IMPACT OF ADOPTING MULTIPLE AGRICULTURAL TECHNOLOGIES ON NUTRITION OUTCOME IN EAST AFRICA: A MULTINOMIAL ENDOGENOUS SWITCHING REGRESSION APPROACH

BY

KACHILEI K. LEVY

A Thesis Submitted to the School of Agriculture and Natural Resources in Partial Fulfilment of the Requirements for the Award of Degree of Doctor of Philosophy in Agricultural Economics and Resource Management

MOI UNIVERSITY

2022

DECLARATION

Declaration by Candidate

This thesis is my original work and has not been presented for a degree in any other university. No part of this thesis may be reproduced without prior written permission of the author and/or Moi University.

Sign:___________________________________ Date:_________________________

KACHILEI K. LEVY

SBE/DHPHIL/AE/02/16

Declaration by the supervisors

This thesis has been submitted with our approval as the university supervisors

Sign:___________________________________ Date:_________________________

DR. VINCENT NG'ENO

Department of Agriculture Economics and Resource Management

School of Agriculture and Natural Resources

Moi University

Sign:___________________________________ Date:_________________________

PROF. SULO K. TIMOTHY

Department of Agriculture Economics and Resource Management

School of Agriculture and Natural Resources

Moi University

DEDICATION

This study is dedicated to my wife Abigale and our sons Levito and Levene for the inspiration to go extra mile.

And, to the God of Birei for "making it happen".

ACKNOWLEDGMENT

My acknowledgement goes to my Supervisors Dr. Vincent Ng'eno and the late Prof. Sulo K. Timothy for their thorough critique, guidance and mentorship throughout my study.

To all my lecturers and my fellow students for their great support during classwork, discussions and execution of the coursework

I am greatly indebted to DAAD for the Scholarship opportunity to pursue my Doctorate Program and also AERC for the research funds. God bless you.

ABSTRACT

Majority of the population of East African households are malnourished and much of the effort to address the problem of stunting, wasting and underweight have focused on interventions that are designed directly to address its immediate causes. It is expected that the adoption of multiple agricultural technologies such as improved beans varieties, bio-fortified maize variety, grafted fruit trees, and garden vegetable techniques can be a means by which malnourished rural households who may have less access to diverse meals, supplements, and fortified foods can enhance their balanced diet but malnutrition still remain a salient problem facing rural households in East Africa. This study determined the factors that affect the adoption of joint multi-agricultural technologies then analyze the impact of the best four combinations adopted in East Africa countries that is; improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques on the household nutrition outcome indicators of underweight (WAZ), wasting(WHZ) and stunting(HAZ). Where TC = base with no technology used, TC1 = Improved beans variety, biofortified maize variety, and grafted fruit trees, TC2 = Improved beans variety, biofortified maize variety, and garden vegetable techniques, TC3 = biofortified maize variety, garden vegetable techniques, and grafted fruit trees, TC4 = Improved beans variety, garden vegetable techniques, and grafted fruit trees. The study utilized a secondary household panel data of Kenya, Tanzania, and Uganda that was collected by IFRI for ten waves from 2007 to 2017 and each country with 500 households. This study utilized multinomial endogenous regression model so as to casual the impact of technology adoption and to correct for the self-selection bias. It was conceptualized that the decision to adopt a combination of multiple agricultural technologies (MATs) is modeled in consumer theory, specifically, a random utility framework. The latent model (U^*_{jit}) which describes the i^{th} farmer's behavior in adopting MATs j(j=1,...4) at time t over any alternative MATs combination was utilized in three stages. In the first stage, the analysis determined the factors for adopting multi-agricultural technologies using a multinomial endogenous switching regression. In the second stage, the inverse mills ration generated in stage one is used as linkage between adoption of technologies nutrition outcome, and on the third stage, the treatment effect was used to establish the relationship between adopters of the joint multiple agricultural technologies and non-adopters. The results show that year increase of the education of household head, general participation in community meetings and barazas increases the adoption of TC1 (45%), TC2 (44%), TC3 (25%), and TC4 (35%) respectively. The 1% percent increase in the adoption of joint technologies, the prevalence of stunting reduces by 17.4%, wasting 15.4%, and underweight by 16.8%. Results of the average treatment effects show that the households who adopted joint multiple agricultural technologies had a positive significant impact (HAZ β= .62, $p<0.01$), WAZ (β = .72, $p<0.01$), and WHZ (β = .74, $p<0.01$) which improves the nutrition status by HAZ (103%), WAZ (87%), and WHZ (84%). The best technology combination was TC3 which impacted all nutrition outcome at the highest percentage HAZ (25.8%), WHZ (24.2%), and WAZ (25.3%). Kenya(reference) had a higher significant propensity of adoption hence higher impact on nutrition outcome than Uganda (β = -.128, $p<0.01$) and Tanzania (β = -.155, $p<0.01$). This study concludes that adoption of multiple agricultural technologies improves household nutrition outcome. The household that adopted the joint multiple agricultural technologies had systematically higher nutrition outcome than the households who did not adopt even after controlling for all confounding factors. Among the three countries Kenya has a higher significant propensity on nutrition outcome. This study offers insight to policymakers, researchers, and extension workers regarding the advancement of factors suitable for joint technology combination to be adopted by the East Africa households. Consequently, this study recommends that household should focus on adopting the multiple agricultural technologies to improve their nutrition status. And more so focus more on the combination of TC3 (Biofortified maize variety, garden vegetable techniques, and grafted fruit trees) since it was the combination with greatest impact on nutrition outcome.

TABLE OF CONTENTS

LIST OF TABLES

ABBREVIATIONS AND ACRONYMS

DHS:	Demographic and Health Surveys
LSMS:	Living Standards Measurements Study
IFPRI:	International Food Policy Research Institute
WHO:	World Health Organization
USAID:	United States Agency for International Development
MATs:	Multiple Agricultural Technologies
SDGs:	Sustainable Development Goals
BNFB:	Building Nutritious Food Baskets
MESR:	Multinomial Endogenous Switching Regressions
ESR:	Endogenous Switching Regression
NU:	Nutritional Outcome
METE:	Multiple Endogenous Treatment Effects
MMNL:	Mixed Multinomial Logit
MNLS:	Multinomial Logit Selection
IMRs:	Inverse Mills ratios
IFAD:	International Fund for Agricultural Development
KARI:	Kenya Agricultural Research Institute
WFP:	World Food Program

OPERATIONAL DEFINITION OF TERMS

Households: Unit of a family and it consists of one (or more) people who live in the same dwelling and share meals. It may also consist of a single-family or another group of people.

Impact: Assessment of the consequences of potential scenarios. It is a field of research that is used to measure levels of improvement within various sectors. Impact studies most often measure the effectiveness of new policy or initiative on a group of people or an organization.

Malnutrition: When a person's diet does not provide enough nutrients or the right balance of nutrients for optimal health.

Multiple Agricultural Technologies: Combination of two or more technologies

Nutrition Outcome: It is the “terminal” variable that is directly influenced by anthropometric measures of underweight, stunting, and wasting.

Nutrition security: It consider the nutritional value of food and the systemic factors that determine an individual's nutritional status.

Stunting (HAZ): It is the impaired growth and development that children experience from poor nutrition, repeated infection, and inadequate psychosocial stimulation. Children are defined as stunted if their height-for-age is more than two standard deviations below the WHO Child Growth

Technologies: Sum of techniques, skills, methods, and processes used in the production

Underweight (WAZ): Moderate and severe with below minus two standard deviations from median weight for age of reference population; severe below minus three standard deviations from median weight for age of reference population.

Wasting (WHZ): Moderate and severe which makes you gradually become thinner and weaker. At below minus two standard deviations from median weight for height of reference population.

CHAPTER ONE

INTRODUCTION

1.0 Overview

This chapter presents the introduction of the study which includes the introduction, background, statement of the problem, objectives, and hypotheses, rationale, significance of the study, and scope.

1.1 Introduction

Nutritional deficiencies are the excesses, or imbalances in a person's intake of food energy and/or nutrients and they affect approximately 3 billion people around the world WHO (2016). Malnutrition hinders the development of human potential in both social and economic development, especially in developing countries. Grassley and Eschiti (2008) explain that African countries have made fighting malnutrition a high priority especially through the adoption of technology in agriculture. Deficiencies of the micronutrients, such as iron, zinc, and vitamin A, are the most devastating among the East African countries (NBS, 2016). Johnson *et al.*, (2015) explain that nutrition outcome is the "terminal" variable that is directly influenced by anthropometric measures of underweight, stunting, and wasting. It is indirectly affected by multiple agricultural technologies specifically, improved beans variety, biofortified maize variety, and grafted fruit trees.

Micronutrient malnutrition also known as Hidden Hunger afflicts many people worldwide, resulting in poor health, low worker productivity, high rates of mortality and morbidity, increased rates of chronic diseases such as coronary heart disease, cancer, stroke, and diabetes (Shapiro *et al.,* 2000). Kennedy *et al.,* (2013) states that micronutrient deficiencies or 'hidden hunger' result from unbalanced diets based on starchy staple crops are prevalent among the population of sub-Saharan Africa. Today, almost 33 percent of the population of Sub-Saharan Africa (SSA), or close to 200 million people are Malnourished, of which close to 60 percent are in countries that are developing (WHO, 2003). The global burden of malnutrition remains large and falls disproportionately on young children and women. Current estimates suggest that low body-mass index, indicative of maternal malnutrition, affects over 10% of women in Asia and Africa, and globally, malnutrition is a cause of 3.1 million child deaths annually, equivalent to 45% of all child deaths in 2011 (Kim *et al.*, 2003). Malnutrition cripple's both economic growth and development. Whereas, future global prosperity and effectiveness are directly linked to the ability of the health and development communities adequately to respond to this challenge. East Africa, nutritional deficiencies are responsible for 1.5–12% of the total Disability Adjusted Life Years (DALYs) (Masset *et al.*, 2016). According to the report of IFPRI, (2015) in East Africa alarming numbers concern malnutrition, which affects more than half of the female population. Many people in East Africa are suffering from multiple micronutrient deficiencies (Masset *et al.*, 2016); in East Africa >50% of the households are estimated to be malnourished Joy *et al.*, (2015) yet this is part of the Millennium Development Goals (MDG) indicators which are the priority when implementing.

To date in East Africa, much of the effort to address the problem of malnutrition has focused on interventions that are designed directly to address the immediate causes of malnutrition (Bodhlyera *et al.*, 2014). These interventions which are termed as 'nutrition-specific' interventions include; support for breastfeeding, food fortification, and dietary supplementation. (Nayga, 2000). But, by appreciating the multiple agricultural technologies, it's possible to harness their benefits to improve diets in

East Africa. These technologies could tackle the problem of micronutrient deficiency (also known as hidden hunger). Enriching new crop varieties like beans with additional vitamins and minerals, it provides a wide-scale opportunity to improve nutrition without needing to change diets drastically. Scientists are already doing this, and since the 1990s have released more than 60 varieties of beans with enhanced levels of zinc or vitamin A in East Africa. This has allowed families whose diets are heavily dependent on beans or maize to improve their nutrition. It has reduced the risk of vitamin A deficiency, which causes as many as 500,000 children to lose their sight every year. It has also prevented zinc deficiency, which can impair immune function. Biofortified maize have been released to East Africa and being tested and grown in more of these countries. Beyond fortifying maize through conventional breeding, grain has been further improved through innovations in genomics. For example, mapping the sequence of plant genes allows researchers to modify the nutrient content of maize in order to improve the quality.

Another simple solution to improving the nutritional value of foods taken is to utilize garden vegetable technique. Despite recent increases in attention to the danger of hidden hunger, comprehensively garden vegetable technique can drastically boost the nutritional value in East Africa household. It is the most cost-effective way to help hundreds of millions of people improve quality of life and nutrition status.

The scientists, the agri-food sector and policymakers together should promote these multiple agricultural technologies since it produces healthier foods that are more nutritious. Ultimately it’s important for household in East Africa to realize that utilizing multiple agricultural technologies as part of achieving a diverse diet can ensure you’re producing and eating more nutritious food thus tackling malnutrition.

With enough attention and support on adoption of multiple agricultural technologies, hidden hunger can be erased in a few decades, significantly improving the lives of the East African households.

1.2 Background of the Study

Agricultural technologies have driven a revolution of global agricultural production since the mid-1960s (Kerbs *et al.,* 1995). According to Foresight (2011), substantial gains in production were achieved in Germany through greater use of improved bean variety, biofortified maize variety, grafted fruit trees, and garden vegetable techniques. This kind of technology model has been applied in East Africa, and it also contributed to growth in some situations, such as of biodiversity and soil fertility, salinization, and water (Altieri, 2002; McIntyre *et al.,* 2009). There is established literature on how technologies affect the mean-variance of crop yield distribution, though much less is known about how technology adoption affects malnutrition (Kim and Chavas, 2003; Du *et al.,* 2012). Previous empirical works of Olarinde *et al.,* (2011); Emily and Tadesse, (2012) have studied the impact of single technology practices on productivity or yield and by implication on food security. The limited studies on the impact of agricultural technologies and practices such as physical conservation structures, improved seeds, crop biodiversity, production risk mitigation then to focus only on single technology adoption analysis (Kim and Chavas, 2003; Kassie *et al.,* 2008; Di Falco and Chavas, 2009; Cavatassi *et al.,* 2011; Kato *et al.,* 2011; Di Falco and Veronesi, 2014).

In recognition of the likely impact of multi-agricultural technologies in East Africa households the report of Food and Nutrition (2003) indicate that the East Africa governments have initiated policies that will reduce the effects of micronutrient malnutrition especially the deficiencies of Vitamin A, Iron and Zinc to improve plant breeding to develop staple food crops that are rich in micronutrients as captured by HarvestPlus, (2003). Thus introduction of the multi-agricultural technologies complements existing approaches by offering a sustainable, low cost method for reaching people with poor health care services. Considerably Becker (2002) indicate that less attention has been given to multiple agricultural technologies that are designed to work on the causes of malnutrition, including crop bio fortification, food security, care and healthier environments.

Cheng *et al.*, 2013 explains how multi agricultural technologies can make a difference from other polices and requires a sound understanding of not only the mechanisms whereby policy impacts on production and household nutritional welfare, but also what coping strategies household adopt, as these will impact on the nutritional outcomes. There exists a need for well-designed studies with sound methodologies and rigorous analytical techniques, as indicated in some earlier reviews (Drichoutis *et al.*, 2005; Stigler, 1961; Dziechciarz, 1983; Haskell, 1995).

The relative lack of research emphasis on the adoption of multi-agricultural technologies to improve nutrition outcomes is surprising FAO (2016) given the importance of the agriculture sector in many poor countries (Chelliah, 1988). In East Africa, agricultural activities are the largest productive sector, contributing 29% of GDP, engaging 65% of the total labor force, and providing a livelihood for more than 86% of the rural population (World Bank, 2007). Even in rapidly developing regions such as South Asia, agriculture contributes 20% of GDP and engages 50% of the total labor force (Hazell, 2010).

Incredible strides have been made to eradicate hunger around the East Africa. New agricultural technology that has grown to lift hundreds of millions out of poverty and hunger. Even as groups that work to end hunger celebrate these incredible achievements, East Africa are still not on track to eradicate hunger in our lifetime, even though all member states had vowed in the year 2000 to end hunger by 2015. In fact, according to NBS (2015) numbers are heading in the wrong direction. The U.N. Food and Agriculture Organization reports that since 2014, the number of people experiencing hunger is on the risen as conflict and climate change in East Africa behind most of this deterioration.

Since it is harder to identify visually, hidden hunger gets far less attention than it warrants. Grossman (1972), states that micronutrient malnutrition causes many of the same health problems as calorie deficiency hunger but hidden hunger is particularly detrimental to young children, women of childbearing age, and the poorest parts of populations in developing countries. Like regular hunger, millions of lives are lost each year and also prevents a greater number from escaping poverty.

