsländer (AEL) (November 12–12, 2015) PhD workshop in Zürich, Switzerland. The paper is published in the International Journal of Agricultural Sustainability (https://doi.org/10.1080/14735903.2018.1558565).

Chapter 3 presents the paper on adoption of simultaneous adoption of technologies titled **"Adoption of interrelated livestock technologies: The case of Best-Bet AAT management practices in Ethiopia"**. Earlier versions of this paper have been presented at the STVM conference in Berlin, September 2016 and TRYRAC stakeholder conference in Lomé, 2017.

Chapter 4 contains the third paper titled **"Returns to livestock disease control – A panel data analysis from Togo"**. The earlier version of this paper has been presented at ICAE conference in Vancouver, Canada. The paper is Published in the European Review of Agricultural Economics, 2019.

The fourth paper on long term climate variability and livelihood diversification is presented in Chapter 5. This paper is titled "**Long term weather variability, portfolio diversification and household welfare: Evidence from rural Togo".**

Table 1.3 Overview of papers in the thesis

Papers	**Title and Authors**	**Paper history**
Paper 1 *(Presented in Chapter 2)*	The impact of integrated livestock disease management for security in Togo (Weyori Emmanuel Alirah, Liebenehm, Sabine and Waibel Hermann)	- Paper presented at the Tropentag conference in Berlin, September, 2015 - Ausschuss für Entwicklungsländer PhD Symposium in Zürich. **- Published** in *International Journal of Agricultural Sustainability (2018)*
Paper 2 *(Presented in Chapter 3)*	Adoption of interrelated livestock technologies- compliments or substitutes: Evidence from Ethiopia (Weyori Emmanuel Alirah and Waibel Hermann)	- Paper presented at the Association of Institutions for Tropical Veterinary Medicine (AITVM) and the Society of Tropical Veterinary Medicine (STVM) conference in September, 2016 in Berlin, Germany
Paper 3 *(Presented in Chapter 4)*	Returns to livestock disease control: A panel data analysis in Togo (Weyori Emmanuel Alirah, Liebenehm, Sabine and Waibel Hermann)	- Presented at the triennial Conference of International Association of Agricultural Economists (IAAE) in Vancouver, Canada. July, 2018 - **Published** in the *European Review of Agricultural Economics*
Paper 4 *(Presented in Chapter 5)*	Long term weather variability, portfolio diversification and household welfare: Evidence from rural Togo (Weyori Emmanuel Alirah, Liebenehm, Sabine and Waibel Hermann)	- Submitted to the 6th African Conference of Agricultural Economists in Abuja, Nigeria -**Under review** in *Environment and Development Economics*-Cambridge

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CHAPTER 2: THE IMPACT OF INTEGRATED LIVESTOCK DISEASE MANAGEMENT ON FOOD SECURITY IN TOGO

This chapter is an extended and modified version of

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Abstract

In sub-Saharan Africa, livestock is one of the key channels through which most households meet their food security needs. Livestock diseases like the African Animal Trypanosomosis (AAT) remain a major constraint to productivity because of the lack of widespread adoption of effective integrated control strategies by farmers. Togo is a small country in West Africa which so far has received little attention by research. Using data from a randomly sampled 445 small scale cattle farmer this paper investigates the adoption and impact of the rational drug use (RDU) on households’ food security. The paper identifies the channels of impact linking them to different food security measures at the household level. We find that farmers who adopt RDU have higher livestock productivity and higher consumption per capita expenditures. They tend to be more food secure, experience lower seasonal food supply fluctuations and experience a lower probability of falling below the food poverty line.

JEL: Q10, Q18, Q16

Keywords: Technology, adoption, sustainable, livestock, food security, impact

2.1. Introduction

Technological innovations developed during the era of the Green Revolution played an important role in reducing poverty and malnutrition worldwide (Evenson and Gollin, 2003). Genetic improvements in crops, such as the development of high-yielding or risk-reducing varieties, or improved inputs, such as fertilizer and pesticides, led to an extraordinary increase in food crop yields per hectare (Pingali, 2012). In sub-Saharan Africa (SSA), however, the Green Revolution strategy of increasing productivity through technological innovations has been less effective and an unacceptable large population continues to suffer from food insecurity. For SSA, technologies are needed that can contribute to improved food security and environmental sustainability (DeFries et al., 2016; Fan and Brzeska, 2016; Barrett, 2016; Pretty and Bharucha, 2015). However, poor infrastructure and institutions together with imperfect or missing markets remain a constraint to achieving the productivity gains of the Green Revolution. Furthermore, declining soil fertility, climate change and its attendant shocks calls for urgent strengthening of other Agricultural sub–sectors such as the livestock sub-sector. This will stimulate agricultural production a critical backbone of livelihoods to be increased horizontally (FAO, 2010; Delgado et al., 1998). In this regards livestock production is able to improve food and nutritional security of households through at least four channels: (i) as a direct source of protein (milk and meat), (ii) supply of draft power and manure for crop production (Liu et al., 2010; Smith et al., 2013), (iii) as a source of income through the sale of livestock and livestock products and (Fafchamps et al., 1998; Amare et al., 2012) (iv) as an asset to smooth food consumption as a result of adverse shocks (Barrett and Carter 2013; Kazianga and Udry, 2006; Fafchamps et at., 1998).

Livestock productivity however remains low among small scale farmers in developing countries especially in SSA. A number of reasons including obsolete production practices, inadequate investment in the sector as well as disease and pests effects explain this phenomenon (Fitzpatrick, 2013; Otte and Knips, 2005; FAO, 2012). Disease such as the African Animal Trypanosomosis (AAT) remains the most important disease with negative economic effects for livestock and livestock keepers in SSA. AAT is a vector-borne disease transmitted by the tsetse fly which is unique to sub-Sahara African and remains a constraint to economic development of the livestock especially cattle sector (Alsan, 2015; Fitzpatrick, 2013; Geerts et al., 2001). For example, AAT decimates domestic cattle populations by about 30–50%, decreases milk and meat offtake by 50%, reduces calving rates and increases calf mortality by 20%. Furthermore, AAT decreases cultivated land by 40% through the reduction in traction capacity, manure output for soil fertility and nutrition recycling. Taking into account all crop and livestock production interactions, AAT is estimated to reduce the total value of agricultural production by 5–10% in SSA (Swallow, 2000). In spite of the negative productivity effects, recent disease data show that AAT has increased in prevalence and severity rates in SSA (Talakai et al., 2014; Tchamdja et al., 2016). One reason for the high prevalence is the lack of effective and efficient control measures. In particular, the continuous reliance and use trypanocides as a main control strategy has resulted in drug resistance making the method largely ineffective as a stand–alone strategy for AAT control (Grace et al., 2008; Clausen et al., 2010). However, unlike in crop production where the concept of integrated crop and pest management has become a well-established component of sustainable intensification practice (Pretty and Bharucha, 2015; Lambert et al., 2016; Hassanali et al., 2008) the concept is only beginning to find place in livestock production especially in the area of disease management because of the inefficiencies of traditional chemotherapy such as drug resistance. The concept of integrated disease control which aims to reduce disease prevalence through good husbandry practices with minimal use of chemotherapy as a last resort is still less common in livestock keeping in developing countries. With rising AAT prevalence and growing cases of drug resistance integrated approach to managing AAT presents a sustainable and efficient way to mitigate the effects of the disease (Liebenehm et al., 2016; Clausen et al., 2010).

In this regards, the concept of Rational Drug Use (RDU) which can be considered to be similar to integrated pest management in crops. RDU as defined by the World Health Organization – WHO (1987) is an integrated disease control strategy that aims to reduce the need for chemotherapy treatment of disease. In the livestock literature, the strategy includes sick animals receiving drugs from a veterinarian according to their clinical need and dose, training of farmers on good animal husbandry practices to reduce risks of disease outbreaks while discouraging farmers from administering trypanocides or other drugs on animals by themselves or any untrained person (Clausen et al., 2012; Beyene and Tesega, 2014). Although the idea of RDU is theoretically convincing, its adoption among cattle farmers in sub-Saharan Africa is low. Furthermore, it is not known if and to what extent RDU adoption benefits the livestock keeper's household (Grace et al. 2008; Liebenehm et al., 2011a).

As a consequence, in this paper we investigate the impact of RDU on household's food security in rural Togo. This is particular interesting because of the peculiar case high food insecurity and poverty – 68.7% poor in rural areas in 2015 – in Togo and the significant role of livestock such as cattle in livelihoods of most rural households. Rural Togo like most rural areas in sub–Saharan African is characterized by the absence of resilient livelihood strategies, low income streams and subsistence agriculture that is rainfed. As a country, Togo also has received little attention by way of research. Hence our paper adds to the literature by looking at the effect of veterinary interventions beyond livestock productivity as policy intervention for stimulating income growth for poverty reduction and food security among the poor in Togo. Specifically, we link livestock productivity to different food security outcomes of the livestock keeper's household. To the best of our knowledge this is a novel estimation in the livestock literature. Previous studies mostly focused on the effect of diseases on livestock productivity (Bennet, 2003; Perry et al., 2002; Fitzpatrick, 2013).

The rest of the paper is organized as follows: Section 2.2 introduces the study area and data setting. In section 2.3 we outline our empirical strategy outlining adoption of RDU and its impact on household food security is presented. Section 2.4 presents the descriptive statistics. The econometric results are presented in Section 2.5. The summary, conclusions and implications are presented in section 2.6.

2.2. Study area and sampling

This study uses a household survey of 445 livestock farming households from Northern Togo conducted in 2013. Cattle farmers who kept at least one type of cattle in the preceding 12 months to the survey were selected as the sampling frame. Through a multi stage random sampling procedure, respondents were selected from the Kara and Savanes regions. Respondents usually were household heads who in most cases are also the decision makers for cattle management including disease control. The study regions have been selected based on the following criteria: (i) importance of cattle production, (ii) abundance of tsetse fly and (iii) areas with significant AAT prevalence and severity. Production and epidemiological data by Talakai et al., (2014) prior to our socioeconomic survey has been used as the basis. Their survey found that the Kara and Savanes regions are the two most important cattle production areas in Togo. For example; the two regions accounts for an estimated 55–65% of the total national cattle population. The cattle are also important input for crop production a main livelihood strategy for them. Aside cattle, farmers typically grow staple cereals (maize, rice, sorghum, beans) in an integrated crop-livestock system. Thus, the animal waste (manure) is used as organic fertilizer while the left over crop after harvesting is fed to livestock. Also, animal draft power is a key crop production input for land preparation.

For sampling, we randomly selected 25 households per village from a list of cattle farming households in 20 villages across the Kara and Savanes Regions. Of the initial sample of 500 households we were able to interview 448 households using a standardized survey instrument. The questionnaire included sections on: (1) household characteristics, (2) agricultural production and productivity, (3) household income and consumption, (4) risks and shocks of households, (5) assets, (6) knowledge, attitude and practices (KAP) of AAT management, and (7) subjective self-assessed food security status.

2.3. Methodology

2.3.1. The adoption decision

The underlying assumption of our empirical analysis of the adoption decision is based on the standard household utility maximization theory where livestock farmers maximize utility given as livestock productivity (profits) under imperfect markets, and missing credit and labor markets (Amare et al., 2012; Yesuf and Koehlin, 2008). As explained earlier sections, AAT is a constraint to maximizing profits in cattle production in SSA. Thus, the theoretical model of adoption of RDU is assumed to be driven by profit function of cattle productivity. RDU reduce disease prevalence and treatment costs two main drivers of profits.

Let's assume the discounted profits received for RDU adoption is denoted as $\mathrm{U_A}$ and that for non-adoption be $\mathrm{U_{NA}}$. It implies adoption will be observed if $\mathrm{U_A} > \mathrm{U_{NA}}$.

Given that the random utility of the household is not observed but the adoption decision is observable, we represent the utility of the *i*th household as a latent variable which is equal to 1 if adoption is observed and zero otherwise. If we represent M^* as the latent variable that captures the discounted random utility from the adoption decision it follows that the *i*th household's adoption decision is represented mathematically as:

$$\mathrm{M}_i = \beta \mathrm{X}_i + \varepsilon_i, \text{where} \quad \mathrm{M} = \begin{pmatrix} 1 & \text{if} & \mathrm{M}^*>0 \\ 0 & \text{otherwise} & \end{pmatrix} \qquad (1)$$

The binary adoption decision (M_i) and takes the value of 1 for adoption and 0 otherwise, X_i is a vector of explanatory variables representing the *i*th household demographic characteristics, herd and farm characteristics, disease characteristics, assets, market and other village level factors and ε_i is the error term which is independent and identically distributed (i.i.d) with a mean and covariance of zero.

For the purpose of this study, we define an RDU adopter as a cattle farmer who has engaged veterinary or para veterinary personnel for the treatment and or advice on prevention of AAT in the preceding 12 months prior to data collection date. The definition of an adopter as a farmer who is using the veterinary service is premised on the fact that veterinary personnel are trained and able to prescribe the appropriate trypanocide and dosage to treat AAT – a key component of RDU.

2.3.2. Impact of RDU adoption on adopters

As discussed in Section 2, adoption can improve the productivity of cattle, increase crop production area and improve household income resulting in improved household food security. In this study we measure food security in terms of food consumption per capita and by two self-assessed binary food security indicators. However, to estimate and identify the true impact of RDU adoption on these outcome variables require rigorous and robust econometric procedures. Assume impact variable Y measures a household's i food security status to be a linear function of the adoption decision M_i and other household and farm level characteristics (Z_i). The impact equation can then be specified as:

$$\mathrm{Y_i} = \gamma \mathrm{Z}_i + \alpha \mathrm{M}_i + \psi_i, \qquad (2)$$

where, α is the coefficient of interest that captures the impact of RDU adoption and ψ is the error term with a mean and covariance of zero. Since treatment is not randomly assigned, the estimates of α from eqn. (2) as the impact of RDU adoption will be biased and inconsistent because of self-selection and endogeneity issues. The adoption decision is influenced by both observable and unobservable heterogeneities that may correlate with the outcome variable $\mathrm{Y_i}$ and the error terms $(\varepsilon_i,\ \psi_i)$ in equations (1) and (2) biasing results of equation 2. The effect is pronounced when the adoption decision is non–random and households decide to either adopt or not. For example, it may be the case that more food secure households or risk seeking households are those who are able to access information on RDU so self–select into adoption. Similarly, the impact of the technology may be enhanced by the high skill or management attributes of adopters. Directly comparing observed food security outcomes of RDU adopters and non–adopters without properly accounting for potential endogeneity and self-selection may under– or overestimate the impact of RDU (Wooldridge, 2002; Shiferaw et al., 2014).

To address the possible issues of self–selection and endogeneity, we estimate the causal impact of RDU through propensity score matching (PSM) technique proposed by Rosenbaum and Rubin (1983). The main idea is to create a pseudo–experimental condition that allows for a statistical comparison of adopters and non–adopters based on their predicted probabilities of adopting. Thus, the propensity score predicts the conditional probability of individual i being in the adoption group $(M_i = 1)$ conditioned on a set of pre-treatment observable covariates (X). The primary assumption underlying the use of the predicted matching estimator is the so called conditional independence assumption (CIA) which states that the adoption decision is stochastic conditional on pretreatment observable covariates (Kassie et al., 2011; Wooldridge, 2002). The assumption implies that observed welfare indicators of adopters and non–adopters (counterfactual) are the same in the pre–adoption period. This means that two households matched by their pre–treatment covariates, then any observed difference in outcome of adopters and non–adopters is because of their adoption status. The CIA assumption mildly assumes that unobserved heterogeneity does not affect adoption decision and requires that all covariates included in the PSM estimation jointly influences adoption and welfare outcomes (Wooldridge, 2002).

Referring to equation 2, if $\mathrm{Y_1}$ and $\mathrm{Y_0}$ are the average impact variable for adoption and non-adoption respectively, then the impact of RDU adoption is estimated as the difference between Y_1 and Y_0 the true situation and the counterfactual which represents the state of the respondent without adoption.

Thus the average treatment effect (ATE) equation observed is given as:

$$Y = MY_1(1 - M)Y_0, \quad M[0, 1] \tag{3}$$

However, since it is not possible to simultaneously observe the same respondent in the adopter and non-adoption groups at the same time, the unobserved counterfactuals cannot be estimated. To address this problem, the PSM approach estimates a propensity score index of households' pre-treatment characteristics which is then used to match respondents. We are then able to compare the consumption per capita, food security and cattle productivity indicators of similar respondents, subject to their adoption status. In this regard, similar households are defined according to their propensity score values. Following from eqn. (1), the conditional propensity score of household i given the pre-treatment covariates X may be defined as:

$$\mathrm{P(X_i) = Pr[M_i = 1/X_i] = E[M/X_i]} \tag{4}$$

Matching is done based on the estimated index of equation (4). Two further conditions are imposed to ensure that matched households are within the same region and characteristics, i.e. the balancing property and common support conditions. The balancing restrictions ensure that the distributions of propensity scores of households used in the matching process are the same regardless of adoption decision. While the common support condition ensures that the propensity scores are bound between 0 and 1 to improve the quality of matches.

Although, different algorithms such as nearest neighbor, kernel-based, and the radius techniques exist for matching adopters with non-adopters, matching based on the propensity score index is more robust because it uses more observations to estimate thus increasing precision of matching (Abadie and Imbens, 2011). As a robustness check for matching on estimated single propensity score obtained in eqn. 4, we also estimate the nearest neighbor algorithm. The nearest neighbor matching (NNM) is based on matching adopters with non-adopters based on a similar weighted function of covariates for each respondent. Matches may be done with or without replacement. Theoretically, both methods should produce similar results, however in practice there is a trade-off in bias and efficiency. For example, the PSM produces more robust estimates with lower variance because it utilizes greater information although this may also be its weakness if the observations used are poor matches. The NNM with or without replacement is a trade-off between bias and variance. Matching with replacement increases matching quality and reduces bias but increases the variance (Smith and Todd, 2005).

The effect of RDU may be different for adopters and non-adopters, thus estimating the ATE which is a weighted outcome for the whole population, may be biased. Hence we estimate instead the average treated effect on the treated (ATT). The ATE in a constrained adoption scenario and may be positive, negative or zero since it includes outcome for both adopters and non-adopters and not give the right impact for adopters. For example, adopters may have both observable and unobservable characteristics that make adoption more beneficial compared to non-adopters (de Janvry et al., 2011). In such a case it is important to estimate the impact of the treatment for those who actually received the treatment rather than the whole population. The ATT is given as the difference between outcome variable of the treated household *i* (Y_{i1}) observable and the unobservable outcome (Y_{i0}) if household *i* had not adopted and is calculated as:

$$ATT = E[Y_{i1} - Y_{i0} | \mathrm{M} = 1] U_A$$

$$ATT = \mathrm{E}\{\mathrm{E}[Y_{i1} - Y_{i0} | \mathrm{M}_i = 1,\ \mathrm{P}(X)]\}$$

$$ATT = \mathrm{E}\{\mathrm{E}[Y_{i1} - Y_{i1} | \mathrm{M}_i = 1,\ \mathrm{P}(X)]\} - ATT = \mathrm{E}\{\mathrm{E}[Y_{i0} - Y_{i0} | \mathrm{M}_i = 0,\ \mathrm{P}(X)]\} \quad (5)$$

Although the PSM is aimed at eliminating bias due to self-selection, concerns may still be raised on the robustness of the results since the strengths of the methodology depends mainly on the holding of the CIA assumptions. However, in a situation where researchers are faced with crosssectional data as it is the case of this paper and in the absence of good instruments to enable other econometric estimations the PSM stands out as the method of choice (Imbens, 2004; Smith and Todd, 2003) albeit with some modifications to ensure the minimal bias as much possible. Following earlier studies Rosenbaum, (2002), Ali and Abdulai, (2010), Caliendo and Kopeinig, (2008) we implement and perform a number of robust and sensitivity test of our results to check for potential hidden bias. As a first precaution, in estimating the propensity scores we follow empirical literature of farm technology adoption and include as many exogenous covariates that that are exogenous to adoption. This is to ensure that local and geographical differences are taken into consideration in matching the respondents. Second, we implement the Rosenbaum bounds to test the sensitivity and robustness of our results to hidden stated level unobservable heterogeneity bias. Third, we perform a covariate balancing test to ensure that the matched group represents an appropriate counterfactual. We further implement the common support in matching adopters with non–adopters. Finally, we compare the performance of the pseudo-R^2's of the matched households before and after matching how the observable covariates match households. Thus if after matching there are no significant difference between treated and control, then the pseudo-R^2 should be small (results of the various test are reported in the appendix).

We establish and test the main hypothesis, i.e. RDU adoption can improve households' food security through four identified channels namely: (i) increased protein intake when milk production increases, (ii) increased household net income due to increased sales and lower expenses for veterinary inputs, (iii) timelier crop production activities resulting in higher crop output and (iv) finally, we expect that reduced animal losses will improve household accumulation of livestock assets which in SSA is considered an insurance against consumption shortfall and welfare loss (e.g. Barret and Carter, 2013; Fafchamps et al.,1998).

2.4. Descriptive Results

2.4.1. Data description

Table 2.1 presents the summarized descriptive statistics of the sampled households. The average household size is 9 with a dependency ratio of 1.2. The household head is 43 years on average and 33% of the respondents have had at least 2 years of formal education. 39% of respondents belong to social networks such as farmer cooperatives and religious groups. The average herd size is 6 cattle units. In terms of morbidity and mortality 47% of respondents recorded at least one cattle death due to AAT during the last 12 months. However, contrasting to this is that the restocking rate is low. 37% of the respondents have adopted RDU. In terms of herd restocking, only 18% of households restocked within the period. The observed low rate of restocking may be attributed to the high cost of cattle combined with the low income of about 269,476 FCFA (US$445) per year. The low income may be a reflection of the lack of off-farm employment opportunities in the study area. Households mainly engage in low income generating activities such as petty trading with few taking up low informal off-farm employment.

Table 2.1 Variable description and descriptive statistics for the sample households

Variable	Variable description	Mean	S.D.
Household characteristics			
Gender of HH	Household head is male	0.91	0.29
Age of HH	Age of household head in years	43	18.71
Size of HH	Total number of household members	9	4.95
Dependency ratio	Ratio of non-working to working age members	1.2	0.94
Education of HH	Household head has formal education	0.33	0.47
Education of HH	Years of formal education of household head	2.2	3.70
HH belongs to a social network	Household head belongs to social network	0.29	0.45
Access to media	Household head has access to media	0.25	0.44
Livestock variables			
Cattle herd size	Number of total cattle kept by household	5.7	31.66
TLU (w/o cattle)	Other livestock units owned aside cattle	0.87	1.70
Death of cattle	If respondent recorded AAT related death	0.83	0.37
Done restocking	If respondent restocked farm	0.18	0.39
Contact with veterinary in 2012	If household had contact with veterinary in 2012	0.28	0.45
Wealth indicators			
Plots of land owned	Number of plots owned by household	2.3	1.76
Land size owned (ha)	Total size of land owned by household	4.8	6.88
Total Asset (CFAF) (‘000)	Total monetary value of assets	283	170,538
Per capita income (CFAF) (‘000)	Per capita income of household in 2012	269	4,352
Per capita consumption (CFAF) (‘000)	Consumption expenditure in WHO adult equivalent scale (AES)	522	703
Dependent variables			
RDU adoption	Households adopting best bet practices	0.37	0.48
Binary food security status	Household is food secure	0.76	0.43
Total number of households = **445**			

Note: HH, Household head; w/o, without; *S.D*, Standard deviation.

Source: Household survey 2013

2.4.2. Cattle producer livelihood in the study region

In this section, we investigate the role of livestock in households' livelihoods in the study area. The different sources of household income including livestock are presented in Table 2.2. In terms of household income, crop production contributes the largest 71% and livestock contributes 20%. Although the contribution of livestock to total income is small compared to crop production, livestock especially cattle is critical to rural livelihoods. For example, draft power and manure two key crop production inputs in SSA (Liu et al., 2010; Smith et al., 2013) are provided by livestock especially cattle. Rural Togo typically depends on animal traction for staple crop production (maize, rice, beans or millet) because of land tenure and subsistence agriculture.

Table 2.2 Sources of household income

Income source	**% Share**
Livestock and livestock products	20.00
Crop production	71.00
Off-farm employment	4.00
Natural resource collection	2.00
Self-employment	3.00

Source: Authors' calculation based on 2013 household survey data

Another important role of livestock is found in its contribution to household savings income which may be used to cushion household against adverse events such as drought, crop failure or other demographic shocks such as sickness or even death as shown in Table 2.3. Although not many households had savings (22%) although not surprising, a majority of the saved income was from livestock sources. For example, 45% of them indicated livestock (this include live sales, sale of products such as draft power, milk, egg and hide) as the source of their saved income with 39% indicating crop sources.

Table 2.3 Source of household savings

Source of savings	% of Households
Cattle	45.00
Other livestock	1.00
Crops	39.00
Self employed	3.00
Salary/wages	2.00

Source: Authors' calculation based on 2013 household survey data

The results from Tables 2.2 and 2.3 show that livestock remains an important livelihood component of the households in the study area in a number of ways: First, as a source of income to supplement consumption and savings, second as an input for crop production and third as a main coping strategy adverse events. The role of livestock especially cattle in the household economy and in food production suggest a likely elastic relation between cattle health and a household's food security. Meaning disease outbreak in cattle causes a more proportionate proportional change in the household's food security outcomes.

In Table 2.4, disease dynamics for cattle is presented. The results show that AAT remains a serious production constraint. 85% of the respondents identified AAT as the main disease problem militating against the production of cattle. About 47% of respondents recorded AAT related mortality. However, one important observation is that AAT knowledge remains largely low among cattle farmers in rural Togo. Example from the KAP questionnaire administered to respondents, we find that farmers were not able to correctly diagnose causes and proper of AAT. For example, out of the 85% households that reported AAT in 2012, only 9% of them were able to correctly identify the tsetse fly as the vector that transmits AAT. Similarly, respondents could not readily identify all distinctive symptoms of AAT and the right formulation of trypanocides to treat animals suffering from AAT. This finding suggests that respondents may be implementing wrong treatment procedures or administering wrong drug formulations that can lead to drug resistance and increased treatment costs in the long run.

Table 2.4 Knowledge and practices on AAT control

Disease variable	Description	% Households
AAT	Respondent indicated AAT as the main problem	85.00
AAT mortality	Household reported cattle death due to AAT in 2012	47.00
AAT prevalence	Household reports AAT in herd in last 12 months	9.00
Causes of AAT	Household head correctly identifies tsetse fly	9.00
Correctly treat AAT	AAT knows how to rightly treat AAT	37.00

Source: Authors' calculation based on 2013 household survey data

In the next step we investigate differences between observable characteristics of adopters and non-adopters of RDU before PSM matching (Table 2.5). The results show no significant differences in terms of household demographic characteristics between adopters and non-adopters. However, adopters differ significantly from non-adopters in wealth endowments such as land, other livestock units (TLU) and access to media. Adopters significantly owned more land, owned more livestock, and also had better access to media and veterinary personnel. Adopters also scored higher in the so called AAT knowledge and attitudes test of AAT from the KAP section of the questionnaire. Adopters also differ significantly from non-adopters in the diagnoses of AAT. These results may suggest the role of information, knowledge and wealth endowments in RDU adoption of RDU.

Adopters further differ from non-adopters in their reported herd and AAT dynamics significantly. For example, while 88% of adopters reported AAT related cattle deaths in 2012, 8% of them restocking herds within the same period, 81% of non-adopter households reported AAT deaths in their cattle with approximately 25% doing restocking their herds. These findings generally suggest that restocking is generally low and may be explained by the costs associated with restocking. This indicates adverse events that affect cattle resulting in loss of animals leads households falling into structural poverty which takes long time to recover from. This is in line with Carter et al., (2007) who found that small scale livestock farmers in Ethiopia find it difficult to recover from shocks related to livestock death.

Comparing the welfare outcomes of adopters and non-adopters show no any significance based on raw computed consumption per capita. The data was therefore transformed to using natural logarithm to linearize big outliers that may be reported by respondents. The result of the linearized data showed that the difference between adopters and non-adopters consumption per capita is significant. In terms of per capita income, adopters also have significantly higher per capita income. We further disaggregate per capita income to net out the role of direct livestock income by adoption category. We find that livestock income plays a significant role in livelihoods adopters than non-adopters by way of its share of the total household per capita income per annum. For example, while livestock income forms about 69% of the total per capita income of adopters, it is only 43% total per capita income of non-adopters. A casual look at the binary food security indicators also show that adopters are significantly more food secure. This further confirms the critical role of livestock to rural livelihoods especially small scale livestock farmers and is in line ILRI, 2002; Delgado et al., 1999; Perry and Grace, 2009 that all conclude that livestock keeping is critical for supporting rural livelihoods in SSA.

Table 2.5 Comparison between adopters and non-adopters

Variable	Adopters N=190 (mean)	Non-adopters N=255 (mean)	Pr(|T|>|t|)
Household characteristics			
Gender (1=male)	0.97	0.98	0.522
Age of HH head	47.43	45.82	0.269
Edu of HH head (years)	2.19	2.42	0.528
Edu dummy of HH head (1=yes)	0.34	0.35	0.828
Social network membership of HH head (1=yes)	0.46	0.41	0.289
Livestock characteristics			
Cattle herd size	5.80	5.10	0.634
Death of cattle in 2012 (1=yes)	0.88	0.81	0.045*
Restock herd in 2012 (1=yes)	0.08	0.25	0.000***
Prevalence of AAT in herd (1=yes)	0.61	0.46	0.002**
Causes of AAT (1=good knowledge)	0.39	0.13	0.000***
Contact with veterinary in 2012 (1=yes)	0.33	0.16	0.000***
Wealth indicators			
Access to media (1=yes)	0.18	0.30	0.006**
Plots of land owned	2.23	2.64	0.012*
Land size owned (ha)	4.61	5.55	0.166
TLU (w/o cattle)	0.62	1.01	0.002**
HH per capita income(CFA-franc) (‘000)	322	450	0.049*
Livestock share of HH total income	0.69	0.43	0.124
Total asset (CFA-franc) (‘000)	285	277	0.607
Per capita consumption expenditure (AES) (‘000)	566	510	0.421
Log per capita consumption expenditure (AES)	12.15	11.95	0.003**
Food security (1=food secure)	0.84	0.77	0.093*
Transitory food insecurity (1=yes)	0.12	0.18	0.045*
Chronic food insecurity (1=yes)	0.04	0.05	0.567

Note: HH, Household; *, ** and *** indicates difference in mean characteristics between adopters and non-adopters at 10%, 5% and 1% level of confidence
Source: Authors’ calculation based on 2013 household survey data

The overall results from the comparison of means of the outcome variables and other covariates in Table 2.5 show that adopters are significantly better off than non-adopters. This suggests a possible role of RDU adoption in improving the household welfare as observed in Table 2.5. However as discussed in section 2, adoption is an endogenous decision so concluding that RDU adoption leads to improved welfare by simply comparing adopters and non-adopters without accounting for individual characteristics will be wrong because of respondent heterogeneities. In this regards, multivariate and econometric procedures that account for such systematic heterogeneities between adopters and non-adopters need to be used in order to net out the true impact of adoption. We proceed with the identification of the impact of RDU adoption using the PSM approach.