The body needs far more than just calories to function and develop properly. Vitamins and minerals are essential to many of the body's core functions, such as immune system health and brain function and the household can achieve through grafted fruit trees and garden vegetables techniques (Forster, 2001). Although there are dozens of important micronutrients, some deficiencies are more prevalent than others, including those of Vitamin A, zinc, iron and folic acid which can be achieved through improved beans variety and biofortified maize variety.

Chary *et al.,* (2013) explains that the effects of the deficiencies vary. A deficiency of iron in the blood, for example, which causes anemia, severely restricts the amount of oxygen that the blood can carry to the body's cells. The result is fatigue, apathy, headaches and poor body temperature control, among other symptoms. The adoption of garden vegetable techniques will help control anemia. A zinc deficiency can cause the body to develop too slowly and can damage the central nervous system, and it lowers the body's ability to fight diarrheal disease. There are 5.7 million cases of diarrheal disease around the East Africa each year (EHNRI) 2000, and it is the second most prevalent cause of death among children under 5. Diarrheal disease compounds the micronutrient malnutrition damage because the body struggles to make full use of available calories and micronutrients, leading to even greater levels of malnutrition. Zinc deficiency can be treated by eating foods rich in protein which is promoted though the adoption of improved beans variety technology.

Vitamin A is crucial for the immune system to combat many diseases, and for maintenance of eyesight, particularly in children. Dewey and Begum (2011) explains that folic acid is associated, among other things, with fetal development, and, when missing from a pregnant woman's diet, can lead to birth deformities. Children suffering from hidden hunger in early childhood are less likely to complete their education, more likely to suffer from chronic disease, and are consequently less productive. This affects their ability to escape poverty and malnutrition later in life, passing the vicious cycle on to their own children. Vitamin A can be thrown from the adoption of grafted fruit trees.

The ideal solution to micronutrient deficiency is a diverse diet, rich in different grains, fruits and vegetables, like the food pyramid recommended by many health agencies around the world. While this would satisfy most micronutrient needs (Krebs-Smith, 1971), a diverse diet is prohibitively expensive for many people, who would have to give up calories to afford better foods, effectively trading one type of hunger for another, therefore adoption of multiple agricultural technologies could be cheaper and easier way for households within East Africa to solving micronutrient deficiency.

Maputo declaration of 2003 and the Malabo declaration of 2014 called upon African governments to allocate 10% of their budget to the agriculture sector to enhance food production and gap malnutrition. Specifically, The Malabo declaration aims to end hunger by 2015 by focusing on nutrition security for inclusive economic growth and sustainable development in through strengthening the development and agricultural technology policies. It commits to ending child stunting and underweight bringing down stunting to 10% and underweight to 5% by 2025. The East Africa countries have ratified and domesticate this declaration and implemented it in individual countries. One of the policies implemented by the East Africa countries is multiple agricultural technologies. According to Martz, 2017 the impact of these technologies on household malnutrition and dietary diversity is still wanting. A significant proportion of the rural household in East Africa suffer from inadequate micronutrient intake (26.7 percent) (NBS, 2016) which is relatively above the world recommended standards of less than 10 percent (WHO, 2010).

There is growing interest in the suggestion that multiple agricultural technologies delivered at the household and village level can improve nutrition outcomes (EHNRI, 2000; World Bank, 2016; Judge *et al.,* 1985). The reviews of (Masset *et al.,* 2016; Pracha, 1984; Wilson, 2015) are broadly consistent in their conclusions. First, that there is relatively consistent evidence that the specific agricultural technology on specific crops rich in certain micronutrients is linked to improved micronutrient status. Second, that it is inconsistent or no evidence for most other agricultural technologies and the relationship between multiple agricultural technology and malnutrition is heterogeneous context-dependent and unlikely to be measurable without considerable error (Conniffe, 1982). Third, that the available evidence base is currently very small, and that most studies have substantial methodological limitations that limit their ability to identify any true effect of multiple agricultural technologies on nutrition outcomes. Finally, each review states that more rigorous and better-designed studies using superior methodologies are needed. This kind of study will facilitate cognitive inferences on the impact of multiple agricultural technologies on nutritional outcome of household. The data gaps that link agricultural technology to nutrition outcome have been previously identified (Wilkins and Beaudet, 1998), the understanding of integrated datasets required for linkages to help them improve nutritional outcomes.

1.2.1 Pathways Linking Agriculture to Nutrition

Agriculture is the sector best placed to affect food production and consumption of nutritious foods needed for healthy and active lives. Agriculture does not directly influence consumer demand but can help make nutritious food available to consumers at affordable prices. The relationship between agriculture and human nutrition, or from food production to food consumption is intuitively direct, but in practice is quite complex. Increased food production should lead to greater food availability, access, and ultimately improved food intake and diets. Yet the persistence of malnutrition as a global public health concern despite the successes in increasing agricultural production belies any notion that malnutrition and undernutrition can be solved entirely from the supply side by increasing agricultural production. The question of how agriculture can more effectively contribute to improved nutrition outcomes therefore requires an answer that encompasses factors other than food supply, and that takes into account the technology that contribute to nutrition. The interface between agriculture and technology provides a far more complete picture of nutrition that relates supply to demand and production to consumption. In terms of nutrition outcomes, the limitations of production-focused agricultural programs and interventions have long been recognized, and finding ways to maximize the potential impact of agriculture on nutrition has been an increasing priority for some within the agricultural community for decades (Wilkins and Beaudet, 1998).

The widely used conceptual framework developed by UNICEF identifies three main underlying determinants of nutritional status: availability and access to food; optimal quality of feeding and caring practices; and a healthy environment and adequate access to health care services. Each of these pathways is necessary, but insufficient in itself, to ensure good nutrition. Agriculture is likely to improve nutrition mainly through the food production pathway. The pathways linking food production with food consumption and human nutrition along the food supply chain can be usefully captured in terms of subsistence-oriented production for the household's own consumption. The indirect relationship between increasing agricultural productivity and nutrition outcomes through the pathways are archetypal; representing model forms which in reality are by no means self-contained or mutually exclusive. Household production for the household's own consumption is the most fundamental and direct pathway by which increased production translates into greater food availability and food security. The different types of foods produced determine the impact of the production increase on diet quality. The production of more staples leads to mainly quantitative increases in energy intakes (Judge *et al.*, 1985). Increased production of fruit, vegetables, dairy foods, eggs, fish, and meat can likewise raise macronutrient intakes, but with greater impacts on micronutrient intakes that can close dietary gaps in essential nutrients like iron, zinc and vitamin A. These more micronutrient-rich food sources can also make staple foods more palatable, and lead to higher still energy intake. Given favorable intra-household processes of food distribution, these developments can greatly improve the food intake and nutrition of the more vulnerable members of the household (Kim and Chavas, 2003; Kassie *et al.,* 2008; Di Falco and Chavas, 2009; Cavatassi *et al.,* 2011; Kato *et al.,* 2011; Di Falco and Veronesi, 2014). In this study the household itself is a net producer of own food consumed, and the surplus food produced can be sold to market once much or most of the households' own food requirements are satisfied. The study conceptualized the framework linking multiple agricultural technology as the pathway of the household endowment of resources to food consumption and the prime determinant of the nutritional status of its members.

1.3 Statement of the Problem

According to IFPRI, (2016) East Africa countries have implemented the use of multiple agricultural technologies specifically, improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques. In contrast to this implementation nothing has changed and the nutrition outcome of stunting, wasting, and underweight remain a salient problem facing rural households (WHO, 2017 and Kassie *et al.,* 2015). Specifically, IFPRI, (2016) explains how the Kenyan government through the ministry of agriculture rolled out biofortified maize variety program across the country which could reduce nutrition deficiencies of provitamin A but NBS (2016) survey shows that underweight was still affecting 50% of the children in rural households yet adoption of this technology was supposed to reduce. Kassie, (2017) states that the government of Tanzania promoted the use of improved beans variety so as to reduce Zinc deficiency but (IFPRI,2018) statistics indicate that stunting is still a concern at 15% in Tanzania's rural households. Masset *et al.,* (2016) state that grafted fruit trees program in Uganda has enabled households to access vitamin C and calcium from the fruits consumption thus expected to enhance child wasting but Joy *et al.,* (2017) in her studies found out that majority of the rural household's recorded high wasting of 15% which is above the recommended 10% despite adopting the grafted fruit trees and garden vegetables techniques. Malnourished children have poor cognitive development, leading to low educational outcomes and half of annual deaths of children aged under five in East Africa and thus, this calls for the urgency of this study.

This gap motivated the call for this research to be undertaken to find out the impact of these multiple agricultural technologies on nutrition outcomes and the possible reasons that have hindered the expected nutrient nourishment in Uganda, Kenya, and Tanzania. There have been no studies related to the impact of joint multiple agricultural technologies and malnutrition in East Africa. To the best of our knowledge, this has not been done in East Africa. This study, therefore, investigated the impact of joint improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques on anthropometric outcome measures of stunting, underweight, and wasting in Kenya, Uganda, and Tanzania. More precisely, the study addressed three interrelated questions. First, what are the factors that affect the adaption of multiple agricultural technologies? Second, which types of joint multiple agricultural technology combinations have an impact on household nutrition status? Third, what are the nutrition gains achieved by households under each type of technology combination in comparison to non-adopters?

Methodologically, many studies estimating impact have significant challenges of farmer's self-selection to participate. Therefore, both sets of decision choices influence farmer's decision on technology which may result in sample selection bias and need to be properly addressed to account for those biases. More so, most of the previous studies have analyzed the impact assessment of a single technology like precision agriculture Abdulai (2016), minimum tillage Jaleta *et al.,* (2016), and improved maize crop varieties (Bezu *et al.*, 2014; Zeng *et al.*, 2015). According to Aldana *et al.,* (2011); Leathers and Smale, (1991) farmers rarely use a single agricultural technology but rather a combination of different technologies adopted in the farm over time, which needs to be accounted for in adoption and impact studies. Some previous studies have used cross-sectional data to assess the impacts of multiple agricultural technologies (Kassie *et al.,* 2015; Manda *et al.,* 2016; Ng'ombe *et al.,* 2017; Teklewold *et al.*, 2013). But there is still little or no evidence on the impacts of multiple agricultural technologies on malnutrition using panel data.

Also, nutrition studies are found in the public health, medical and dietary literature where they employ different theories and methodologies from economics (West, 2000). Therefore, Pingali (2015) explains that there is a need for the field of agricultural economics to pay greater attention to the associations between agricultural technology and nutrition outcomes to solve the theoretical and methodological gap in the analysis.

1.4 General Objective

This study determined the factors that affect the adoption of joint multi-agricultural technologies then analyze the impact of the best four combinations adopted in East Africa countries that are; improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques on the household nutrition outcome indicators of underweight (WAZ), wasting(WHZ), and stunting(HAZ).

1.4.1 Specific Objectives

Specifically, the study analyzed the following objective:

1. Analyze the factors that affect the household adoption of multiple agricultural technologies
2. Determined the impact of joint multiple agricultural technologies on household nutrition outcome
3. Determined the average adoption effect of multi-agricultural technology on household nutrition outcome

1.5 Hypotheses

The following hypotheses were tested:

i) Adoption of improved crop production are not affected by the multiple agricultural technologies

ii) Household nutrition outcome is not affected by joint multiple agricultural technologies

iii) None-adopters of multi-agricultural technologies have better nutrition outcome than adopters

1.6 Significance of the Study

Adopting multi-agricultural technologies like improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques can help address stunting, wasting, and underweight by increasing food adequacy of micronutrient intakes among households. It also enables policymakers to understand the avenues of great benefits in constituting and implementing nutritional policies.

Intermediaries in agricultural technologies are expected to understand how to facilitate the farmers for better nutritional impacts and prepare for the most efficient indirect technologies they can adopt. According to Jaleta *et al.,* (2016) approach of grafted fruit trees technologies is expected to impact the sustainability of the agricultural operation and improvement of health development. (Pingali, 2015), Murithi and Matz (2015) explain how integral biofortified maize variety is aimed to generate a better bargain position in agriculture to improve the child's weight and growth. Additionally, it provides a sound understanding of not only the mechanisms whereby multiple technologies impact food production and household nutritional welfare, but also what coping strategies households adopt on different technology, as these will impact their household livelihood.

This study also had significance on the consumer theory and multinomial endogenous switching regression empirical model of multiple agricultural technology since it used panel data to analyze its impact on stunting, underweight and wasting in East Africa households.

1.7 Scope of the Study

The study focused on the impact of joint multiple agricultural technologies; improved beans variety, biofortified maize variety, grafted fruit trees, and use of garden vegetables techniques in East Africa households and its effect on the nutritional outcome through the indicators of stunting, underweight, and wasting. The selection of this scope was done by considering the extent of the implementation of four joint multiple agricultural technologies in Kenya, Tanzania, and Uganda. A panel data of 2007-2017 was analyzed. The methodology scope was done considering the kind of panel data available and the extent of the multiple technologies. Multinomial endogenous switching regression empirical model was utilized.

CHAPTER TWO

LITERATURE REVIEW

2.0 Overview

This chapter presents a review of literature related to the impact of multiple agricultural technology on nutrition outcome in East Africa using a multinomial endogenous switching regression approach. It presents the theoretical frame work as well and the conceptual framework to the variables of the study.

2.1 Review of Key Concepts and Related Terms

2.1.1 Improved Beans Variety

Improved beans are a variety of beans which provide a nutritious, high protein source of food, have higher nutrient value than common beans they are the most important source of dietary protein and an important source of vitamins and essential minerals. In addition, as beans are legumes, they play a critically important role in smallholder agroecology and soil fertility due to their ability to fix nitrogen into the soil. Khoury *et al.*, (2014) explains that the importance of improved beans for health, farm productivity, and livelihood generation is greatest for the most vulnerable subset of smallholder farmers, particularly women, children, and the most impoverished families. Despite the enormous importance of improved beans for African farming communities, bean production receives only a fraction of the formal investments in genetic improvement compared with investments in other crops. According to IFPRI (2015), a regional agricultural innovation center, this bean variety has the ability to resist some perennial beans diseases like Angular Leaf Spot, Root Rot, Bacterial Blight and Rust blamed for damaging 25 per of beans yield globally. Unlike other beans varieties which takes up to 120 days to mature, Improved beans variety takes half of that, and can, therefore, be grown for more seasons.

2.1.2 Biofortified Maize Variety

Biofortification of maize is the development of micronutrient-dense staple maize using traditional breeding and modern biotechnology which improve nutrition, as part of an integrated, food systems strategy. According to Kennedy *et al.,* (2010) eating provitamin A maize has been shown to be as effective as taking Vitamin A supplements, and a 2014 study by Khoury *et al.,* found that using provitamin A maize to prepare traditional foods can significantly improve children's health. Such health-boosting varieties of maize are aimed at resource-poor families or rural communities who rely on staple crops for much of their diet because they are often deficient in essential vitamins and minerals. Zinc plays an essential role in maintaining optimal childhood growth and a healthy immune system. By enhancing the micronutrient content of staple crops like maize, regular consumption improves nutrition and health. In terms of grain yield and other economically important traits, the new varieties are more competitive than earlier generations of pro-vitamin A hybrids and other popular white maize varieties currently under production.

2.1.3 Grafted Fruit trees

It is a horticultural technique whereby tissues of plants are joined so as to continue their growth together. Grafted fruit trees provide nutritious components in foods that the body needs to grow strong and healthy. A grafted fruit trees contains a range of nutrients. Fruit tree portfolios are location specific combinations of indigenous and exotic fruit tree species that can provide year-round harvest of vitamin-rich fruits and, at the same time, fill 'hunger gaps' and specific 'nutrient gaps' (Kim et al., 2003). This is aimed at enhancing the diversity of fruits on farms and in food systems for increased consumption and better diets, while addressing seasonal fruit availability.

Fruits deliver important nutrients for healthy and strong bodies such as vitamins A, C, B6 and minerals.