2.4.3. Choice of explanatory variables

Following Flaten et al. (2005), we model the RDU adoption decision as a function of: (1) household demographic characteristics and livestock characteristics play an important role in how a cattle farmer perceives the risk of AAT, (2) perceived risk, farm characteristics and role of cattle in the household. Following the empirical literature of farm technology adoption (Adesina and Baidu-Forson, 1995; Valeeva et al., 2011; Liebenehm et al., 2011b), we include specific household demographics such as age, household size, dependency ratio, and level of formal education of the household head. According to Tornimbene et al. (2014), observable household characteristics should be considered in the adoption decisions because such characteristics determine knowledge and awareness level of the farmer. Access to information is important if positive traits or benefits of any new farm technology will be known tried and adopted by farmers (Adesina and Baidu-Forson, 1995). In this regards to capture the role of access to information in RDU adoption, we include presence of veterinary office. Veterinary personnel are an important part in the adoption of RDU.

Similarly, information about adverse effects of AAT, attitudes of other farmers in the community either increases or reduces the probability of RDU adoption. We thus include a variable that captures the knowledge score of the farmer. The dummy takes a value of one if the respondent is able to correctly identify the cause of AAT. We also include membership of social network as a proxy to capture informal information sharing and the role of collective action. Such informal networks are important source of information and shaping of behavior among rural farmers in developing countries where formal extension services are weak (Weyori et al., 2017). Other variables such as wealth of household captured as the number of cattle; number of plots owned and land size that have been reported to influence technology adoption have been controlled for (Asfaw et al., 2016; Liebenehm et al., 2011b; Adesina and Baidu-Forson, 1995). Current adoption of new input may be shaped by past experience of the adopter. To capture this expectation, we include a dummy that measures how effective previous AAT used have been based on farmers' own assessment. Some indigenous cattle breeds such as N'dama can naturally resist AAT infections hence the type of cattle breeds may determine the level of investment in disease control inputs. In this regards we also include a dummy that captures if respondent has N'dama cattle in the herd. According to Valeeva et al. (2011), past events and experiences of farmers in relation to recorded mortalities informs the type of disease management policy among resource constrain small scale farmers. This suggests that risk perception of AAT is important for RDU adoption. A respondent who perceive a higher probability of AAT outbreak in addition to other negative past experiences stands more likely to invest in adopting RDU to mitigate future losses. Reported AAT mortality and morbidity has been included to capture the risks behavior of the respondent towards AAT. A bull dummy has also been included to capture the effects of economic benefits such as income from hiring out such animals for land preparation purposes or on own farm. Negative shock events may cause household to readjust their management decision. For example, crop failure prospects may cause livestock farmers to shift resources into livestock production allowing the adoption of practices that hitherto would not be possible. A dummy for agricultural related shocks is therefore included to capture this effect.

The econometric results of the models are presented in the next section

2.5. Model Results

2.5.1. Adoption decision

The conditional probabilities of adoption with marginal effects are presented in Table 2.6. The likelihood ratio test that all coefficients are jointly equal to zero is rejected **(Pseudo likelihood = -236.902, Prob > Chi2 = 0.000)** at the 1% level. Other statistics such as sensitivity and specificity show that model is able to predict the adoption category to a high degree. A graph of the model specificity and sensitivity shows that in all 78% of the adoption decision are correctly predicted (Appendix Figure 2.A1).

In terms of the factors that influence adoption of RDU, the results from Table 2.6 show that a number of significantly influence adoption of RDU. In terms of demographic variables that affect adoption, the result shows that larger households have a slightly lower likelihood of RDU adoption. However as expected wealthier households (as measured by asset value per capita) are more likely to adopt. For an additional 1000 CFA-Franc asset value, the probability of adoption increases by 5%.

For example, the result shows that for every unit of farm animals other than cattle, the odds of adoption is reduced by 5%. Respondents who did re-stocking in the 2012 are 17% are less likely to adopt RDU. If a respondent has recently restocked new animals, it is reasonable to assume that these were healthy animals which could explain the negative relation. Usually farmers buy animals from regions with lower AAT prevalence. Also, owning of bull reduces the probability of adopting RDU by 10%. The negative correlation between bulls and RDU adoption is contrary to expectation because of the importance of bulls to agro-pastoral livelihoods in rural area. However, we observe that bulls are N'dama breed which are AAT resistant (Dayo et al., 2009; Murray et al., 1982) and this could explain the observed negative effect. Similarly, households that experience agricultural shocks are 17% more likely to adopt RDU.

In terms of the disease variables, farmers' AAT knowledge significantly increases the probability of RDU adoption by 27%. This result is in line with the findings of Liebenehm et al., (2011b) in Mali and Burkina Faso. The validity of the knowledge variable is supported by the positive relationship between adoption and farmers' access to veterinary services. This is in line with the broader literature on agricultural extension which shows that effective extension services are critical for adopting complex farm technologies (e.g. Asfaw et al. 2012; Di Falco et al., 2011; Kassie et al., 2011; Morris, 2002). This is especially important for RDU strategy where farmers are dissuaded from treating animals themselves with drugs. The effectiveness of AAT control inputs used by farmers is also positively associated with RDU adoption. Respondents who positively assessed trypanocide use increases adoption of RDU by 10%. Buying inputs from open markets reduces the probability of adoption by 12%. This result suggests that if a farmer cannot buy trypanocides from the registered veterinary shops he is less likely to adopt RDU because of the low efficacy of drugs from the informal market. Results of Tchamdja et al. (2016) who sampled and tested some trypanocides from Togo show that a large proportion of trypanocides from the informal markets were sub-standard with low active ingredients.

Overall the results of our adoption model show that most of the coefficients are statistically significant and have the expected sign. The predictive quality of the model is also satisfactory judging from the statistical test parameters such as ROC curve. Similarly, the Hosmer-Lemeshow goodness of fit returns a p-value of 0.178.

In the next stage, we perform the matching estimation that allows for the impact RDU determination.

Table 2.6 Logit estimates (with marginal effects) of the propensity to adopt RDU

Variable	Coefficient	Marginal effects	Robust standard error	*z-value*
Household characteristics				
Age	0.01	0.00	0.01	1.15
HH size	-0.06	-0.01*	0.03	-2.40
Dependency ratio	-0.10	-0.02	0.14	-0.67
Education (1=has formal education)	-0.13	0.02	0.43	-0.30
Education years	-0.05 ()	-0.01	0.06	-0.89
Social network (1=belongs to social network)	-0.01	-0.001	0.28	-0.03
Assets value (log)	0.26	0.05**	0.08	3.17
Farm characteristics				
No. of plots of land	-0.80	0.01	0.08	-0.96
TLU (w/o cattle)	-0.30	-0.05**	0.27	-3.25
Restocking in 2012	-0.95	-0.17**	0.36	-2.67
Bull dummy	-0.60	-0.10**	0.24	-2.52
Agricultural shock (1=crop shock)	0.15	0.17***	0.04	3.61
Disease variables				
Knowledge on causes of AAT	1.52	0.27***	0.26	5.81
Effectiveness of trypanocides	0.53	0.10*	0.27	2.01
Veterinary contact	0.80	0.14**	0.27	3.02
Source of trypanocide (1=Open market)	0.67	-0.12*	0.28	-2.36
Constant	-3.24		0.59	-3.42
Model statistics				
Log likelihood ratio			-236.902***	
% correct predictions			71.91	
Specificity			81.58	
Sensitivity			57.54	
No. of observations			448	
Pseudo R^2			0.21	
Wald chi-square			109.32***	

Note: HH, Household; TLU, Tropical livestock units; w/o, without; *, ** and *** indicate 10%, 5% and 1% level of significance

Source: Authors' calculation

In the next section we examine the impact of adoption.

2.5.2. Impact of RDU adoption

The results of the impact estimation based on PSM matching and NN matching techniques is presented in Table 2.7. The matching quality as assessed by the common support condition indicates a considerable overlap between adopters and non-adopters (see Appendix Figure A1). Also, the results from the covariate balancing tests before and after matching show that the standardized mean difference for covariates used in matching is reduced from 22.4% to about 7.1 to 9% after matching. Similarly, the p-values of the likelihood test of joint significance of covariates is rejected after matching with the pseudo-R^2 also dropping significantly after matching (Table A1 in appendix). The general conclusion from these results is that the matching process is fairly successful and the group of adopters and non-adopters do not significantly differ after matching.

The results show that RDU adoption has a positive impact on household consumption per capita. Consumption expenditure per capita of adopters is increased by between 22–25% points. This is consistent with empirical literature (Asfaw et al., 2012; Kassie et al., 2011; Becerril and Abdulai, 2009) that report similar positive impact of farm technology adoption on household consumption expenditure per capita. This impact we explain as being triggered through higher cattle productivity a critical determinant of disposable household income as shown in the Table 2.2 and 2.3. Given that the total consumption expenditure aggregation comprised of food and non-food components, this may not give a fair representation of the effect on improving food security. Therefore, we disaggregate the total consumption expenditure per capita allowing us to estimate the impact of adoption specifically on the food consumption expenditure per capita[3] component. The result of the impact of RDU adoption food consumption expenditure is presented in Table 2.8. The results show a significant increase in the food consumption expenditure of RDU adopters compared to non-adopters. Adopters are able to increase their food expenditure by between 5–12% points (Table 2.8). Thus from Table 2.7 and 2.8, we conclude that households that adopted RDU are simultaneously able to increase their total consumption expenditure as well as the proportion of expenditure spent on food. Higher expenditure suggests improved food security in terms of accessibility and utilization for adopters. This will improve both the frequency of meals taken and nutritional status by households.

[3] We adjusted the household FCE to the standard WHO adult equivalent scale. This allow for comparison between households regardless of their composition. The adult-equivalent scale takes into account the composition of households such as gender, age on the food expenditure (Blaylock 1991).

Table 2.7 Impact of adoption on total and food consumption expenditures per capita

Outcome variable	**Algorithm**	**ATT**	***Standard error***	***z-value***
Log total consumption expenditure (AES)	NNM[1]	0.22*	0.14	1.66
	NNM[2]	0.25*	0.10	2.42
	PSM[3]	0.24*	0.11	2.07
	PSM[4]	0.22*	0.11	2.10
Log food consumption expenditure (AES)	NNM[1]	0.05	0.08	0.57
	NNM[2]	0.10*	0.05	1.79
	PSM[3]	0.04	0.06	0.79
	PSM[4]	0.12*	0.05	0.79

Note: AES, Adult equivalent scale; FCE, Food consumption expenditure per capita; *, ** and *** indicate 10%, 5% and 1% level of significance
NNM[1] = single nearest neighbor matching with replacement, common support and caliper 0.06
NNM[2] = five nearest neighbor matching with replacement, common support and caliper 0.06
PSM[3] = Propensity score matching (1:1) with common support and bandwidth 0.06
PSM[4] = Propensity score matching (1:5) with common support and bandwidth 0.06
Source: Authors' calculation

We further go a step further to estimate the impact on self-assessed food security of respondents reported in Table 2.8. Similar to the results in consumption expenditure, the results show that adopters are more likely to be between 13 – 18% more likely to be food secured than non-adopters. Also, adopters are less likely to experience fluctuations in food availability to household members. Depending on seasons (before or after crop harvesting season), food availability and supply can be different. Our results, however, show that RDU adoption reduces the likelihood of food fluctuations by 11–17% points. This suggests a smoothening effect of increase income because of cattle productivity as well as enhances crop production.

Table 2.8 Impact of adoption on subjective binary food security

Outcome variable	Algorithm	ATT	*Standard error*	*z-value*
Binary food security	NNM[1]	0.14*	0.09	1.67
	NNM[2]	0.15**	0.05	3.02
	PSM[3]	0.13*	0.07	1.85
	PSM[4]	0.14*	0.07	1.90
Transitory food insecurity	NNM[1]	-0.17**	0.09	-2.66
	NNM[2]	-0.11*	0.06	-2.08
	PSM[3]	-0.10	-1.60	-1.60
	PSM[4]	-0.14*	0.08	-1.81

Note: *, ** and *** indicate 10%, 5% and 1% level of significance, matching algorithms as defined in Table 2.7
Source: Authors' calculation

Finally, using the regional food poverty line[4] as a proxy for food security we further test the robustness of the results in Tables 2.7 to 2.9. Using the 2012 established food poverty lines of 206,968 FCFA and 210,202 FCFA for Kara and Savana regions respectively; we investigate the impact of RDU adoption in pushing households out of poverty based on the minimum food poverty line. These results are presented in Table 2.9. The results show that adopters are 10–24% less likely to fall below the food poverty line in both regions. This may be explained by increased household disposal income from enhanced animal productivity and reduced expenditure on disease management. Poverty is generally pronounced in these regions of Togo with about 75–90% of households being poor and living below the poverty line of US$1.25 per day (IMF, 2014).

Table 2.9 Impact of adoption on food security (food poverty line)

Outcome variable	**Algorithm**	**ATT**	***Standard errors***	***z-value***
Food-poverty line	NNM[1]	-0.10*	0.060	-2.49
	NNM[2]	-0.11**	0.052	-2.61
	PSM[3]	-0.24***	0.054	-2.22
	PSM[4]	-0.11*	0.071	-2.50

Note: * 10%, ** 5% and *** 1% significance, matching algorithms as defined in Table 2.6
Source: Authors' calculation

This result therefore suggests that farm technologies that enhance farm productivity can be a sustainable pathway to improve household food security and also climb out of poverty. In this regards, stimulating the RDU adoption will help households improve their income to improve overall food security and welfare because of the spread in ownership of livestock and the critical role of livestock in their livelihoods.

2.5.3. Channels of RDU impacts

Having identified overall positive impacts of RDU adoption on a household's food security; we investigate and show potential channels of impact for RDU adoption. Specifically, we investigate these channels: cattle productivity measures (milk, traction), cattle net-income and share of veterinary input expenditure. These results are presented in presented in Table 2.10. First, we found that RDU adoption increases in milk production by approximately 28–53 liters by cows. Milk produced is either consumed at home or sold in the local village market to

[4] The food poverty line is defined as the amount of expenditure below which an individual is not able to purchase enough food to meet the recommended daily calorie needs.

purchase other ingredients or cereals. Increase milk production will therefore lead to improve protein source food in household diets, improve nutrition and food accessibility especially for children.

Table 2.10 Channels of RDU impact

Outcome variable	**Algorithm**	**ATT**	***Standard error***	***z-value***
Milk production (liters)	NNM[1]	3.90	18.89	0.21
	NNM[2]	28.65*	14.12	2.03
	PSM[3]	53.13***	12.42	4.28
	PSM[4]	43.53**	20.67	2.25
Share of staple land under traction (hectares)	NNM[1]	0.05	0.031	1.61
	NNM[2]	0.06**	0.03	2.22
	PSM[3]	0.12***	0.024	4.77
	PSM[4]	0.11**	0.039	2.80
Net income (cattle products) -CFAF	NNM[1]	60,033**	19289	3.11
	NNM[2]	30,748**	14295	2.15
	PSM[3]	47,017**	20801	2.26
	PSM[4]	3075	2587	1.19
Veterinary cost per cattle TLU-CFAF	NNM[1]	-28,555*	13229	-2.16
	NNM[2]	-9449	6632	-1.42
	PSM[3]	-27,292*	15259	-1.78
	PSM[4]	-3957	7566	-0.53

Note: *, ** and *** indicate 10%, 5% and 1% level of significance, matching algorithms as defined in Table 2.6
Source: Authors' calculation

Second, we also found that the share of cereal land under traction as a total of the land cultivated increased by between 6% and 12% for adopters as compared to non-adopters. As discussed in earlier sections, RDU adoption improves cattle health and lead to increase productivity of draft animals. The effect of improved productivity of draft animals is increase draft power for crop production and timeliness of other farm activities such as seeding, and weed control to increase crop yields and income. Timeliness of crop cultivation is especially important in SSA because crop production is mainly rain–fed therefore land preparation inputs like draft power needs to be available as and when rains set in. Third, we also found that RDU adoption increased livestock net–income by between CFAF 47,017 (US$ 77) and CFAF 60,033 (US$ 99). There is also an observed decrease in veterinary costs per TLU by between CFAF 27,292 (US$ 45) and CFAF 30,748 (US$ 50) as a result of reduction in the overall treatment requirements of animals in the long run a benefit of improved herd management practices a critical component of RDU.

2.6. Summary and Conclusions

The increase in AAT's prevalence and the increase in drug resistance as a result of the overuse and misuse of trypanocides has been a major challenge for livestock production, especially for cattle production in sub-Saharan Africa. The concept of an integrated approach to disease control, Rational Drug Use (RDU), as an alternative to the conventional AAT control methods that primarily rely on trypanocides for treatment is becoming increasingly recommended. RDU adoption among small-scale cattle farmers is however low. Critically missing is an empirical study showing what drives RDU adoption and its impact on households. In this paper, focusing on small-scale cattle farmers in Togo, we identified adoption drivers and channels of impact of RDU. Our results show that the overall adoption of RDU remains low among cattle farmers. Household size, ownership of other livestock, herd restocking and the poor efficacy of trypanocides constrain RDU adoption.

In terms of the impact of RDU adoption, we show that adopters experience a positive and significantly higher food security outcome. RDU adoption also increased cattle productivity in terms of milk and traction hours and reduced long term inputs and veterinary costs. Adopters are less constrained with cash because of the increase of steady income inflows from enhanced animal productivity and also because of the savings from veterinary costs. Through complementary food purchases, they are thus able to maintain their food consumption, especially during the lean season. In addition, the adoption of RDU reduces significantly the probability of falling below the food poverty line.

This study thus shows that RDU adoption has multiple positive effects in terms of increased productivity and the improved food security of the poor and vulnerable small-scale livestock keepers. Improving livestock health by introducing knowledge-intensive integrated control measures is a promising way to enhance livelihoods and to improve the food security of small-scale cattle dependent households in sub-Saharan Africa. This suggests that policy interventions that enhance livestock, especially those that enhance cattle productivity, are important to help rural households escape poverty and food insecurity. To stimulate and increase the adoption of improved livestock technology in Togo (and perhaps in all of sub-Saharan Africa) and to reduce the influx and use of low quality and substandard trypanocides, policy-makers should aim at making local veterinary personnel an integral component in the provision of disease inputs. Better monitoring and control regimes for the importation of disease inputs such as trypanocides should also be implemented.

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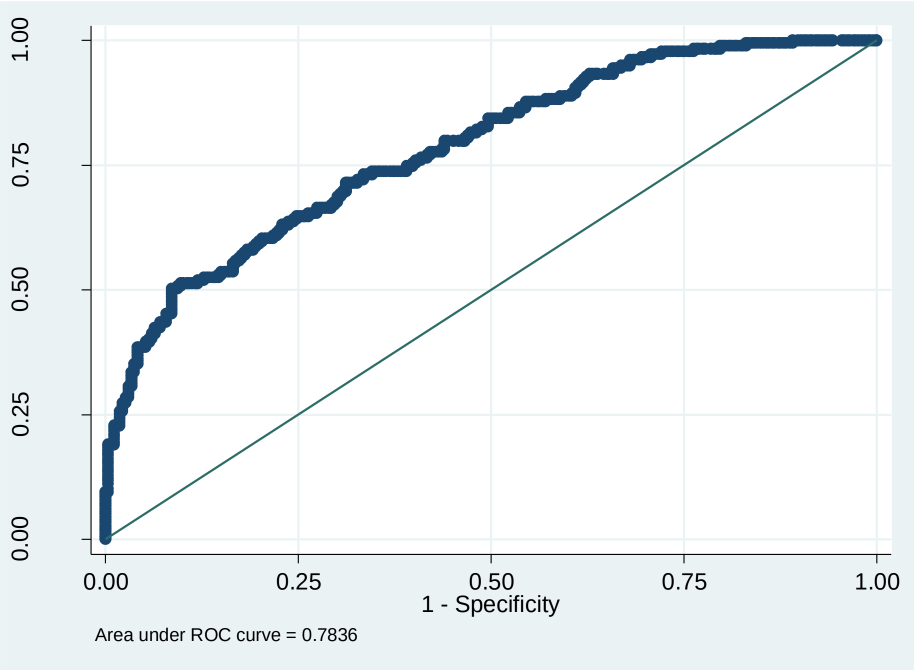

Figure 2.A1 ROC statistic and area under the curve

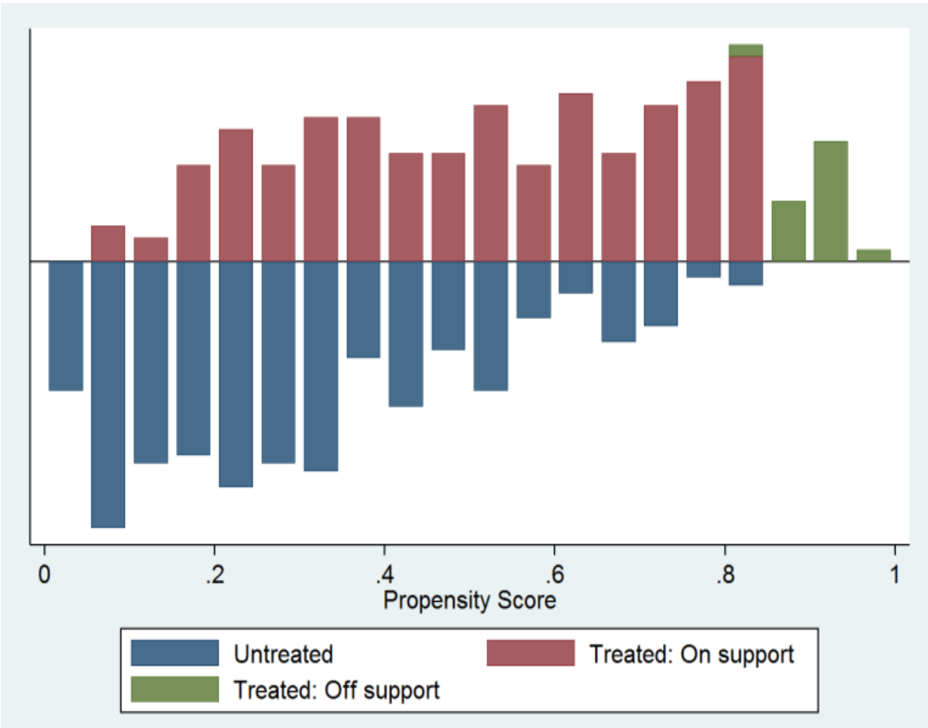

Figure 2.A2 Propensity score distribution and common support for propensity score estimation

Note: Treated on- and off-support are adopting households that have matches and no matches in the control group respectively; source: own calculation based on household survey data.
Source: Authors' calculation based on 2013 household survey data

Table 1.A1 Matching quality indicators for before and after matching

Matching Algorithm	Model specified	Pseudo R^2 before matching	Pseudo R^2 after matching	P>chi^2 before matching	P>chi^2 after matching	Mean bias before matching	Mean bias after matching	%|*bias*| reduction
NNM[1]	Logit	0.211	0.049	0.000	0.336	22.4	9.7	56.7
NNM[2]	Logit	0.211	0.028	0.000	0.883	22.4	7.7	65.6
PSM[3]	Logit	0.211	0.032	0.000	0.826	22.4	8.2	63.4
PSM[4]	Logit	0.211	0.020	0.000	0.994	22.4	7.1	68.3

*Note: * significant at 10%, ** significant at 5% and *** significant at 1% levels;*
NNM[1] = single nearest neighbor matching with replacement, common support and caliper 0.06
NNM[2] = five nearest neighbor matching with replacement, common support and caliper 0.06
PSM[3] = Propensity score matching (1:1) with common support and bandwidth 0.06
PSM[4] = Propensity score matching (1:5) with common support and bandwidth 0.06

CHAPTER 3: ADOPTION OF INTERRELATED LIVESTOCK TECHNOLOGIES: THE CASE OF BEST-BET AAT MANAGEMENT PRACTICES IN ETHIOPIA

This paper is an extended and revised version of the paper:

"Understanding the adoption decision of livestock farmers: the case of Best-Bet AAT management practices in Ethiopia." This paper was presented at the Association of Institutions for Tropical Veterinary Medicine (AITVM) and the Society of Tropical Veterinary Medicine (STVM) conference in September, 2016 in Berlin, Germany

Abstract

Using data from 485 small scale livestock farmers in Ethiopia, this paper investigates adoption interrelated best bet practices (BBPs) to manage the African animal trypanosomosis (AAT). The study investigates whether the BBPs are complementary or substitutionary in nature based on how farmers adopt them. The results show that there is significant negative correlation between the BBPs suggesting a possible substitution effect. Our results further show that different household and village level characteristics drive BBPs adoption. Specifically, these drivers are education, information and wealth variables. The results also show a positive correlation between BBPs adoption and livestock productivity. These results suggest an opportunity for policy formulation to strengthen and improve institutions that are central to education and information delivery and also to maintain or improve household accumulation of specific assets in order to improve BBPs adoption.

JEL classification: Q10, Q12, Q18, C32

Keywords: Trypanosomosis, adoption, multivariate probit, livelihoods, best–bet–practices, Ethiopia

3.1. Introduction

Livestock keeping is an important livelihood strategy for rural households in the highlands of Ethiopia especially because of declining soil fertility, climate variability and other constraints that affect staple crop production (Gelan et al., 2012). The importance of livestock is estimated to grow in coming years as more crop land become less productive and the demand for protein related food increases because of population growth and rising urbanization. However, livestock productivity has stagnated or growing slower than expected because of diseases and the low or lack of improved input use. Livestock diseases affect farmers negatively through it effects in increasing production cost, dampening demand for livestock products, crop production, human health and on the environment. The most important disease with economic effects on livestock production and productivity in sub–Saharan Africa (SSA) is the African Animal Trypanosomosis (AAT).

AAT causes production losses between US$ 1.0–1.2 billion and US$ 4–4.5 billion per annum in treatment costs (Mattioli et al., 2004; Budd, 1999). However, its control remains elusive for a number of reasons. First, an upsurge of drug resistance has rendered trypanocide the most popular control method ineffective against AAT (Grace, 2005; Clausen et al., 2010). Second, the lack or insufficient regulation of veterinary input market causing the influx of substandard trypanocides. Third, the peculiar nature of the tsetse fly has rendered the vector control methods either ineffective or unsustainable in the long run. Fourth, the use of AAT resistant breeds remains less attractive among farmers because of low economic returns and productivity traits (low milk production, small size, and low productivity) that are important to farmers (Clausen et al., 2010; Mungube et al., 2012). AAT control must shift from conventional trypanocide methods to a more integrated approach with emphasis on disease preventive practices and enhancing the immune system of animals.

The use of integrative practices although not new in the agricultural literature it is limited in the livestock literature (Hendrickx et al., 2004; Holmes, 1997). Integrated AAT control practices hereafter called Best Bet Practices (BBPs) include need based use of trypanocide by– or under the supervision of trained animal health personnel, use of sustainable and effective vector control methods (impregnated insecticide nets, pour-ons and traps) and use of a range of husbandry practices that improves livestock health e.g. strategic deworming and feed supplementation (Hendrickx et al., 2004; WHO, 1987; Clausen et al., 2010). Benefits of BBPs are twofold. First, optimal trypanocidal use has direct effect in reducing the growing drug resistance menace in SSA. To the livestock keeping household, this will result in some savings in the long run. Second, BBPs adoption reduces general disease prevalence and other infections. Improved livestock health translates to productivity and incomes gains to the farmer. However, notwithstanding these potential benefits, adoption of BBPs generally remains low among cattle farmers in SSA (Liebenehm et al., 2011; Grace, 2005). The empirical question then is; why farmers are not adopting BBPs to minimize disease effects and enhance livestock productivity? This means empirical investigations are needed to understand technology adoption decision of rural livestock keepers minimize the rising negative effects of AAT and trypanocide resistance. Also, empirical literature that investigates the simultaneous adoption of integrated livestock disease control practices is scant. The objective of this paper is to contribute to filling this gap in the empirical literature. The paper uses data from the European Commission funded Trypanosomosis Rational Chemotherapy (TRYRAC) project for sub-Saharan Africa to investigate the drivers of several BBPs among cattle farmers in Ethiopia. We specifically investigate the simultaneous and interdependent adoption of (1) rational drug use (RDU), (2) vector (tsetse) control, (3) regular deworming, (4) feed supplements (good husbandry).

The contribution of this paper to the existing literature is two-fold. First, the choice of empirical strategy employed i.e. multivariate probit (MVP) model makes a more comprehensive and robust analysis of the interdependence of the BBPs possible. The paper provides evidence on the complementarity or substitutability in technologies disseminated as a bundle such as BBPs. To the best of knowledge this is a novelty in the livestock literature. Second, the paper provides evidence of the role of policy relevant variables such as extension services, farmer knowledge and the role of focal persons in adoption of technology. This is especially important for Ethiopia where policies have traditionally been targeted to enhancing the productivity of cereals and other cash crop (coffee) sub-sectors (Gelan et al., 2012).