2.1.4 Garden Vegetable Techniques

A vegetable garden technique also known as a vegetable patch or vegetable plot is a garden that exists to grow vegetables and other plants useful for human consumption which apply appropriate cultivation techniques. By utilizing effective techniques in home gardens with good seed and appropriate vegetable cultivation technologies, vegetable production can be significantly increased with increase nutrition content. This will enable the rural households in East Africa to secure more vegetable for their consumption. Consuming more fresh fruits and vegetables is one of the most important things you can do to stay healthy. According to Krebs-Smith et al., (2000) when you pick vegetables right from your garden, the vitamin content will be at its highest. Also, you are reducing the risk of eating vegetables that contain harmful chemicals you know exactly what you're eating. In addition, getting kids involved in the gardening process will make it more likely for them to try the vegetables.

2.1.5 Nutritional Outcome

Nutritional outcome is the measurement of dimensions of physical size, such as height or weight, and comparison with distributions of the same measurement in a presumably healthy and well-nourished reference population. Children whose weight falls below the range of normal variation for children of the same age observed in a reference population are identified as underweight. Underweight may reflect small stature, excessive thinness, or both. These two dimensions are differentiated in two more refined anthropometric measures - weight for height and height for age. If the child's weight falls below the range of normal variation for children of the same height, it is considered wasted. If its height falls below the range of normal variation for children of the same age, it is considered stunted. Wasting is generally interpreted as an indicator of acute malnutrition - a current or recent crisis involving extreme weight loss. Stunting, in contrast, indicates early malnutrition. Either a past episode (or episodes) of acute malnutrition, or a routinely limited diet over an extended period, has resulted in growth impairment, even though current nutrition may be adequate.

Malnutrition does not result from a lack of food only Hausman (1978) there are many contributing factors such as agricultural policy, health care and education level. About 1.4 billion people FAO (2016) are now overweight or obese, including in countries with low income and middle income. Obesity is sometimes related to poor diets quality just like food related to non-communicable diseases such cardiovascular disease and sometimes diabetes. Their cost associated with child undernutrition are high, averaging 8% of the gross domestic product (GDP) in developing countries, with a range from 13% of GDP per annum in a country like Tanzania to more than 16% of GDP in Uganda and 8% in Kenya (UBOS, 2010).

Kim et al., 2011 stated that income growth and opening up of markets are all leading to positive changes in diets and thus nutrition outcome. As a result of the balanced meal transition there is a result in the decline of the staple cereals consumption due to increase in the number and quantity balanced diet food groups that are consumed hence improving nutrition outcome (Olney *et al.,* 2009).

2.1.6 Anthropometric Measures

Anthropometry is the scientific study of human body measurements to assess the nutritional outcome of children. World Bank (2016) explains that anthropometric measure is an important feature for determining malnutrition that is; being overweight, stunting and wasting. Anthropometric indicators determine the prognosis of chronic diseases (Pelletier *et al.,* 1995). These measurements are used in determining the prevalence of agricultural policy and evaluate the need for nutritional support in those policies (Kennedy *et al.*, 2013).

Anthropometry alone is not sufficient to diagnose nutritional problems in individuals, although it identifies children whose situation should be examined further in making such a diagnosis. If the lower bounds of normal variation were set so low as to exclude all cases of healthy small size, much actual malnutrition would not register (Leroy and Frongillo, 2007). In order to obtain a reasonable degree of sensitivity, cut-offs are set high enough that a small proportion of individuals fall below them, despite good health and adequate nutrition. At the same time, some who are naturally larger may fall above the cut-offs, even when they are, in fact, malnourished.

The lower limit of the range of normal variation in anthropometry has been variously operationalized. One common practice has been to define a cut-off at some set percentage of the median from the reference population. According to Pelletier *et al.,* (1995) 80 per cent of the weight for age, has been the most widely used cut-off, but milder or more severe underweight has been defined in terms of higher or lower percentage cut-off points. For other anthropometric measures, different percentage cut-off points have been identified. Recent work has more consistently used a cutoff two standard deviations below the mean of the reference population. Using standard deviations is preferred to using percentage cut-offs because comparability across measures and for the same measure at different ages is not compromised by greater or lesser variability (Schmi, 1993). Roughly 3 per cent of healthy children will be more than two standard deviations below the mean of a healthy reference population, but most children this small are correctly identified as being at nutritional risk. Those more than two standard deviations below the mean are usually identified as moderately malnourished, while those falling three standard deviations or more below the mean are severely malnourished. While it is desirable to enhance marginal diets of children who are showing no clinical signs of growth faltering, it is preferable to target children at greater risk, if resources are limited. It is worth repeating that none of these cut-off points has any necessary functional significance, despite their utility in helping to identify hungry individuals (WHO, 2003).

Meaningful individual diagnosis involves repeated measurement over time. Repeated measurement allows a child's growth trajectory to be compared with that of normal growth, rather than simply relying on a one-time measurement relative to a cut-off point. The repeated measurement process is referred to as "growth monitoring" and can be used to determine if small children are growing normally; it can also identify larger children whose growth has become compromised, even before their size drops below some cut-off. Weight loss, as opposed to unusually low weight, is a more reliable indicator of nutritional crisis. Similarly, a period during which no increase in height occurs tells us more than does a one-point observation of unusual shortness, which might have resulted either from such a crisis (or repeated crises) at any time up to the present or from a pattern of uninterrupted slow growth. Growth monitoring has been promoted as part of the UNICEF/WHO "GOBI" (growth monitoring, oral rehydration therapy, breast-feeding, and immunizations) initiative for child survival. Its utility in this context is in alerting the mother and the health practitioner to developmental problems at an earlier stage, and thus encouraging intervention before much damage has occurred.

Body weight and height is measured while subjects wore light clothing and no shoes. Body mass index (BMI) is calculated as weight (kg) divided by height (m^2). Waist circumference is measured at the midpoint between the bottom of the rib cage and above the top of the iliac crest during the minimal respiration. Resting blood pressure is taken three times by a trained technician using a standardized protocol. The mean value of the two last measurements is used to express the systolic and diastolic blood pressure. The average of three recorded measurements was used in all data analyses.

2.1.7 Dietary Diversity

Dietary diversity (DD) is defined as the number of different foods or food groups consumed over a given reference period. It has long been recognized by nutritionists as a key element of high quality diets. Increasing the variety of foods across and within food groups is recommended in most dietary guidelines. with the current recognition that dietary factors are associated with increased risks of chronic diseases, dietary recommendations promote increased dietary diversity along with reducing intake of selected nutrients such as fat, refined sugars and salt.

Lack of dietary diversity is a particularly severe problem among poor populations from the developing world because their diets are predominantly based on starchy staples and often include little or no animal products and few fresh fruits and vegetables. These plant-based diets tend to be low in a number of micronutrients, and the micronutrients they contain are often in a form that is not easily absorbed. Although other aspects of dietary quality such as high intakes of fat, salt and refined sugar have not typically been a concern for developing countries, recent shifts in global dietary and activity patterns resulting from increases in income and urbanization are making these problems increasingly relevant for countries in transition as well.

Despite the well-recognized importance of dietary diversity, there is still a lack of consensus about what dietary diversity represents especially in East Africa. There is also a lack of uniformity in methods to measure dietary diversity and in approaches to develop and validate indicators. Experience from developed countries in measuring dietary diversity in the context of assessing overall dietary quality abounds, but measurement approaches, indicators and validation methods differ widely between studies. Experience from the developing world is scant, and again differences in methodological and analytical approaches affect the comparability and generalizability of findings.

The Household Diversity Score (HDS) provides a guide and approaches on how to measure HDS as a proxy to how families access food stuff (Masset *et al.,* 2016). Food and Nutrition (2013) explains how to calculate different food groups which contains better quality diet and it can also use Individual Dietary Diversity Score (IDDS), supposed as a proxy measure of individual's diet quality. The HDS, can be used as a proxy measure of the socio-economic status of the household.

When a child receives inadequate diet it becomes more susceptible to disease (WHO, 2012). In return the disease depresses appetite and inhibits the absorption of nutrients in food which then to compete for a child's energy. Not only having enough diet intakes but also nutrients must be consumed in appropriate balance for the human body to absorb the energy, protein, fat, and micronutrients taken (Food and Nutrition, 2013).

2.1.8 Micronutrient Intake

Micronutrients intake is referred to as vitamins and minerals that are vital to healthy development, disease prevention, and wellbeing that is consumed. With the exception of vitamin D, micronutrients are not produced in the body and must be derived from the diet. Micronutrients are key factors in a range of cellular and biochemical functions including the release of energy for the synthesis, movement, and other functions. Subclinical deficiency of several micronutrients, for example, antioxidants (vitamin C, E, A, and selenium), folic acid, vitamin B12, and vitamin B6 may lead to effects on intracellular homocysteine concentration, that may have important consequences on the progression of chronic diseases by affecting inflammation and presence oxidative stress (Nayga, 2000).

You and Nayga, (2005) explains that though people only need small amounts of micronutrients, consuming the recommended amount is important. Micronutrient deficiencies can have devastating consequences. At least half of children worldwide younger than 5 years of age suffer from vitamin and mineral deficiencies.

According to the 2010-14 Round of the National Sample Survey (NSS), about 80 percent of the people living in rural areas in East Africa had caloric intakes below the recommended values of 2400 calories per adult. The poorest 30 per cent of East Africa population could consume, on an average, lower than 1700 calories per day. The lowest 10 per cent among these received less than 1300 calories per 7 days (Glei and Goldman, 2000; World Bank, 2016). A multi-centric study conducted in Tanzania on the use of carotene-rich food to combat vitamin A deficiency revealed that the main factor behind this was low level of consumption of Green Leafy Vegetables (GLVs).

Lukmanji *et al.,* (2008) explains that in terms of agricultural productivity, the East Africa countries performed poorly compared to the rest of sub-Saharan Africa, especially in cereal productivity compared to agricultural land which is allocated to family farms use this may have led to high micronutrient deficiencies recorded.

2.1.9 Health Status

In 1948, WHO defined health status as a state of complete physical, mental and social well-being, and not merely the absence of disease. Health can be considered in terms of a person's body structure and function and the presence or absence of disease or signs (health status); their symptoms and what they can and cannot do. Health care is the prevention, treatment, and management of illness and the preservation of health through the services offered by health care organizations and professionals. It includes all the goods and services designed to promote health, including the preventive, curative and palliative interventions, whether directed to individuals or to populations (Von Braum, 1995).

Health status is a multidimensional concept, requiring multiple indicators and multiple methodologies for adequate measurement. Several different indicators of health status are usually included in health surveys, including single summarizing measures; questions relating to disease incidence and prevalence; and questions relating to functioning (physical, cognitive, emotional, and social) or disability (Stewart and Ware, 1992).

Health-status measures serve several purposes. In this study they are taken as outcome measures for program evaluation. They are also used on a one-time basis to provide a functional and psychosocial profile of household that are applied serially to monitor the responses to standard interventions of agricultural technologies. It is interesting to recall what Wickramasinghe *et a.,* said in 2003: “Despite persistent problems in conceptualization and measurement, quality of life is an idea whose time has come; its appraisal is now demanded in many clinical trials from which it was formerly excluded.” Increasingly, governmental agencies use health values to inform policy decisions. However, many flaws and limitations are associated with the dominant research paradigm that underpins the instruments currently available to quantify a subjective phenomenon such as health.

Malnutrition in East Africa manifests itself most clearly in underweight and stunted children. It also has long-term effects, both for the life prospects of the child and for their country as a whole. The World Bank's Global Monitoring report 2012 stated that most of the malnourished child has on average a seven-month delay in schooling, a 0.7 grade loss in schooling which leads to potentially a 10-17 percent reduction in life-time earnings. This affects future human capital and then to reduce national GDP to around 3 percent (FAO, 2016). In terms of health care governments face several challenges, including lack of funds and poor infrastructure. WHO (2018) explains how health status is compounded by epidemics, poverty and varying public health care from country to country. The standard of health care facilities in East Africa is low by global standards (World Bank, 2018). There has been much improvement in recent years but challenges such as underfunding with only 6% of the GDP, which translates as $51 per capita, compared to $4,000 per capita in the European countries, WHO (2018) also found out that there is chronic staff shortages with average of one doctor in 35,000 people and a lack of medical technology mean that provision is inadequate for both the population in rural areas. Despite this, the health care system in East Africa ranks at 156th which although poor is still above many neighboring regions such as West Africa and South Asia. The government does have a universal health care programme, but the quality and scarcity of facilities which are generally only available in urban areas means that rural areas residents may not benefit (FAO, 2014).

2.1.10 Hunger

Hidden hunger is a form of an unbalanced diet when important nutrients are lacking, such as iron, iodine, zinc or vitamin A. At first glance, the consequences are not necessarily very visible, but over the long-term these nutrient deficiencies lead to serious diseases. In particular, children are unable to develop correctly, neither mentally nor physically. The risk of death is high. Worldwide, two billion people suffer from chronic nutrient deficiency, including in industrialized countries. Hidden hunger not only harms individuals, but can inhibit the overall development of an affected region, as the efficiency and health of people decreases (Wilkins and Beaudet, 1998).

Ramezani (1995) stated that hunger affects the weakest in society, children are particularly badly affected. In traditional societies they suffer heavily from the consequences of structural inequalities. Women have little access to education or opportunities to earn a livelihood. Most do not have their own resources, such as land or capital. At the same time, they frequently struggle with the double burden of farm work and raising children. As a result, many children do not receive enough care or food. A lack of knowledge about nutrition and hygiene issues increases this risk.

Around the world, more than enough food is produced to feed the global population but more than 690 million people still go hungry (Pitt and Rosenzweig, 1985). After steadily declining for a decade, world hunger is on the rise, affecting 8.9 percent of people globally. From 2018 to 2019, the number of undernourished people grew by

10 million, and there are nearly 60 million more undernourished people now than in 2014. Before this increase in recent years, the world had been making significant progress in reducing hunger. In fact, in 2000, world leaders joined the United Nations and civil society in committing to meet eight Millennium Development Goals by 2015: the first of which was “to eradicate extreme poverty and hunger.”

Hunger is strongly interconnected with poverty, and it involves interactions among an array of social, political, demographic, and societal factors. People living in poverty frequently face household food insecurity, use inappropriate care practices, and live in unsafe environments that have low access to quality water, sanitation, and hygiene, and inadequate access or availability to health services and education—all of which contribute to hunger.

Conflict is also a key driver of severe food crises, including famine—a fact officially recognized by the UN Security Council in May 2018. Hunger and undernutrition are much worse when conflicts are prolonged and institutions are weak. The number of conflicts is on the rise, some worsened by climate-related shocks. People and organizations working to combat hunger must take conflict-sensitive approaches, much more so than in the past.

Gragnolati and Marini (2003) reported that low access to food, high nutritional needs, the agricultural productivity gap, and vulnerability to environmental shocks are the most salient problems facing Tanzania's rural population. By several measures, the country ranks among the least well-nourished countries in the world. The 2013 Comprehensive Food Security & Vulnerability Analysis (CFSVA) conducted by the World Food Program (WFP) in East Africa revealed that about 5 percent of household's experience poor food consumption, and 15 percent of those living in rural areas have borderline food consumption though slightly more varied but still nutritionally inadequate meals (UBOS and WFP, 2013). The global hunger index score is 26.4 which categorize the hunger level as "serious" in 2016 (Smith and Haddad, 2015).

2.2 Multiple Agricultural Technologies on Nutrition Outcome

Improved agricultural technologies are critical for increasing agricultural productivity, household income, and food security and nutrition outcome (Diao *et al.*, 2010; Kassie *et al.*, 2018; Zeng *et al.*, 2017). In many developing countries including East Africa, adoption of multi agricultural technologies such as improved beans variety, biofortified maize variety, grafted fruit trees and use of garden vegetables techniques has been increased (Abdulai, 2016; Arslan *et al.*, 2013). Low crop yields and high levels of food insecurity which causes malnutrition are explained by low adoption to these new technologies (CSO, 2016; Fisher *et al.*, 2015; Jain, 2007; Kassie *et al.*, 2015). Use of improved beans variety, especially the adoption of drought tolerant varieties has acts as strategy against climate change Fisher *et al.*, (2015) leading to higher and more stable yields and incomes thus medicating malnutrition (Manda *et al.*, 2016; Ng'ombe *et al.*, 2017). According to Jaleta *et al.*, 2016 the use of grafted fruit trees leads to improve long-term production and environmental benefits by reducing soil erosion, nutrient depletion, off-site sedimentation, and conserving soil moisture.