The rest of the paper is organized as follows: Section 2 presents an over-view of the current state of AAT in Ethiopia. Section 3 presents the conceptual and analytical framework with emphasis on the empirical method of choice. The study area and data setting is presented in section 4. In section 5 the MVP results and discussion is presented while section 6 summarizes and concludes the paper.

3.2. AAT outlook and management in Ethiopia

Trypanosomiasis is an important zoonotic cattle disease that is transmitted mechanically by the tsetse fly Glossina *spp.* (*tabanus* and *stomoxys*). While acute case of the disease is fatal, most cases remain chronic resulting in loss of appetite, weight and prolonged diarrhea (Simarro et al., 2010). To the farmer, AAT causes direct losses through morbidity, mortality and reduced productivity of animals. In terms of crop production, AAT limits the use of animal draught power, timely implementation of cropping activities or in some cases total abandonment of productive fertile lands for crop production (Shaw et al., 2015; Bekele et al., 2010). This can further worsen liquidity problems and consumption. In Ethiopia, livestock farmers along the Ghibe River are the most at risk of AAT (Sheferaw et al., 2016). Farmers in these areas are typically affected disproportionately because of their dependence in cattle to support most of their livelihood activities and the absence of adequate or sustainable coping strategies (Carter et al., 2007). The control of AAT thus can be an important policy instrument to improve the welfare outcome of these households.

Different control methods have been developed and introduced to cattle farmers in the Ghibe river region for managing AAT. While use of trypanocidal drugs remains popular among, drug efficacy issues and upsurge in trypanocidal resistance strains make it less effective (Grace et al., 2010; Liebenehm et al., 2011; Clausen et al., 2010). For example, up to 90% of treated cattle tested in Ethiopia showed resistance to trypanocides (Miruk et al., 2008; Moti et al., 2012). Also, vector control and use of trypanotolerant cattle breeds have limitations when implemented alone. For example, tsetse fly control methods such as aerial/ground spraying, targeted pesticide spraying or use of odor baited traps although effective in the short run faces sustainability issues because of budgetary demands. Low productivity returns (low milk) and other economic traits on the other hand makes the use of trypanotolerant breeds less appealing to farmers (Clausen et al., 2010; Bauer et al., 1999). These reasons reinforce the need for an integrated approach where multiple tested and effective control strategies are used complementarily to control AAT the most important livestock disease.

3.3. Conceptual and estimation strategy

We model the adoption decision along the discounted expected utility maximization theory and risks attitudes of households. Farmers as rational economic agents are risk averse and will mitigate losses caused by AAT by choosing a combination of practices that will yield the highest returns on their cattle. Adoption of BBPs offers a sustainable pathway to mitigating this risk in their farms. As described in earlier sections of this paper, BBPs is a bundle of complementary practices that are mutually exclusive available to the farmer. We argue that utility is not only maximized by full scale adoption of these practices but utility may be maximized in partial adoption. Following the framework of Gramig et al. (2010) the expected profit maximization function is given as:

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

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. The disease load is a function given as $D(V_P, R)$such that (R) is variable inputs and V_P is a $\mathrm{K} \times 1$ vector of disease management inputs. P_V is a $\mathrm{K} \times 1$ vector of disease control input prices that corresponds to the disease control inputs V_P. If we denote V_P by $y_k \in [0,\ \infty]$ such that $y_k$represents a mean positive integer count of BBPs. K is a list of mutually exclusive practices such that the adoption of one does not inhibit the adoption of others as long as doing so will increase the marginal utility.

Following the utility maximization theory, the farmer will adopt y_k based on the assessment of expected returns by way of effect on AAT load occasioned by the k practices. Formally, adoption will be observed for $y_k > 0$ if

$$\pi_k^A > \pi_k^{NA} \qquad (2)$$

where, π_k^N and π_k^{NA} are the utility (profits) from adoption and non-adoption of k practices respectively. Substituting eqn. (2) into eqn. (1) and rearranging gives:

$$P_Q Q_0[F(D(0)) - F(D(y_k))] > P_k \qquad \forall y_k > 0 \qquad (3)$$

We assume farmers know the effectiveness of y_k in eqn. (3) given as $F(\mathrm{D}(\mathrm{y_k}))$. It follows that the number of y_k adopted dependents on prevalence and severity of disease $F(\mathrm{D})$ and is only observed if the utility maximized from adoption is greater than the cost of the practice P_k as in eqn. 3. From the foregoing framework, the adoption model should be estimated after the established relationship between individual management practices and disease prevalence or severity is estimated. However, in this study, we bypass this step and estimate directly the adoption decision because the BBPs we consider have a positive correlation with managing AAT severity and prevalence (Clausen et al., 2010; Mungube et al., 2012). In the next section we describe how we empirically implement and estimate our model.

3.3.1. Empirical model specification

The multi variate probit (MVP) model is used to empirically estimate the joint adoption BBPs while identifying the complementarity or substitutability of the individual practices. If substitution effect is observed among practices, then the probability of adoption for each additional BBP will decrease after the first an indication of negative correlation. Similarly, the reverse will be observed if practices complement each other (positive correlation). Therefore, failure to account for such correlations will result in bias and inefficient estimates. The MVP model jointly estimates the adoption of the different BBPs while taking into account the potential correlations between the error terms (Belderbos et al., 2004). Furthermore, MVP captures unobservable correlations among outcome variables producing coefficients that are robust to hidden bias compared to discrete binary models (Yegbemey et al., 2013).

If we assume that the i^{th} farmer faces a decision of adopting a set of K binary BBPs (such that k includes veterinarian treatment, regular deworming, use of feed additives and vector control). Adoption of the k^{th} BBP for the i^{th} farmer will be observed if:

$\mathrm{Y}_{ik}^{*} = \pi_k^A > \pi_k^{NA} > 0$, where Y_{ik}^{*} is a latent variable and is a linear function of household characteristics, farm and other village level fixed effects given as:

$$Y_{ik} = \beta \mathrm{X}_i + \varepsilon, \qquad (4)$$

where, $\mathrm{Y}_{ik} = \begin{cases} 1 & \text{if } \mathrm{Y}_{ik}^{*} > 0 \\ 0 & \text{otherwise} \end{cases}$ and X represents various demographic, technology and village level characteristics that are expected to influence the adoption decision and ε is the error term.

The adoption decision for the different BBPs is specified as follows:

$$\mathrm{Y}_{i1} = \beta \mathrm{X}_{i1} + \varepsilon_1, \text{ for } \mathrm{K} = 1 \quad \text{(veterinarian treating)} \qquad (5)$$

$$\mathrm{Y}_{i2} = \beta \mathrm{X}_{i2} + \varepsilon_2, \text{ for } \mathrm{K} = 2 \quad \text{(vector control)} \qquad (6)$$

$$\mathrm{Y}_{i3} = \beta \mathrm{X}_{i3} + \varepsilon_3, \text{ for } \mathrm{K} = 3 \quad \text{(feed additives)} \qquad (7)$$

$$\mathrm{Y}_{i4} = \beta \mathrm{X}_{i4} + \varepsilon_4, \text{ for } \mathrm{K} = 4 \quad \text{(deworming)} \qquad (8)$$

As explained, one advantage of the MVP estimation procedure is that it explicitly allows the error terms ($\varepsilon_1, \varepsilon_2, \varepsilon_3$ and ε_4) to freely correlate allowing eqns. (5) – (8) to be jointly estimated. Since the adoption of multiple practices is possible, the error terms jointly follow a multivariate normal distribution with a zero conditional mean and variance normalized to zero with a covariance matrix ρ:

$$\mathrm{E}[\varepsilon_1] = \mathrm{E}[\varepsilon_2] = \mathrm{E}[\varepsilon_3] = \mathrm{E}[\varepsilon_4] = 0 \tag{9}$$

The covariance matrix ρ is given by:

$$\begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 \end{bmatrix} \tag{10}$$

The leading diagonals of the matrix representing the error terms has a value of 1 while the off-diagonal covariance matrix representing the unobservable correlations between the BBPs that are to be estimated.

3.3.2. Factors affecting farm technology adoption

According to the empirical literature, a variety of variables on household, farm, institutional and village level drive adoption (Adesina and Baidu-Forson, 1995; Chi et al., 2002; Mafimisebi et al, 2006; Doss, 2006). Household head age is often associated with willingness to take risk. For example, younger farmers are considered less risk averse and are more likely to try out or adopt new technology or practices (Adesina and Baidu-Forson, 1995; Ward et al., 2008). New technology adoption sometimes requires additional labor or resources to implement and several studies have found household size a proxy for labor to be a critical determinant of new technology use albeit mixed. For example, one strand of literature argues that households with higher working age class remains important for labor intensive technology. Household sizes may diversify into other off-farm employment opportunities as coping strategy against risk reducing the probability of such households adopting farm technology because of increase labor availability. Also, bigger household size can exert pressure on household expenditure because of household consumption needs that may reduce the available capital required to invest in new technology (Doss, 2006; Kassie et al., 2013; Khonje et al., 2018). Access to information is important for household decision on adopting new farm technology (Shiferaw et al., 2012). Formal education may be a proxy for access to information on technology and as well as understanding the benefits of a technology. For example, Asfaw et al. (2012), Abdulai et al. (2008) and Kassie et al. (2018) all find that educational level of household heads influence adoption decisions although the direction of effect may depend on the years of education and the characteristics of the farm technology. As noted by Ward et al. (2008) increase formal education is positively correlated with the opportunity for off-farm employment serving as a disincentive for on farm investment. This is especially the case if the new technology would require additional investments. In this study, we hypothesize that household head education improves access to information as well as increasing the understanding of livestock disease management therefore increasing adoption.

Farmer experience given as the number of years measured as the number of farming years can determined to a large extent their willingness to adopt a new technology. Experience comes with accumulation of knowledge to be able to elicit the benefits a new technology quickly. In terms of disease and pest control technology, experience is especially critical because more experienced farmers are able to assimilate the negative effect of outbreaks on their livestock and therefore driving adoption of technology for their control. For example, according to Chi et al. (2002) farmers who have reported disease incidence in the past among their flock were more likely to adopt improved management practices. However, experience may also have a negative effect on accepting new technology especially when there is bad experience with technology adoption in the past. In this case farmers self-innovate to mitigate the losses reducing the adoption of mainstream farm technologies. To reverse such effects, enhance education that on the benefits of the technology must the roll out of the new technology (Adesina and Baidu-Forson, 1995). To capture the effect of past disease experience, we include reported AAT morbidity and mortality in the herd. AAT is associated with decline in cattle productivity hence we expect that past incidence of the disease would push households to prioritize disease prevention and management in the future by adopting BBPs.

Farm level variables such as herd size and cattle species are also important determinants of disease management practices adopted by farmers (Mafimisebi et al., 2006). Although herd size captures wealth effects, it may also capture unobservable traits such as the risk attitudes of the farmers. According to Abdulai et al. (2008), although small scale farmers are typically risk averse to new technology adoption, the prospects of an extra investment requirement of new technology is usually the underlining factor constraining adoption farmers. In this regards therefore, the wealth role of heard effects outweighs the proxy risks attitude as a driver of technology adoption. To capture both the wealth constraint effect of technology adoption we include herd size and asset value of the household minus livestock in Ethiopia Birr in our estimation. Livestock diversification measured as ownership of other livestock measured as the Tropical Livestock Units (TLU) determines how much time and resources are devoted to cattle management and disease control in particular. Disease effect on the herd is determined by the mix of the herd since the type of management system is determined to the large extent by the category of cattle kept (Taye et al., 2012). For example, the effect of AAT on a herd where majority of the cattle are made of calves will be less compared to full adult calves. This is because calves are mostly left in the kraals when cows are sent to graze in the fields. The decision of the farmer to invest in AAT control for his animals can thus be shaped by the category of cattle owned. To capture the effects of the cattle category in the adoption decision, we include dummies to control for presence of calves in herd.

Finally, to enhance knowledge of AAT such as causes, transmission, control and impacts can be a critical determinant in the disease management decision of the farmer. For example, farmers can adopt vector control practices such as traps, the use of impregnated nets to control tsetse flies when they know that a reduction in the tsetse fly loads will lead to a reduction in AAT in the herd. Similarly, preventive practices such as feeding the animals well, avoiding tsetse hot spots or prevention of secondary infections through deworming can be adopted by farmers with enhance knowledge and education. The knowledge variable is especially important in our study of rural farmers in SSA where farmers are still likely to attribute the disease in their animals to spirituality of competitors or enemies, magic or just bad luck hence cannot be prevented or treated. A proper understanding of AAT would remove these misconceptions and drive the adoption and use of BBPs. To capture this knowledge effect, we include in our estimation a variable that capture the farmer ability to identify AAT (ability to identify the cause of AAT) and its effects. To capture different heterogeneous locational effects such as tsetse population and other spatial effects on the adoption decision, we further include as controls dummies for the 3 different districts.

3.4. Study area and data description

The data for this study is from a comprehensive household survey conducted in 2013 European Commission for the Trypanosomosis Rational Chemotherapy (TRYRAC) project in Ethiopia. Cattle farming households from 20 villages spread across Cheha, Abeshege, and Enemor and Eaner Woredas (Districts) in the SNNP region were surveyed for the study. 20 Respondent household heads per village were randomly selected from a list of cattle keeping households in each village compiled by the agricultural/veterinary services in consultation with the village head. To ensure the complete randomization of the sample, a unique random number system was generated and assigned to each household using computer algorithms. These unique numbers were then put into a pot and randomly drawn and the corresponding household identified to be surveyed. A comprehensive questionnaire was developed together with stakeholders (private and public veterinary personnel, cattle farmers and village opinion leaders) in the management and control AAT in the SNNP region. The questionnaire was translated into the indigenous Amharic language, pretested and necessary adjustments made with the assistance of regional and district veterinary officers. Trained local University students with experience in the local village and district setting were trained and used to administer the questionnaire as a way to ensure the highest data quality and etiquettes. Data collection period was between January and March 2013 and included information on household demographics, agricultural production (input and output) data, consumption and expenditure data, assets as well as risks and shocks the household reported. All recall data was based on the last 12 months prior to survey date. We also collected the knowledge, attitudes and practices (KAP) of farmers on AAT management and control. The KAP captured how knowledgeable respondents are about AAT, such as morbidity and mortality, as well as treatment and prevention of AAT.

The unit of analysis is the household head or the person responsible for taking decisions relating to cattle production and disease management in the household. Thus, the survey questionnaire was administered to the household head. Other household members were allowed to be present and in some cases help to compute data especially consumption expenditure which is usually provided by woman respondents. This is to minimize possible recall bias.
In the next section we present the descriptive statistic of respondent households.

3.4.1. Descriptive characteristics of households

Table 3.1 presents selected characteristics of the respondents. Majority (94%) of the respondents are males an indication of gender disparity in the ownership of productive assets as well as decision making at the household level in the study. The average household head is 47 years with a mean household size of 7 and own at least one 0.65 ha plot of land. Formal education is low among respondents. The average education of the household is 3 years of formal education with 51% of the respondents having some kind of formal education. About 89 % of the households belong to at least one social network group (farmer group, Edir group, or cultural association).

Next, we compare adopters and non-adopters of BBPs using Pearson chi^2 test and two sample t-test for categorical and continuous variables respectively. We find that adopters and non-adopters do not differ significantly in most demographic characteristics aside age. Adopters are significantly younger (46 years) compared to non-adopters (50 years). Adopters have a higher per capita income than non-adopters and also recorded significantly higher AAT prevalence, scored higher in terms of knowledge AAT and also reported more number of drug resistance cases in their herd (see Table 3.1). These findings may indicate the role of disease prevalence, drug resistance and other disease characteristics in the adoption and intensity of use of BBPs by the household. As explained in the factors driving adoption, risks attitudes play critical role and could be the reason for the observed in age differences between adopters and non-adopters since the literature on technology adoption show that younger farmers are more likely to try new technology (Ward et al., 2008; Adesina and Baidu-Forson, 1995).

Table 3.1 Household characteristics of respondents

Variable	**Pooled Sample**		**Non–adopters**		**Adopter**		**P-value**
Household characteristics	*Mean*	*S.D*	*Mean*	*S.D*	*Mean*	*S.D*	*Pr(|T|>|t|)*
Age of HH (years)	47	13.41	50	11.9	46	13.43	0.005**
Gender HH (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 hh (1=yes)	0.88	0.75	0.48	0.50	0.51	0.50	0.495
Years of formal education hh (years)	3.02	3.71	2.7	3.60	3	3.68	0.428
Social network (1=yes)	0.89	0.31	0.86	0.34	0.90	0.30	0.360
Income per capita (PPP$)	590.3	2107	382	532	647	2358	0.044*
Farm characteristics							
Own land (1=yes)	0.99	0.10	0.97	0.16	0.99	0.10	0.166
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
Cattle herd size	1.17	1.20	1.01	1.12	1.20	1.20	0.320
AAT information							
Prevalence of AAT in last 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)	1.56	1.75	1.3	0.26	1.6	0.11	0.396
HH reporting cattle death (%)	52.16	50.0	56.7	49.7	50.9	50.0	0.2928

Note: *** p<0.01, ** p<0.05, * p<0.1 level of significance, S.D; standard deviation, hh; household head; ha, hectare

Source: Authors' calculation

Livestock products present most rural households in SSA the only viable and sustainable pathway to the capital market being the only capital asset owned that can be liquidated to generate cash income in the absence of well-developed and integrated labor and other factor markets (Herrero et al., 2012; Leta et al., 2016). Livestock products such as draught power, milk, and manure and transport (Table 3.2) have been produced by respondents in 2013. From Table 3.2, we find that these products are for own home consumption with a fraction of the total proportion sold locally to supplement household income. Draught power and manure are important inputs for staple crop cultivation. In addition, income from livestock products and live animal's sales can be used to buffer households against economic shocks such as loss of employment and falling crop prices.

Table 3.2 Cattle products by households and how they are used in 2012

		Mean output	Usage (%)	
Type of product	**Units**	**p.a**	**Home**	**Sold**
Traction	Hectares	45.7	96	4
Transport	Hours	347	96	4
Milk	Liters	116.9	94	6
Manure	Kilograms	49.8	98	2
Meat	Kilograms	60	82	18

Note: HH, household; p.a, per annum
Source: Authors' calculation

As discussed earlier, the BBPs include rational drug use (RDU) i.e. trypanocides administered by veterinary personnel, feed supplements (good husbandry routine), regular deworming and vector control (use of traps and insecticides or "pour-ons" to treat tsetse flies and other biting insects). The adoption and use of these practices is presented in Table 3.3. Most (about 89%) of the respondents adopted at least one of the BBPs. This can be an indication that respondents are concerned about the control and management of AAT and the associated infections. This is not surprising because of the high incidence of AAT reported among respondents (see Table 3.1). The other reason may be the continuous and sustained of the Ethiopian government and development partners to control AAT in most cattle producing regions (Degu, 2012; Shaw et al., 2015; Leta et al., 2016). However, very interesting is that from Table 3.3, the intensity of adoption BBPs remains low among respondents. This finding is problematic given the inefficiencies of the individual packages when adopted alone especially sustained use of trypanocides; the single known cause of drug resistance among cattle.

Table 3.3 Intensity of best bet practices adopted

BBPs adopted	Households	Percentage
0	53	11
1	223	46
2	210	43

Source: Authors' calculation

In Table 3.4, we present the specific actual BBP adopted. We find RDU (treatment with ISM/DIM[5]) and feed supplements to be most adopted among respondents. About 60% of the respondents adopted RDU while 45% adopted feed supplements. From Table 3.4, regular deworming of cattle remains the least popular practice with only 5% of respondent having dewormed their animals in the last 12 months prior to the survey.

Table 3.4 Distribution of adoption of best bet practices by respondents

Best bet practice	Frequency	Percentage of HHs
Call a vet to treat	290	59.67
Regular deworming	25	5.14
Feed supplements	220	45.27
Vector control (traps & insecticides)	108	22.22

Note: HH, household; p.a, per annum
Source: Authors' calculation

As seen in Table 3.4, RDU is popular among respondents and that could be a possible cause of the high resistance rate among cattle in the study area as reported by Taye et al., (2012) and Moti et al., (2012).

To understand the relationship between the BBPs presented in Table 3.4, we perform a pairwise correlation test. The results are presented in Table 3.5 indicating a negative correlation between BBPs except for vector control and RDU that is positive. These results suggest that BBPs are adopted as substitutes rather than complementing one another. Two possible explanations may be adduced for the negative correlation: First, lack or inadequate information and training by extension services on BBPs. Farmers are not well informed about increase curative and preventive benefits when the BBPs are adopted and implemented as a bundle together. This

[5] Isometamidium (ISM) and diminazene (DIM) the two most effective and widely available trypanocides for treating AAT.

reduces the likelihood of multiple practice adoption. Second, resources constrain may prevent respondents from adopting more BBPs even if they are interested.

Table 3.5 Spearman correlation tests of best bet practices

	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 1 % level
Source: Authors' calculation

There may be a spillover effect of the role of veterinary personnel which explains the positive relation between RDU and vector control practices. Veterinary personnel administering the RDU may directly treat the animals against insects and thus explaining the positive correlation observed.

The adoption of BBPs is expected to improve livestock productivity outcomes through its impact in reducing AAT and other disease loads. In the following we present and discuss the possible impact of BBPs adoption on milk output. Figures 3.1–3.4 presents the cumulative distribution of milk production in liters with and without the adoption of each BBPs. The results show that milk output for adopters holds first order stochastic dominance for all BBPs except for deworming where it has a second order stochastic dominance (Figure 3.2). These results suggest that adoption of BBPs has positive impact on cattle productivity – high milk output.

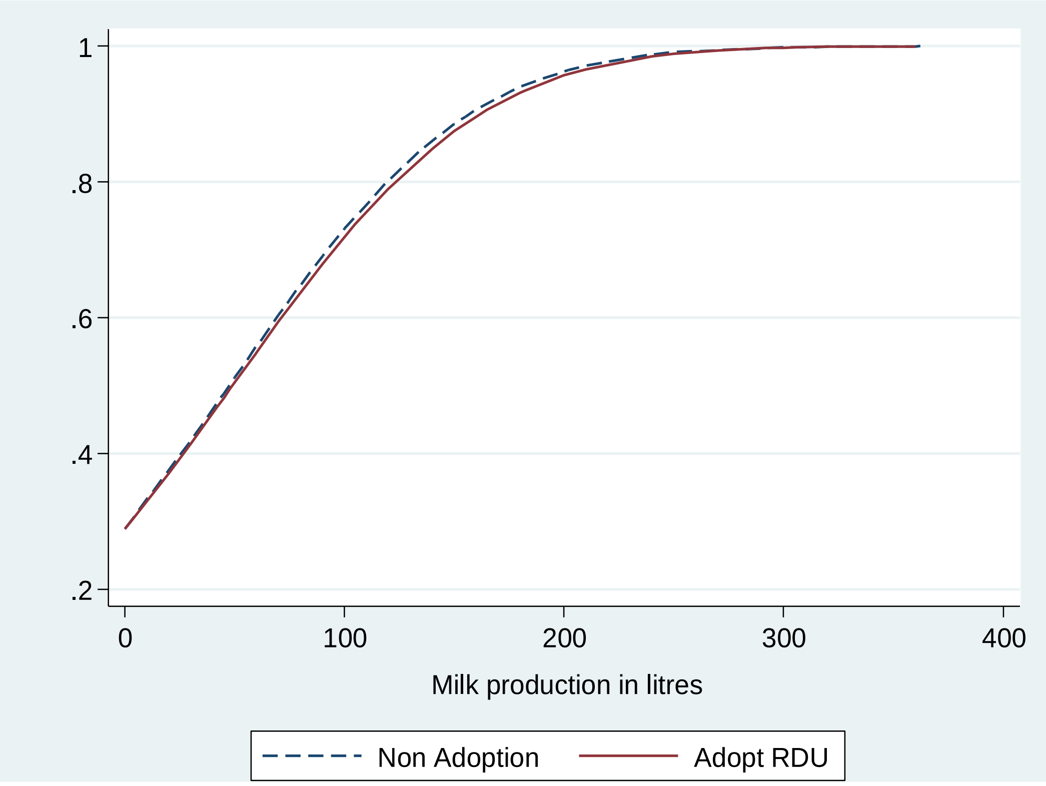

Figure 3.1 Impact of RDU adoption on milk production in liters

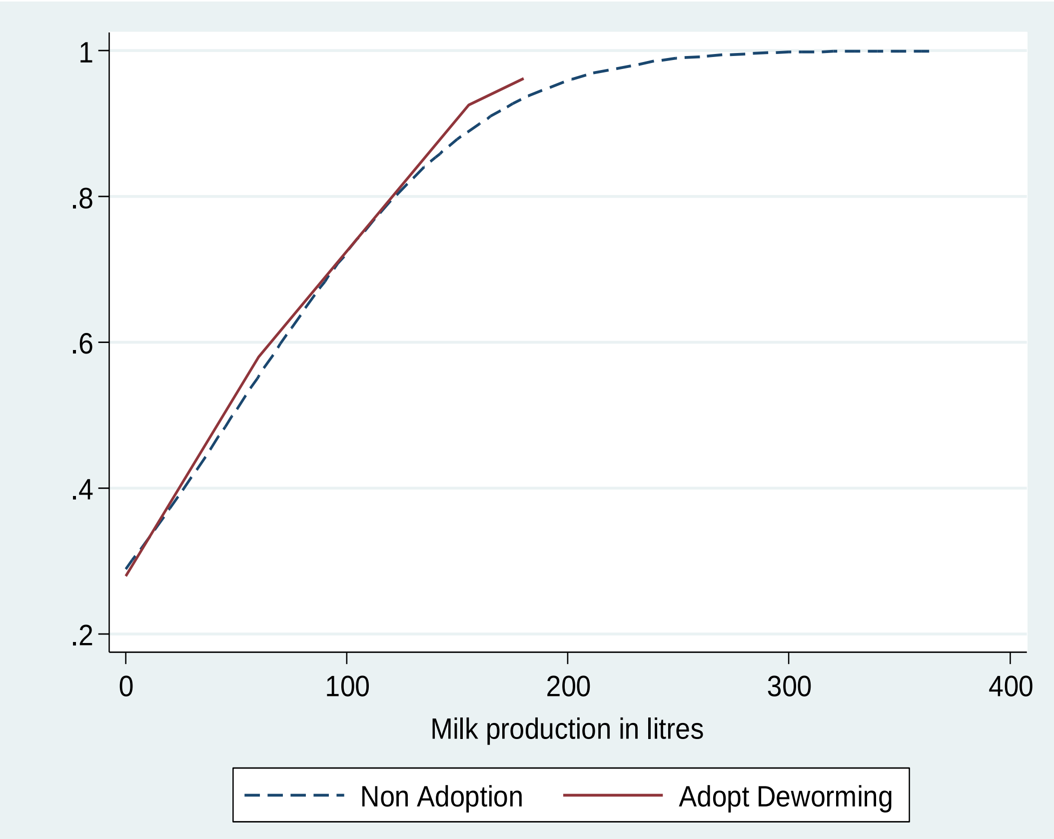

Figure 3.2 Impact of deworming on milk production in liters

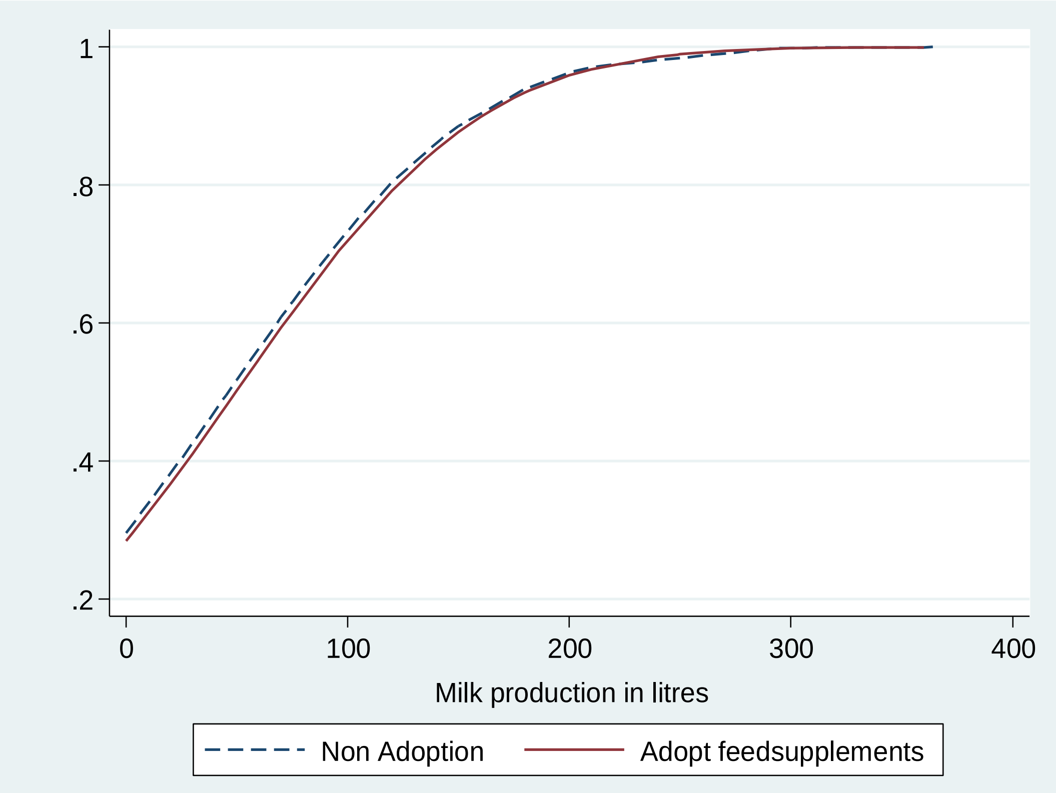

Figure 3.3 Impact of feed supplements on milk output in liters

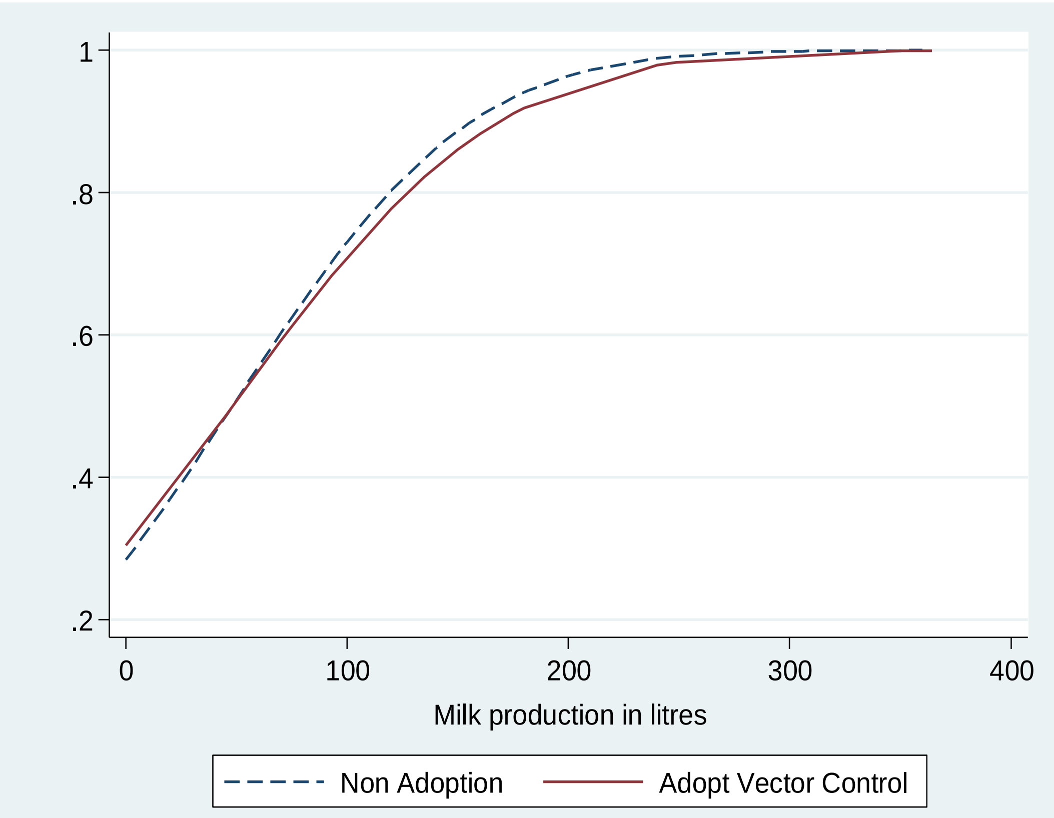

Figure 3.4 Impact of vector control on milk output in liters

Although Figures 1–4 suggest a positive impact of BBPs on the cattle productivity, we interpret these results advisedly because causal inference need vigorous analytical strategies to determined which are beyond the scope and objective of the current study. Nonetheless these results provide a good premise to promote and stimulate the adoption of BBPs for control and management of AAT and other coinfections.

In the next section we present the econometric results of the adoption model.

3.5. Results and discussion

The results of the multivariate probit (MVP) estimation is presented and discussed in this section. Before we discuss the econometric results, first, we discuss the model goodness of fit in Table 3.6. The model fits our data well with a Wald's test chi^2 (101) = 475.63, P = 0.000 which means that we reject the null hypothesis that all regression coefficients are jointly equal to zero. Similarly, the likelihood ratio test (Chi^2 (6) = 128.594, P<0.000) of independence of the error terms is strongly rejected at 99% confidence level. We therefore reject the hypothesis that the decision to adopt BBPs is mutually independent therefore our choice of the MVP model acceptable for modelling the adoption of BBPs in this study. Two of the covariance of the error terms are statistically significant (rho21 and rho42) which indicates a significant correlation between the outcome equations giving supporting our choice of the MVP model. The covariance of the error terms of all equations estimated is presented in Table 3.6.

Table 3.6 Covariance of the error 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:
Chi2 (6) = 128.594 Probability > chi2 = 0.0000
Source: Authors' calculation

Returning to the regression results in Table 3.7, we find that adoption of BBPs is influenced differently by household and village level covariates. For example, we find that age of the household head is only significant and positively influences RDU adoption. Older farmers may be able to accumulate experience to understand that veterinary treatment of yields good results.

It could also suggest that older farmers use the veterinary to overcome the labor requirements in self–treatment. Household head having formal education significantly increases the adoption of RDU and feed supplementation. This suggests a bridging role of education between research and technology users to fully appraise adoption benefits. This finding is consistent with the findings of Asfaw et al., (2012); Kassie et al., (2013); Manda et al., (2018). However, we find a reverse effect of education on adopting deworming. This is counterintuitive and may suggestive an information asymmetry and lack full information. This reflects the inability of respondents to link worm control (deworming) to a disease (AAT) that is caused by the tsetse fly.

Land ownership has a mix effect on BBPs adoption. Farmers who had multiple plots are more likely to adopt vector control but less likely to adopt RDU. Land ownership is a proxy for wealth thus suggests the role of wealth in adopting new technology especially when new investments are a pre-requisite as is the case with vector control. This finding is in line with Teklewold et al. (2013) and Manda et al. (2018) who find similar wealth effects on technology adoption in Ethiopia and Zambia respectively.

Respondent's membership of social network increases the likelihood of adopting deworming. Social networks in the absence of strong formal extension institutions serve as information sharing platforms where farmers share knowledge and experiences thereby shaping technology use decisions. This is consistent with Kassie et al. (2013) and Wollni et al. (2010) who conclude that social network exerts a positive influence on members to increase technology adoption. However, we find a reverse effect of social network on RDU adoption. This is counterintuitive and suggest free rider problem caused by misinformation or inadequate education about AAT where farmers think their cattle can benefit when others in their social network administer RDU.

Ownership of television positively increases adoption of vector control suggesting the role of access to information. However, we find the opposite effect on adopting feed supplements. Although this is counterintuitive we explain this negative effect on the lack of advertisement of livestock feed supplement in media in rural area where farmers mainly free graze their livestock. In terms of the role of knowledge of the diseases, we found that farmers who correctly identified the cause and transmission mechanism of the AAT increase the likelihood of adopting vector control. This is consistent with the finding of Liebenehm et al. (2011) in Mali and Burkina Faso. We include a location dummy to capture the locational effects of the kraal on farmer's adoption decision. The results show that farmers who had their kraals close to a watershed were more likely to adopt vector control and significantly less likely to adopt feed supplement with no effect on RDU. In terms of the role of shocks, it was found that reported crop shocks in the previous year increases vector control adoption but reduces deworming adoption. Inputs such pesticides usually have an overlap function for crop production hence reducing the costs constraint faced in purchasing new inputs to adopt vector control. The role of input constraint may be shown in the correlations results presented in Table 3.5 where a negative relation between vector control and deworming is observed. This means respondents are only able to adopt and implement one practice at a time and not both simultaneously.

Table 3.7 Coefficients estimates of the MVP model of adoption

Explanatory variables	Dependent variables			
	Rational Drug Use	**Vector control**	**Deworming**	**Feed supplement**
Age (years)	0.012 (2.07)*	-0.011 (-1.60)	-0.011 (-1.05)	-0.005 (-0.80)
Gender (male=1)	-0.151 (-0.55)	0.086 (0.29)	0.327 (-0.83)	0.359 (1.31)
Dependency ratio	-0.046 (-0.52)	-0.02 (-0.19)	0.116 (0.56)	-0.016 (-0.16)
Household size	-0.003 (-0.12)	0.005 (0.17)	0.105 (-1.95)	0.01 (-0.3)
Formal education(yes=1)	0.458 (2.79)**	-0.302 (-1.72)	-0.888 (2.96)**	0.490 (-2.55)*
Above primary school (yes=1)	-0.008 (-0.05)	0.075 (0.36)	-0.187 (-0.50)	-0.04 (-0.21)
Number of plots	-0.253 (-4.79)***	0.231 (4.36)***	-0.176 (-1.20)	0.059 (1.1)
Land size (ha)	0.083 (1.91)	-0.113 (-3.04)**	-0.275 (-0.84)	-0.087 (-2.23)*
Other social network membership (yes=1)	-0.540 (-2.25)*	0.402 (1.54)	0.172 (0.44)	-0.168 (-0.59)
Farmer association membership (yes=1)	-0.385 (-2.31)*	0.145 (0.84)	0.512 (1.97)*	0.107 (0.59)
Herd size	0.195 (3.74)***	-0.103 (-1.78)	0.003 (0.05)	-0.027 (-0.47)
Owns calves dummy (yes=1)	0.362 (1.78)	-0.343 (-1.69)	-0.628 (-1.75)	0.066 (0.31)
Other livestock (TLU)	-0.088 (-0.51)	0.078 (0.38)	-0.518 (-1.52)	-0.336 (-1.71)
Asset value (log)	-0.083 (-1.05)	0.247(2.06)*	-0.001 (-0.00)	0.054 (0.53)
Owns TV (yes=1)	-0.096 (-0.59)	0.771 (4.18)***	0.076 (0.29)	-0.584 (-2.87)**
Owns knapsack (yes=1)	-	0.243 (1.96)	-	-
Source of trypanocides (open market=1)	0.709 (4.24)***	-1.062(-4.24)***	-0.11 (-0.40)	-1.123(-5.72)***
Knows cause of AAT (yes=1)	-0.408 (-1.98)*	0.576 (2.66)**	0.287 (0.66)	0.09 (0.4)
Veterinary contact (yes=1)	0.456 (3.21)**	-0.154 (-1.00)	-0.463 (-2.05)*	0.960 (6.38)***
Crop shock (disease/pest)	0.07 (0.51)	0.300 (2.06)*	-0.834 (-3.55)***	0.051 (0.33)
AAT death in last 12 months (yes=1)	0.03 (0.23)	0.238 (1.63)	-0.012 (-0.05)	-0.02 (-0.14)
Neighbor adopts BBPs (yes=1)	-0.406 (-2.10)*	0.115 (0.42)	0.204 (0.5)	1.220 (5.33)***
Household close to watershed (yes=1)	0.185 (1.12)	0.444 (2.27)*	-0.369 (-1.21)	-0.394 (-1.93)
Location dummy				
Cheha Woreda	0.243 (1.39)	-0.215 (-1.10)	-1.093 (-3.06)**	0.539 (2.73)**
Enemor Woreda	0.346 (2.06)*	-0.325 (-1.76)	-0.827 (-2.99)**	-0.229 (-1.24)
Constant	0.533 (0.63)	-3.792 (-3.32)***	-0.154 (-0.10)	-1.721 (-1.57)

Note: *** p<0.01, ** p<0.05, * p<0.1 level of significance; Tropical Livestock Unit (TLU), robust standard errors are in brackets. (Reference Woreda is Abeshege)
Source: Authors' calculation

Access to veterinary personnel positively influences adoption of RDU and feed supplement. Farmers who had at least one veterinary visit in the last six months are more likely to adopt RDU and feed supplements consistent with the study of Degu (2012) who found agricultural personnel plays a critical role in livestock technology dissemination and adoption in Ethiopia. The mixed results of access to veterinary services may suggest that the service is not fully engaged in new technology dissemination. This presents an opportunity for strengthening of agricultural services to enhance technology adoption. The results also show that farmers' ownership of a knapsack sprayer increases the likelihood of adopting vector control. Our results also show that buying trypanocides (inputs) from the open market increases the adoption of RDU but has the reverse effect on deworming and feed supplements.

Controlling for the district of respondents' it was found that adoption varies across the three districts. The results show that respondents in the Cheha and Enemor and Eaner districts are less likely to adopt deworming compared to Abeshege district. However, RDU and feed supplements are more likely to be adopted by farmers in Enemor and Eaner districts compared to Abeshege. The adoption pattern may suggest that infrastructure, the Ghibe River as a tsetse habitat and overall adoption rate at the district play a role.

3.6. Summary and conclusion

Animal disease, especially the AAT, poses a serious constraint to cattle productivity in sub-Saharan Africa (SSA). AAT incidence affects negatively crop production, household income, savings as well as health and nutrition. Previous studies have shown that the control of AAT can result in a more than proportionate improvement of the livelihoods by livestock keeping households. However, inefficiencies, mostly due to wrong treatment practices has resulted in unintended negative consequences such as drug resistance, increased coinfections and reinvasion of previously eliminated areas of tsetse flies. While empirical literature documents benefits of the so called integrated BBPs, the adoption remains low especially in SSA. This paper uses detailed household and farm level data to investigate determinants of adoption of four interrelated BBPs in rural Ethiopia.

The results of this paper are important for disease management and control policy formulation. The paper demonstrates need for adequate understanding of the relationship between technologies that are disseminated and adopted as a bundle. This enable appropriate dissemination messages to be developed to enhance adoption. The results indicate that the BBPs adoption in general is low in the study area with majority of respondents still depending on the sole use of trypanocide to manage AAT. Furthermore, most of BBPs exhibit a substitution effects which is counterintuitive. This explains the low adoption intensity (maximum of 2 practices out of a possible 4) by livestock farmers. However, this finding is important for designing extension messages of these BBPs to reduce or completely eliminate this negative correlation amongst practices to enhance the benefits of BBPs when adopted in complementary.

This suggests the need for enhanced education on the importance of adopting multiple BBPs in the management of AAT among small scale farmers in rural areas.

On the determinants of adoption, the results show that adoption of different BBPs is driven by different household, and district level as well as institutional variables. Specifically, the result underscores the important role of education, access to information and household wealth and strong and efficient social networks in driving adoption of BBPs in Ethiopia. Household demographics such as age have impact on various BBPs adoption. Similarly, access to veterinary services has a heterogeneous effect on adopting the various BBPs suggesting an opportunity to increase BBPs adoption by improving their capacity and equipping them. In this regards, programs and interventions that improves the access to information and inputs such as input subsidy payments targeted to trypanocides should be considered to lower cost of veterinary service charge to stimulate BBPs adoption. Similarly, policies targeted to improve household asset base such as improved credit access to credit should be pursued as deliberate policy to improve BBP adoption. This will promote cattle health and productivity two important determinants of household welfare for cattle dependent households.

Based on the results, we recommend an improvement in designing extension messages with emphasis on the productivity benefits of combined adoption of BBPs rather than adopting individually. This may be through enhanced training and education of veterinary personnel, focal farmers and more stakeholders. Efforts should also be made to stimulate complementary adoption of BBPs by reducing credit constraint, access to inputs and addressing efficacy issues of inputs.

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CHAPTER 4: RETURNS TO LIVESTOCK DISEASE CONTROL– A PANEL DATA ANALYSIS FROM TOGO

This is an extended and revised version of:

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Abstract

Using a unique panel data set of 445 small–scale cattle farm households from Togo, we investigate the impact of veterinary extension interventions along a thorough impact pathway. More specifically, we separately investigate potential improvements in farmers' knowledge and the adoption of practices and examine how these improvements in herd management and animal health may translate into measurable welfare effects at the household level. Using different econometric estimation strategies, we control for selection bias and possible program endogeneity. The results – which are robust across different specifications – show a positive impact of the interventions on improving farmers' knowledge and husbandry practices translating to the adoption of improved practices. Our results show that the interventions resulted in improved livestock health and productivity while reducing veterinary costs. In terms of household welfare, we find that participating in the interventions increased consumption per capita and decreased vulnerability to poverty of participating households. The results highlight the important role of targeted interventions that aim to improve the health of livestock – a key asset within rural livelihoods in sub-Saharan Arica.

Keywords: Livestock, poverty, vulnerability, interventions, fixed-effects, sub–Saharan Africa

JEL Classification: C36, I30, Q10, Q16

4.1. Introduction

Agricultural production is a major source of household livelihood in sub-Saharan Africa (SSA), offering employment to approximately 60% of the population (IMF, 2014; World Bank, 2014). To sustain their livelihoods, the rural poor must diversify their income sources and strengthen their productive assets to prevent their income from falling below a critical level. Growth in the agricultural sector must continue if poverty in SSA is to decline, mainly because agriculture is more inclusive than formal employment (Taffesse and Tadesse, 2017; Ravallion et al., 2007). Livestock, especially cattle, are an important component of household agriculture in the northern regions of Togo. Cattle serve a multitude of purposes, including draft power for farm cultivation, manure, store of value (insurance), and emergency income, and they supplement the nutritional needs of households (Pica-Ciamarra, 2015; Kazianga and Udry, 2006). Furthermore, in the context of nonexistent off-farm employment opportunities and imperfect credit and insurance markets, cattle remain the only channel into the liquid economy.

However, cattle production is constrained by African animal trypanosomosis (AAT), a livestock disease that has a considerable negative economic effect on household livelihoods. It is estimated that in the SSA region, the disease causes losses of approximately US$ 4.5 billion dollars, including trade losses, cattle mortality, disease control costs and a loss of productive farm working hours (Cecchi and Mattioli, 2009; FAO, 2011; Bud, 1999). At the household level, AAT has direct negative implications for household well-being, such as increased vulnerability to food insecurity and a reduced ability to mitigate idiosyncratic and systemic shocks that could lead to income loss (Liebenehm, Affognon and Waibel, 2011a). For example, Affognon (2007) found that cattle farmers in Mali and Burkina Faso lose approximately €9.50 to €22.00 per tropical livestock unit (TLU) p.a. as a result of AAT.

Current control and prophylactic measures remain ineffective or unsustainable and often result in drug resistance (see Clausen et al., 2011; Grace et al., 2009). Thus, an international multidisciplinary team of scientists, acting in cooperation with governmental and nongovernmental stakeholders with funding from the European Commission, launched the so-called trypanosomosis rational chemotherapy (TRYRAC) program in 2012 (www.trypanocide.eu) to improve small-scale farmers' AAT management practices. TRYRAC is an integrated approach that involves a combination of preventive and curative measures with the goal of reducing overall disease prevalence, encouraging the responsible use of trypanocides to reduce drug resistance and improving the general health condition of animals (WHO, 1987). TRYRAC interventions have promoted an integrated approach to disease control, including participatory extension methods, such as mass media, and trainings for selected farmers on good husbandry, tsetse control, and worm and tick control strategies.

In this paper, we investigate whether and to what extent livestock disease control interventions improve the welfare of small-scale cattle farmers. We collected household panel data on farmers who participated in the TRYRAC program and those who did not, both before and after the TRYRAC intervention took place. This dataset enables us to estimate the impact of AAT control on household welfare. More specifically, we proceed as follows. First, we analyze whether disease control interventions improved cattle farmers' knowledge and disease control practices which, in turn, may lead to improvements in animal health. We assume that increased knowledge could be different from the actual adoption of practices because the adoption decision may be driven by other confounding factors. Second, we investigate the impact of disease control interventions on farm households' welfare, measured as per capita consumption, poverty headcount and vulnerability to poverty.

The paper is among the first to conduct a rigorous impact assessment of livestock disease control in SSA. While the literature on the impacts of technology targeted to livestock is scant, our study complements recent empirical literature on the impact of crop technologies on household well-being in SSA (see Amare et al., 2012; Shiferaw et al., 2008; Asfaw et al., 2012; Kassie et al., 2011). Our study is unique in several ways. First, this study focuses on a region characterized by high poverty, a lack of formal employment opportunities and a lack of credit and input markets. Thus, the study provides new insights for policy recommendations that would improve the livelihoods of vulnerable households in SSA. Second, to the best of our knowledge, this study is the first to evaluate the impact of interventions in the livestock sector at the household level using panel data. Third, the study examines broader welfare outcomes, going beyond stochastic household poverty, to investigate vulnerability to poverty as a determinant of future welfare.

Our estimation procedure uses different methodological approaches to deal with program endogeneity and self-selection bias issues with impact estimation. Overall, the results suggest that the TRYRAC intervention has a positive impact on rural household welfare outcomes. In particular, the empirical results show that by participating in the interventions, households can increase their livestock productivity and reduce the prevalence of AAT and other disease infections in 2016. We show that an increase in productivity has contributed to an increase in household consumption per capita while reducing the probability of falling into stochastic poverty and vulnerability.

The rest of the paper is structured as follows. In section 2, we describe the intervention. The empirical and theoretical methods are presented in section 3. The study area, data setting and collection methods are described in section 4. Section 5 presents the results and discussion, and section 6 summarizes the paper and presents the study's conclusions.

4.2. The TRYRAC intervention program

4.2.1. Background information

AAT is caused by *Trypanosoma spp.*, a pathogen transmitted by the tsetse fly (*Glossina spp.*). Alsan (2015) recently identified the tsetse fly as a historical constraint to economic development in SSA. While acute cases of the disease are fatal, most cases of AAT are chronic, affecting animals over a longer time period with a loss of appetite, prolonged diarrhea and reduced productivity (Simarro et al., 2011). Estimates put the cost of AAT in SSA at approximately US$4.5 billion through animal mortality, lost productivity and treatment cost (Swallow, 2000; FAO, 2011). At the household level, AAT leads to production, consumption and income losses, which perpetuate poverty and food insecurity among the rural poor (Fafchamps et al., 1998; Perry et al., 2002; FAO, 2011). The effect of AAT is high in northern Togo, which is regarded an important cattle production zone. For this reason, the European Union, through its Global Program for Agriculture Research for Development, funded the trypanosomosis rational chemotherapy (TRYRAC) intervention, targeting small-scale cattle producers in the Kara and Savana regions of Togo.

The TRYRAC project represents international cooperation by academic, governmental and nongovernmental organizations aimed at optimizing AAT management in SSA-Togo, Mozambique and Ethiopia. The overall objective is to improve the livelihoods of resource-poor small-scale livestock (cattle) keepers in the selected countries. The project has been implemented in three phases, i.e., (i) baseline, (ii) implementation and (iii) endline. In the first phase, a baseline survey was conducted to identify AAT prevalence rates in each of the project countries. For Togo, this rate was identified in the Kara and Savana regions, in which AAT prevalence rates range between 24% and 28% (Tchamdja et al., 2016). Socioeconomic data at the household level, village information and epidemiological data were then collected in 2013. The second phase involved the rollout of the interventions simultaneously across randomly selected treatment villages in the Kara and Savana regions starting in 2014. For the purposes of project implementation, the selection of sample villages followed a two-step random sampling approach. At the first stage, 20 villages were randomly selected from 72 villages in Kara and Savanes regions with recorded AAT prevalence and livelihoods depending on cattle keeping. At the second stage, the 20 selected villages were randomly assigned to treatment (7 villages) and control (13 villages) groups. All of the cattle keepers in the treatment villages were eligible to participate in the program interventions. Thus, the problem of self-selection needs to be addressed in the estimation approach that we describe in our identification procedure in the next section. To reduce cross-contamination of the controls to the lowest minimum possible, the control and the treated villages were at least 65 km apart.

The TRYRAC intervention was composed of two components and implemented by local experts from Institut de Conseil *et* D'appui Technique (ICAT) and Veterinaires Sans Frontiers (VSF), together with support from local veterinary and village cattle herder associations in the treatment villages. First, participatory extension methods (e.g., mass media and posters) were used to educate cattle farmers on improved production practices, specifically AAT management. Second, training sessions were organized for cattle farmers on good husbandry and tick and worm control. During the implementation period, farmers in treated villages continually received education, training and other information relative to AAT management. However, the project did not provide direct subventions, such as subsidies or inputs.

Finally, in 2016, an endline survey was conducted with the same households that participated in the baseline survey in 2013. Repeated observations of identical households before and after the intervention facilitates a rigorous assessment of economic impacts. However, as farmers in treatment villages self-select into the intervention, we must account for potential biases arising from self-selection. Before describing our methodological approach, we briefly introduce the data collection processes during the baseline and endline surveys in the following section.

4.2.2. Data setting

To determine the impact of the TRYRAC program, we use two rounds (2013/2016) of household-level survey data from 500 randomly selected households (25 per village) in the Kara and Savanes regions of Togo. The sampling frame was a list of all cattle-keeping households each village prepared in consultation with the village head and local veterinary office. Formal household interviews were implemented using a structured pretested questionnaire and were administered by experienced and trained local enumerators. The household head or person responsible for making major cattle production decisions was interviewed. To reduce enumerator bias, we ensured that none of the stakeholders, such as veterinary personnel, were used or involved in the questionnaire administration. Enumerators were mainly selected from Kara University and were required to speak at least one of the local dialects and to understand the farming system in the study area. This step was taken to reduce noise in the data, given that most cattle farmers have little or no formal education (2 years on average) and depend on recall data.

During the baseline survey in 2013, demographic, consumption and income data were collected at the household level. Additionally, each household's knowledge, attitudes and practices related to AAT were also collected. Furthermore, general cattle management practices in terms of worms, ticks, and feeding have been collected. These questions were in line with the knowledge, attitudes, and practices (KAP) questionnaire guidelines used in similar studies for livestock disease control (Tornimbene et al., 2014; Grace et al., 2009; Liebenehm, Affognon and Waibel, 2011b). For a detailed description of the questionnaire, refer to Weyori et al. (2018). The follow-up survey was conducted in May 2016, two years after the interventions were rolled out, using the baseline questionnaire with an additional section to identify the treated households. More than 93% of the baseline households (476) were interviewed during the impact survey with an attrition[6] rate of 6.8%, or 33 households. We restricted our study to households for which sufficient information was available in both survey waves to form a balanced panel of 443 unique households. For purposes of the impact estimation we define treated households as the ones that participated in the TRYRAC program activities, while those households that did not participate in the interventions are considered as controls.

4.3. Methodology

4.3.1. Identification and empirical estimation strategies

The estimation of TRYRAC's impacts at the household level is not a trivial exercise because of the potential selection bias and endogeneity associated with the program's setup. However, the availability of panel data allows us to follow numerous quasi-experimental identification strategies to estimate the impact. Specifically, we exploit the fact that project villages were

[6] There were three main reasons for attrition. First, some of the households moved out of their original villages and hence could not be traced during the impact survey. Second, other households (18 households) refused outright to participate in the impact survey because they had expected to be remunerated during the baseline survey, which was not the case. Third, the final group of households was left out on purpose because their baseline data were insufficient, missing or incomplete, thus restricting any useful impact analysis.

randomly selected for treatment and control to implement the difference-in-difference fixed–effects estimator and the two-stage least squares (2SLS) fixed-effects instrumental variable (FE-IV) approaches. We also implement a propensity score matching approach based on baseline covariates to assess the robustness of the fixed effects and 2SLS results.

4.3.1.1. The difference-in-difference (DD) fixed effects

We specify the impact of the TRYRAC intervention as follows:

$$\mathrm{Y}_{it} = \delta_t + \tau_i + \alpha\left(\acute{D}_i * \mathrm{T}_{post}\right) + \beta_1\mathrm{X}_{it} + \beta_2\mathrm{V}_{jt} + \varepsilon_{it} \tag{1}$$

where Y_{it} is the outcome variable ($Y =$ knowledge score, practices, AAT prevalence, veterinary expenditures, productivity (livestock net income), household income per capita, and consumption per capita) of the i^{th} household in period *t* (*t*=2013, 2016) and T_{post} is a binary indicator for the post-intervention period (2016). $\acute{D}_i$ is the treatment status of the i^{th} household. The interaction term $\acute{D}_i \times \mathrm{T}_t$ captures the treatment effect of TRYRAC. We also include X_{it} and V_{jt}, a rich set of exogenous time-varying household- and village-level characteristics, respectively. δ_t and τ_i are time and household fixed effects. ε_{it} is the idiosyncratic additive error term with a zero-mean. The standard errors are clustered at the village level to account for serial correlation. The DD-fixed effects estimation eliminates the double jeopardy of selection bias arising from households' unobserved confounders and time trends in outcome variable through the common trends assumption, which implicitly assumes that (i) unobserved heterogeneity causing self-selection are time-invariant and additive, and (ii) the outcomes of treated and control households would follow a similar trend over time in the absence of the treatment[7]. Although we are not able to perform an empirical falsification test of the second assumption of the common trends assumption because of the absence of long pre-intervention data, the systematic similarities between treatment and control villages at the baseline presents a strong basis to assume this assumption holds true. Furthermore, a pre-intervention comparison of treated and control households does not show any significant differences on key characteristics and the outcome variables (see Tables 5 and 4).

[7] Intervention villages were randomly selected from a pool constructed based on their similarities and to the best of our knowledge, there were no parallel or similar ongoing interventions that differently affected participants and non-participants in the study villages to violate our parallel trends assumption.

The issue of self-selection bias from unobserved household heterogeneity in eqn. 1 is eliminated through the fixed effects assumption[8] as long unobservable confounders are time-invariant.

In our estimation we further control for any observable pre-intervention conditions by implicitly controlling for pre-treatment observed time-varying covariates that are correlated with the treatment decision of households but remain exogenous to the treatment itself.

Finally, we estimated the DD-fixed effects of the form

$$Y_{it} = \alpha(\acute{D}_i * T_{post}) + \beta_1 X_{it} + \beta_2 V_{jt} + \varepsilon_{it} \quad (2)$$

However, a violation of the unobserved time-invariant assumption where treatment decision is correlated with time-varying unobservable heterogeneity could affect the consistency of the DD estimator. To further test the consistency of our DD-fixed effects result, we also estimate a 2SLS FE-IV. We describe this approach in the next section.

4.3.1.2. Fixed-effects instrumental variable approach

The estimation of equation (2) could suffer bias if unobserved individual heterogeneity τ_i, is time-varying. This leads to omitted variable bias. The result is an error term that contains variables that are also correlated with the participation decision, i.e., $\mathrm{cov}(\acute{D}_{it}, \varepsilon_i) \neq 0$, which violates the OLS assumption of independence between the covariates and the error term.

In the following, we relax the time invariant assumption of unobserved individual heterogeneity in eqn. 1 by instrumenting the treatment decision of the household to estimate the impact of TRYRAC by the fixed effects instrumental variable approach (FE-IV), in which the predicted values of decision to participate are fitted in the outcome equation. In this way, we are able to isolate the true impact of TRYRAC treatment decision from the contamination effect of the omitted unobserved individual heterogeneity.

In a two-stage process, we specify the two stage FE-IV estimation as follows.