Crop biotechnology and grafted fruit trees management has greatly developed upon in recent times where desired trait is exported from a particular species of crop to an entirely different species without pest damage to attain desirable characteristics in terms of nutrients content, flavor of the diet, faster growth rate, size of harvested products and resistance to diseases and pests (Fisher *et al.,* 2015).

Singh *et al.,* (2016) argue that multiple agricultural technologies can contribute to malnutrition reduction in three major ways. First, multiple agricultural technologies help in developing yield-increasing technologies contributing to an increase in the stable food on which the poor receive a considerable share of their nutrients. It's supported by Remans *et al.,* (2015) who state that the development of improved beans variety, which boost food production both and increasing nutrients per cropping season and by facilitating multiple cropping which remain a critical component of the research strategy to achieve first Millennium Development Goal (MDG) of halving malnutrition by 2050. Second, multiple agricultural technologies help to conserve natural resources since the poor lack alternative means to intensify agriculture except forced to overuse or misuse the natural resource bases to meet basic needs. Third, because the poor tend to reside in unflavored or marginal agricultural areas, research should aim at developing technologies suitable for these areas hence increasing production of stable crops.

The introduction of multiple technologies in agriculture will provide a sustainable way of reaching people with poor access to stable crop with high nutrients content (West, 2002). Kennedy *et al.,* (2010) explain that multiple technologies provide benefits year after year at a lower cost than either dietary supplements or fortification through food processing. Multiple agricultural technologies are aimed at reaching populations groups who consume most of the staple food they produce and are often missed with other nutrition interventions (Khoury *et al.,* 2014). It is anticipated by Muriithi and Matz, (2015) that adoption of multiple agricultural technologies such as improved beans variety, biofortified maize variety, grafted fruit trees and garden vegetables techniques can be a means by which malnourished rural households who may have less access to diverse meals, supplements, and fortified foods.

According to the World Bank (2016) in most of Sub-Saharan Africa, agriculture is a strong option for spurring growth, overcoming poverty, malnutrition and enhancing food security. Masset *et al.,* (2016) found out that of the total population of Sub-Saharan Africa in 2016, 66% lived in rural areas and more than 90% of rural population depends on agriculture for their livelihoods. Improving the productivity, profitability, and sustainability of smallholder farming is therefore the main pathway out of poverty and malnutrition in using agriculture for development in East Africa (World Bank, 2016).

As per USAID (2017) report, Kenya is facing food insecurity with around 3.4 million people are suffering from acute food insecurity. It has made substantive strides in reducing the prevalence of stunting, wasting, and underweight nationally, falling from 35 percent in 2008 to 26 percent in 2014 (KNBS *et al.*, 2015; KNBS and ICF Macro 2010). It is most prevalent among children 18–23 months, showing that there has been poor complementary feeding, hygiene, and sanitation practices which are likely to have contributed to stunting the situation. It is also evident from the KNBS *et al.,* (2015) that Children whose mothers did not complete primary education and those who have no education background about technology are more likely to be stunted at 34 percent and 31 percent than those of mothers with a secondary and agricultural technology knowledge at 17 percent. According to KNBS *et al.,* (2015); MOH (2011) in Kenya Vitamin A deficiency is one of the low effects of malnutrition at 9 percent in children under 5 years. In Kenya Food and Nutrition, (2013) agriculture is the backbone of the economy and the main employment and development strategy with more than 75 % of the total workforce. However, Khoury *et al.,* 2014 indicated that agricultural technology is still yet to be fully utilized having been proposed and implemented in recent years. This will help reach maximum yield productivity and food security (USAID, 2017). According to Sachs *et al.*, (2017) Kenya currently ranks 125 of 157 countries progressing towards the Sustainable Development Goals.

In Uganda malnutrition is considered a major resource drain nationally (UBOS, 2013). According to UBOS statistics (2017), undernourished women were 12 percent and malnutrition contributed to about 40 percent of child deaths. It also reported that the number of stunted children below 5 years was 37 percent, wasted was 5 percent and underweight was 22 percent. Bachou (2012) states that malnutrition is mainly caused by micronutrient and the efforts to alleviate micronutrient deficiency are keen on the key micronutrients of iodine, iron, and vitamin A. Uganda produces a wide range of crops and animal products with two cropping seasons per year yet the population still faces problems of malnutrition, famine, and hunger (Iannotti *et al.*, 2018). FAO (2018) mentioned the factors that contribute to poor nutritional status such as food intake, morbidity, malaria, inadequate maternal and child care, poor water, sanitation and health services, low income, and food production. This calls for the importance of taking a multisectoral approach when dealing with the nutritional problems of Uganda (Iannotti *et al.,* 2017).

The UBOS survey UBOS (2001) estimated Vitamin A Deficiency in women at 50 percent, but only 11 percent were able to receive vitamin A capsules postpartum. 26 percent of children under five, were considered Vitamin A deficient while only 38 percent managed to received supplements. Micronutrient deficiencies are significantly higher in rural areas than urban areas and with major differences between regions and socio and educational status (UBOS, 2001). Harvey *et al.,* (1999) observed that the intake of animal protein was scarce and limited the bioavailability of all micronutrients. It was also observed that the major source of vitamin A was green leafy vegetables, boiled or steamed, and taken with little fat. This concluded that 50 percent of children had an inadequate vitamin A intake and that the risk of vitamin A deficiency was higher in poor than in better-off, households.

Several interventions have been taken however they are curative including food supplementation, commercial fortification, and dietary diversity among others (Hazell, 2010). The government of Uganda and have partnered with NGOs to develop more varieties of crops that provide adequate vitamin A, zinc, or iron to more households. The orange-fleshed varieties of sweet potato (OFSP) that are rich in carotene, the precursor of Vitamin A, to address VAD; and iron-rich varieties of Phaseolus crop to combat IDA has been biofortified.

In Tanzania, micronutrient malnutrition has been a major issue to socio-economic development and contributes fully to the underdevelopment of already underprivileged groups. Malnutrition can reduce the production capacity of a population hence his cost of living due to increased rates of illness. According to the 2010 Tanzania's DHS, around 34% of children suffer from Vitamin A and around 36% of women also suffer from vitamin A deficiency. Also, the Malaria Indicator Survey report of 2015-16 indicates that 58% of the children are anemic; this indicates high prevalence rates of severe public health problems.

Malnutrition is estimated to cost Tanzania over US$ 518 million per financial year, this is around 2.7% of the gross domestic product (GDP) as per the statistics of the

Tanzania Food Fortification Action Plan (2009). To mitigate malnutrition, multi-agricultural technology then to promote the consumption of diversified diets, supplementation, and food fortification are some of the classical strategies deployed in Tanzania. Although these strategies have attained results, they have several limitations. To compact this micronutrient malnutrition situation, the Tanzania Food Fortification Action Plan in collaboration with other partners has worked on different approaches to prevent micronutrient deficiencies. The National Multisectoral Nutrition Action Plan (NMNAP) was created in 2017 to cover a five-year plan for the period until 2021. It was designed to Scale-up multiple technologies and control micronutrient deficiencies as one of its seven key result areas. In the action plan, technology use is prioritized as an important intervention.

The impact of agriculture and nutrition on household welfare is the subject of the extensive literature in health and agricultural economics (WHO, 2002) but not on the multiple agricultural technologies. By ensuring the coordination between multi-sectors in designing it is possible to identify and manage some aspects that agriculture cannot do alone. It is difficult to design agricultural and agri-food technologies that support the diversity of foodstuffs they targeted specific priority products and supply chains. It is also important to update explicit empirical studies on links between agriculture technology and nutrition (Ramezani, 1995). The few recent studies of this type tend to concentrate on localized projects and positive effects, particularly of small-scale livestock farming or family gardens. World Bank (2006) noted that it is, therefore, necessary to (i) reposition the question of the links between agriculture technology and nutrition in the current context, taking into account the different forms of agricultural technologies applied across East Africa countries, the dual nutritional burden like stunting, underweight and wasting (ii) extend deliberations to the scale of countries agricultural technology policies. Lastly, most recent studies on the impact of agriculture and technology on nutrition outcome (Malapit *et al.,* 2013, Masset *et al.,* 2016, Kassie et al., 2014 and Khoury *et al.*, 2014) are found in the public health, medical and dietary literature, it did not address the multiple agricultural technologies and indicating that the field of agricultural economists should be pinning greater attention to nutrition.

In Tanzania, multiple agricultural technologies are nutrition intervention strategy that increases micronutrient content through improved varieties of crops, agricultural practices, agronomic or biotechnological means. The main aim of multiple agricultural technologies contributes to the reduction of micronutrient deficiencies such as iron, zinc, and vitamin A due to improved micronutrient in the staple food crops that are produced by low-income households with the help of projects like Building Nutritious Food Baskets (BNFB) which reduce hidden hunger by utilizing sustainable investments of technology.

The recent empirical literature has begun to document the substantial impact that agricultural policies impose on the countries and communities involved the use of joint multiple agricultural technologies (Walker, 1991). Comparatively less attention has been devoted to the estimation of the effects of agricultural technologies on household nutritional impact (Elhorst, 2014). It is due to the paucity of useful and reliable data that enables researchers to explore the relationship between agricultural technology and household nutritional outcomes in a rigorous fashion that goes beyond either discussion of the state agency or broad macro analysis. As per World Bank, (2007) chronic undernourishment is widespread throughout the East Africa region.

The causes and consequences of malnutrition are often a complex mix of inter-linked agricultural policies and economic factors (Kerr, 2009).

The belief that "agriculture contributes not just to food production, but also on human nutrition and health" is widely held, and it underpins ongoing efforts globally to "make agricultural technologies nutrition-sensitive" (Hazell, 2010). The links between health and agriculture are complicated, bidirectional, and sometimes counter-intuitive (You and Nayga, 2005). Multiple frameworks have been developed to identify critical pathways between nutrition and agricultural activities (FAO, 2010). The latest frameworks, developed for a DFID-funded study Park (2014) identified the principle pathways that link agricultural technology with nutrition-related outcomes either indirectly or directly. According to Evans (1972), the pathways start with agricultural technology that may relate to changes in agricultural technologies such as new crop varieties, agricultural practices such as home gardening, or food production. Tribe (2014) claim that the direct effects of changes in agricultural technologies are captured in the link to changes in food consumption and health outcomes in populations. The indirect effects Elias (2013) identify the impact of changes in technologies and the food environment on agricultural employment and farm incomes, and the knock-on effect of changes in crops on the ability to purchase foods and services that can be both beneficial and harmful to health (Park, 2014). Macro-level factors that can influence agricultural technology and nutritional outcomes include policy, economy, culture, and governance (Cooley and Prescott, 1973).

Some efforts have been made, Nayga, (2006) to evaluate whether increasing the size and efficiency of the agricultural technology will in itself lead to enhanced nutrition outcomes. Generally, these efforts rely on a statistical analysis of existing datasets or modeling of future scenarios and assess the association of growth in the agricultural technology with nutrition outcomes, usually in children (Dwivedi and Srivastava, 1978). The associations are assumed to work along multiple pathways according to Kim *et al.,* (2011) that include increased food availability at the household and community level, increased non-farm and farm incomes, and more indirect linkages between increased agricultural sector productivity and measures of national economic development. Mayne *et al.,* (2013) state that the principal challenge in such work is that inferring a causal link between agricultural technology and improved nutritional status is not straightforward, especially given that any relationship will be highly context-specific (Ganster and Schaubroerk, 1991). Using a mixture of statistical and modeling approaches for a variety of country settings, some studies suggest that there is a positive relationship between agricultural technology and nutrition outcomes in children (Rao and Gritures, 2000). This finding has however not been supported by other studies for single countries (You and Nayga, 2005), or in analysis using multiple country datasets (Foster, 2001). The lack of concordance in findings Weerahewa (2004) is likely due to different methodological approaches and significant methodological challenges and to the long results chain between agricultural technology and better nutrition outcomes.

Ganster and Schaubroek, (1988); Koppmair *et al.,* (2017) explain that multi-agricultural technologies may therefore produce complex effects on nutrition. In East Africa, relative price changes are very pronounced between cereals – having benefited from strong agricultural support – and non-cereal products. The rise in prices of the latter (legumes) might explain the weak improvement in nutritional status, or even its deterioration (Guthrie *et al.,* 2013), despite increased incomes over the past twenty years in East Africa (Wilkins and Beaudet, 1998).

Agricultural policies targeting staple food products may have perverse effects on diets and nutrition (Lukmanji *et al.,* 2008). It is difficult to blame agricultural policies for the increase in chronic illnesses, as many factors are involved in the nutritional transition and WHO (2002) indicated a strong evidence base that demonstrates that nutrition specific interventions are critical to improve nutrition outcomes and child survival.

2.3 Theoretical Frame Work

2.3.1 Consumer Theory

The theory of consumer behavior uses the law of diminishing marginal utility to explain how consumers allocate their incomes (Abdulai and Regmi, 2000). The random utility-maximization model is built based on the assumptions that Consumers are assumed to be rational, trying to get the most value out of their money. The random utility-maximization rule states: consumers decide on how to allocate their money incomes so as last dollar spent yields the same amount of extra marginal utility on every product purchased (Beck and Katz, 2007). A utility-function describes the level of satisfaction and happiness that a consumer then to obtains from consuming various goods and services. A utility function has different levels of arguments and each of which affects the consumer's overall satisfaction level (Gottlier, 2004). The Tradeoff can be considered when consumers face one or more argument when they are making consumption decisions (Dielman, 1983).

Utility theory is also about people's choices, preferences and decisions with judgements or any goods with a worth value and is based are an individual's preference-indifference relation (Abonazel, 2014).

Interpretations and classification of utility-theory are in two ways by Chana (2009) that is; prediction and prescription. The predictive approach then to predict actual choice behavior while the prescriptive approach is saying how a person ought to make a decision. In psychology the primarily interest is in prediction while in economics both prediction and prescription are of interest but statistics Araar (2007) emphasis on decision making under uncertainty.

The farm household is assumed to maximize its utility subject to technology, budget and market constraints. Drawing on Binkley and Nelson (2008), the utility function to be maximized can be represented as a vector of consumption goods, including purchased commodities, own consumed agricultural goods and leisure. In such a situation, the idea proposed by Kariya (2000) and Schmidt (1978) is first to solve for the optimal solution given the choice regime to which the household belongs, then to choose the one leading to the highest utility.

The study by Angeline Mujeyi (2019) on the adoption determinants of multiple climate smart agricultural technologies in Zimbabwe: Considerations for scaling-up and out utilized this theory. Also similar study by Menale Kassie *et al.,* (2018) applied the random utility theory on the study about production Risks and Food Security under Alternative Technology Choices in Malawi: Application of a Multinomial Endogenous Switching Regression. As guided by this studies the consumer theory was utilized in this research.

2.3.2 Utility Theory

We can build a static model to estimate households' nutrition status responses when agricultural technology is implemented (Ball, 1988). The nutrition outcome is assumed to maximize utility subject to agricultural technology measured by dietary diversity, dietary diversity, and micronutrient intake (Bory, 2001).

It is assumed that there are two composite variables in the theory as put by (Abonazel, 2009). The first group of which we will treat as a single product is nutrition indicators denoted as (Y), while the other group is agricultural policy denoted by (X) as shown in equation (1) below. Consumers also get utility from the nutritional outcome (NU) they possess and others time components (T).

Let the utility function of a typical policy impact be:

$$U = U\ (Y, X; NU, T, S) \qquad (1)$$

Which is a quasi-concave and twice differentiable. S is a vector of demographic variables and other policy shifters like political situation in a country.