In the first stage, we estimate the predicted propensity of the household to be treated through the instrumental variable Z.

[8] The unobserved fixed effects assumptions states that α is only unbiased and consistent for the ith household if τ_i is time-invariant, additive and $\mathrm{cov}(\acute{D}_{it}, \tau_i) = 0$ (Angrist and Pischke, 2009; Wooldridge, 2010).

$$\acute{D}_i = \beta_1 X_t + \gamma Z_{it} \quad (3)$$

In the second stage, the predicted probability of the i^{th} household to treat, $\widehat{D}_i$, from eqn. 3 is plugged into the outcome equation (eqn. 4) as follows:

$$Y_{it} = \delta_t + \beta_2 X_t + \alpha(\widehat{D}_i * T_{post}) + \varepsilon_{it} \quad (4)$$

Since treated villages have been randomly selected for the intervention, we instrument the household's decision to treat through a binary variable Z that equals 1 if a household is located in a treatment village and zero otherwise (Duflo, Glennerster and Kremer, 2008; Angrist and Pischke, 2009). We argue that households' decision to participate in the intervention may be highly correlated with the village treatment status. That is, residing in an intervention village increases the possibility that households access TRYRAC information, thereby participating in the intervention. This is expected to reduce the information asymmetry that would usually inhibit the adoption of new technologies among these households (Frölich and Lechner, 2010; McKenzie et al., 2010; Makamu et al., 2018).

The coefficient α in eqn. 4 gives the intention to treat effect (ITT) of TRYRAC, which is consistent under the assumption of exclusion restriction[9]. The estimated α under the assumption of independence and monotonicity is also interpreted as local average treatment effect (LATE) or impact of TRYRAC on the compliers, i.e., those who have been induced by the randomly assigned instrument to be treated (Imbens and Angrist, 1994). Given that our instrument meets these assumptions we interpret α as LATE of TRYRAC.

In addition to the above strategies, we estimate a parametric propensity score matching (PSM) approach for treatment and control households based on their baseline characteristics. We estimate the impact for treated households that are reasonably matched with control households within a common support. For brevity, the PSM results are reported in Appendix A4.

4.3.2. Impact pathway and outcome variable definition

Understanding the household-level impact pathways of any presumably welfare-enhancing interventions, such as the TRYRAC program, involves great complexities. We assume that the

[9] The exclusion restriction states that the instrument, Z, should be correlated with the decision to be treated and does not have a direct effect on the outcome variable, but only affects the outcome variable indirectly conditioned on treatment status. The first-stage regression results of our estimation show that our choice of instrument meets the exclusion restriction assumption (Appendix A. 1).

TRYRAC interventions first affect farmers' specific disease and disease management knowledge. Second, the effect of improved knowledge may then lead to the adoption of improved practices. However, the adoption decision may depend not only on knowledge but also on access to and the availability of improved inputs. Third, once farmers' disease management knowledge and practices are improved, we may expect an improvement in animal health. Improved animal health could affect household welfare through at least four separate channels. First, as a source of protein through milk and meat, it can improve food security and nutrition. Second, draft power and manure are important inputs for crop production and improve household consumption. Third, additional income from the sale of livestock products and services and possibly crops, along with reduced production costs through improved animal health, can smooth household consumption and income shocks. Fourth, livestock sales can smooth consumption in cases of adverse events (Rosenzweig and Wolpin 1993; McPeak 2004; Verpoorten 2009; Islam and Maitra, 2012).

Following the layout of these impact pathways, we first investigated the impact of TRYRAC interventions on farmer knowledge, which is measured based on aggregate scores on tests that ask questions about the causes and treatment of AAT[10]. Second, we investigate whether improved knowledge enhances the adoption of improved disease (AAT and worm) control practices rolled out through the TRYRAC program. Third, we examine whether improved knowledge and practices lead to improvements in animal health using the AAT prevalence rate in the herd, veterinary expenditures and animal productivity (given as total output values, i.e., the net income received by respondents from livestock output) as outcome indicators. Finally, we investigate the welfare impacts that are expected through improvements in animal health. To do so, we observe changes in consumption expenditures per capita and net benefits accrued to the household in per capita income as the result of reduced veterinary expenditures. To estimate the consumption expenditure per capita variable for the household, we include all household expenditure items in the last 12 months preceding the interview date for both periods

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[10]The knowledge and practices scores were calculated by asking farmers questions and allocating scores according to three different knowledge categories:

i. Disease-specific knowledge, e.g. symptoms, causes, mode of transmission, etc.

ii. Curative and management knowledge of trypanosomosis, including the quality and quantity of trypanocides usage, how to administer medication;

iii. Preventive and treatment knowledge based on as strategies adopted to manage AAT and other disease infections by the respondent.

Total accumulated points from (i) and (ii) gives the total knowledge score, while (iii) gives the practices score of the respondent. Following the integrated pest management approach for crops, categories are calculated as a percentage of the maximum possible score for each (Tornimbene et al., 2014; Liebenehm et al., 2011).

(before and after). To calculate this, we pool the household total reported consumption expenditures at 2012 nominal prices adjusted by the adult equivalent scale. This includes all durable and nondurable goods and services consumed and used, respectively, by all household members. We define net livestock income as the total gross income from livestock products less input cost (veterinary service charge plus input costs), feed (if any), and hired labor (where applicable) per annum. We do not consider households' labor cost for herding animals because most households in this region depend on their own labor in cattle production; thus, the cost of a household's own labor resulted in negative income.

As a further welfare measure, we also estimate the impact of the interventions on stochastic poverty outcomes. Following Foster et al. (1984), we compute the Foster-Greer-Thorbecke (FGT) poverty measures (poverty incidence, poverty gap) comparing the per capita household income to the international US$1.90 per day poverty line. Given the stochastic nature of household poverty, we therefore estimate the impact on future vulnerability to poverty. Households in SSA are often trapped in either transitory or structural poverty because of the absence of forward-looking interventions that consider their vulnerability to poverty.

Following the approach of Chaudhuri (2003) and Hoddinott and Quisumbing (2003), we estimate the impact of TRYRAC interventions on reducing vulnerability to poverty. We define household vulnerability to poverty, V_i, as the probability that the i^{th} household will record a consumption outcome that is below the poverty line defined as Z in $t+1$ period conditioned on households' socioeconomic characteristics (X_i), and other exogenous variables (β_n) at time t, i.e.,

$$\mathrm{V}_{it} = \Pr\left(C_{it,t+1} \leq \mathrm{Z} \mid \mathrm{X}_i, \beta_n,\ \varepsilon_i\right) = \frac{\mathrm{Z}-(\hat{C_i}-\hat{\sigma_i})}{\widehat{2\sigma_i}} \quad (5)$$

We classify households with a probability threshold above 0.5 as vulnerable to poverty and those below this threshold as not vulnerable. We estimate a reduced form of eqn. 5 in the form

$$\mathrm{V}_{it} = \alpha \mathrm{T}_t + \gamma \mathrm{X}_{it} + \beta_1 \mathrm{S}_{it} + \beta_2 \phi_t + \beta_3 \acute{D}_i + \mu_{it} \quad (6)$$

where T is a binary indicator for pre- and post-treatment periods and captures the time fixed effects, X_{it} refers to time-varying household characteristics, $\acute{D}_i$ is the program participation status of the i^{th} household, S_{it} and ϕ_t are reported idiosyncratic and covariate shocks. μ_{it} is the idiosyncratic additive error term with a zero mean. Eqn. 6 is estimated using a logit model.

4.4. Descriptive statistics

In this section, we present the descriptive statistics of the households. We look at their demographics, livestock holdings, knowledge and practices towards disease management, and income diversification strategies. These statistics provide an outlook of the sample and the quality of the counterfactual households used in the econometric estimations.

Table 4.1 shows the socioeconomic characteristics of the households by participation. Households do not differ significantly across categories. Household heads are, on average, 49 years old, married (polygamous), poorly educated (82% with no formal education) and less diversified in terms of income sources. The household size is generally large, ranging from 5 to 35, with a sample average of 10. The dependency ratio is 1.14. Crop production and livestock rearing constitute the main economic activities in the study area, contributing to more than 88% of total household income. The average farm size is 2.4 hectares, and crop production is 100% rain fed with no irrigation facilities.

Table 4.1 Descriptive statistics of households in treated and comparison groups at baseline[11]

Variable		Pooled HH	Control HH	Treated HH	Diff.
HH age (years)		49	49.5	49	0.5
Household age grouping (%)					
	18–24 years	2	2	2	0.0
	25–34 years	15	14	15	1.00
	35–44 years	25	25	25	0
	45–54 years	25	23	27	4
	55–65 years	20	20	19	1
	> 65 years	14	16	13	1
HH gender (male=1)			0.96	0.99	
HH education category (%)					
	No formal education	82	82	82	0
	Primary education	10	12	9	3*
	Secondary education	6	5	8	3*
	Higher education	2	1	2	1
Household size		11	10	10	
Farm size (hectares)		2.4	2.3	2.35	-0.05
More than 1 wife (1=yes)		0.89	0.87	0.90	0.03
Dependency ratio		1.14	1.13	1.15	-0.02
Social network (1=yes)		0.33	0.31	0.37	-0.06
Agriculture land owned (ha)		2.36	2.36	2.36	0
Income diversification (%)					
	Agriculture (crop)	65	69	61	8
	Agriculture (livestock)	23	20	30	-10
	Off-farm	4	6	2	4
	Self-employed	2	1	2	-1
	Natural resources	2	2	2	0
Observations		**443**	**229**	**214**	

Note: HH denotes household head
Source: Authors' calculation

Livestock keeping is very prominent in the study area, as presented in Table 4.2. Respondents are typically small-holder livestock farmers with herd sizes ranging from 2 to 100 cattle and an average herd size of 9 cattle per household. Cows are kept mainly for reproductive purposes, while bulls are kept for traction and/or as a store of value. In addition to owning cattle, households kept other livestock, such as goats, sheep and chickens.

[11] Although some differences exist between the control and treated households' pre-intervention period, statistical comparison of Table 4.1 show that households did not differ significantly. This homogeneity is likely are likely to persist overtime without any exogenous intervention

Table 4.2 Distribution of different livestock species kept by household

Livestock Type	2013 Percent of households	2013 mean herd size	2016 Percent of households	2016 mean herd size
Calves	21	7	21	6
Heifers	14	6	19	5
Cows	20	10	24	11
Bulls	25	5	24	3
Oxen	17	16	13	4
Sheep	28	10	28	15
Goats	28	8	29	9
Poultry	35	36	36	34
Pigs	7	6	6	9

Source: Authors' calculation

Table 4.3 presents the breakdown of the main livestock diseases that our sampled households reported. In particular, AAT remains a key constraint to cattle productivity in Togo. For example, more than 85% of the respondents in our sample reported the disease in their herd across the two survey waves. Although Table 4.3 shows a marginal drop in AAT incidences over time in the total sample, AAT still remains a major constraint for respondents. A disaggregation of AAT incidence by program participation status across the two waves shows a decline in AAT incidence (approximately 5%) in the intervention villages, while the control villages recorded a slight increase (2 percentage points) in AAT incidence.

Table 4.3 Top five diseases reported by respondents by treatment category

	2013			2016		
Disease incidence=yes	**95%**			**87%**		
Problem	Pooled (% hh)	Treated (% hh)	Control (% hh)	Pooled (% hh)	Treated (% hh)	Control (% hh)
Trypanosomosis[12]	23	27	25	25	22	27
Tick and worm	12	17	18	15	13	13
Diarrhea	13	12	13	8	9	10
Skin abrasions	8	10	10	9	8	9
Injury	6	9	7	8	5	6
Observations	443	214	229	443	214	229

Source: Authors' calculation

In Table 4.4, we report the knowledge and practice scores of respondents as well as indicators of animal health. We found that participants' knowledge scores were significantly (28%) higher than those of nonparticipants in 2016. The knowledge score indicates respondents' knowledge of ATT causes, transmission, prevention and treatment. Similarly, participants' practice score, which is a total score measuring improved practices in managing AAT, ticks, worms and other diseases, increased by 11% in 2016. Table 4.4 also shows significant differences in two animal health indicators between the treatment and the control group in 2016. Expenditures for veterinary inputs are lower and the value of animal outputs is higher for participants. These results suggest that TRYRAC intervention is positively correlated with increased knowledge and improved practices and health.

[12] The actual percentage of AAT incidence could be higher than what is reported in Table 4.2 because farmers may not have been able to accurately diagnose AAT. For example, while diarrhea and skin abrasions may be distinct sicknesses, they are also recognized symptoms of AAT.

Table 4.4 Knowledge, practices and animal health

	2013			2016		
Indicator	**Treated**	**Control**	**Diff.**	**Treated**	**Control**	**Diff.**
Knowledge score	9.12 (7.15)	8.8 (8.77)	0.4	37 (15.50)	12.5 (15.36)	28***
Practice score	14.15 (8.97)	13.51 (10.82)	0.64	29 (12.88)	18 (19.57)	11***
Veterinary input cost PPP$	21.91 (45.13)	22.67 (41.14)	0.76	2.41 (6.41)	4.81 (13.22)	2.40***
Total output value PPP$	37.37 (61.75)	37.56 (65.17)	0.19	159.75 (405.40)	91.61 (269.70)	68.14***
Observations	214	229		214	229	

Note: Significance of differences was assessed by t-test. Standard deviation in parentheses *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' calculation

Table 4.5 presents a comparison between welfare outcomes of TRYRAC treated and control groups before and after the intervention. Focusing on the baseline year first, we do not find significant differences between these groups. However, we find significant differences in the period after the intervention in terms of consumption, income and poverty reduction. More specifically, while consumption improved over time in both groups, the increase was significantly higher among participants (28% points). A closer look at total household income reveals that both participants and nonparticipants recorded a decrease over time. Participants recorded a drop of PPP$ 37.27, while non-participants recorded a drop of PPP$ 53.16. One possible explanation for the participants' lower drop in total income is that participation could have served as a smoothing mechanism by stabilizing livestock income, thereby reducing the total income shortfall.

Table 4.5 Welfare measures by treatment status

	2013				2016			
Indicator	**Pooled**	**Treated**	**Control**	**Diff.**	**Pooled**	**Treated**	**Control**	**Diff.**
Consumption per capita (PPP $)	1004.68	1043.66	968.27	75.39	1260.10	1442.87	1089.31	353.56**
	(770.78)	(764.05)	(776.91)		(1533.3)	(1843.8)	(1149.4)	
Total HH income per capita (PPP $)	772.55	845.73	704.16	-141.59	691.92	808.47	651	157.48**
	(941.12	(945.61)	(925.19)		(736.03)	(708)	(742.41)	
Proportion of poor (< US$ 1.90/day)	0.47	0.46	0.48	-0.02	0.48	0.42	0.53	-0.11**
	(0.49)	(0.50)	(0.50)		(0.50)	(0.50)	(0.50)	
Poverty gap (%)	0.15	0.16	0.15	0.01	0.17	0.15	0.18	-0.03
	(0.01)	(0)	(0)		(0.01)	(0)	(0)	
Poverty severity (%)	0.078	0.073	0.082	-0.09	0.096	0.090	0.101	-0.011
	(0.005)	(0)	(0)		(0.009)	(0)	(0)	
Vulnerability (%)	0.25	0.25	0.26	-0.01	0.28	0.22	0.25	-0.03
	(0.43)	(0.44)	(0.43)		(0.42)	(0.43)	(0.42)	
Observations	443	214	229		443	214	229	

Note: Significance of differences was assessed by t-test. Standard deviations in brackets; calculation of poverty indices based on the US$ 1.90 PPP
Source: Authors' calculations

In terms of poverty and vulnerability, we found that approximately 47% of our sample respondents were living below the poverty line in 2013, whereas 48% were below the poverty line in 2016. The poverty headcount decreased by 4% points for participants and increased by 5% points for nonparticipants over time. Additionally, the poverty gap decreased by 1% points among participants and increased by 3% points among nonparticipants. Approximately 30% of all respondents in our sample were vulnerable to poverty. However, this figure decreased for participants by 3% points, while it decreased for nonparticipants by 1% point in 2016. These observations point to three important inferences: First, poverty remains high over time in the total sample. Second, there are slight improvements in the static and dynamic poverty indicators for TRYRAC participants. Thus, TRYRAC interventions could have an impact on reducing poverty by improving consumption and smoothing total income.

In summary, the unconditional summary statistics presented above suggest that the TRYRAC interventions improved participants' knowledge, practices and welfare outcomes relative to nonparticipants'. However, these findings could be driven by other exogenous factors because program participation is likely to be endogenous. In the next section, we present the results of the multivariate econometric estimation strategies to net out the impact of TRYRAC while controlling for different estimation concerns, as discussed in the methods section.

4.5. Results and discussion

According to our impact pathway layout, we first investigate the impact of the TRYRAC intervention on cattle farmers' knowledge and practices and animals' health. Second, we analyze whether improvements in outcomes from the first step trigger improvements in households' welfare indicators.

4.5.1. Impact on farmers' knowledge and practices and animals' health

Table 4.6 shows the average effects of the treatment (ATT) on knowledge, practices and animal health for the different estimation strategies introduced. Columns 1 and 2 show the DD-fixed effects estimation with and without controls, respectively. Column 3 presents the fixed-effects instrumental variable estimates.

Our results generally show a significant positive impact of TRYRAC interventions, as the knowledge and adoption of improved practices to enhance livestock health improved among treated households across all the model specification. Specifically, Table 4.6 shows that TRYRAC intervention improved the AAT knowledge of participating households by approximately 30%. The impact coefficients do not significantly differ when we add time-varying household and village characteristics in column 2, an indication that the correlation between treatment and covariates is low. FE–IV returns similar results as the DD–FE estimates. These findings are similar to the results of Liebenehm, Affognon and Waibel (2011a), who report knowledge increases for cattle farmers in Mali and Burkina Faso after veterinary interventions were introduced.

In the next step, we show whether farmers apply the observed improved knowledge in their disease management decisions. We report the effect of knowledge score on improved practices that households adopted for AAT management (Table 4.6). Our conservative model results show that knowledge gained from the intervention increases the adoption of improved disease management practices by approximately 9%. In terms of numbers, this result means that treated households adopted and implemented 3 additional improved practices as a result of the gained knowledge. For every 10% increase in knowledge score, farmers adopted 1 improved practice.

This means that farmers gained higher knowledge which resulted in them adopting and implementing 3 additional improved practices.

Given that TRYRAC interventions improved farmers' knowledge and use of improved practices in managing diseases, we would expect these to translate into improvements in animal health. To test this hypothesis, we investigate the impact of TRYRAC interventions on AAT prevalence, veterinary input expenditures and productivity, measured as income from livestock output (milk, draft, and manure). On average, the results show a reduction in the number of sick animals (3 animals on average) for treated households' herds compared to the control households. Although this reduction is modest, the possible positive spillover effect for animals in the control villages could explain this result. This has the possibility of improving their health outcome. Cattle in the study area are kept in an open range system, exposing herds in the treated and control villages to both positive and negative spillover effects. For example, improved disease management practices resulting from the intervention at the treated villages may also lead to a reduction in the tsetse population and disease prevalence, causing a positive spillover effect benefit for the herds of nonparticipating households. However, a negative implication explained by the free-rider effect of non-participants' herds causing reinvasion and coinfections may reduce the estimated welfare benefits accruing to treated herds. That said, we expect the positive benefit to outweigh the negative effect. To this end, we compare the health outcome of herd and find that health status of all herd (both treated and control households) in the post-intervention period generally improved an indication of a higher spillover effect.

In line with the stated impact path identified in this study, improved animal health is also expected to result in higher productivity and a reduction in input or production costs which is mainly veterinary costs (trypanocides, other medications and service charges). Specifically, we investigate the impact of the interventions in reducing veterinary inputs costs through a reduced need for trypanocide, insecticides and deworming drugs. Table 4.6 shows that TRYRAC reduced veterinary input expenditures by approximately PPP$ 8.62 to PPP$ 12.63 (1,950 CFAF to 2,850 CFAF) depending on the estimation regime. This figure is equivalent to approximately US$3–5.5 per annum per cattle head and translates to a total savings of approximately US$27–50 per herd (with minimum herd size of 9) per annum.

Table 4.6 Impact on knowledge, practices, and disease prevalence

Outcome Variable	Basic DID (1)	Full MLS DID (2)	FE-IV (3)
Knowledge score	0.302***	0.302***	0.327***
	(0.026)	(0.038)	(0.027)
Practices score	0.095***	0.092***	0.100***
	(0.021)	(0.025)	(0.021)
AAT Prevalence	-2.885***	-3.061***	-3.302***
	(0.812)	(0.786)	(0.555)
Veterinary input cost (PPP$)	-8.620**	-10.275**	-12.633**
	(4.209)	(4.031)	(4.967)
Controls	**No**	**Yes**	**Yes**
Fixed effects	**Yes**	**Yes**	**Yes**
Observations	**886**	**886**	**886**

Note: Clustered robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; standard deviations in brackets; AES = adult equivalent scale; PPP = purchasing power parity: Controls: age, household size, dependency ratio, education of household head, social network dummy, and farm size.
Source: Authors' calculations

4.5.2. Impact on farmers' income and consumption

Table 4.7 presents the results for TRYRAC welfare effects in terms of consumption per capita and income from cattle production. In terms of income, we found that improved cattle health has resulted in higher productivity, which leads to an increase in net income from cattle output such as milk, traction and manure. Net income from the cattle products of the treated households increased on average between 16% and 84% more than the control households in the period. This result indicates that with good management practices, cattle's contribution to household income could double relative to the current figures.

In terms of welfare impacts at the household level, the results show a significant positive effect on total household income per capita for the treated. We find an income increase of between 29% and 47% for intervention participants. Although this figure may seem to represent a large jump in household income, this is intuitively consistent for two possible reasons. First, there are large positive effects from reducing the veterinary expenses (production costs) and increasing the livestock productivity (increasing incomes) of the treated households. Second, livestock contributes a greater proportion of direct total household income (Table 4.3). Intuitively, better livestock management results in fewer losses, with increased productivity to improve overall income. In terms of consumption, we did not find any significant results for the treated households although there is an increase in the consumption outcomes for the treated households in post-intervention period. For example, a simple comparison of treated and control households show that consumption increased on average by PPP$ 337.89 and PPP$ 93.89 respectively post-treatment period. Numerous reasons may be given for the observed result. The positive spillover of the treatment on the control groups leads to increased consumption outcomes, which effectively absorbs the treatment effects on the treated. Additionally, the per capita consumption of households is typically low; therefore, there will need to be a more than proportionate increase in consumption expenditure for any statistical significance to be observed.

The foregoing results give credence to the fact that improved cattle health translates into higher livestock productivity (livestock net income), household income and consumption per capita. In the following, we report the impacts of the intervention on stochastic poverty and vulnerability to poverty as a forward-looking welfare indicator for the treated household.

Table 4.7 Impact of TRYRAC on household welfare

Outcome Variable	**Basic OLS DID (1)**	**Full MLS DID (2)**	**FE-IV (3)**
Net livestock income (log)	1.843***	1.520**	1.16*
	(0.628)	(0.651)	(0.678)
Total net income per capita (log)	0.297*	0.448**	0.512***
	(0.160)	(0.146)	(0.152)
Consumption per capita p.a. (AES) (PPP$)	278.170*	242.002	206.202
	(162.444)	(149.762)	(166.434)
Controls	**No**	**Yes**	**Yes**
Fixed effects	**No**	**Yes**	**Yes**
Observations	**886**	**886**	**886**

Note: Clustered robust standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1; standard deviations in brackets; AES = adult equivalent scale; PPP = purchasing power parity: Controls: age, household size, dependency ratio, education of household head, social network dummy, and farm size.
Source: Authors' calculations

4.5.3. Impact on poverty and vulnerability

Finally, Table 4.8 presents the impact of interventions on poverty and vulnerability[13]. In column 1, we report the impact of the interventions on reducing the poverty headcount ratio. Our results show that TRYRAC reduced the poverty head count ratio by approximately 12% points, which is statistically significant at the 10% level. This result may indicate that TRYRAC interventions that have triggered improvements in a household's consumption and net income also translate into a reduction in poverty.

In column 2, we report the impact of TRYRAC on vulnerability to poverty in the future. Our findings show that participating households were 7% less likely than nonparticipants to be vulnerable to future poverty. Similar to the argument above, this result suggests that TRYRAC interventions contributed to smoothing income and consumption and thus reduced the likelihood of participating households falling below the poverty line in the future. The result is line with the findings of Khonje et al. (2018), who report the significant welfare impact of technology adoption in eastern Zambia and the recent study of Parvathi (2018) who finds that improved livestock production can improve food security outcomes among livestock farmers.

Table 4.8 Impact on poverty head count and vulnerability to poverty

	Poverty headcount *(Fixed effects)*	**Vulnerability** *(Fixed effects)*
	(1)	**(2)**
TRYRAC (Participation)	**-0.118***	**-0.072****
	(0.064)	(0.037)
Year (1=2016)	-0.036	-0.008
	(0.080)	(0.057)
Constant	0.918**	0.754***
	(0.438)	(0.224)
Controls	**Yes**	**Yes**
Observations	886	886

Note: Clustered standard errors in parentheses*; *** p<0.01, ** p<0.05, * p<0.1*
Controls: age, household size, dependency ratio, education of household head, social network dummy, and farm size
Source: Authors' calculations

[13] For brevity, the FGLS procedure predicting the future log–consumption and consumption variance for the estimation of vulnerability are not reported. These can be provided by authors upon request.

4.6. Conclusions and policy implications

The role of livestock in improving the livelihoods of rural households remains critical in rural SSA, where credit, formal employment and other factor markets are highly imperfect or absent. Cattle in particular have the potential to improve household livelihoods, thereby reducing the poverty and consumption volatility that tend to make households vulnerable to both stochastic and structural poverty. However, the negative effects of livestock diseases, such as AAT, have dwarfed this potential. It is estimated that AAT affects an area of approximately 10 million km², causing the death of approximately 3 million cattle annually in SSA. The use of chemotherapy remains the most common control method used by livestock farmers to manage AAT. However, the upsurge in resistance to trypanocides and other unsustainable disease management practices makes control of the disease elusive.

Using a balanced household panel data set from Togo, this paper investigated the impact of veterinary interventions launched within the scope of the EU-funded TRYRAC project on small-holder welfare in SSA. We discuss the linkage between knowledge gain and the adoption of livestock husbandry practice for disease prevention and management and how these improvements in herd management and health may translate into measurable welfare effects at the household level. We employed different econometric estimation strategies to control for selection bias and program endogeneity that are likely to arise as a result of the non-randomization of program participation. We specifically exploit the exogenous randomization of the intervention villages to implement a difference-in-indifference (DD), the instrument variable fixed-effects and the propensity score matching (PSM) estimation strategies.

We find results that are robust across all estimation strategies employed. Specifically, the results show a positive impact of TRYRAC interventions on improving knowledge that remains significant and robust across all model specifications. We show that treated households had an increase in knowledge score of approximately 30% compared to the control group because of their treatment status. This resulted in increased adoption of improved livestock management practices. For example, the results show that for every 10% increase in knowledge, participants adopted 3 more improved cattle husbandry practices. We also found that the adoption of improved practices resulted in a drop in AAT infections. Fewer AAT infections lead to increases in productivity by between 64–95% in terms of income. This further translates to a savings in veterinary cost of US$3–5.5 per cattle head per annum, which translates to an annual saving of approximately US$27–50 per herd for the average herd size in our sample. In terms of household welfare, we found that the interventions improved household income per capita by between 27% and 47%. We also found that this resulted in increased consumption per capita expenditure of between PPP$ 250 and PPP$ 290 and reduced poverty and vulnerability by 12% and 7%, respectively. Thus, the overall conclusion of this study points to the important role of interventions targeted at improving the health of livestock and improving rural livelihoods in SSA.

Based on our analysis, we submit the following policy recommendations. First, the case of TRYRAC shows the effectiveness of well-planned extension programs that include radio, market and village outreach programs to increase dissemination and increase the knowledge of the target group. To scale up technology adoption, there should be increased farmer and local partner participation in the technology dissemination chain. Second, ownership of farm implements such as the animal-drawn plows should be encouraged among cattle farmers by removing the bottlenecks and the bureaucracy in access to credit. Farmers could also be helped to form cooperatives to operate animal-drawn machinery pools. This step would increase household income and improve crop production, which are the key determinants of rural poverty and vulnerability in rural SSA.

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Appendix A4

Table A4.1 First stage results of 2SLS regression for each outcome variable

Receives treatment (1=yes)	Knowledge score (1)	Improved practices score (2)	AAT in herd (3)	Net livestock income (4)	Consumption per capita (5)	Income (PPP$) (6)	Veterinary costs (PPP$) (7)
Impact of intervention	0.964***	0.720***	0.919***	0.896***	0.944***	0.918***	0.901***
	(0.026)	(0.021)	(0.010)	(0.010)	(0.010)	(0.018)	(0.010)
Age of household head (years)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Household size	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Dependency ratio	0.006	0.006	0.006	0.006	0.006	0.009	0.009
	(0.017)	(0.018)	(0.016)	(0.017)	(0.016)	(0.017)	(0.017)
Education of household head (years)	0.006	0.007*	0.006*	0.006	0.006	0.005	0.005
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Household head married (1=yes)	-0.001	0.000	-0.001	-0.001	-0.001	0.002	0.002
	(0.029)	(0.015)	(0.034)	(0.034)	(0.034)	(0.018)	(0.034)
Household is a Muslim (1=yes)	0.071**	0.081	0.074**	0.075**	0.072**	0.067***	0.068**
	(0.028)	(0.020)	(0.029)	(0.029)	(0.028)	(0.016)	(0.029)
Household head is member of community group (1=yes)	0.035	0.034	0.035	0.035	0.035	0.034	0.034
	(0.029)	(0.033)	(0.026)	(0.026)	(0.026)	(0.039)	(0.026)
Farm land size (log)	0.017	0.019*	0.017	0.017	0.017	0.011	0.012
	(0.017)	(0.011)	(0.017)	(0.017)	(0.017)	(0.013)	(0.017)
Owns land (1=years)	-0.033	-0.028*	-0.032*	-0.032	-0.033*	-0.029**	-0.029
	(0.027)	(0.014)	(0.018)	(0.018)	(0.017)	(0.014)	(0.018)
Owns animal plow (1=yes)	0.015	0.015	0.015	0.015	0.015	0.008	0.008
	(0.053)	(0.028)	(0.026)	(0.026)	(0.026)	(0.033)	(0.026)
Value of assets (log)	0.003	0.002	0.003	0.003	0.003	0.008	0.008
	(0.009)	(0.011)	(0.007)	(0.007)	(0.007)	(0.013)	(0.007)
Owns radio (1=yes)	0.001	0.001	0.001	0.001	0.001	-0.005	-0.005
	(0.026)	(0.031)	(0.025)	(0.025)	(0.025)	(0.035)	(0.025)
Owns mobile phone (1=yes)	-0.035	-0.032	-0.034	-0.034	-0.035	-0.035	-0.035
	(0.032)	(0.017)	(0.028)	(0.028)	(0.028)	(0.019)	(0.028)
Number of formally employed members	0.039	0.037	0.039	0.039	0.039	0.036	0.036
	(0.040)	(0.035)	(0.039)	(0.038)	(0.039)	(0.037)	(0.039)
Experienced demographic shock (1=yes)	-0.072**	-0.068**	-0.072**	-0.072**	-0.072**	-0.074	-0.074*
	(0.035)	(0.033)	(0.028)	(0.028)	(0.028)	(0.039)	(0.028)
Economic shock (1=yes)	-0.002	-0.005	-0.003	-0.003	-0.003	-0.010	-0.011
	(0.031)	(0.022)	(0.042)	(0.042)	(0.042)	(0.022)	(0.043)
Livestock-related shock (1=yes)	0.155**	0.146**	0.155**	0.154**	0.155***	0.173	0.173**
	(0.076)	(0.067)	(0.059)	(0.058)	(0.059)	(0.077)	(0.060)
Risks averse (1=yes)	-0.038	-0.037	-0.038	-0.038	-0.038	-0.030*	-0.030
	(0.036)	(0.030)	(0.024)	(0.024)	(0.024)	(0.031)	(0.024)
Resides in treatment village (1=yes)	**0.090***	**0.114***	**0.095*****	**0.097*****	**0.092*****	**0.087****	**0.088****
	(0.065)	(0.055)	(0.029)	(0.029)	(0.028)	(0.050)	(0.029)
Year	-0.364***	-0.249 ***	0.338***	-0.330***	-0.354***	-0.337***	-0.329***
	(0.072)	(0.049)	(0.080)	(0.056)	(0.056)	(0.052)	(0.058)
Constant	0.341***	0.330 **	-0.342***	0.337***	-0.340***	0.311	0.310***
	(0.082)	(0.034)	(0.056)	(0.080)	(0.080)	(0.034)	(0.081)
Obs.	886	886	886	886	886	861	886

Robust standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

Table A4.2 Second stage results of 2SLS regression for all outcome variables

	Knowledge score (1)	Improved practices score (2)	AAT in herd (3)	Net livestock income (7)	Consumption per capita (4)	Income (PPP$) (5)	Veterinary costs (PPP$) (6)
Impact of intervention	**0.310******	**0.090******	**-2.992******	**1.349*****	**183.137*****	**0.509******	**-10.073*****
	(0.026)	**(0.022)**	**(0.662)**	**(0.616)**	**(76.336)**	**(0.171)**	**(4.510)**
Age of household head (years)	0.001	-0.000	-0.063***	0.015	8.252	-0.006	0.118
	(0.001)	(0.001)	(0.023)	(0.026)	(6.565)	(0.007)	(0.184)
Household size	-0.003*	0.005**	0.047	0.141	8.753	-0.115***	1.524**
	(0.002)	(0.002)	(0.104)	(0.111)	(16.020)	(0.021)	(0.633)
Dependency ratio	-0.013*	-0.003	0.194	-0.274	-14.515	0.082	-1.342
	(0.008)	(0.008)	(0.300)	(0.416)	(40.781)	(0.102)	(2.229)
Education of household head (years)	0.003	0.001	0.107	0.063	-38.798	0.006	-0.068
	(0.003)	(0.004)	(0.117)	(0.107)	(24.107)	(0.027)	(0.930)
Household head married (1=yes)	0.056***	0.024*	0.008	-0.372	-100.914	0.254**	-3.132
	(0.021)	(0.012)	(0.560)	(0.573)	(121.631)	(0.129)	(3.705)
Household is Muslim (1=yes)	-0.012	-0.011	1.072	0.344	-91.263	-0.703**	-18.744*
	(0.039)	(0.028)	(1.028)	(1.196)	(91.731)	(0.356)	(10.380)
Household head is member of community group (1=yes)	-0.022	-0.036**	0.261	-2.022***	-240.905**	0.159	7.725*
	(0.014)	(0.015)	(0.636)	(0.582)	(120.012)	(0.106)	(4.362)
Farm land size (log)	0.020	0.001	0.743	-0.185	129.633**	0.151	-0.095
	(0.014)	(0.011)	(0.565)	(0.434)	(65.415)	(0.122)	(1.985)
Owns land (1=years)	0.036	0.033**	0.088	-0.078	185.250*	-0.111	-0.471
	(0.029)	(0.016)	(0.693)	(0.692)	(105.179)	(0.177)	(3.953)
Owns animal plough (1=yes)	0.021	0.008	1.020**	0.040	140.618	0.096	-5.279
	(0.014)	(0.015)	(0.516)	(0.735)	(96.645)	(0.135)	(3.765)
Value of assets (log)	0.006	0.003	0.454**	0.329**	88.357	-0.061	0.199
	(0.004)	(0.005)	(0.182)	(0.132)	(68.574)	(0.051)	(1.105)
Owns radio (1=yes)	-0.006	-0.010	-0.316	-0.051	-237.939*	0.199*	1.870
	(0.016)	(0.010)	(0.431)	(0.463)	(135.260)	(0.105)	(4.632)
Owns mobile phone (1=yes)	0.003	0.006	-0.038	0.027	-54.319	0.096	2.084
	(0.015)	(0.011)	(0.416)	(0.430)	(166.775)	(0.087)	(4.298)
Number of formally employed members	-0.009	-0.004	-0.128	-0.567	120.837	0.235**	5.167
	(0.016)	(0.016)	(0.783)	(0.532)	(145.854)	(0.095)	(6.090)
Experienced demographic shock (1=yes)	0.010	-0.018	0.062	0.723*	22.264	-0.318***	0.337
	(0.013)	(0.013)	(0.448)	(0.435)	(60.558)	(0.103)	(3.493)
Economic shock (1=yes)	-0.006	0.002	0.570	-1.787**	102.106	-0.076	-2.018
	(0.023)	(0.016)	(0.763)	(0.721)	(102.994)	(0.264)	(7.854)
Livestock-related shock (1=yes)	0.064**	0.029*	1.271	-0.892	26.837	0.481**	-2.069
	(0.027)	(0.017)	(0.799)	(0.889)	(137.988)	(0.194)	(7.601)
Risk averse (1=yes)	0.027*	0.015	-0.165	1.167**	-51.925	-0.119	-4.027
	(0.014)	(0.010)	(0.473)	(0.565)	(84.535)	(0.162)	(3.250)
Year	0.120***	0.071***	-2.049**	-1.428	155.093	0.058	-20.063***
	(0.035)	(0.017)	(0.954)	(1.076)	(138.871)	(0.251)	(6.782)
Constant	-0.074	0.025	2.433	1.727	-7.730	7.632***	14.426
	(0.081)	(0.076)	(2.941)	(2.115)	(642.551)	(0.499)	(12.169)
Obs.	886	886	886	886	886	861	886

Clustered standard errors in parenthesis, *** p<0.01, ** p<0.05, * p<0.1

Table A4.3 Full estimates of the results of impact of intervention on poverty headcount and vulnerability

	Poverty headcount *(Fixed effects)*	**Vulnerability** *(Fixed effects)*
	(1)	**(2)**
TRYRAC (Participation)	-0.118 (0.064)*	-0.072 (0.037)**
Year	-0.036 (0.080)	-0.008 (0.057)
Age of household head	-0.023 (0.016)	-0.019 (0.008)**
Age2	0.000 (0.000)	0.000 (0.000)**
Household size	0.0495 (0.022)**	0.061 (0.015)***
Household size square	-0.000 (0.000)	-0.001 (0.000)
Household head is married (1=yes)	-0.114 (0.057)**	0.017 (0.036)
Polygamous (1=yes)	0.188 (0.098)*	-0.404 (0.087)***
Farmland (log)	-0.150 (0.059)**	-0.221 (0.041)***
Farmland square (log)	0.037 (0.027)	0.043 (0.014)***
Dependency ratio	-0.010 (0.034)	-0.033 (0.022)
Formal education (1=yes)	-0.025 (0.064)	-0.095 (0.037)**
Owns plow (1=yes)	-0.066 (0.052)	-0.089 (0.037)**
Owns motor (1=yes)	-0.064 (0.062)	-0.221 (0.039)***
Owns mobile (1=yes)	-0.066 (0.052)	-0.153 (0.034)***
Agriculture association (1=yes)	-0.002 (0.068)	-0.052 (0.042)
Leader association (1=yes)	0.0982 (0.072)	-0.000 (0.056)
Crop shock (1=yes)	-0.084 (0.077)	-0.024 (0.052)
Illness shock (1=yes)	0.0305 (0.049)	-0.015 (0.031)
Income shock (1=yes)	0.089 (0.082)	0.041 (0.055)
Livestock shock (1=yes)	-0.155 (0.072)**	-0.030 (0.052)
Covariate shocks (1=yes)	-0.032 (0.146)	-0.059 (0.077)
Constant	0.918 (0.438)**	0.754 (0.224)***
sigma_u	0.360	0.261
sigma_e	0.451	0.291
rho	0.389	0.445
F(21, 422)	2.87	7.20
Prob > F	0.000	0.000
Observations	886	886
R^2	0.11	0.306

Note: Clustered standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1
Source: Authors' calculations

Table A4.4 Results of matching algorithms

Outcome variable	**Matching Algorithm**	**ATT**	**Robust AI standard errors**	**z-statistic**
Knowledge score	PSM	0.289***	0.022	12.69
	NNM	0.297***	0.217	13.66
Practices score	PSM	0.080***	0.019	4.22
	NNM	0.088***	0.016	5.39
AAT prevalence	PSM	-2.070***	0.383	-5.39
	NNM	-2.200***	0.346	-6.35
Log livestock income (PPP$)	PSM	1.036	0.749	1.38
	NNM	1.516**	0.472	3.21
Log total income (PPP$)	PSM	0.431**	0.141	3.06
	NNM	0.404**	0.124	3.25
Consumption per capita (adult equivalent scale)	PSM	440.94**	136.80	3.22
	NNM	447.16**	144.07	3.29

Note: PSM, matching on single propensity score, NNM, nearest neighbor matching without replacement, *** p<0.01, ** p<0.05, * p<0.1

Source: Authors' calculations

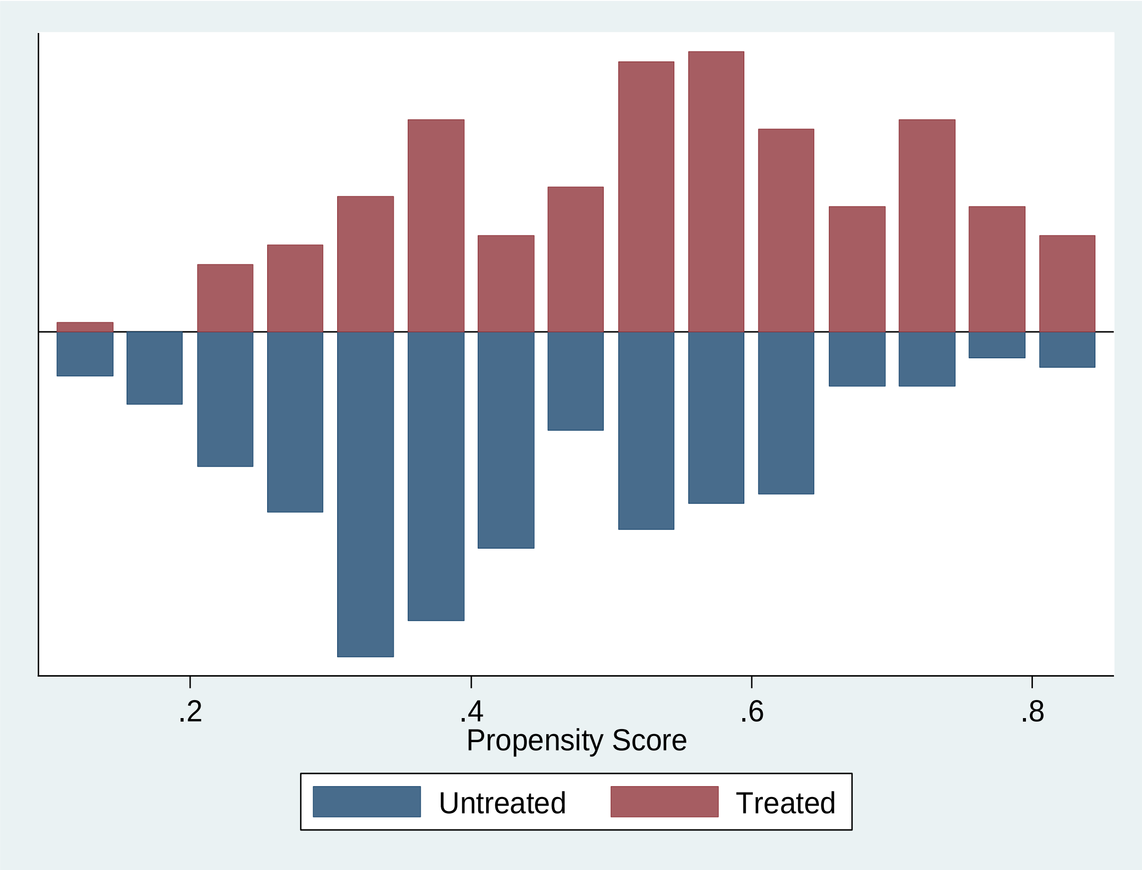

Figure 5A.1 Propensity scores distribution of treated and control household using baseline observables

CHAPTER 5: LONG-TERM WEATHER VARIABILITY, PORTFOLIO DIVERSIFICATION AND HOUSEHOLD WELFARE: EVIDENCE FROM RURAL TOGO

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Abstract

Using matched georeferenced household panel data and long historical rainfall data from northern Togo, this paper investigates livelihood diversification and households' welfare outcomes in the face of increasing weather variability. Our results show that long-term rainfall variation is decelerating diversification, while more short-term deviations accelerate crop diversification. Furthermore, diversification is more likely to occur in wealthier households. In terms of welfare implications, our results indicate that livestock diversification in particular has the potential to improve a household's welfare. Local institutions seem to be supportive of crop and livestock diversification and contribute to decreases in poverty. However, the current arrangement of agricultural institutions in Togo is not effective in mitigating negative effects from an increasingly risky environment. The paper concludes that there is a necessity to strengthen credit, agricultural and market institutions for stimulating diversification in the agricultural portfolio.

Keywords: Diversification, weather variability, consumption, correlated random effects, Togo

***JEL Classification*: Q01, C36, Q10, Q16**

5.1. Introduction

Climate change and associated weather shocks challenge the achievement of improvements in food security and poverty reduction in developing countries, especially in sub-Saharan Africa (SSA), where livelihoods mainly hinge on rain-fed agriculture (Esikuri, 2005; Shiferaw et al., 2014). In addition, formal off-farm income-generating activities are traditionally limited and hindered in rural areas because of imperfect or missing credit and insurance markets, low levels of employable skills, as well as a weak formal employment sector (Amare et al., 2018; Dercon and Krishnan, 1996; Reardon and Taylor, 1996). Lack of insurance and credit markets impedes participation of households in higher return upstream ventures. In rural SSA, households either pursue livelihood intensification or diversification strategies to mitigate climatic shocks. A recent review of the diversification literature by Loison (2015) concludes that household diversification remains critical to livelihoods and welfare, especially in SSA with missing markets and increase risks of climate variability. Although livelihood diversification presents an important pathway for development of rural SSA economies, a better comprehension of the decision in the midst of increasing weather variability and attendant shocks remains critical (Arslan et al., 2017; FAO, 2012; Taffesse et al., 2011).

For example, a better understanding of the different factors and how they shape household diversification in the presence of policy institutions is relevant for informing policy. Therefore, this study is both a necessity and timely. On the one hand, this paper can contribute to a better understanding of household portfolio diversification, i.e., it will contribute to identifying possible policy entry points to stimulate specific diversification strategies with good growth potential. On the other hand, it can also identify important strategies with high returns on rural welfare that should be pursued to elevate rural poverty and reduce vulnerability.

This paper contributes to the empirical diversification literature in a number of ways. First, the study identifies drivers of key diversification strategies (crop, livestock and income) in an increasingly exposed environment. Specifically, the study focuses on the effect of opportunity and survival driven factors, with emphasis on climate- and policy-related institutional variables. Second, the study provides empirical evidence of the role of diversification as coping strategy against climate variability shocks. Third, study contributes to understanding the impact of diversification on rural welfare outcomes.

The rest of the paper proceeds as follows. We begin by reviewing the literature on diversification. We then proceed to conceptualize the empirical estimation strategies employed.

This is followed by the data description, estimation strategies and results. The paper ends with a summary of the main results and policy implications.

5.2. Literature review

5.2.1. Household diversification patterns and welfare outcomes

Diversification in the context of small-scale farmers is regarded as a conscious process by the household to adopt or combine different portfolios of activities to increase returns from production inputs or improve welfare outcomes (Ellis, 1998; Di Falco and Veronesi, 2013; Start, 2001). The portfolio combinations may include off-farm employment to make use of excess labor, a mix of different crop and livestock species or self-employment activities. A review of the diversification literature of SSA shows that households increasingly depend on multiple portfolio combinations to sustain their livelihoods instead of traditional subsistence farming (Bryceson, 2002; Loison, 2015; Losch et al., 2012). Livelihood diversification has a direct income and consumption stabilizing with a direct effect on consumption and wellbeing. Where output markets are accessible and well integrated, additional crop or livestock output can be sold to supplement household income. Diversification further serves as safety net for the rural poor and also tool for asset accumulation for economic growth across classes (Andersson Djurfeldt, 2013; Barret et al., 2001a; Bezu and Barret, 2012; Ellis, 1998; Fafchamps et al., 1998; Losch et al., 2012; Prowse, 2015; Schlenker and Lobell, 2010).

While diversification is a conscious effort by the household, there are broad strands of literature that explain the motives for household diversification: (1) purely as a survival mechanism to cushion against some distress or ad hoc conditions i.e. diversification is driven by “push” factors and (2) asset accumulation motivation created by the presence of some proper economic, infrastructure and market opportunities diversification is driven by “pull” factors (Barret et al., 2001b; Bryceson, 1999; Dimova and Sen, 2010; Ellis, 1998; Loison, 2015; Martin and Lorenzen, 2016). Push factors are negative events that force the expansion of a household’s portfolio of activities to cope the distress. For example, climate or weather variability, land constraints, the absence of developed and integrated factor markets, lack of infrastructure, and constrained access to credit and insurance markets. These factors dominate developing countries (Amare et al., 2018; Haggblade et al., 2010; Loison, 2015). Pull factors on the other hand, encompass improved infrastructural development, access to nonfarm opportunities, and access to land and improve inputs and improve technology or increased educational attainment. Households expand or diversify their portfolios to take advantage of the improved markets. Pull factors are often dominated by asset diversification and indicate the wealthy wanting to increase their income streams and indicates the transition from small scale to commercial agriculture (Chamberlin et al., 2014; Ellis and Freeman, 2004).

5.2.2. Climate variability and livelihoods

Climate variability has both direct and indirect on household productivity, diversification and welfare outcomes. Directly, climate variability negatively impacts agricultural production, by affecting crops grown, the uptake and use of technology, increases in crop disease and pestilence, the loss of biodiversity, land degradation and the loss of fauna and reduced livestock productivity through prolonged drought (Amare et al., 2018; Asfaw et al., 2015; Dercon and Christiaensen, 2011; Barbier, 2010; Hansen et al., 2004; Tibesigwa, Visser and Turpie, 2015). Households are then forced to draw down productive assets, engage in natural resource exploitation or increase rural-urban migration as stop-gap emergency measures to stabilize welfare (Guatam, 2006; Scheffran et al., 2012; Shiferaw et al., 2014). Indirectly, climate variability can lead to higher food prices caused by reduced farm yields or higher production costs, increasing food insecurity and malnutrition among net purchasers of food. These indirect effects will be high in SSA, where food expenditures remain the single highest budget item, accounting for up to 70% of total household per capita expenditures (Fafchamps et al. 1998; Weyori et al., 2018).

To mitigate these adverse effects and protect welfare, rural agricultural households adopt a combination of diverse livelihood activities that are less dependent on weather outcomes. For example, households try to engage in off-farm employment and other income-generating activity portfolios. However, entry barriers such as high-end skill requirements, absence of well-developed and functioning credit and insurance markets hinder diversification away from agriculture (Barret et al., 2001a; Reardon, 1997; Shiferaw et al., 2014).

From the foregoing, we establish and test the following hypotheses. First, long-term rainfall variability lowers household consumption while increasing poverty. Second, increase portfolio diversification improves welfare in two ways: (1) additional income directly increases consumption and (2) asset accumulation reducing vulnerability to poverty. We test first hypothesis, we estimate the effect of coefficient of variation of rainfall an indicator of climate variability on consumption per capita and poverty headcount. To test the second hypothesis, we estimate the impact of household level diversification on welfare outcomes (consumption per capita and poverty headcount) in high climate variability environment. In this way, we further test if the various diversification strategies have any mitigating effects of weather variability shocks.

5.2.3. Climate variability and livelihoods in Togo

Agricultural is the backbone of rural livelihoods in Togo, constituting approximately 43% of national GDP. The sector also accounts for approximately 50% of national export earnings and employs approximately 70% of the population. Agriculture is especially important for the northern regions of Togo, where poverty and food insecurity are rife, and up to 75% (90%) of the population in Kara (Savana) live below the poverty line, which is far above the national average of 61%. The dependence on rain-fed subsistence agriculture and the lack of diversified livelihood strategies are among the root causes of poverty and inequality aside from the political unrest that the country experienced in the past (NAPA-Togo, 2009). According to a World Food Program report, approximately 71% of Togolese are vulnerable to food insecurity as a result of their low agricultural capacities and productivity as well as, erratic weather conditions.

Northern Togo is characterized by a tropical climate with annual average temperatures ranging from 25°C-40°C and average rainfall figures of 1200 mm-1500 mm. The normal rainfall season begins in April and ends in late October each year. Togo's rainfall patterns continue to vary, making long-term trend analyses difficult. Available data indicate that rainfall has decreased significantly since 1960, reducing an average of 2.3 mm per month or 2.4% per decade from 1960 to 2006 (Kandji et al., 2006; McSweeney et al., 2010; World Bank, 2010). The dry period has become longer and hotter, negatively affecting crop yields and productivity. Togo is exposed to increase climatic shocks and stress in recent times. For example, the annual mean temperature of Togo has increased by 1.1°C since 1960, which is more than the global average over the same period. This increase is even more pronounced in the northern regions of the Kara and Savana regions (NAPA-Togo, 2009). The situation gives credence to the vulnerability of livelihoods to various shocks, especially climate variability, which directly affects agriculture a main livelihood strategy.

Furthermore, simulated results from a long-term climate variability analysis show that staple crops, such as maize and rice, suffer the most through lower yields, rising production costs and increased output price because of climate variability (Wheeler, 2011; World Bank, 2008). Livelihood diversification by way of crop and livestock mix and other alternative income-generating strategies to cope with the negative impact in the medium to long term is important to sustain consumption and welfare. The choice of rural Togo for this study is important for two reasons: First, it gives an understanding of household diversification in rural Togo a previously uninvestigated area. Second, the study allows us to identify policy stimulating variables that can be targeted to improve household diversification in the face of accelerated rainfall variability as a result of climate change.

5.3. Conceptual framework and estimation strategy

5.3.1. Conceptual framework

To understand household diversification decisions and how they may help a household cope with rainfall variability, we conceptualize the study on the context of the livelihood framework. The intuition behind the framework is that household assets and endowments shape the type of activities and opportunities undertaken to protect livelihoods against shocks. In the context of rural SSA, households are predominantly poor and lack adequate capital assets to invest in high yielding returns or to cope with exogenous shocks such as droughts (Shiferaw et al., 2014; Amare et al., 2018).

As discussed above, households in SSA remain vulnerable to rainfall shocks because of their dependence on rain-fed agriculture coupled with the lack of irrigation infrastructure. In the absence of formal off-farm employment opportunities that could act as stop-gap measures to insure households against such weather shocks, the situation becomes even more severe, leaving them trapped in structural poverty. Household vulnerability is therefore directly linked to risk mitigation strategies that are shaped by the endowments and assets of a household (Menon, 2009). For example, productive assets can be liquidated by way of sales in times of stress to mitigate the immediate shortfall in income or food supply to reduce household vulnerability. Additionally, additional income can enable households to further diversify into higher return portfolios that they would naturally be excluded from because of liquidity and credit constraints. Diversification may thus reduce households' sensitivity and exposure to shocks and risks.

In the next section, we present the empirical estimation strategy to test our hypotheses above.

5.3.2. Empirical estimation strategy

Following the inseparable agricultural household model in the presence of risks and market imperfections, households choose a combination of strategies that maximizes utility. Therefore, the observed diversification outcome is modelled as a function different "push" and "pull" factors given household endowments. In the context of this study, we employ the Gini-Simpson index to measure household diversification outcome. The index is given as $S_j = \left(1 - \sum_j n_j^2\right)$, where n_j is the number of unique units of diversification options available to the household that corresponds to the j index($j = l, c, y,$ representing livestock, crop and income respectively).

We follow Arslan et al. (2017) and define the diversification categories options as follows: (1) livestock diversification the contribution of different tropical livestock units (TLU)[14] to the total TLU of the household, (2) crop diversification as the number of different crop species cultivated on a household's available farmland and (3) income diversification as the monetary shares of household total monetary income disaggregated into five distinct categories, i.e., crop, livestock, off-farm self-employment, formal employment and natural resource extraction. The resulting indices have a lower limit of zero (specialization) and a higher limit of one (full diversification).

To investigate the first hypothesis, i.e., identify drivers of household diversification decisions; we jointly estimate a group of linear regression models by applying the seemingly unrelated regression (SUR) procedure proposed by Zellner (1962). This accounts for potential correlations between the error terms of the different diversification decisions. We specify the 3 equations as follows:

$$S_{lit} = \beta_{1l}\Gamma_{pt} + \beta_{l2}\mathrm{X}_{it} + \beta_{l3}\mathrm{K}_p + \beta_{l4}\bar{\mathrm{X}}_i + \mu_{lit} \quad (1)$$

$$S_{cit} = \beta_{1c}\Gamma_{pt} + \beta_{c2}\mathrm{X}_{it} + \beta_{c3}\mathrm{K}_p + \beta_{c4}\bar{\mathrm{X}}_i + \mu_{cit} \quad (2)$$

$$S_{yit} = \beta_{1y}\Gamma_{pt} + \beta_{y2}\mathrm{X}_{it} + \beta_{y3}\mathrm{K}_p + \beta_{y4}\bar{\mathrm{X}}_i + \mu_{yit} \quad (3)$$

where S_{it} is the i^{th} household's diversification index at time *t* (2013, 2016) with respect to livestock (l), crop (c), and income (y) diversification. Γ_{pt}, is a vector of weather variables (coefficient of variation (CoV) of rainfall and lagged rainfall anomaly) at the prefecture level[15], and X_{it} represents a rich set of exogenous household and farm level variables. K_p captures village fixed effects such in institutions and infrastructure, e.g., agricultural services, access to credit and output markets. The error term, $\mu_{it,}$ is a composite term made of a time-varying

[14] We estimate the TLU for all livestock except cattle primarily because of the fact that most of the respondents in this study are cattle farmers.

[15] Rainfall data is only available at the prefecture. The villages used for this study were matched with the nearest weather station so that no village was assigned to a weather station too far away that may not reflect the actual weather conditions.

component that is normally distributed and independent of X_{it} plus a time-invariant unobserved effect component. To cater to the time-invariant unobserved heterogeneity effects (potential endogeneity issues), we follow Mundlak (1978) and Wooldridge (2002) and include the average of time varying X_{it} given as $\bar{X}_i$ which is allowed to freely correlate with the error term, $\mu_{it,}$. Eqns. (1)–(3) are estimated by a seemingly unrelated regression with correlated random effects procedure allowing the error to correlate across equations. The coefficient β_1 gives the role of climate variability on diversification, e.g. it is positive if diversification is driven by rainfall variability and negative if the reverse is true (Arslan et al., 2017, Kandji et al., 2006).