U has the following properties: $U\ (0, 0; NU, T, S) = 0$ Which suggest that nutrition outcome is essential for the individual policy implementation such that $U_N > 0$, $U_p > 0$. The expected direct effect of policy implication and nutrition outcome in the utility will signifies that there is a pleasurable positive impact on nutrition outcome from the policy to be implemented. However, $U_{pp} < 0$ because each added unit of the policy will have less nutrition outcome effect. In addition, following Anriquez and Stamoulis (2007) we will define time components as specific arguments in the utility function to the Agricultural Policy.

2.3.3 Theory of Technology Diffusion

The technology diffusion and adoption literature suggests that many different attributes of individuals may influence them to act in different ways. Studies by *Olwande et al.*, (2015), and Nayga (1996) suggest that adoption behavior of farmers is explained by farmer attributes, farm attributes, infrastructure attributes and perceptions about agricultural technologies. According to Telser (1964), socioeconomic characteristics, personality values and communication behavior of individuals influence their way of adopting innovations such that some individuals adopt innovations earlier than others. Vinod and Ullah (1981) analyze innovation and diffusion of knowledge. Diffusion of new technologies is slow because of informational barriers: it takes time and effort for firms to learn new technologies. Technologies are disembodied, and there is no role for capital goods producers. (In fact, there is no capital in their model.) In the model, the capital goods producer plays a crucial role in both innovation and diffusion. It assumes any informational barriers, but lack of skill prevents some people from using a new machine. Anh and Chelliah (1999) construct a vintage human capital model where new and old capital is complementary inputs. The marginal product of investment depends not only on the vintage of technology but also on the amount of old capital available for that specific vintage. Even when new technologies are available, people invest in old technologies if there exists abundant old capital for these technologies. As a consequence, diffusion of new technologies is slow. It does not assume any complementarity between old and new capital. In the model, diffusion is slow because new machines are difficult to use. Alston *et al.,* (1998) study diffusion of a new technology which is embodied in capital goods. The vintage-specific installation cost and production cost fall over time, due to (external) learning by doing. This leads to a gradual diffusion of a new technology. Thus, the diffusion is totally due to the fall of the adoption cost. Their main focus is on the shape of the diffusion curve. In their model, firms are homogeneous before adoption; in contrast, we emphasize the multiple technologies difference among household users.

2.4 Empirical Model Specification

2.4.1 Multinomial Adoption Selection Model

Reviews of the choice model in agricultural technology utilizing probability found in (Berkson, 1944) states that agriculture today has a dual structure consisting of large-scale with model behind this choice experiment and it consider a farmer's choice for home alternatives that will be a function of the probability that the utility associated. Regarding interesting variables, although their effect is expected to be positive or negative in the choice model, most of them are discrete dependent variables (Adesina *et al.,* 2000; Adesina and Chianu, 2002; Ojiako *et al.,* 2007; Akinola *et al.,* 2010; Dey *et al.,* 2010; Idrisa *et al.,* 2012). Adesina *et al.,* (2000) used the logit model in their study and the result implies that male farmers are more likely to adopt than female farmers. In addition, the age was negatively significant variable which suggested that younger farmers are more likely and willing to adopt improved technologies. The variable on possession of full rights over trees had positive significant and suggested to have positive influence on the likelihood to adopt improved technologies. Finally, the education variable also has a positive effect on the farmer's adoption decisions.

Furthermore, in their review Shiyani *et al.,* (2002) examined the adoption impact decision of improved chickpea varieties in farms Gujarat, India, which used a tobit model. In their study, they found out that several variables were significantly influencing the farmers' adoption decisions which include crop maturity rate, land size, and yield risk. The land size coefficient was found to be negative on the adoption of new chickpea varieties this explains that new variety adoption is growing faster for small households than for large housed farmers. They found out that the experience of growing chickpea to be positively significantly, this indicate that the farmers with higher experience were more likely to adopt new varieties.

Ojiako *et al.*, (2007) analyzed the adoption of the improved soybean variety in northern Nigeria, with the objective of identify the factors that could influence the farmers' decision to adopt the improved variety using both logit and tobit models. They found out that farmers adopted at over 65% on the improved variety. They state the reason for adoption as superior yield, grain size, color, resistance to pesticides and diseases.

2.4.2 Multinomial Endogenous Switching Regressions (MESR)

The reviews about multinomial endogenous switching treatment regression in multi-agriculture can be found in many other studies. It utilizes the Kessie *et al.*, (2014) which outline the strategy used to estimate the impacts of the adoption of subsidy inputs programs (SIPs) on maize yield and downside risk. Consistent estimates of the yield function on effect of SIPs on downside risk and the cost of risk. They estimated the relationship between maize yield (Qji) and a set of exogenous variables Z plot characteristics, inputs, demographic factors, resources, etc., for each chosen combination of SIPs following the Antle (1983) flexible moment based approach and the Bourguignon *et al.*, (2007) multinomial selection-bias correction framework. The base category, non-adoption of SIPs is denoted as j = 1. In the remaining combinations (j = 2, 3, 4), at least one SIP is adopted. The stochastic production function to evaluate the food security and downside risk implications of SIPs adoption for each regime (SIP combination) j is given as:

$$\begin{cases} Regime\ 1: Q_{1i} = \alpha_1 z_{1i} + \theta_1 \bar{Z}_{1i} + \mu_{1i} & if\ I = 1 \\ \quad \vdots \qquad\qquad \vdots & \qquad j = 2,3 \ldots 8 \\ Regime\ J: Q_{ji} = \alpha_j z_{ji} + \theta_j \bar{Z}_{ji} + \mu_{ji} & if\ I = j \end{cases} \quad (4)$$

This approach can minimize the problem of unobserved heterogeneity (Mundlak, 1978; Wooldridge, 2002). To control for the unobserved heterogeneity, including the level of inputs, can help to address plot-specific unobservable as they contain useful missing information regarding land quality. If farmers accessed private information about unobservable effects such as how good the soil is on the plot, they will accordingly adjust their factor input decisions (Fafchamps, 1993; Levinsohn and Petrin, 2003). If the u's and ε's are not independent with a consistent estimation of α θ requires the selection correction terms inclusion of the alternative choices in (4). Bourguignon *et al.*, (2007) explain that the consistent estimates of *a* and *h* can be obtained by estimating the following MESTR models for the outcome equations (4):

$$\begin{cases} Regime\ 1: Q_{1i} = \alpha_1 z_{1i} + \sigma_1 \bar{\lambda}_{1i} + \theta_1 \bar{z}_{1i} + \ell 1i \quad if\ I = 1 \\ \quad\quad \vdots \quad\quad\quad\quad \vdots \\ Regime\ J: Q_{ji} = \alpha_j z_{ji} + \sigma_j \bar{\lambda}_{ji} + \theta_j \bar{z}_{ji} + \ell 1i \quad if\ I = 1 \end{cases} \tag{5}$$

Here, e is the error term with an expected value of zero, r is the covariance between ε and u, k is the inverse Mills ratio computed from the estimated probabilities in equation (6) as follows:

$$\lambda_{ji} = \sum_{m \neq j}^{j} \rho_j \left[\frac{\hat{p}_{mi} In(\hat{p}_{mi})}{1 - \hat{p}_{mi}} + In(\hat{P}_{ji}) \right]; \rho \tag{6}$$

We will therefore model the relationship between the nutrition outcome variables and a set of explanatory variables that will be estimated for each technology and combination choice e.g., non-adaption as reference category (CIV_0 CMB_0 SFE_0), j = 1; Improved varieties (CIV_1 CMB_0 SFE_0), j = 2; Biotechnology crop management (CIV_0 CMB_1 SFE_0), j = 3; grafted fruit trees (CIV_0 CMB_0 SFE_1), j = 4; precision agriculture (CIV_1 $CMB_1 SFE_1$), j = 5; combination of CIV and CMB, j = 6; combination of CIV and SFE, j = 7; combination of CMB and SFE, j=8 .

2.4.3 Propensity Score Matching (PSM)

Propensity score matching (PSM) refers to the pairing of treatment and control units with similar values on the propensity score, and possibly other covariates, and the discarding of all unmatched units (Beran and Millar, 1994). A study by (Mocan &

Tekin, 2006) on the economics of catholic schools uses a propensity score matching method to control for positive selection into Catholic schools and finds that Catholic school attendance reduces the propensity that female students use cocaine and have sex.

It is primarily used to compare two groups of subjects but can be applied to analyses of more than two groups. According to Gupta and Rohatgi (1982) PSM builds on a statistical comparison group which is based on a model of the probability of participating in the treatment, using observed characteristics. It takes that the participants are then matched on the basis of probability or propensity score to nonparticipants. The average treatment effect of the program is then calculated as the mean difference in outcomes across these two groups (Fomby *et al.,* 1984). The validity of PSM depends on the following conditions. First, the conditional independence or the unobserved factors which does not affect participation. Secondly, sizable common support in propensity scores across the participant and nonparticipant samples. It is a useful approach when only observed characteristics are believed to affect program participation.

PSM develops a statistical comparison regimes Smith and Blundell (1986) by modeling the probability of alternatives in the program on the basis of observed characteristics unaffected by the choice. Then the regimes are matched on the basis of this probability and propensity score, to nonparticipants, using other methods. They calculate the average treatment effect of the alternative to the mean difference in outcomes across the regimes (Rao and Griliches, 2000). PSM is useful when only observed alternatives affect regimes participation. This assumption effects on the rules governing the targeting of the alternatives, as well as any factors driving self-selection of households into the regime. If it is available, then actually the pre-program baseline data on participants and nonparticipants can be used to calculate the propensity score and to match the two regimes on the basis of the propensity score. The necessary assumptions for identification of the regime effect are (a) conditional independence and (b) presence of a common support. Conditional independence states that given a set of observable covariates X that are not affected by alternative potential outcomes Y are independent of alternative assignment T. If Y_i^T represent outcomes for participants and Y_i^C outcomes for nonparticipants, conditional independence implies. This assumption is also called unconfoundedness stated by Fomby *et al.,* (1984) and it implies that uptake of the program is based entirely on observed characteristics. To estimate the TOT as opposed to the ATE, a weaker assumption is needed. Also, there may be random selection of households but not random allocation of treatments to the multiple technologies and may not be representative of the general population therefore this model could not apply for our study.

2.5 Summary of Literature

Food insecurity, malnutrition, and lack of technology remain persistent problems in Sub-Saharan Africa. Multiple agricultural technologies have been proposed as a possible solution to simultaneously address the challenges of malnutrition. Narrowly defined, multi-agricultural technologies entail raising agricultural productivity while improving the technical resource base. Yet there is little empirical evidence on if adoptions of multiple agricultural technologies standpoint do indeed improve nutrition. To fill this gap, this study will use representative household panel survey data from Kenya, Uganda, and Tanzania to analyze the nutrition effects of rural households' adoption of multi-agricultural technologies. We will consider three technologies using multinomial endogenous switching treatment regression.

According to the literature reviewed, productivity increases in agriculture due to technology, policy change, and other parts of the food system are essential to provide food for future generations but do not ensure food security or improved nutrition. Many factors that influence human nutrition and the impact of multi-agricultural technologies on malnutrition is not surely automatic and predetermined. The nutrition impact is either positive or negative, and the magnitude of the impact may be influenced by the design of agricultural technologies and rural development projects and policies. Both undernutrition of stunting, underweight and wasting are costly for human development and economic growth, and both are influenced by agricultural policy (Neumann, 1993).

A review of the literature by Rivers and Vuong (2008) on the impact of technology pathways from agriculture to improved nutrition and health confirms the existence of important evidential lacunae that will continue to hamper activities in agriculture aimed at supporting nutrition until they are appropriately addressed. The FAO has recognized that actions aimed at "increasing production of staple crops, are by themselves often not enough to accelerate reductions in hunger and malnutrition" (Smith and Blundell, 2000). The problem is that even a narrower technology focus of agriculture producing outputs of higher nutrient density than others (such as horticulture and livestock), suffers the same reality. The provision of higher levels of one or other nutrient, or one or other commodity, had not yet been shown to translate into enhanced physiological outcomes. Once again, it is important to emphasize that the current lack of evidence does not mean that multiple agricultural technologies does not support gains in nutrition and health, rather than the evidence of positive impacts is still weak. Even that conclusion would be confounded by the host of methodological weaknesses that are identified in the existing studies in this area (Masset *et al.,* 2013).

As noted in the literature review, agricultural technologies typically can improve nutrition by increasing food production and rising incomes. It makes important contributions though the impact of income itself on nutritional status is limited and can take many years to show its effects. A more diverse food system can also underpin diversification of the diet and provide additional benefits in terms of more stable income, production, and prices (Bouis and Haddad, 1990). As it currently exists, the empirical knowledge base on technology impact on nutrition outcome in East Africa can be summarized in the words of Kluve *et al.,* (2012) that despite the presence of clear potential of agricultural technology to improve nutrition developing countries but the evidence base for this relationship is wanting. Recent systematic reviews of studies (Food and Nutrition 2013; Singh *et al.,* 2016; Elias, 2013) which have evaluated multiple agricultural technologies interventions for improving nutrition reveal little strong evidence of impact, and a need for more and better-designed research.

Research on agricultural technological improvements is very much crucial to increase agricultural productivity and performance, thereby reducing malnutrition. However, evaluation of the impact of these agri-technologies on the welfare of rural households' has been very shallow due to lack of appropriate methodologies and most of past research has not moved beyond estimating economic surplus, productivity, and profitability on single technology rather than multiple agricultural technologies. There is also a need for more agricultural Economic empirical models to analyze the Agricultural policy outcome on nutrition, as it stands most of the studies are under public health.

Following Deb and Trivedi (2006); Wilson (2015) impacts of multi-agricultural technologies on adoption and nutritional status is modeled using multinomial endogenous switching regressions (MESR) and multinomial endogenous treatment effects (METE). However, in case the selection bias originating from observed and unobserved heterogeneity is not addressed it will give inconsistent estimates. Kassie *et al.*, (2015, 2018) state that farmers may endogenously self-select and decisions are likely to be influenced by unobserved factors that may be correlated with outcome variables. Selection bias is a key challenge in adoption and impact assessment studies based on non-randomized experimental data. Considering the methodology most studies like Kassie *et al.,* (2011) generally use propensity score matching (PSM) in impact evaluation when observable selection bias occurs. However, it is noted that the PSM approach cannot correct the problem of selection bias from unobserved factors (Abdulai, 2016; Jaleta *et al.,* 2016). The advantage of MESR and METE models over PSM is they compute an inverse Mills ratio using the theory of truncated normal distribution and latent factor structure, respectively to correct selection bias as explained by (Bourguignon *et al.,* 2007). From the literature reviewed, this study will utilize the consumer theory specifically, the random utility framework. This framework allows the combination of the multinomial logit model to analyze the different multi-technology combinations. It will also adopt the multinomial endogenous switching regression empirical model as this will take care of the self-selection biases from the households in the multi-technology utilization.

2.6 Research Gap

The current state of empirical evidence in east Africa for impacts on nutrition ascribed to defined agricultural interventions is weak and mixed at best (KNBS, 2014). Statistically significant impacts have been documented by (Menon and Ruel, 2013; Fleming *et al.*, 2014) in a few cases, mainly in terms of micronutrient status (usually Vitamin A), but even in such instances, the effects across all nutrients have not been documented on occasion where impacts on child growth lean towards the positive. The lack of sound, empirical evidence on effectiveness at scale, and cost-effectiveness of all kinds of agricultural intervention on nutrition remains a significant hurdle to policy advocacy and investment. The sooner methodologically rigorous studies can produce findings that offer guidance on how best to leverage agriculture's potential for nutrition the better (Omore and Baker, 2011).

CHAPTER THREE

RESEARCH METHODOLOGY

3.0 Introduction

This chapter described the theoretical framework within which the collected data was analyzed. Analytical framework and estimation procedures are also outlined. Both the theoretical and empirical models that were employed in the study are described and the procedures that were followed in estimating the parameters are illustrated accordingly. Methods that were used in the collection of the data is presented. Finally, the procedures followed in data analysis and variables are presented in this chapter.