To investigate the effect of climate variability on household welfare variables (consumption per capita and poverty), we estimate the following model:

$$\Upsilon_{ikt} = \beta_{\Upsilon 0} + \beta_{\Upsilon 1}\Gamma_{pt} + \beta_{\Upsilon 2}X_{it} + \beta_{\Upsilon 3}\bar{X}_i + \beta_{\Upsilon 4}(K_{pt} * \Gamma_{pt}) + \mu_{it} \quad (4)$$

where Υ_{ikt} is consumption per capita at the adult equivalent scale and poverty headcount[16]. The poverty line used for this estimation is the internationally defined poverty line of US$ 1.90/day. In addition, we control for the same covariates as in eqns. 1–3 and $K_{pt} * \Gamma_{pt}$, i.e., an interaction between rainfall variability and institutional variables (access to credit, output markets and agricultural extension service) that captures the role of institutions acting as policy instruments and tests for the mitigating effect of these institutions on consumption and poverty in a highly variable environment. The Mundlak correction terms are also included to address possible endogeneity arising from unobserved heterogeneity. Eqn. 4 is estimated through the logit and generalized least squares (GLS) correlated random effects model for poverty and consumption outcomes, respectively. The issue of inherent endogeneity issues is corrected for as above. After establishing the impact of climate variability on household welfare, we further extend eqn. 4 to capture the impact of the different diversification portfolios on consumption and poverty in the presence of weather variability shocks. We estimate the role of diversification and climate risk effects on households' welfare as follows:

$$\Upsilon_{ikt} = \beta_{\Upsilon 0} + \phi_1 S_{lit} + \phi_2 S_{yit} + \phi_3 S_{cit} + \beta_{\Upsilon 5}\Gamma_{pt} + \beta_{\Upsilon 6}X_{it} + \beta_{\Upsilon 7}(S_{it} * \Gamma_{pt}) + \beta_{\Upsilon 8}\bar{X}_i + \mu_{it}$$
(5)

[16] Given that household income is linked to both consumption and poverty outcomes, we restrict our welfare estimation to consumption and poverty headcount. Households are less likely to over underestimate their income than they are to report their income earnings.

We also introduce a new interactive term ($S_{it} * \Gamma_{pt}$) that captures the interaction between the level of diversification and the weather variable (CoV) in the estimation to show the mitigating effect of the different diversification strategies against weather variability shocks on household welfare. We interpret the coefficient, $\beta_{\Upsilon 3,}$ as follows: If the nominal value of $\beta_{\Upsilon 7}$ is significantly positive, it means that the given diversification strategy is able to completely offset the negative effects of rainfall variability on consumption (poverty) for household i. The potential endogeneity issues arising from the inclusion of the diversification variables as a determinant of household welfare are addressed to the extent that they are caused by time-invariant unobserved heterogeneity and thus are addressed through the Mundlak correction factor captured by including the term $\beta_{\Upsilon 8}\bar{X}_i$ in estimating eqn. 4 (Wooldridge, 2010; Wen and Maani, 2018). The remaining variables in eqn. 5 are defined as in eqn. 1–3.

5.4. Data and variable description

The data involve two sources: (i) panel household and village level survey data from the European Union (EU) commission project Trypanosomosis Rational Chemotherapy – TRYRAC[17] and (ii) historical weather data on rainfall and temperature obtained from the National Oceanic and Atmospheric Administration (NOAA). The survey was conducted in 20 randomly selected villages in the Kara and Savanna regions in northern Togo. A total 443 households were randomly selected and interviewed for the baseline survey in 2013. These were also reinterviewed in 2016 to form a balance panel.

The survey questionnaire was administered by trained enumerators who collected comprehensive household information on household characteristics, agricultural production (crop and livestock), off-farm and self-employment, assets and consumption and food security measures. Additionally, a detailed section was included to elicit various ex-post shocks and ex-ante expected risks and coping strategies of households. We specifically asked respondents for shocks that they experienced in the last five (two) years preceding the baseline (follow-up) survey date relating to the family (socio-demographic shocks), farm (climatic shocks), and job and income (economic shocks). We also asked about the frequency of the particular shock experienced and its severity given as the estimated loss of welfare. Finally, respondents were

[17] The Trypanosomosis Rational Chemotherapy is an EU sponsored project funded through its Global Program for Agriculture Development (ARD). The project includes a number of improved practices for the control of trypanosomosis among small scale livestock farmers in sub Saharan and eastern Africa (Togo, Ethiopia and Mozambique). For details visit http://www.trypanocide.eu/

also asked if they had recovered from the shock, and if yes, how long it took to recover and how they coped or were still coping with the shock in case they had not yet recovered. The subjective shock measure was complemented by asking households about expected risks in the future.

Household data were merged with the georeferenced village level rainfall data for the period 1985-2015 downloaded from the African Climatology Version 2 (ARC2) of NOAA. The rainfall data are a daily measure of precipitation with a spatial resolution of 0.1 degrees (~10 km)[18] using the latest estimation techniques[19]. We follow the works of Arslan et al. (2016) and Asfaw et al. (2015) and capture the long-term rainfall variability as the coefficient of variation (CoV) of the long-term seasonal rainfall for the period 1985–2015. To capture the behavior of households with regard to immediate weather shock events, we also estimate the deviation of the lagged mean seasonal rainfall from the long-term mean measure for the 2009 to 2013 crop season.

5.4.1. Descriptive statistics

Table 5.1 presents the descriptive statistics for the main variables of interest. In terms of demographic, farm characteristics and diversification, our respondents are mostly male, with only 2% of the respondents being females. In terms of household composition, the average household size is 10, with a dependency ratio of 1.27. This relatively high dependency ratio may indicate insufficient labor to meet agricultural and other production needs. To make up for a possible shortfall, households may exploit other labor sources, such as from social networks or even child labor. This issue is especially critical in the absence of developed labor markets and the critical role of labor in household diversification (Barret et al., 2001a). Respondents are generally subsistence farmers who own, on average, 2.5 ha of farm land growing mostly multiple crops (e.g., maize, sorghum, groundnuts and some vegetables) and different livestock species. We also find that households do not own substantially valuable assets. Although the use of draft power to till the land remains quite popular in the region, ownership of the animal drawn implements is low.

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[18] For a detailed description of the algorithms used in deriving the climate data see: http//www.cpc.ncep.noaa.gov/products/fewa/AFR_CLIM/AMS_ARC2a.pdf

[19] Due to collinearity between rainfall and temperature, we did not include temperature in our analysis, i.e., high temperature is associated with low rainfall and vice versa.

In terms of household diversification, we find that households are increasing the number of crops cultivated. Crop diversification is increased on average from 48% to 82% from 2013 to 2016 respectively. Livestock diversification, on the other hand, increased marginally from 36% in 2013 to 39% in 2016. Over the same period, income diversification remains the lowest, with 19% and 23% diversification in 2013 and 2016, respectively. Household income and consumption per capita are low, and approximately 41% of our households are below the poverty line. These results from Table 5.1 suggest there seems to be a correlation between increased diversification and consumption as there is an observed growth in consumption per capita, just as overall diversification indicates an increase. In contrast, total household income decreases over time.

Table 5.1 Descriptive statistics of selected variables

	2013 (N=443)		2016 (N=443)	
Climate variables	**Mean**	**Std. dev**	**Mean**	**Std. dev**
CoV rainfall (1985-2015)	54.4	13.6	54.4	13.56
rain anomaly lagged period[a]	0.62	0.22.07	0.62	0.22
Household variables				
Age of household head (years)	47.26	14.62	50.97	14.65
Education of household head (years)	2.45	3.93	2.12	3.59
education of household head (1=yes)	0.35	0.48	0.02	0.15
social network (1=yes)	0.45	0.50	0.42	0.49
Household size	9.84	4.80	11.68	5.63
Dependency ratio	1.27	0.90	1.01	0.75
Number of wives	1.59	0.89	1.50	0.90
Asset (log of assets value)	7.22	1.01	8.22	1.75
Farm size (hectares)	2.83	4.17	2.60	2.56
Access to transport	0.19	0.39	0.19	0.39
Owns motor bike	0.00	0.07	0.05	0.22
Owns a bull plow	0.00	0.07	0.07	0.25
Household member formally employed	0.14	0.40	0.08	0.31
Household head is leader in agricultural association	0.04	0.19	0.22	0.41
Demographic shock (1=yes)	0.30	0.46	0.66	0.47
Risk taker (1=yes)	0.38	0.49	0.28	0.45
Distance to agriculture office (km)	12.26	12.84	12.26	12.84
Distance to market (km)	4.96	8.91	4.96	8.91
Access to credit (1=yes)	0.16	0.36	0.16	0.36
Diversification indices				
Livestock diversification index	0.36	0.25	0.39	0.25
Income diversification index	0.19	0.19	0.22	0.26
Crop diversification index	0.48	0.26	0.82	0.19
Welfare indicators				
Household income per capita (PPP$)	772.55	936.73	727.07	763.03
Consumption per capita (AES)[b] (PPP$)	1004.68	770.78	1260.10	1533.34

Notes: [a] Rainfall anomaly lagged period is given as the percentage of deviation of rainfall during the 2009/2010 from the long-term average. [b]The per capita consumption is adjusted for household composition in terms of gender and age using the adult equivalent scale (AES).
Source: Authors' calculation

Next, we examine the specific shocks and mitigation strategies reported by households during the period. Table 5.2 shows that households experienced a wide range of shocks.

We find that most of our respondents (75%) have experienced at least one main type of shock in the last 5 years before the baseline survey in 2013. However, this number increased greatly in 2016, suggesting the increasing vulnerability of respondents to risks and indicating the lack of or inadequacy of current risk mitigation strategies in the study area, which leaves livelihoods exposed to shocks. The impact of climatic shocks remains the highest source of welfare loss in the sample, causing, on average, 169,842 CFAF (PPP$ 738)[20] loss to household welfare in 2013. This result is not surprising given the dependence of households on weather-related livelihoods such as crop and livestock production. Demographic shocks that include the illness of household members, death or accidents remain the second highest cause of welfare loss, with approximately 46% of respondents reporting at least one type of demographic shock in 2013. However, the highest contributor to welfare loss in 2016 was a demographic shock costing respondents on average 178,736 CFAF (PPP$ 776). This result means that these two shock items are able to completely wipe out the household annual income of PPP$ 772 (PPP$ 727), impoverishing the household and drawing such households deeper into poverty and vulnerability. It is important to note from Table 5.2 is that all reported shocks resulted in a significant loss of income, suggesting the failure or lack of risk mitigation strategies in the study area to prevent shock events or reduce the impact of such events.

Table 5.2 Reported shock categories and associated loss in CFA-Francs

	Frequency		**Percent of HH**		**Loss CFA-Francs**	
Shock category	*2013*	*2016*	*2013*	*2016*	*2013*	*2016*
Demographic	251	217	46.31	43.93	144,592	178,736
Climatic/natural	111	94	20.48	19.03	169,842	126,924
Economic	28	68	5.17	13.77	116,625	98,150
Social/conflict	14	20	2.58	4.05	94,928	206,282
No shock	138	16	25.46	3.24	-	-
Average loss					141,602	149,987

Source: Authors' calculation

In Table 5.3, the severity and duration of shocks reported by households is presented. The majority of respondents perceived all self-reported shocks as highly severe and needed more than 1 year to recover. The possible explanations for this long adverse effect may be argued as follows: First, a lack of adequate household assets and resources to mitigate ex-ante risks increases the vulnerability of households to a wider effect of ex-post shocks. Second, as shown

[20] This figure is the estimated loss suffered by the respondents' household through crop and animal losses and the destruction of dwellings as well as other tangible assets.

in the diversification indices, households are generally less diversified in their portfolios, which may largely reduce their livelihood coping abilities in general.

Table 5.3 Subjective impacts of shock events and duration of the impact

	Demographic shocks (%)		**Climatic shocks (%)**		**Economic shocks (%)**		**Social/conflict shocks (%)**	
Severity	*2013*	*2016*	*2013*	*2016*	*2013*	*2016*	*2013*	*2016*
High	88.52	81.02	89.19	78.49	71.43	80.60	78.57	65.00
Medium	11.07	16.20	9.01	20.43	17.86	19.40	14.29	20.00
Low	0.41	2	1.8	-	3.57	-	7.14	5.00
No impact	0	4	0	1.08	7.14	-	0	10.00
Duration to recover from event								
< year	46.55	30.56	29.9	34.04	30.43	31.34	15.38	40
1 year	20.26	10.19	29.9	17.02	34.78	19.40	15.38	10
> 1 and less than 2 years	14.22	9.26	19.59	9.57	17.39	11.94	23.08	5
> 2 years	18.97	50.00	20.62	39.36	17.39	37.32	46.15	45

Source: Authors' calculation

Table 5.4 shows that households mainly disinvest (selling off livestock, land and crop), liquidate savings, use their social network ties and reduce the number of meals per day or even skip entire meals as coping strategies. The most dominant coping strategy is the use of savings by approximately 35%. Although livestock sales represent only 24%, the actual contribution may be as high as 59% since household savings are mostly from the income received from sales of livestock and livestock products. The importance of livestock in SSA was pointed out by Fafchamps et al. (1998) who found that sales of live livestock had an important income smoothing effect during drought periods in Burkina Faso.

Table 5.4 Most important coping strategies of households

Coping strategy	**Frequency of respondents**	**Percentage**
Sold livestock	90	24
Sold land	23	6
Savings (cash at home)	134	35
Sold crop	80	21
Relied on social networks	28	7
Reduced food consumption	15	4
Migration	3	0.5

Source: Authors' calculation based on 2013 field data

In terms of shock coping strategies, up to 21% and 7% of respondents, respectively, relied on crop sales and social networks (family and friends) (Table 5.4). The use of remittances (0.5%) and the reduction of consumption (4%) are the other coping strategies adopted by respondents.

Different off-farm livelihood portfolios and their roles to the household economy in terms of disposable income is presented in Table 5.5. Crop and livestock income accounts for up to 90%[21] of total household income. Households are less diversified away from on-farm activities. For example, off-farm and self-employment activities contribute approximately 8% (7%) of total disposal household income in 2013 (2016) respectively while natural resource extraction contributes 1.7% (2.7%), remittances and transfers contributed 0.6% (0.9%) to total disposal household within the same period respectively. A closer look at Table 5.5 also shows that there was a drop in the overall contribution of the various portfolios to household income in 2016.Table 5.5 suggests the existence of entry barriers to nonfarm income-generating activities.

Table 5.5 Household livelihood diversifications aside from crops and livestock

	Percentage of households (%)		**Share of total household income (%)**		**Average nominal value per capita (CFAF)**	
Income source	*2013*	*2016*	*2013*	*2016*	*2013*	*2016*
Natural resource	50	29	1.65	2.72	8,290.76	2,239.10
Self-employment	11	7	2.94	1.45	7,532.51	2,899.32
Off-farm employment	10	10	5.66	5.26	3,608.21	4,235.51
Remittances/transfers	10	10	0.61	0.91	2,608.79	1,360.00

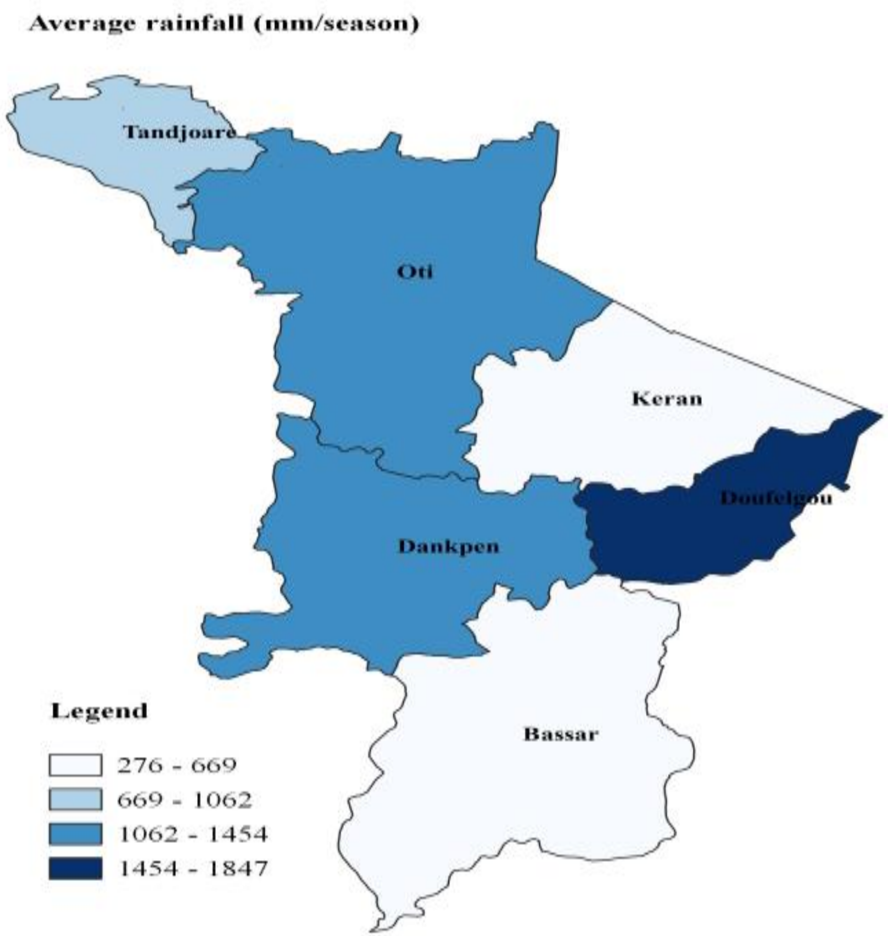
Source: Authors' calculation

Next we present the rainfall distribution over the study area. In Figure 5.1 the long-term CoV and long-term average rainfall is presented. Figure 5.1 shows a pattern of association that indicates a site-specific relationship between the CoV and mean rainfall outcome. The overall pattern in Figure 5.1 indicates that rainfall deviation is less pronounced in the Savana region (Oti and Tandjoaré prefectures) compared to the Kara region (Kéran, Dankpen, Bassar and Doufelgou prefectures), suggesting that households in the Savana region are less likely to be affected by rainfall variability shocks compared to households in the Kara region.

In Figure 5.2, a presentation of the different household diversification strategies by prefecture is given. The upper part of Figure 5.2 shows household diversification outcomes for 2013, while the lower portion gives diversification for 2016. Households in Savana are more diversified

[21] This is not shown in this table but may be provided.

compared to Kara. Comparing the rainfall variability pattern presented in Figure 5.1 with diversification patterns of respondents as shown in Figure 5.2 shows a possible negative association instead of positive as expected. This suggests that diversification is not adopted by households to mitigate weather variability shocks, which is contrary to our hypothesis of respondents relying on portfolio diversification as a mitigation strategy. Furthermore, Figure 5.2 suggests that livelihood diversifications are driven by specific local characteristics, which require rigorous econometric methods to investigate. In the next section we investigate and present vigorous results of determinants of diversification and if diversification mitigates climate variability shocks to households.



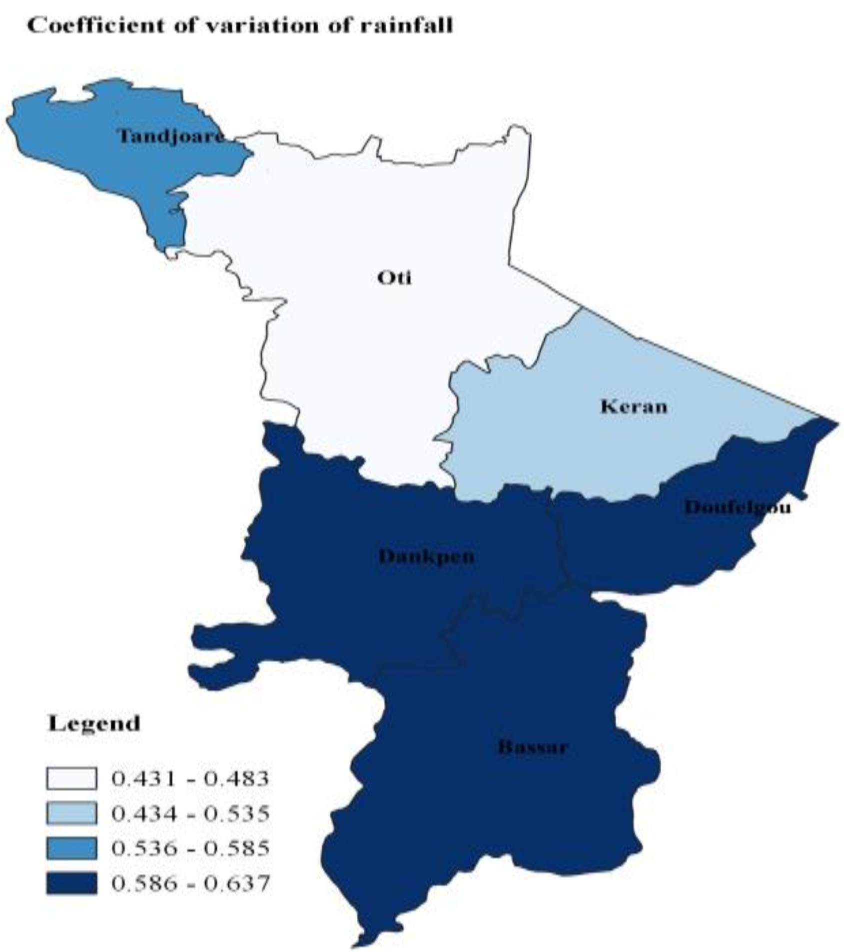
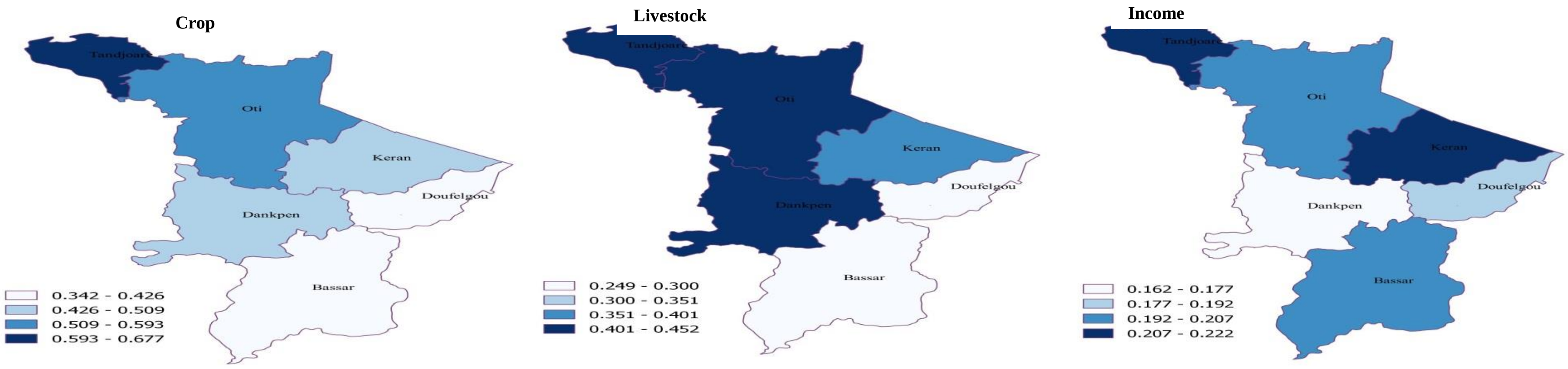


Figure 5.1 Long-term (1985–2015) average rainfall and the coefficient of variation by prefecture

2013 Gini-Simpson indices



2016 Gini-Simpson indices

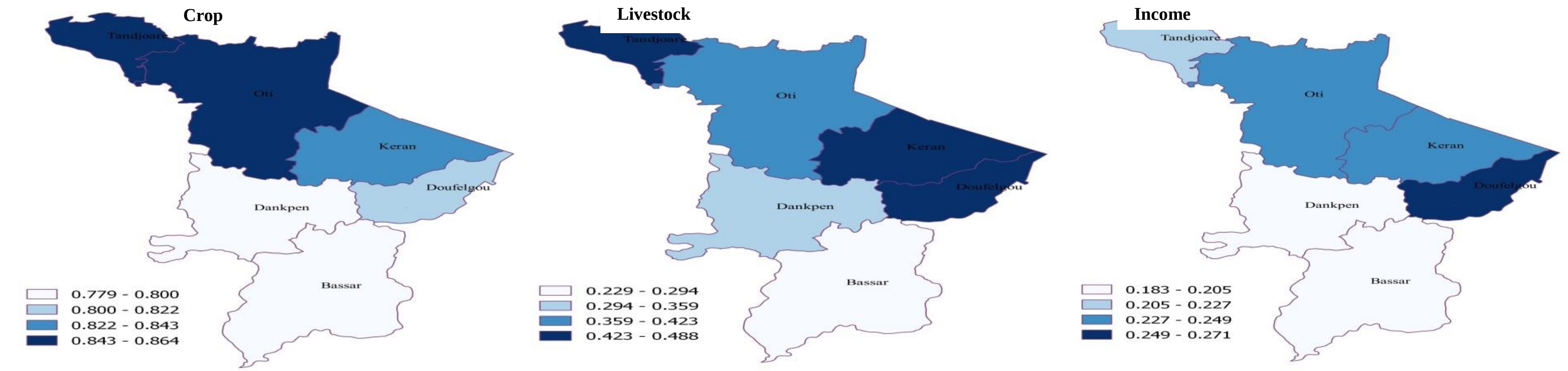


Figure 5.2 Diversification indices of respondents in 2013 and 2016 by prefecture

An economic comparison between Kara and Savana show that households in the Savana region are wealthier, have more access to credit, take more loans and have higher consumption per capita compared to the households in Kara (see Table 5.6). These results suggest the role of wealth and credit in stimulating growth and the expansion of the local household economy – diversification – as depicted by the diversification outcomes as shown in Figure 5.2.

Table 5.6 Comparison of wealth of respondents by Region

	Pooled			**2016**		
variable	Kara (N=504)	Savana (N=382)	Change (t-test)	Kara (N=252)	Savana (N=191)	Change (t-test)
Consumption (PPP$) (Base year 2012)	1015	1287	272.30**	1034	1558	523.63**
Income (PPP$)	796.62	688.05	-108.58*	756	689	-67.46
Assets (PPP$)	3992	6248	2255.20***	4149	6202	2053***
Credit Access	0.59	0.77	0.18***	0.57	0.76	-0.20***
Accessed loan	0.31	0.32	0.11	0.31	0.33	0.01
Poverty	0.44	0.35	-0.085**	0.43	0.36	-0.08*

Note: *** p< 0.01, ** p < 0.05, * p < 0.1 significance level

Source: Authors' calculation

The foregoing descriptive statistics suggests that households are less diversified away on-farm activities, with livestock production remaining an important contributor to disposal household income. Furthermore, climate variability i.e., rainfall variability shock effects causes a welfare loss of up to PPP$ 776 per annum. The majority of households lack strong and resilient coping strategies to mitigate unexpected events and therefore take longer period (>12 months) to recover in during such negative effects. The results of diversification and rainfall variability patterns do not show a visible positive correlation. These results, however, should be explained with caution given that no rigorous tests have been conducted to determine the actual relationship between the variables. In the next section, we present the results of our econometric estimation of the determinants of diversification and the role of diversification in household welfare.

5.5. Econometric results

This section follows a three-part presentation. First, we report the results on the determinants of a household's diversification decision with attention to the role of weather variability (CoV and lagged rainfall anomaly). In the second part, we present the results of the impact of weather variability on welfare outcomes. Finally, we present the results of the impact of the different diversification strategies on welfare in a high rainfall variable environment.

5.5.1. Determinants of household diversification decision

Table 5.7 presents the results of the determinants of the three different diversification strategies, i.e., crop, livestock and income diversification, estimated through the SUR with Mundlak correction. Columns 1 to 3 present the results of the specification in eqns. (1) to (3), while columns 4 to 6 include interaction terms between institutional variables and the indicator variable for high rainfall CoV. The purpose of the interaction terms is to test whether the effects of rainfall variability are changing in the presence of different institutions.

Focusing on the first specification (columns 1 to 3) shows a negative coefficient of rainfall variation (CoV) on livestock diversification, while there are no significant associations with crop and income diversification. This finding conflicts with what we expected and with the findings of Arslan et al. (2017) and Asfaw et al. (2015) in Zambia and Malawi, respectively. The negative coefficient in our study indicates that long-term rainfall variability does not appear to act as a push factor for household diversification but rather tends to reduce the rate of household livestock diversification. There are two possible explanations for the negative association between long-term rainfall variability and livestock diversification. First, larger rainfall variability in the long term is likely to have larger adverse impacts on livestock production, reducing the likelihood of escaping from a perpetuating downward trend. Second, the lack of access to and availability of improved inputs and technologies, such as a variety of irrigation facilities, increase the negative feedback loop between long-term risk and the ability for diversification.

However, the coefficient of the second main variable of interest, i.e., lagged rainfall anomaly, is positively associated with crop diversification, but does not affect livestock or income diversification. In other words, rainfall anomaly from the previous cropping season measured as the deviation from the long term coefficient of variation increases the incentive for crop diversifications. Taking both coefficients into considerations, our results suggest that long-term rainfall variation is decelerating livestock diversification. However, more ad-hoc severe deviations from the long-term average accelerate crop diversification.

The other household-specific control variables included in the model yield different significant effects among the different diversification decisions. For example, education, household size and owning a motorbike are positively associated with crop diversification. These results suggest the critical role of labor in crop production in subsistence agriculture. Education and ownership of a motorbike are indicators of wealth and suggest that crop diversification is driven by wealth. We also find that plot size is negatively associated with crop diversification, which is counterintuitive. However, it may be indicative of land exploitation and constraints in other critical inputs needed to operate on fatigue soils such as modified seeds and fertilizer.

With respect to livestock diversification, we obtain only one other household specific correlation coefficient that is significant, i.e., plot size. In contrast to crop diversification, plot size seems to be positively associated with livestock diversification. Larger plots that allow animals to graze and collect leftovers after harvest may stimulate the diversification of livestock.

As we did not find a statistically significant effect of our main variables of rainfall shocks on income diversification, we do find significant correlation coefficients on household size, idiosyncratic shocks such as the death of a household member, owning a plow and owning a motorbike. The ownership of motorbikes and plows are indicative of wealth and, hence, stimulating income diversification. These items are also important inputs of alternative income sources. For example, households with a plow could rent out their bullocks for land preparation to others for which they are paid. This practice is especially important for the SSA region, where cattle remain an integral part of land preparation and crop production. Similarly, a motorbike could be used for transport services. Furthermore, experiencing a demographic shock such as the death of household members significantly increases the probability of income diversification. This result seems intuitive since the household needs to find ways to manage the shortage in earnings created by the loss of the family member. In addition, there is also the need to raise resources to cover the funeral costs. Finally, household size is negatively associated with income diversification, which is counterintuitive. This result may, however, be explained by the marginal returns to labor. Given the lack of well-developed labor markets, investing the excess labor in crop production will be more productive to the household than renting out the labor for lower wages.