3.1 Research Design

The combination of descriptive and analytical techniques, combined with the other research delivery mechanisms, was used to achieve the objective for the impact of multiple agricultural technologies on adoption and nutrition outcome in East Africa households by the use of a multinomial endogenous switching regression approach. The panel household data from Kenya Uganda and Tanzania were analyzed.

Various analytical techniques were used. First, the analysis involved a review of the objectives and instruments of multi-agricultural technologies on adoption and nutrition outcome (Wilson, 2015). Second, the linkage between adoption and technologies through a multinomial endogenous switching regression, and treatment effect was used to establish the relationship between adopters of multiple agricultural technologies and non-adopters (Dielman, 2008).

3.2 Types of Data

The selected area of study is in East Africa countries namely Kenya, Tanzania, and Uganda. To analyze the mapping of the nutritional indicators the Demographic health surveys (DHS) and IFRI data were reviewed before extraction. Specifically, the data source used for Multi-agricultural technology is a unique primary household panel data of 2007-2017 in Kenya, Tanzania, and Uganda. The survey started in the planting season of 2007/2008 and the data collection took place in selected districts in Kenya, Tanzania, and Uganda through to 2016/2017 season. The survey was conducted by IFRI in collaboration with Kenya Agricultural Research Institute (KARI), Kenya; Makerere University, Uganda; and Maruku Agricultural Research Institute (MARI), Tanzania. The funds to carry out the survey were provided by International Fund for Agricultural Development (IFAD) and FAO. The survey was designed to collect valuable information on several household compositions, health status, agricultural technology, and its characteristics. The analysis was based on a comprehensive and nationally-representative household survey carried out in the three countries on their farming systems. A total of 1,500 households were analyzed (500 for Uganda, 500 for Kenya, and 500 for Tanzania).

3.3 Analytical Models

The endogenous switching regression (ESR) framework was modeled simultaneously in two stages. In the first stage, the farmer's choice of alternative technologies was estimated using a multinomial logit selection (MNLS) model accounting for unobserved heterogeneity. The inverse Mills ratios (IMRs) were calculated from the estimated probabilities in the MNLS model. In the second stage, impacts of each combination of multi-agricultural technologies were evaluated using OLS with IMRs as additional covariates in order to account for selection bias from time-varying unobserved heterogeneity as follows;

a) The impact of the combination of technologies adoption on the underweight.
b) The impact of the combination of technologies adoption on stunting.

c) The impact of the combination of technologies adoption on the wasting.

Other empirical studies explained by Di Falco, (2014); Kassie *et al.*, (2015) have also applied ESR in impact evaluation. The malnutrition data was calculated based on the standardization of Z-scores.

3.3.1 Random Utility Theory

It was conceptualized that the decision to adopt a combination of multiple agricultural technology (MATs) is modeled in consumer theory, specifically a random utility framework. Following Kassie *et al.*, (2015, 2018) consider the latent model (U^*_{jit}) below which describes the i[th] farmer's behavior in adopting MATs j(j=1,….4) at time t over any alternative MATs combination,

. m:

$$U^*_{jit} = \alpha_j X_{jit} + \omega_j \bar{X}_{ji} + \varepsilon_{jit} \text{ with } U \begin{cases} 1 \text{ if } U^*_{jit} > max_{m\neq 1}(U^*_{mit}) or\ \tau_{1it} < 0 \\ \vdots \qquad\qquad \vdots \\ J \text{ if } U^*_{jit} > max_{m\neq j}(U^*_{mit}) or\ \tau_{jit} < 0 \end{cases} for\ all \quad (1)$$

$m \neq j$

Where X_{jit} is a vector of observed exogenous covariates that represents household and farm level characteristics, institutional support services, household assets, demographics, district dummies, plot characteristics, geographical variables and weather shocks—and α and ω are vectors of parameters to be estimated, and ε_{jit} is the random error term.

3.3.2 The Multinomial Logit Model (MNLS)

On the 1st stage the estimation of the MNLS model could be inconsistent due to correlation of unobserved factors with explanatory variables. To address this, we followed Mundlak (1978) and Wooldridge (2010) approach where the means $\bar{X}_{ji}$ of all time-varying covariates are included as additional covariates in the MNLS model.

Unlike the adoption decision which is observable, utility derived from adoption of MATs is unobservable. Therefore, Eq. (1) entails that the ith farmer will adopt a combination of MATs j to maximize expected benefits if the technology provides greater utility than an alternative combination m, m ≠ j; e.g., if $T_{jit} = \max_{m \neq 1}(U^*_{mit} - U^*_{jit}) < 0$, assuming that ε_{jit} are independent and identically Gumbel distributed (Bourguignon *et al.*, 2007). As shown by Mc-Fadden (1973), the probability that a household i at time t will choose technology j can be expressed as MNLS model with:

$$p_{jit} = \Pr\left(\tau_{jit} < 0 | X_{jit}\right) = \frac{\exp(\alpha_j X_{jit} + \omega_j \bar{X}_{ji} \quad)}{\sum_{m \neq 1}^{j} \exp(\alpha_m X_{mit} + \omega_m \bar{X}_{mi}} \quad (2)$$

Where p_{jit} is the probability that individual *j* chooses alternative *i*, X_{mi} a vector of observed variables specific to individual *j* and alternative *i*. The MNLS model structure of Eq (2) was motivated from two very different but formally equivalent perspectives. Specifically, a MNLS structure was generated from an intrinsic motivation to allow flexible substitution patterns across alternative error component structure to accommodate unobserved heterogeneity across individuals in their sensitivity to absorbed exogenous variables.

Thus, the MNLS model in Equation above was estimated using *mlogit* command in Stata Statistical Software (STATA 14).

3.3.3 Multinomial Endogenous Switching Regression (MESR)

In the MESR 2^{nd} stage, the relationship between the nutrition outcomes variables in terms of stunting, wasting and underweight were estimated for the highest best technology combinations so as to take care of collinearity as a set of explanatory variables (Z) choice as follows:

i. TC1 is a joint combination of improved beans variety, biofortified maize variety, and garden vegetables techniques, j = 1;

ii. TC2 is a joint combination of improved beans variety, biofortified maize variety and grafted fruit trees, j = 2;

iii. TC3 is a joint combination of biofortified maize variety, grafted fruit trees and garden vegetables techniques, j = 3;

iv. TC4 is a joint combination of improved crop, grafted fruit trees and garden vegetables techniques, j = 4.

The impact equation to represent nutrition outcome implication in each possible regime (j) is given as:

$$\begin{cases} Regime\ 1: y_{1it} = \beta_1 z_{1it} + \vartheta_1 \bar{Z}_{1i} + \mu_{1it} if\ U = 1 \\ \quad\quad\quad\quad \vdots \quad\quad\quad \vdots \quad\quad\quad\quad\quad\quad\quad\quad\quad j = 2,3 \ldots 4 \\ Regime\ J: y_{jit} = \beta_j z_{jit} + \vartheta_j \bar{Z}_{ji} + \mu_{jit} if\ U = j \end{cases} \quad (3)$$

where $\mathbf{y_{jit}}$ are the nutrition outcome variables of the farmer household ***i*** in regime *j* at time *t* and the error terms ($\boldsymbol{\mu_{jit}}$'s) are distributed with E ($\boldsymbol{\mu_{jit}}$ / X,z) = 0 and var ($\boldsymbol{\mu_{jit}}$ / X,z) = δ^2_j. $\mathbf{y_{jit}}$'s are observed if only one of possible adoption combinations will be used.

We added the means of all time-varying variables $\bar{Z}$ in Eq. (3) as additional regressors in order to get consistent estimates. This approach can minimize the problem of unobserved heterogeneity (Mundlak, 1978; Wooldridge, 2010). The error term ($\boldsymbol{\mu_{jit}}$) is comprised of unobserved individual effects (c_i) and a random error term ($\boldsymbol{\mu_{it}}$). Therefore, OLS estimates in Eq. (3) will be biased if $\boldsymbol{\varepsilon_{jit}}$**'s** and $\boldsymbol{\mu_{jit}}$'s are not independent. A consistent estimation of β_j and υ_j requires inclusion of the selection correction terms of the alternative choices in Eq. (3). In the multinomial choice setting, there are *j*-1 selection correction terms, one for each alternative adoption combinations. Following Di Falco (2014) and Kassie *et al.*, (2015, 2018), the second stage of MESR with consistent estimates is specified as follows:

$$\begin{cases} Regime\ 1: y_{1it} = \beta_1 z_{1it} + \sigma_1 \hat{\lambda}_{1i} + \vartheta_1 \bar{Z}_{1i} + \mu_{1it} if\ U = 1 \\ \quad\quad\quad\vdots \quad\quad\quad\quad \vdots \\ Regime\ J: y_{jit} = \beta_j z_{jit} + \sigma_j \hat{\lambda}_{ji} + \vartheta_j \bar{Z}_{ji} + \mu_{jit} if\ U = j \end{cases} j = 2,3 \ldots 4 \qquad \ldots(4)$$

Where μ_{jit} is the error term with an expected value of zero, δ is covariance between ε_{jit}'s and μ_{jit}'s, $\hat{\lambda}_{jit}$ is the inverse Mills ratio computed from estimated probabilities in Eq. (3) as follows:

$$\hat{\lambda}_{jit} = \sum_{m \neq j}^{j} \rho_j \left[\frac{\hat{P}_{mi} In(\hat{P}_{mi})}{1 - \hat{P}_{mi}} + In(\hat{P}_{jit}) \right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

At this point ρ is the correlation between ε_{jit}'s and μ_{jit}'s. Standard errors in Eq. (4) was bootstrapped to account for the heteroscedasticity arising from the generated regressors due to the two stage estimation procedure.

Hence, households can choose to adopt modern technologies if they understand their inherent characteristics or potential benefits Adegbola and Gardebroek, (2007); Maeshiro, (2016); Zeng *et al.*, (2017) through early experience (Aldana *et al.*, 2011; Leathers and Smale, 1991). We performed correlation analysis and a simple falsification test (Di Falco *et al.*, 2011). Many other empirical studies such from Abdulai, (2016); Kassie, *et al.*, (2015) have used similar variables in impact evaluation as instruments.

Estimates and predictions from equation (4) enabled us to estimate treatment effects and compute individual exact impact of stunting, wasting and underweight due to choice of each form of multi-agricultural technology. According to Kassie, *et al.*, 2015 this approach will not only correct for selection bias due to unobserved heterogeneity but also controls for selection bias due to observed heterogeneity.

3.3.4 Estimation of Average Treatment Effects on Nutrition Outcome

To model the effects of adopting MATs on nutrition, we estimated multi-endogenous treatment effects (METE), which corresponds to Eq. (6) in this section. It compares expected values of outcomes of adopters and non-adopters of multiple agricultural technologies in actual and counterfactual scenarios. METE was used because it was extended to model binary outcomes that is those who adopt and those who did not adopt multiple technologies as opposed to multi-endogenous switching regression (MESR) which only considers continuous outcomes.

Like MESR framework, METE is also modeled simultaneously in two stages. In the first stage, a farmer chooses one of the four multi-agricultural technologies (MATs). Following Deb and Trivedi (2006) the first stage is estimated as mixed multinomial logit (MMNL). Derivation process of MMNL (Deb and Trivedi, 2006) is excluded because it is similar to multinomial logit selection (MNLS). In the second stage of multi-endogenous treatment effects (METE), we assessed the effects of adopting multiple agricultural technologies (MATs) on nutrition as a binary outcome. Following Abreu *et al.*, (2015), the expected outcome equation for individual, j, j = 1…5 is formulated as:

$$E\left(NOH_{\theta it} = 1 | d_{jit}, z_{it}, \bar{z}_{i,} \hat{\zeta}_{it}\right) = z'_{it}\beta + \bar{z}'_{i,}\vartheta) + \sum_{j=1}^{j} \gamma_j \, d_{jit} + \sum_{j=1}^{j} \lambda_j \, \xi_{jit} \quad (6)$$

Where $NOH_{\theta it}$ is nutrition outcomes for household *i* at time *t* measured by y_{ijt} as household malnutrition; $NOH_{\theta it} = 1$ if y_{jit} is lower than the malnutrition line; z_{it} is a set of exogenous covariates with associated parameter vector β; d_{ijt} represents binary variables for observed treatment choice; and γ_j denotes treatment effects relative to non-adopters and its coefficient gauge effects of adopting MATs on nutrition outcome. If the decision to adopt MATs is endogenous, assuming d_{ijt} to be exogenous results in inconsistent estimates of $\gamma_{j.}$

$E(NOH_{\theta it} = 1|d_{jit}, z_{it}, \bar{z}_{i,} \hat{\zeta}_{it})$ is a function of each of latent factors ζ_{ijt}, e.g., the outcome is affected by unobserved factors that affect selection into treatment, for METE model to be identified, Deb and Trivedi (2006) recommend use of instruments. We used the same instruments. We also included the means of all time-varying variables ($\bar{z}$) as proxy for major shocks to account for unobserved heterogeneity and potential simultaneity as explained above. Malnutrition equations was estimated using. *teffects ra (Zht ZUnWt ZhW) (UTC1 UTC2 UTC3 UTC4)*. Where, *(UTC1 UTC2 UTC3 UTC4)* are the binary of the house hold adopting or not adopting the joint technology.

CHAPTER FOUR

EMPIRICAL RESULTS AND DISCUSSIONS

4.1 Overview

This chapter presents results and discussions of major findings of this study. It is composed of three sub-sections. Sub-section 4.2 is the discussion of the results on descriptive statistics of the East Africa households and sub-section 4.3 is the econometric analyses and discussion of the analyzed results.

4.2 Descriptive Analysis

It presents the comparison of means of selected variables by adoption status for the surveyed 500 households in Kenya, 500 households in Uganda, and 500 households in Tanzania. Some of these characteristics are the explanatory variables of the estimated models and will present further on. It also provides the descriptive statistics of the household adoption of technology as per social composition and household level of education.

4.2.1 Household Social-economic Profile

The description of variables used in the multinomial logistic regression model is shown in table 4.1. The mean or frequencies and standard deviation of the variable are discussed. The marginal probability measures the expected change in the likelihood of a particular choice being selected with respect to a unit of change in an independent variable. An increase in a particular characteristic variable increases the adoption rate for some technology combinations and the rate of adoption then to decrease for other technology combinations.

Most of the household (64.3%) are male-headed with an average mean level of education in terms of the number of years spent in school as 10 years. This indicates that most of the household heads are fairly educated with Table 4.3 showing that 54.67% of the household heads attained the secondary level of education. On average 87% of the household used modern crop system technologies observing 82% of the inputs which is quite high and 87% of them utilized irrigation systems. This enabled the households to produce their products whole year round thus stabilizing supply and markets prices. In terms of productive land, the average size of arable landholding is about 3.7 acres while, those who farm in their own land is 84.5%, this increases the household returns on investment.

Table 4. 1: Description of Variables used in the Multinomial Logistic Regression Model

Variable	Description	Mean	Std. Dev.
Region	1= If household in East Africa	0.72	.3775063
Sex head	1= If household headed is man	0.643	.453735
Edu head	Years	10.388	.7093129
Size	Arable farm in acres	3.7373	.841117
Ownership	1= Household owned land	0.84512	.5995988
Permanent Job	1= If HH is employed	0.4806	.9745754
Crop system	1 = modern farming	0.8696	2.991803
Labor Agri	1 = If family labor is available	0.510667	.5000529
Quantity	1 = if inputs were available	0.823333	.3815136
Disease Control	1 = if disease and pest control was used	0.447333	1.618942
Risk	1 = if risk is positive	0.632	.5270533
Part time Work	1 = if casuals laborers	0.396667	3.286922
Ex-ed	1= if they access extension services	0.74343	.64747482
Irrigation	1 = if use irrigation	0.87	.3364156
Credit to org	1= if member to credit organization	0.17132	2.353674
Food Sold	1 = if they sell the produce	0.167333	.3733977
Food stored	1 = if store the farm produce	0.5853	.4974545
Value addition	1= if the value addition was done	0.27263	.53637445
Group membership	1 = if member to community groups	0.79266	.4055316
Community Active	1 = if member to co-operative groups	0.85333	.2794703
Markets	Distance to Market (Km)	2.737333	.841117

Sources: Author's own computation, 2021

Very few household (17%) can qualify for credit from the credit organization but since majority 85% are active members of co-operative societies and group membership (79%) they then to utilize this membership for their financial supports an indication of social capital among households. This has been made possible also though since 74% of the household access extension services through various platforms such as field days, farmers' trainings, workshops, agricultural shows, and farm demonstrations.