With respect to institutional variables, we obtain a statistically significant effect on the coefficient of credit access on crop diversification. The result suggests the critical role of liquidity in subsistence farming. Credit access is also positively associated with livestock diversification. Other policy interventions that increase the likelihood of diversifying livestock are agricultural services and access to information. However, focusing on the specification in columns 4 to 6, the interaction terms between institutions and high rainfall variability show no significant coefficients on the interactions. In other words, these institutions fail to stimulate household diversification in a high climate variability environment. One can conclude that policy targeted at stimulating crop and livestock diversification in areas that are exposed to high climate variability should consider access to credit and agricultural services as critical components.

Table 5.7 Determinants of household diversification outcomes (SUR model results)

	Without policy variables			**With policy variable interactions**		
	Crop diversification (1)	**Livestock diversification (2)**	**Income diversification (3)**	**Crop diversification (4)**	**Livestock diversification (5)**	**Income diversification (6)**
Long-term CoV of rainfall (1985-2015)	-0.001(0.001)	-0.003(0.001)***	-0.001(0.001)	-0.005(0.001)***	-0.004(0.001)**	0.001(0.001)
Rainfall deviation lagged (2014/2015)	0.012(0.001)**	0.000(0.003)	0.000(0.004)	0.012(0.003)***	-0.001(0.004)	-0.001(0.004)
Age of household head (years)	0.002(0.001)	-0.001(0.001)	0.001(0.001)	0.002(0.001)	-0.001(0.001)	0.001(0.001)
Education of household head (years)	0.002(0.006)	0.003(0.006)	-0.011(0.006)	0.001(0.006)	0.003(0.006)	-0.011(0.006)*
Education of household head (1=yes)	0.063(0.023)**	-0.023(0.025)	-0.008(0.026)	0.054(0.023)*	-0.024(0.025)	-0.005(0.026)
Household size	0.013(0.005)*	0.009(0.005)	-0.020(0.006)***	0.008(0.005)	0.009(0.006)	-0.019(0.006)***
Dependency ratio	0.002(0.018)	0.017(0.018)	-0.001(0.019)	-0.004(0.017)	0.017(0.0.019)	0.001(0.019)
Death of income earner (1=yes)	0.019(0.015)	0.019(0.106)	0.039(0.016)**	0.011(0.015)	0.016(0.016)	0.041(0.016)**
Log of farm size (ha)	-0.001(0.018)*	0.041(0.019)**	-0.020(0.020)	0.001(0.018)	0.041(0.020)*	-0.021(0.020)
Owns a traction plow	-0.057(0.042)	0.012(0.048)	0.138(0.046)**	-0.063(0.042)	0.007(0.045)	0.145(0.046)**
Assets (log)	-0.011(0.008)	-0.0.004(0.009)	-0.015(0.009)	-0.006(0.008)	-0.004(0.009)	-0.015(0.009)*
Own motor bike (1=yes)	0.233(0.051)***	0.077(0.054)	0.172(0.056)**	-0.230(0.051)***	0.070(0.055)	0.174(0.056)***
Access to media (radio) (1=yes)	0.020(0.014)	0.052(0.015)***	0.029(0.014)*	-0.018(0.013)	0.035(0.014)*	0.028(0.014)*
Access to credit	0.030(0.015)**	0.052(0.016)***	0.000(0.016)	-0.102(0.067)	-0.066(0.071)	0.082(0.074)
Distance to Agricultural office (Km)	0.000(0.001)	0.002(0.001)***	0.001(0.001)	-0.003(0.004)	0.004(0.004)	0.006(0.004)
Distance to market	0.000(0.001)	-0.002(0.001)*	-0.001(0.001)	-0.004(0.004)	0.002(0.004)	-0.005(0.004)
Year (1=2016)	0.069(0.025)***	0.340(0.022)***	0.040(0.026)	0.141(0.060)	0.066(0.064)	0.070(0.066)
CoV##Agricultural office				0.000(0.000)	0.000(0.000)	0.000(0.000)
CoV## Credit				0.001(0.001)	0.002(0.001)	-0.001(0.001)
CoV##Market				0.000(0.000)	0.000(0.000)	0.000(0.000)
Constant	-1.011(0.369)	-0.150(0.121)	0.521 (0.402)	-0.788(0.389)	-0.599(0.414)	0.431(0.428)
R-squared	0.535	0.188	0.158	0.547	0.192	0.162
Chi²	1019.72***	205.27***	166.60***	1068.51***	211.03***	170.76***
Observations (Panel)	**886**	**886**	**886**	**886**	**886**	**886**

Note: *** p< 0.01, ** p < 0.05, * p < 0.1 significance level, standard errors in brackets (Full estimation with Mundlak correction is attached as Appendix 5.A1) **Source:** Authors' calculation

5.5.2. Effect of weather variability on consumption and poverty

Before investigating the welfare impacts of diversification, we analyze the direct effects of rainfall shocks on households' consumption and poverty in Table 5.8. Rainfall variability may affect households' welfare through its adverse impacts on agricultural outputs, reduced income and consumption. We therefore investigate the direct effects of rainfall shocks on per capita consumption expenditures and poverty given as the consumption per capita expenditure below the $1.25/day poverty line. Columns 1 and 2 show the model results without the interaction between the policy variable and weather variability, while columns 3 and 4 show the results with the interaction terms.

With respect to the first two columns, we find that weather variability captured by the CoV and lagged rainfall anomaly variables are negatively correlated with consumption and positively correlated with poverty headcount. In other words, both shock indicators are negatively associated with a household's welfare. This result is consistent with the studies by Arslan et al. 2017, Tesfeya and Assefa, 2010, Asfaw et al. 2015, and Dercon, 2006 that show that climate variability is associated with welfare loss.

With respect to policy institutions, we do not find any association between any of the institutions and the consumption outcome (column 1). However, access to the agricultural office and credit are significant and negatively correlated with poverty (column 2). In columns 3 and 4, the results with the interaction term, i.e., how the policy institution, access to credit, and distance to the agricultural office and markets help households mitigate the negative effects of climate risks on welfare is reported. The interaction terms for market access are negative for consumption, although the direct impact of a market is positive. This result is an indication that output markets in their current forms are less effective in highly variable regions. However, the effect of access to credit and distance to the agriculture office remain insignificant. In terms of poverty, the results show a strong positive correlation between access to agriculture and credit institution terms and poverty outcomes. Similar to consumption, the direct impact of these institutions is negative, indicating that they are not able to mitigate the negative effects of climatic risks in highly variable regions. The results in columns 3 and 4 generally suggest that the adverse effects of rainfall shocks on welfare cannot be offset by these institutions.

The results indicate that the distance to markets variable is positive and significantly associated with increased consumption. This result shows that output markets can mitigate negative weather variability shocks on welfare through improved consumption.

Table 5.8 Impact of weather variability on consumption per capita and poverty

	Consumption per capita (*CRE–GLS)* (1)	**Poverty *(CRE–logit)* (2)**	**Consumption per capita *(CRE–GLS)* (3)**	**Poverty *(CRE–logit)* (4)**
CoV (1985 – 2015)	-0.017 (0.003)***	0.048 (0.012)***	-0.015 (0.004)***	0.040 (0.009)***
Lagged seasonal rainfall deviation (2014/2015)	-0.022 (0.003)***	0.061 (0.026)**	-0.021 (0.004)***	0.060 (0.026)**
Household head age	0.008 (0.005)*	-0.024 (0.007)***	0.008 (0.005)*	-0.025 (0.010)**
Education (years)	-0.016 (0.019)	0.029 (0.047)	-0.017 (0.019)	0.034 (0.042)
Education (1=yes)	-0.089 (0.075)	0.554*** (0.136)	-0.085 (0.075)	0.542 (0.110)***
Household size	0.013 (0.018)	0.106 (0.044)**	0.013 (0.018)	0.105 (0.050)**
Number of wives	0.109 (0.030)***	-0.213 (0.105)**	0.111 (0.030)***	-0.214 (0.109)*
Dependency ratio	0.059 (0.059)	-0.496 (0.117)***	0.056 (0.059)	-0.496 (0.156)***
Member of household in formal employment (1=yes)	0.074 (0.088)	-0.398 (0.040)***	0.080 (0.088)	-0.413 (0.098)***
Death of income earner (1=yes)	0.037 (0.047)	-0.224 (0.064)***	0.035 (0.047)	-0.226 (0.047)***
Member of social group (1=yes)	0.154 (0.072)**	-0.300 (0.231)	0.178 (0.073)**	-0.386 (0.183)**
Agriculture land size (log)	0.088 (0.062)	0.089 (0.436)	0.095 (0.062)	0.085 (0.567)
Asset value (log)	0.045 (0.028)	0.136 (0.191)	0.042 (0.028)	0.141 (0.186)
Own motor (1=yes)	0.624 (0.176)***	-0.979 (0.250)***	0.608 (0.176)***	-0.935 (0.232)***
Owns plowing implement (1=yes)	0.467 (0.146)***	-1.790 (0.099)***	0.444 (0.146)***	-1.746 (0.094)***
Distance to nearest Agriculture office	0.002 (0.002)	-0.013 (0.003)***	-0.004 (0.011)	-0.017 (0.001)***
Distance to nearest local market	-0.001 (0.002)	0.006 (0.008)	0.028 (0.011)**	-0.080 (0.048)*
Access to credit	0.057 (0.047)	-0.242 (0.038)***	0.082 (0.205)	-0.336 (0.048)***
Year (1=2016)	-0.101 (0.080)	-0.041 (0.232)	-0.097 (0.080)	-0.035 (0.252)
Interacting CoV with institutions				
CoV##Agricultural office			0.000 (0.000)	0.000 (0.000)*
CoV##Access to credit			-0.000 (0.004)	0.002 (0.000)***
CoV##Output Market			-0.001 (0.000)***	0.002 (0.001)
Constant	16.367 (1.115)***	-9.476 (7.078)	15.948 (1.176)***	-8.344 (6.503)
Observations (Panel)	**886**	**886**	**886**	**886**

Clustered standard errors are in parenthesis, significance *** p<0.01, ** p<0.05, * p<0.1 (full estimation with Mundlak correction is attached as Appendix 5.A2)

Source: Authors' calculation based

5.5.3. The effect of diversification on consumption and poverty

In Table 5.9, we present the results of the impact analysis of different diversification strategies on the consumption and poverty status of a household. Columns 1 and 2 show the direct effects of diversification controlling for rainfall shocks. Columns 3 and 4 introduce interaction terms between rainfall shocks and diversification to test whether diversification can offset the negative effects of rainfall shocks.

Columns 1 and 2 show that livestock diversification is positively associated with improved welfare, increasing consumption and reducing poverty. However, we find the reversed effect for crop diversification. In contrast to what one would expect, crop diversification is associated with decreases in consumption and increases in poverty. One possible explanation of this result may be that crop diversification hinges on additional inputs, such as improved seeds or irrigation facilities (Asfaw et al., 2014). With respect to the welfare effects of income diversification, we do not find any statistically significant effects.

Finally, we focus on columns 3 and 4 and examine the potential mitigation effects of diversification against rainfall shocks. The only (weakly) significant interaction term is between rainfall shocks and livestock diversification. Comparing the magnitude of the adverse effect of rainfall shocks with the magnitude of the interaction term with livestock diversification indicates that livestock diversification can reduce, but not offset, the adverse effects of rainfall shocks on consumption. However, there are no mitigating effects of crop and income diversification on consumption and no mitigating effects on poverty. Albeit of weak significance (at only 10%), the results indicate a critical motivation for livestock diversification in protecting the welfare of the poor with regard to weather variability in rural SSA.

Table 5.9 Impact of diversification on per capita consumption expenditure and poverty

	Consumption per capita *(CRE-GLS)*	**Poverty** *(CRE-Logit)*	**Consumption per capita** *(CRE-GLS with interaction terms)*	**Poverty** *(CRE-Logit with interaction terms)*
	(1)	**(2)**	**(3)**	**(4)**
Livestock diversification	0.261(0.097)***	-0.916(0.375)**	-0.960(0.407)**	0.580(1.619)
Crop diversification	-0.371(0.099)***	1.204(0.394)***	-0.504(0.365)	2.697(1.496)*
Income diversification	0.077(0.101)	-0.438(0.383)	0.230(0.405)	-2.696(1.570)*
Long-term CoV of rainfall (1985-2015)	-0.015(0.004)***	0.045(0.016)***	-0.022(0.006)***	0.063(0.025)**
Rainfall deviation lagged season (2014/15)	-0.009 (0.002)***	0.027 (0.009)***	-0.007 (0.002)***	0.025(0.010)***
Log of farm size (ha)	0.078(0.061)	-0.239 (0.240)	0.086(0.062)	-0.224 (0.241)
Owns a traction plow	0.323(0.139)**	-1.410 (0.731)*	0.309(0.160)*	-1.335 (0.738)*
Received a loan before (1=yes)	0.032(0.049)	-0.016 (0.166)	0.046(0.044)	-0.021 (0.168)
Access to credit	0.094(0.049)*	0.018 (0.178)	0.093(0.046)*	0.017 (0.180)
Owns a radio (1=yes)	-0.032(0.047)	-0.313 (0.182)*	-0.024(0.051)	-0.286 (0.185)
Own motor bike (1=yes)	0.439(0.164)**	-0.597 (0.872)	0.433(0.219)*	-0.567 (0.854)
Distance to Agriculture office (km)	0.002(0.002)	-0.008 (0.006)	0.002(0.002)	-0.008 (0.006)
Distance to market	0.002(0.003)	0.001 (0.007)	0.002(0.003)	0.001 (0.007)
Year	0.066(0.083)	0.083 (0.330)	0.064(0.083)	-0.020 (0.168)
Constant	11.404(0.394)***	3.245(1.776)*	11.805(0.456)***	2.053 (2.059)
Interacting diversification with CoV				
CoV*livestock diversification			0.022(0.007)***	-0.027(0.029)
CoV*crop diversification			0.002(0.006)	-0.024(0.025)
CoV*income diversification			-0.003(0.007)	0.042(0.028)
Observations (Panel)	**886**	**886**	**886**	**886**

Note: *** p< 0.01, ** p < 0.05, * p < 0.1 significance level, robust standard errors in brackets, household characteristics such as age, education, household size, assets, and farm size are included in the full estimation (Full estimation with Mundlak correction is attached as Appendix 5.A3).

Source: Authors' calculation based

5.6. Summary and conclusion

Sustainable and resilient livelihoods are critical to rural small-scale farmers in SSA in the face of increasing climate variability and its related shocks. This issue is especially important in the SSA setting, where livelihoods depend on agriculture and agriculture-related activities with little or no irrigation facilities. As policy makers and development agencies clamor for a sustainable growth path for rural poor households in SSA, sustainable strategies in the form of livelihood diversification must be at the forefront (Angelsen and Dokken, 2018; Michler and Josephson, 2016). Using representative household-level panel data with high-resolution weather data from the NAAO, this paper investigated the diversification choices of households. Specifically, we investigated the role of weather variability as a "push" factor or as a "pull" factor in diversification. In addition, we investigated the effects of the different diversification strategies in mitigating weather variability.

We find that income diversification is very low in the study area, which is a general indication of the absence of off-farm income-generating activities (both formal and informal). Income mainly comes from on-farm employment complemented with livestock and crop sales. Households have more diversified crops, which are largely composed of staple crops and, to some extent, livestock. However, we find that most of the crops produced by households are mainly cereals and legumes with little attention paid to cash crops.

Our analyses show a number of interesting findings. First, the results show that long-term weather variability reduces crop and livestock diversification, which is contrary to most findings in the SSA region. However, short-term deviations from the long-term mean in the previous season are positively associated with crop diversification but negatively associated with livestock diversification. Second, diversification in rural Togo is driven more by pull factors than push factors given a number of different wealth indicators (land, ownership of cattle plow, radio ownership) that are positively associated with high diversification. Third, we find that access to credit will increase the diversification outcomes of households, which is an indication that household diversification may be constrained by capital requirements. Fourth, the results show a positive correlation between diversification choice and welfare outcome, which is especially true for livestock diversification in mitigating the negative effect of rainfall variability on consumption.

Based on the conclusion of this paper, a number of policy implications are suggested. Policies that stimulate livestock diversification, such as access to credit and veterinary services to improve the health and productivity of livestock, should be pursued to improve household welfare and mitigate the effect of weather variability, as the results show in this paper. Additionally, the formation and strengthening of livestock cooperatives to reduce the overhead cost of starting a livestock farm in rural areas is encouraged. This approach can allow a larger number of households to own livestock to scale up the benefits of livestock ownership for the lower income households that hitherto had not benefited.

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Table 5.A1 Full Mundlak estimation results of determinants of household diversification outcomes (SUR model results)

	Without policy variables			With policy variable interactions		
	Crop diversification (1)	**Livestock diversification (2)**	**Income diversification (3)**	**Crop diversification (4)**	**Livestock diversification (5)**	**Income diversification (6)**
Long term CoV of rainfall (1985-2015)	-0.001(0.001)	-0.003(0.001)***	-0.001(0.001)	-0.005(0.001)***	-0.004(0.001)**	0.001(0.001)
Rainfall deviation lagged (2014/2015)	0.012(0.001)**	0.000(0.003)	0.000(0.004)	0.012(0.003)***	-0.001(0.004)	-0.001(0.004)
Age of household head (years)	0.002(0.001)	-0.001(0.001)	0.001(0.001)	0.002(0.001)	-0.001(0.001)	0.001(0.001)
Education of household head (years)	0.002(0.006)	0.003(0.006)	-0.011(0.006)	0.001(0.006)	0.003(0.006)	-0.011(0.006)*
Education of household head (1=yes)	0.063(0.023)**	-0.023(0.025)	-0.008(0.026)	0.054(0.023)*	-0.024(0.025)	-0.005(0.026)
Household size	0.013(0.005)*	0.009(0.005)	-0.020(0.006)***	0.008(0.005)	0.009(0.006)	-0.019(0.006)***
Dependency ratio	0.002(0.018)	0.017(0.018)	-0.001(0.019)	-0.004(0.017)	0.017(0.0.019)	0.001(0.019)
Death of income earner (1=yes)	0.019(0.015)	0.019(0.106)	0.039(0.016)**	0.011(0.015)	0.016(0.016)	0.041(0.016)**
Log of farm size (ha)	-0.001(0.018)*	0.041(0.019)**	-0.020(0.020)	0.001(0.018)	0.041(0.020)*	-0.021(0.020)
Owns a traction plow	-0.057(0.042)	0.012(0.048)	0.138(0.046)**	-0.063(0.042)	0.007(0.045)	0.145(0.046)**
Assets (log)	-0.011(0.008)	-0.0.004(0.009)	-0.015(0.009)	-0.006(0.008)	-0.004(0.009)	-0.015(0.009)*
Own motor bike (1=yes)	0.233(0.051)***	0.077(0.054)	0.172(0.056)**	-0.230(0.051)***	0.070(0.055)	0.174(0.056)***
Access to media (radio) (1=yes)	0.020(0.014)	0.052(0.015)***	0.029(0.014)*	-0.018(0.013)	0.035(0.014)*	0.028(0.014)*
Access to credit	0.030(0.015)**	0.052(0.016)***	0.000(0.016)	-0.102(0.067)	-0.066(0.071)	0.082(0.074)
Distance to Agricultural office (Km)	0.000(0.001)	0.002(0.001)***	0.001(0.001)	-0.003(0.004)	0.004(0.004)	0.006(0.004)
Distance to market	0.000(0.001)	-0.002(0.001)*	-0.001(0.001)	-0.004(0.004)	0.002(0.004)	-0.005(0.004)
Year (1=2016)	0.069(0.025)***	0.340(0.022)***	0.040(0.026)	0.141(0.060)	0.066(0.064)	0.070(0.066)
Mean dependency ratio	-0.001 (0.020)	0.007 (0.023)	-0.003(0.021)	0.004 (0.020)	0.006 (0.021)	-0.005 (0.022)
Mean household size	-0.008 (0.005)	-0.003 (0.006)	0.016 (0.006)**	-0.004 (0.005)	-0.012 (0.006)*	0.014 (0.006)*

Mean household education years	-0.000 (0.006)	0.000 (0.007)	0.014 (0.006)*	0.001 (0.006)	-0.004 (0.006)	0.013 (0.006)*
Mean household age	-0.001 (0.001)	0.000 (0.002)	-0.001 (0.002)	-0.000 (0.001)	0.000 (0.002)	-0.001 (0.002)
Mean employed members	-0.015 (0.027)	-0.021 (0.031)	0.156 (0.030)***	-0.018 (0.027)**	-0.048 (0.029)*	0.159 (0.030)***
Mean land (log)	0.084 (0.025)***	0.009 (0.028)	0.036 (0.027)	0.075 (0.025)***	-0.009 (0.026)	0.035 (0.027)
Mean Asset (log)	0.055 (0.010)***	0.068 (0.012)***	-0.010 (0.111)	0.050 (0.010)*	0.065 (0.011)**	-0.009 (0.011)
CoV##Agricultural office				0.000(0.000)	0.000(0.000)	0.000(0.000)
CoV## Credit				0.001(0.001)	0.002(0.001)	-0.001(0.001)
CoV##Market				0.000(0.000)	0.000(0.000)	0.000(0.000)
Constant	-1.011(0.369)	-0.150(0.121)	0.521 (0.402)	-0.788(0.389)	-0.599(0.414)	0.431(0.428)
R-squared	0.535	0.188	0.158	0.547	0.192	0.162
Chi²	1019.72***	205.27***	166.60***	1068.51***	211.03***	170.76***
Observations (Panel)	**886**	**886**	**886**	**886**	**886**	**886**

Note: *** p<0.01, ** p<0.05, * p<0.1, Robust standard errors are in parenthesis

Table 5.A2 Full Mundlak estimation results of the impact of weather variability on welfare

	Poverty (1=yes)	Log Consumption per capita	Poverty (1=yes)	Log Consumption per capita
	(1)	**(2)**	**(3)**	**(4)**
CoV (1985 – 2015)	0.048 (0.012)***	-0.017 (0.003)***	0.040 (0.009)***	-0.015 (0.004)***
Lagged seasonal rainfall deviation	0.061 (0.026)**	-0.022 (0.003)***	0.060 (0.026)**	-0.021 (0.004)***
Mean seasonal rainfall (1985 – 2015)	0.119 (0.066)*	-0.045 (0.010)***	0.112 (0.062)*	-0.041 (0.010)***
Household head age	-0.024 (0.007)***	0.008 (0.005)*	-0.025 (0.010)**	0.008 (0.005)*
Education (years)	0.029 (0.047)	-0.016 (0.019)	0.034 (0.042)	-0.017 (0.019)
Education (1=yes)	0.554*** (0.136)	-0.089 (0.075)	0.542 (0.110)***	-0.085 (0.075)
Household size	0.106 (0.044)**	0.013 (0.018)	0.105 (0.050)**	0.013 (0.018)
Number of wives	-0.213 (0.105)**	0.109 (0.030)***	-0.214 (0.109)*	0.111 (0.030)***
Dependency ratio	-0.496 (0.117)***	0.059 (0.059)	-0.496 (0.156)***	0.056 (0.059)
Member of household in formal employment (1=yes)	-0.398 (0.040)***	0.074 (0.088)	-0.413 (0.098)***	0.080 (0.088)
Death of household (last 12 months)	-0.224 (0.064)***	0.037 (0.047)	-0.226 (0.047)***	0.035 (0.047)
Member of social group (1=yes)	-0.300 (0.231)	0.154 (0.072)**	-0.386 (0.183)**	0.178 (0.073)**
Agriculture land size (log)	0.089 (0.436)	0.088 (0.062)	0.085 (0.567)	0.095 (0.062)
Asset value (log)	0.136 (0.191)	0.045 (0.028)	0.141 (0.186)	0.042 (0.028)
Own mobile phone (1=yes)	-0.979 (0.250)***	0.624 (0.176)***	-0.935 (0.232)***	0.608 (0.176)***
Owns plowing implement (1=yes)	-1.790 (0.099)***	0.467 (0.146)***	-1.746 (0.094)***	0.444 (0.146)***
Distance to Agriculture office	-0.013 (0.003)***	0.002 (0.002)	-0.017 (0.001)***	-0.004 (0.011)
Distance to local market	0.006 (0.008)	-0.001 (0.002)	-0.080 (0.048)*	0.028 (0.011)**
Access to credit	-0.242 (0.038)***	0.057 (0.047)	-0.336 (0.048)***	0.082 (0.205)
Mean dependency ratio	0.319 (0.145)**	-0.072 (0.066)	0.314 (0.108)***	-0.068 (0.066)
Mean household size	0.156 (0.033)***	-0.101 (0.018)***	0.151 (0.036)***	-0.100 (0.018)***
Mean household education years	-0.107(0.028)***	0.021	-0.108(0.027)***	0.021
Mean household age	0.033 (0.000)***	-0.010 (0.005)**	0.034 (0.003)***	-0.010 (0.005)**
Mean employed members	-0.189 (0.280)	0.042 (0.123)	-0.185 (0.350)	0.037 (0.122)
Mean land (log)	-0.617 (0.500)	0.112 (0.077)	-0.628 (0.616)	0.115 (0.077)
Mean Asset (log)	-1.238 (0.287)***	0.291 (0.031)***	-1.241 (0.288)***	0.291 (0.031)***
Year (1=2016)	-0.041 (0.232)	-0.101 (0.080)	-0.035 (0.252)	-0.097 (0.080)
CoV##Agricultural office			0.000 (0.000)*	0.000 (0.000)
CoV##Access to credit			0.002 (0.000)***	-0.000 (0.004)
CoV##Output Market			0.002 (0.001)	-0.001 (0.000)***
constant	-9.476 (7.078)	16.367 (1.115)***	-8.344 (6.503)	15.948 (1.176)***
Panel Observations	**886**	**886**	**886**	**886**

Note: *** p<0.01, ** p<0.05, * p<0.1, Robust standard errors are in parenthesis

Table 5.A3 Full Mundlak estimation results of impact of diversification on welfare

	Consumption per capita *(CRE-GLS)*	**Poverty** *(CRE-Logit)*	**Consumption per capita** *(CRE-GLS with interaction terms)*	**Poverty** *(CRE-Logit with interaction terms)*
	(1)	**(2)**	**(3)**	**(4)**
CoV (1985 – 2015)	-0.015(0.004)***	0.045(0.016)***	-0.022(0.006)***	0.063(0.025)**
Lagged seasonal rainfall deviation	-0.009 (0.002)***	0.027 (0.009)***	-0.007 (0.002)***	0.025(0.010)***
Livestock diversification	0.261(0.097)***	-0.916(0.375)**	-0.960(0.407)**	0.580(1.619)
Crop diversification	-0.371(0.099)***	1.204(0.394)***	-0.504(0.365)	2.697(1.496)*
Income diversification	0.077(0.101)	-0.438(0.383)	0.230(0.405)	-2.696(1.570)*
Household head age	0.008(0.004)*	-0.030(0.017)*	0.009(0.004)**	-0.035(0.018)**
Education (years)	-0.015(0.019)	0.015(0.073)	-0.018(0.019)	0.012(0.073)
Education (1=yes)	-0.099(0.072)	0.637(0.278)**	-0.096(0.071)	0.640(0.280)**
Household size	0.027(0.016)*	0.050(0.070)	0.020(0.016)	0.069(0.071)
Dependency ratio	0.053(0.055)	-0.454(0.219)**	0.040(0.054)	-0.403(0.221)*
Number of wives			0.109 (0.031) ***	-0.241(0.130)*
Death of household (last 12 months	0.006(0.048)	-0.171(0.180)	0.030(0.048)	-0.206(0.182)
Agriculture land size (log)	0.067(0.057)	0.202(0.216)	0.050(0.057)	0.244(0.217)
Asset value (log)	0.051(0.026)**	0.008(0.118)	0.049(0.026)*	-0.010(0.119)
Owns a motor (1=yes)	0.558(0.167)***	-0.747(0.689)	0.551(0.165)***	-0.748(0.688)
Owns radio (1=yes)	0.003(0.043)	0.055(0.166)	0.004(0.042)	0.063(0.169)
Owns plowing implement (1=yes)	0.370(0.136)***	-1.755(0.582)***	0.391(0.134)***	-1.735(0.582)***
Received a loan before (1=yes)	0.038(0.048)	-0.128(0.182)	0.038(0.048)	-0.122(0.184)
Access to credit	0.097(0.048)**	-0.347(0.187)*	0.064(0.048)	-0.292(0.190)
Distance to Agriculture office	0.002(0.002)	-0.013(0.007)*	0.002(0.002)	-0.011(0.007)
Distance to local market	0.002(0.003)	0.000(0.009)	0.002(0.003)	0.000(0.009)
Mean dependency ratio	-0.075(0.062)	0.330(0.242)	-0.068(0.062)	0.281(0.245)
Mean household size	-0.101(0.017)***	0.170(0.073)**	-0.105(0.017)***	0.180(0.074)**
Mean household education years	0.019(0.019)	-0.094(0.075)	0.020(0.019)	-0.087(0.076)
Mean household age	-0.011(0.005)**	0.040(0.018)**	-0.012(0.005)***	0.047(0.019)**
Mean employed members	0.075(0.090)	-0.489(0.340)	0.031(0.090)	-0.415(0.344)
Mean land (log)	0.150(0.080)*	-0.747(0.303)**	0.153(0.079)*	-0.778(0.305)**
Mean Asset (log)	0.307(0.033)***	-1.145(0.183)***	0.305(0.032)***	-1.118(0.184)***
wife			0.109(0.031)***	-0.241(0.130)*
CoV##livestock diversification			0.022(0.007)***	-0.027(0.029)
CoV##crop diversification			0.002(0.006)	-0.024(0.025)
CoV##income diversification			-0.003(0.007)	0.042(0.028)
Constant	11.404(0.394)***	3.245(1.776)*	11.805(0.456)***	2.053
lnsig2u:_cons		-12.215(26.285)		-12.253(25.721)
Panel observations	**886**	**886**	**886**	**886**

Note: *** p<0.01, ** p<0.05, * p<0.1, Robust standard errors are in parentheses