Few households (16%) sell their produce direct from the farm gates while majority (59%) store their farm produce so as to sell when they have a better market (Table 4.1). 27% of the household practice value addition to their farm produce an indication of small scale farming among the communities. Approximately 51% of the labour in the farms were came from the household members while, 39% from the causals who work as part-time employees. This increased positively the risk of adopting technology by 63% since the drive to succeed is high for household members than the casuals. Concerning the plot characteristics, the mean distance from the nearest market to the farm was 2.8km this encouraged more households to practice farming since they could easily sell their products.

Table 4.2 show the rate of technology adoption of male headed household verses the household headed by a lady. Improved beans variety was the technology highly adopted with 30 percent. Since this was the entry to the joint multiple technology adoption. While garden vegetable techniques were the least adopted at 20.13% due to the fact that a higher level of technology is applied.

Grafted fruit trees and integrated grafted fruit trees were adopted largely by the female-headed house. The female-headed household adopted easily to garden vegetables techniques, this was possible because females are key decision-makers on household leftovers which turned to compost. According to Beran and Millar (1994), the use of manure for compost means less waste and expenses that could not strain the household since most of the female-headed household since most of the female household was a single mother household.

Table 4.2: Comparative Rate of Technology Adoption Based per Household Head

Technologies	Male	Head Female	Total
Improved Beans Variety	342 (76%)	108(24%)	450
Biofortified maize variety	322(78.92%)	86(21.11%)	408
Grafted fruit trees	168(49.41%)	172(50.58%)	340
Garden vegetable techniques	148(49%)	154(51%)	302
Total	**980(65.33%)**	**520 (34.67%)**	**1500**

Sources: Author's own computation, 2021

Grafted fruit trees is a flexible and holistic decision that appears to be made by the household head. Female-headed households adopted this technology more than the male-headed household because it entails the use of predictors of pesticide exposure which was easier for women to accept than these male counterparts (Bos and Koetter, 1990). 51 percent of the female-headed household adopted garden vegetable techniques. According to Von braun *et al.,* (1994) women are more health-conscious than their male counterparts hence to prevent the negative effects of the insecticide on human health and the environment they adopted integrated grafted fruit trees also, to avoid the high cost of insecticide. It was confirmed by Chellieh (1998) that economic characteristics such as capital and labor also affects the female headed household in the decision to adopt integrated rest management since it is not capital and labor-intensive.

Biofortified maize variety was largely adopted by the male-headed household at 78.92%. The technology applied is more scientific and needed high capital to achieve.

Gottlieb (2004) found out that the sustainability of carbon building soil management practices required integration of social components into research particularly from a household perspective which was more favorable for the male-headed household than their female counterparts.

According to Fomby *et al.,* (1984) the male-headed household explored and synthesized the use of social organic carbon practices has potential gradual climate change and boosted climate-smart soil and land management practices hence building healthy soil combined with conservation and restoration. The female-headed household had a low adoption rate on biofortified maize variety at 21.11% due to the broad range of gender interrelated enabling and constraining factors such as factor planning and implementation processes.

Male-headed households had the lowest number of non-educated at 3.76% compared to 16.7% (Table 4.3) for the female headed household. Most of the female-headed households were single mothers with high poverty status. The education level of male-headed households increases access to skilled deliveries, particularly where fees might be incurred because male-headed households had greater control over household finance and resource and can accordingly manage and regulate the seeking of education for their sisters and wives (Anriquez and Stamoulis, 2007).

A household with the tertiary education level that adopted multiple agricultural technologies was low with a percentage (8.38 percent) for male-headed households and 0.86% for the female headed household. This shows that those with a higher level of education preferred working in professional jobs rather than in the farms as put by Ball (1988) that many young people preferred white color jobs in Africa.

Table 4.3: Comparative Analysis of Gender of the Household Head with Education Level

Sex Head	None	Primary	Secondary	Tertiary	Total
Male	43(3.76%)	381(32.63%)	634(54.04%)	97(8.380%)	1155
Female	56(16.7%)	100(28.58%)	186(53.09%)	3(0.86%)	345
Total	**99**	**481**	**820(54.67%)**	**100**	**1500**

Sources: Author's own computation, 2021

Poverty in the female-headed household is not an isolated case as the literature maintains that women make up a disproportionate number of the poor. Koppmair *et al.,* (2017) suggest an increasing proportion of female-headed households with low education levels in developing countries.

The education level of the household headed by females had the lowest percentage (0.86%) on higher education level (Tertiary). Lower access to economic resources reduces women's chances of getting a higher education and the risks of having low education. It is also explained by Leroy and Frongillo (2007) that those households headed by women are linked to the gender gap in East Africa in access to other social shocks or have fewer options for ex-ante and ex-post coping strategies to adopted multiple agricultural technologies. It also explains that households of lone mothers and single women may be more vulnerable to economic shock owing to the obstacle faced by women in accessing higher education levels.

The male-headed households who adopted multiple agricultural technologies and has a secondary education level were 54.04% while their female counterparts were 53.09%. This indicates that the majority of the farmers in East Africa were of average education level. It is compost of a predominant smallholder sub-sector and the relatively small number of large scale (Alston *et al.*, 1998). Supported by the findings of the World Bank (2008) majority of the smallholder farmers in East Africa are household members who could not join the tertiary colleges.

Joint adoption of multiple agricultural technologies led to four combinations of technologies from which the household can choose (Table 4.4). From the analysis the combinations of technologies take the highest best bundle so as to take care of collinearity from lower combinations.

Where, Improved beans variety =1, biofortified maize variety = 2, Grafted fruit trees = 3, garden vegetables techniques = 4.

Therefore, the best joint technologies are; TC1 = Joint Technology of (1,2,4), TC2 = Joint Technology of (1,2,3), TC3 = Joint Technology of (2,3,4), TC4 = Joint Technology of (1,3,4)

Table 4. 4: Descriptive Statistics of the Joint Technology used in Estimations

Variable	Description of joint technology	Mean	Std. Dev.
TC1	1= Joint Improved beans variety, biofortified maize variety, garden vegetables techniques	0.8884	1.071
TC2	1= Joint Improved beans variety, biofortified maize variety, garden vegetable techniques	0.861333	1.20133
TC3	1= Joint of biofortified maize variety, Grafted fruit trees, garden vegetables techniques .	0.8728	1.028
TC4	1= Joint Improved beans variety, Grafted fruit trees, garden vegetables techniques	0.89667	1.6779
IMR	Inverse mills ratio	1.325815	1.605939

Sources: Author's own computation, 2021

As shown in Table 4.4, 88% of the household adopted joint (TC1) Improved beans variety, biofortified maize variety, and garden vegetables techniques combination while those who adopted Joint TC2, TC3, and TC4 were 86 %, 87%, and 89 % respectively. It shows that the rate of adopting the four bundle of technology was almost the same with an average being 87.5% and is explained by the nature of resources that the household utilize.

Table 4.5: Rate of Technology Adoption per Region

Technologies	**Kenya**	**Tanzania**	**Uganda**	**Total**
Improved Beans Variety	132 (23.91%)	216(39.13%)	204(36.95%)	560(37.8%)
Biofortified maize variety	120(28.03%)	172(40.18%)	136(31.77%)	438(29.53%)
Grafted fruit trees	138(51.49%)	60(22.38%)	70(26.11%)	278(18.86%)
Garden vegetable techniques	110(43.65%)	52(20.63%)	90(35.71%)	254(16.8%)
Total	**500**	**500**	**500**	**1500**

Sources: Author's own computation, 2021

Improved bean varieties were the most adopted technology at 37.8 percent (Table 4.5). Apart from this technology being the entry to the adoption of multiply agricultural technologies for this program, they were also provided at subsidies prices (FAO, 2018). Tanzania was the leading adopter of improved beans variety at 39.13 percent, followed by Uganda at 36.95 percent then Kenya at 23.91 percent. Tanzania was leading because they enacted the new seeds act in 2003 with subsequent regulation in 2006 and the plant breeder right act of 2010 that influence change and adoption of the new seed legislation (FAO, 2018).

Grafted fruit trees utilization was highly adopted in Kenya (51.49 percent) followed by Uganda (26.11 percent and then Tanzania at 22.38 percent. In Kenya WHO (2002) stated that farmers using organic fertilizer for crop planting had increased by 56 percent better than the other East African countries as from 2002 the argument supported by Waterlow and Payne (1975) indicating that other Ugandan and Tanzania farmers have for the longest time going about the issue of garden vegetables techniques wrongly, with many collecting animal waste and spreading it on the field immediately.

Biofortified maize variety was adopted the most in Tanzania (40.18 percent). As put by USAID (2017) the project on development of soil carbon map based on datasets in Tanzania which aimed to map the organic carbon content of Tanzania, this made sure Tanzania becomes the first-ever comprehensive soil inventory in East Africa. Integrated Garden vegetable techniques were the least adopted technology in East Africa with a 16.8 percent adoption rate. Kenya had the highest adoption rate at 43.65 percent and Uganda 35 percent while Tanzania was least at 20.06 percent. This is in line with the findings of Wang and Ni (1995) which explains that east Africa has not enhanced both export market access and vegetables handling safety thus a low rate of adoption. The vegetables being perishable it requires intensive capital especially to middle income households in East Africa thus explaining the low rate of adoption of garden vegetable techniques.

Table 4.6: The Rate of Technology Adoption as per the Level of Education

Technologies	**None**	**Primary**	**Secondary**	**Tertiary**	**Total**
Improved Beans Variety	30(5.12%)	178(30.37%)	320(54.60%)	58(9.89%)	586
Biofortified Maize Variety	32(7.44%)	146(33.95%)	224(52.09%)	28(6.51%)	430
Grafted Fruit Trees	20(7.09%)	98(34.75%)	156(55.31%)	8(2.28%)	282
Garden Vegetable Techniques	17(8.41%)	59(29.20%)	120(59.40%)	6(2.97%)	202
Total	**99**	**481**	**820**	**100**	**1500**

Sources: Author's own computation, 2021

Table 4.6 shows that the household headed by a member with no education had the least adoption rate of improved bean variety at 5.12 percent, with a household headed by a secondary school leaver leading in the adoption of improved beans variety at 54.6%. Smith and Blundell (1986) in their study supported the idea that lack of education brings upon lack of adequate information about technologies, and price risks, and therefore low adoption rate to these technologies. Johnson *et.al.,* (2015) found out that many secondary school leavers in East Africa would access the internet and are mostly active in training and hence their perceived attributes of innovation that then to increase their percentage difference on the rate of adoption of technology. Results from table 4.6 also noted that households headed by the secondary school leaver were leading adopters of the four technologies implemented by 52.09% in biofortified maize variety, 55.31% in grafted fruit trees, and 59.4% in garden vegetables techniques. Abdulas and Regmi (2000) emphasized that secondary school leavers are easily reachable and generally have a high interest in farming. This enhances the understanding of instruction given and also improves the farmer's level of participation in agricultural activities. According to Beck *et al.,* (2007), this is so because of the training they attended and they are pro-active which enables them to access information needed to decide to use innovation and practices new technology. It also increases their managerial competence and therefore enhances their ability to diagnose, assess, comprehend, and respond to financial and production problems especially in integrated grafted fruit trees (Chang'al, 2009). It was also noted that most of the secondary school leavers were members of co-operative societies, focus group discussion, and opinion leaders in the society, this boost their technologies adoption rate. Malapilt *et al.,* (2013) in their assessment of farmers' knowledge on garden vegetables techniques indicate that about 50 percent of farmers in East Africa utilize garden vegetables techniques since it has been an old technology and the materials were readily available.

A household headed by a member with tertiary education had a low adoption rate to all the technologies with improved beans variety at 9.8 percent, biofortified maize variety at 6.5 percent, grafted fruits trees at 2.28 percent, and garden vegetables techniques at 2.97 percent. These results are supported by Magnus (1982) that primary school leavers are trained through hands-on experience in East Africa and are not required to have a college degree.

It was found out that household headed by a member with tertiary education was doing commercial farming instead of subsistence farming thus it was easier to use chemicals to control. They also utilize inorganic fertilizers from agro vet instead of practicing garden vegetables techniques. Cunia and Briggs (1984) mention that large farms are owned by the learned and wealthy cannot be considered linear replicas of small ones. Incentives to use inputs vary with production scale that is large farms use different technologies than small farms thus the use of garden vegetables techniques and integrated grafted fruit trees was low at 2.97% and 2.28% respectively because it could not fit large scale farming practice by the household headed by members with tertiary education. In agreement WHO (2002), found out that associates and bachelor's degree graduates in agricultural courses took up farming as their careers. This finding is in agreement with Avery (1977) that the relationship between the level of farmers' education with the agricultural course was positive, continuous, and significant. A similar result was also supported by Cheng *et al.,* (2013) on their agricultural input results.

4.2.2 Correlation Analysis

Table 4.7 shows the result of the correlation analysis between the nutrition outcome of stunting (HAZ), underweight (WAZ) and wasting (WHZ) and the joint technology adoption of TC1, TC2, TC3 and TC4.

Table 4. 7: Correlation Analysis of Nutrition Outcome and Joint Technology

	HAZ	WAZ	WHZ
TC1	-0.0338	- 0.0415	-0.0361
TC2	-0.0002	-0.0232	-0.0057
TC3	-0.0591	-0.0990	-0.0779
TC4	-0.0447	-0.0120	-0.0337

Sources: Author's own computation, 2021

Joint agriculture technology affects health and nutrition in tangible ways. It is a source of energy and nutrients and increased agricultural productivity leads to better nutrition. The result shows a general negative and low association between joint technologies TC1, TC2, TC3, and TC4 and the nutrition outcome of stunting, wasting, and underweight.

These findings are supported by Baltagi, (2011) that indicators of the level of agricultural technology adoption have a strong and significant negative association with indicators of nutrition outcome among households, a result suggesting that increment of agricultural technology adoption can be a powerful tool to reduce malnutrition across the vast majority of the population in East Africa.

Table 4.8 shows the pairwise comparisons results of means with equal variances determined by the highest-level interaction of the variables specified in the pairwise comparisons results of means (pwmean) WAZ WHZ HAZ, over (technology bundle, education of household head, and gender). The results show that there is a significant difference in the means for non-adopters' household with education background and household headed by women to underweight, wasting and stunting with evidence of mean of 5.845, 5.355, and 5.956 respectively.

Table 4.8: Pairwise Comparisons of Means Results by treatments on Nutrition Outcome

Treatment	(1) WAZ	(2) WHZ	(3) HAZ
0bn.Utech#1bn.educhhd#1bn.sexhead	-5.845***	-5.355***	-5.956***
	(0.201)	(0.275)	(0.460)
0bn.Utech#1bn.educhhd#2.sexhead	-3.139***	-3.587***	-3.645***
	(0.348)	(0.0924)	(0.154)
0bn.Utech#2.educhhd#1bn.sexhead	-2.727***	-2.613***	-2.100***
	(0.0674)	(0.127)	(0.213)
0bn.Utech#2.educhhd#2.sexhead	-1.375***	-1.076***	-1.803***
	(0.151)	(0.249)	(0.416)
0bn.Utech#4.educhhd#1bn.sexhead	0.0308	-0.0168	-0.00713
	(0.0462)	(0.0891)	(0.149)
0bn.Utech#4.educhhd#2.sexhead	-0.0392	0.000440	0.0271
	(0.0953)	(0.0351)	(0.0586)
1.bn.Utech#4.educhhd#1,2.sexhead	0	0	0
	(0)	(0)	(0)

Sources: Author's own computation, 2021

Household which did not adopt multiple agricultural technologies and headed by male with no education background had a significant mean difference to WAZ, WHZ, and HAZ at 3.139, 3.587, and 3.355 respectively. Both the household headed by male and female but did not adopt technology and their highest education level as primary school showed significant difference in the means to WAZ, WHZ, and HAZ. Results show that both the household headed by male and female with tertiary education level though did not adopt the multiple technologies had no significance means difference with the highest interaction to WAZ, WHZ, and HAZ.

4.3 Empirical Results and Discussion

4.3.1 Factors affecting the adoption of Multiple Agricultural Technologies

Multinomial logit regression results for factors influencing the adaption of joint MATs are presented in Table 4.9. There were four major joint multiple technologies that were adopted by households in East Africa for the production of the crop that are;

improved beans variety, grafted fruit trees, biofortified maize variety, and use of garden vegetables techniques. At every point in time, the household made a choice of three best joint technologies to implement with a base of “no technology”, this was informed by the multinomial logit model which runs the highest combinations of the technology in a household. The combinations with less than three joint technologies were analyzed however the results were not presented because it detected the issue of collinearity thus omitting some technologies the findings which supports the work of Kassie (2018). The best joint technologies are;

TC = base with no technology used, TC1 = Joint Technology of (1,2,4), TC2 = Joint Technology of (1,2,3), TC3 = Joint Technology of (2,3,4), TC4 = Joint Technology of (1,3,4). Where, Improved beans variety =1, biofortified maize variety = 2, garden vegetable techniques= 3, grafted fruit trees = 4.

The only factor that affects the probability of adoption of the four joint multiple agricultural technology combinations apart from education level was the regional diffusion of technology in comparison to base category. A household located in the East Africa region increases the chances of adopting the four joint technology innovation by TC1 (21%), TC2 (31%), TC3 (30%), and TC4 (23%). This supports the work of Alcacer *et al.,* (2018) that regional locations diffuse certain modern technology faster if it would be congruent with the regional user behavior. This indicates that the growth of improved crop using the biofortified maize variety and garden vegetables techniques was adopted in the three East African countries of Uganda, Kenya, and Tanzania. The factors that influenced the adoption of a combination of three joint technologies were the education level of the household head, the general participation in community meetings, and barazas and diseases that cause problems. Given region there may be a variety of economic and political factors with different relevant agronomic characteristics that might be specific in adopting technologies. It supports the work of Messet *et al.,* (2012) that the probability of adoption of technology depends on the critical mass knowledge in agriculture within the country.

Table 4.9: Multinomial Logistic Regression for Factors Influencing the Joint Technology Adoption.

Variable	TC1	TC2	TC3	TC4
Region	.2146***	.31661***	.292928***	.23959***
Sex head	.6140266	.2391623	.1011699	.224311***
Edu head	.452735***	.444651***	.25488***	.358028***
Size	.07031	-.0070594	-.0151722	.144211***
Ownership	.5515478	.2680692***	.0227853	.0198754
Permanent Job	.59324	-.0207033	.4497901**	.2899868
Crop system	.8802955	-.1394908	-.1223626	.2748402***
Labor Agri	.289384***	.1498006	-.0260566	.2251113
Quantity	-.2885715**	-.18956**	-.0022094	-.0014606
Disease Control	.1985906**	.2323897***	.2800733***	.1956313
Risk	.0145512	.0018817	.11922***	-.020856
Part time Work	.2135629	-.0357523	-.0404361	-.418365***
Ex-services	.302435***	-.1842981	-.4378921	-.0509544
Irrigation	.62464	.3188364**	.4767842***	.2883762
Credit to org	.3431908	-.233378	-.1264379	.3182167**
Food Sold	.5596567	.0307152	-.1958371	-.3637021
Food stored	.5512521	.1513067	.3568699**	.3302557
Value addition	-.1649092	.4314859***	.3578355	-.0592925
Group membership	.526215**	-.4747665	.1956892	.2662125
Community Active	.14522***	.189402**	.1632703**	.1114577
Markets	-.32094**	-.2355264**	-.4138172**	-.151446**
Observations		3,877		

Sources: Author's own computation, 2021

Standard errors in parentheses. No TC as the reference category

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Variable description:

Region: Countries of Kenya, Uganda, and Tanzania

Sex head: The gender of the household head

Edu head: Years of schooling of the household head

Size: Land size of the household

Ownership: If the household own the land

Permanent job: If household member has a permanent job

Crop system: Household practicing modern crop farming

Labor Agri: Available family labor

Quantity: The amount of inputs available for households per season

Disease Control: Household management to control pest and disease

Risk: Risk perception and risk attitude of the household

Part time work: Part time workers in the household

Ex-services: Extension services offered

Irrigation: If the household utilized irrigation

Credit to org: Household obtain credit from organization

Food Sold: Household sold extra food produced

Food stored: Household stored food in anticipation of dry season and better prices

Value addition: Household did value addition of their products

Group membership: Household member being organized community groups

Community Active: Household members participating in community meetings

Markets: Distant of the household to the markets

The level of education of the household head has positive effects on the probability of adoption of TC1, TC2, TC4, and TC3. A year increase of the education of household head increases the adoption of TC1 (45%), TC2 (44%), TC3 (25%), and TC4 (35%). Education level of household head has a high probability of adopting new technologies for a high level of education than those with a lower education level. The marginal effect of education on technology adoption is significantly larger and expectedly positive for improved bean crops as the level of education rise especially on the making of garden vegetables techniques. Hendrickson (1995) found out that there is a positive correlation between the level of education and the rate of using intergraded pest control. The household in east Africa with a higher level of education than to be innovative in doing integrated grafted fruit trees and garden vegetables techniques than with households with a lower level of education. There is a positive relationship between education and the adoption of new technology.

Elias (2013) indicated that the years of schooling and score in a numeracy test of the household head were key variables in the ability of farmers to acquire information and adopting new technology. Fertilizer adoption is influenced more by institutional and educational factors than by economic ones. Also, education is positively and significantly related to the use of improved bean varieties but not significantly related to the probability of adopting improved crop. The adoption of chemical fertilizer is positively correlated with the number of school years of the head of households with a secondary school education adopted soil and water conservation measures as compared to that of heads with no formal education. The model developed by Fleming *et al.,* (2014) shows that the educational level of other adult household members has an impact on fertilizer adoption than the household head level of education. Educated people perform their work and functions with higher efficiency and thus, adopt new technologies faster. Adoption studies have emphasized education as an important explanatory factor in household decision-making. It can be concluded that the accumulation of knowledge via education is an important factor for economic development.

An increase in the distance to the nearest market is associated with less likelihood of adopting all the four technology combinations. The results further indicate that 1 km increase in the distance to markets the household adoption of TC1, TC2, TC3, and

TC4 likely reduces by 32%, 23%, 41%, and 15% respectively. These findings resonate with some researches who found that excessive distance to markets negatively impact on adoption of technology such as inputs. The household who had distance constraining them will thus end up using low yielding unimproved and retained seeds. An increase in distance to output market means access to market is inconvenient, the household then to have post-harvest loss and thus reducing the nutritional content of their produce. When a household member participates in group markets like buying improved crop and equipment for preparing garden vegetables techniques there is a positive adopting joint technology since they will make informed decisions. Singh *et al.,* (2016) explain that markets and externalists could be major barriers to technology adoption but these inefficiencies can be overcome through farmers' groups which are key to boosting agricultural information dissemination knowledge of markets and pricing as a result it increases the adoption of technologies and improved yields.

Results show that the adoption of disease control methods is positively related to TC1, TC2, and TC3. A season management of diseases and pest by the household leads to adoption of TC1 (19%), TC2 (23%), and TC3 (28%). Availability of diseases outbreaks management leads to households adopting improved beans variety, garden vegetables techniques, and integrated grafted fruit trees so as to control these problems. Technology adoption is essential in disease control in that high susceptibility of logical landraces to pests and diseases on improved beans variety among smallholder farmers encouraged them to adopt the integrated grafted fruit trees methods.

Household member participation in community meetings and barazas positively increases the adoption of TC1, TC2, and TC3 by 14%, 19% and 16% respectively. This indicates that the drives of the community and the leaders of society have helped to push down the idea of community empowerment through technology thus the members than to follow their lead. Household members who participate in the meetings then to benefit from improved beans variety distributed in the meetings and the various lessons of making garden vegetables techniques. Community meetings the information on technology, especially on biofortified maize variety and garden vegetable techniques, is freely shared leading to trust and confidence in the adoption of this technology by members. The meetings also facilitate the networking and learning process since the members than to have a more direct role in both initiating and design of the technology implementation (Mayne and Stern, 2013).

A positive and significant effect of membership to any group or organization on TC1 indicates that the household increased the adoption by 52% and organizations are mainly on the farmer's sanitization programs and community developments on the importance and use of improved beans variety and garden vegetable techniques. Ehlers in his study (2010) concluded that extension access and organizational membership have a strong effect on the use of biofortified maize variety and garden vegetables techniques on planting improved crop in that the membership in local groups and organizations attitude towards the technology is advance affected. Results also show that household whose member's participated in general community meetings had a positive significant impact on joint TC3 by 52%, hence indicate that community network ties are generally consequential because friends and members are often viewed as convenient and trustworthy sources of information thus teaches and encourages the participants on the utilization of soil garden vegetables techniques and integrated grafted fruit trees on the production of improved beans variety. When a household member has membership in any savings or credit organization the probability of adopting technology combination TC4 is more likely at 31%. This will help the household with funds to buy improved beans variety and implement integrated grafted fruit trees since they will not have financial constraints.

A positive and significant effect of family labor on TC1 indicates that when a household member is involved in farm labor the adoption of improved beans variety, biofortified maize variety, and garden vegetables techniques is more likely to increase by 29%. Becker, (2002) explains that this is fundamental to the advancement of the agricultural industry, labor savings, and household members could provide the leadership from within the adoption and raise the standards of influence on the adoption especially on garden vegetables techniques and biofortified maize variety. It supports the conclusion of Sadoulet and Janvry (1995) that shortages of family labor have been used to explain the non-adoption of technology in Africa; meanwhile, the higher rural labor supply has been associated with greater levels of adoption of labor-intensive rice varieties in Taiwan. Additionally, hired labor positively affects TC1. Professional labor could ensure the right procedure and utilization of garden vegetables techniques and biofortified maize variety and the right variety of the improved crop. The skill upgrading and the adoption of technologies have altered the production and sufficient diffusion of multiple technologies in rural households.

However, technology generally requires more labor inputs, and so labor shortages may prevent adoption. Labor availability is often mentioned as a variable affecting farmers' decisions of adopting new agricultural practices or inputs. Some new technologies are relatively labor-saving, while others are labor-intensive. A serious shortage of labor will motivate landowners to adopt new technologies. When local labor markets are functioning properly, farmers can hire labour as needed. When these markets are not functional, households must supply their own labour for farm activities, and so they may choose not to adopt technologies that would require more labour at any specific time than the household can provide. Therefore, a farm household with a large number of active members is more likely to be in a position to test and then adopt potentially profitable new technology.

Results also shows that a household with a permanently employed member is positively significant to the adoption of TC3 hence when a member of the household gets a permanent job they will increase the chances of adopting joint TC3 by 45%. Zellner (1962) using the endogenous treatment effect model to account for selection bias on household technology adoption decision found out that permanent employment to a member of a house had a positive and significant effect on the use of biofortified maize variety and garden vegetable techniques. Employment choices and opportunities have changed the way households regard technological innovations and their adoption.

Whereas, part-time labor was found to have negative and significant impact on the adoption of TC4 (42%), this means that when household employ farm causals on part time basis the adoption of technology combination TC4 reduces by 42% since part-time workers in the farm does not give the household a chance to take total control of their technology adoption especially the garden vegetable techniques. The adoption rates of improved beans variety are low and the implementation of joint technologies remains poor since the household has less time to implement innovations (Wickramasinghe *et al.*, 2013).

Adoption of TC1 and TC2 is negatively related to the quantity of crop variety planted per season by 29% and 19% respectively. The adoption of technologies at the farm level is more on the quality than the quantity. The quantity can be an obstacle that prevents the uptake of technology of soil carbon and garden vegetables techniques since the increase of the improved crop should be accompanied by the increase in the other two technology combinations. Moreso, the more the quantity of crop planted the less adoption of joint improved crop, biofortified maize variety, and garden vegetable techniques. You *et al.,* (2005) explains that when a household increases the quantity of crops planted there should also be a significant increase in farming size to accommodate better technology otherwise it will have a negative impact.

The land ownership is positively significant affecting households who adopt the joint TC2 technology by 27% since it's been hypothesized that the land ownership encourages agricultural technology adoption especially biofortified maize variety and garden vegetable techniques. The biofortified maize variety technology has a profound impact on land ownership with a print title since the household than to make long term decision. Many empirical studies have focused on the link between land ownership and access to credit, as ownership of land is often thought to be a prerequisite for obtaining credit Malapit and Quisumbig (2014) have established the difference in economic performance between titled and untitled farmers. Per unit of used land, titled farmers invest more inland, use more inputs, and generate higher levels of output than untitled farmers. It is generally held that tenants of farmland are less likely to invest in conservation practices and households with borrowed and rented land do not apply any measures to their fields. However, tenants are more likely to use conservation tillage than full owners. Land ownership increases the likelihood of using soil protection measures in general and that land security is positively and significantly associated with hedgerow adoption in particular. Kennedy (1985) has shown that investment in water supply for maize production is influenced by the deeds of land tenure in western Africa. Land registration enhances tenure security and land titles improve economic performance mostly by facilitating access to institutional credit. Furthermore, insecurity of land tenure increases the risks for farmers and, may decrease their adoption of new technologies.

Land size positively affects the adoption of joint TC4(14%) it confirms that slowing growth rates on-farm technology adoption especially integrated grafted fruit trees and improved variety are coupled by limited lands. It brings farm inefficiencies and economic constant therefore it concluded that the size of the plot cultivated by the household is positively significant to joint adoption of technologies. Empirical studies have consistently provided that farm size represented by land area then to be significantly related to the adoption of multiple joint technologies. A small farm size impedes the efficient use of improved crop and the adoption of garden vegetables techniques. Kluve *et al.,* (2012) have illustrated that farm size significantly and positively influence the adoption of improved beans variety in a study conducted in Kenya. There is a positive relationship between the adoption of multiple technologies and farm size in southern Uganda. Though, there is a limit to the positive relationship between farm size and joint technology adoption. The adoption of grafted fruit trees and garden vegetables techniques on farms in Tanzania increased with farm size up to one hectare, then the size was no longer significant.

The results show that irrigation whether by traditional means or modern means positively enhances the adoption of TC1(31%) and TC2(47%). The implications of irrigations have the essence of biofortified maize variety technology thus conserving water for improved beans variety. The widespread irrigation of low-water volume reduces the biofortified maize variety and lessens the expenses of grafted fruit trees hence encouraging households to adopt the joint technology.

The household decision to store crop before selling in order to fetch higher prices had a positive significant influence on the adoption of joint TC3 (35%) as the integrated grafted fruit trees technology helps households to store their improved beans variety for a long time without being destroyed by pest and diseases.

Value addition on the processing of the crop is positively significant on joint TC2 indicating that households were willing to adopt the technology by 43% due to the idea of value addition. The household could increase the use of garden vegetables techniques, Improved beans variety, and biofortified maize variety since they knew they could do value addition of their products hence earning bigger and better income and nutritional value. Nayga (2000) explains that the value addition has a strong effect on household adoption of technologies because the decision goes beyond the food consumption to the impact in the nutrition of the household that results from the food they produced and process.

Risk perception and risk attitude are positively significant to the adoption of TC3 (11%) technology hence averting risks that to leads the decision-maker to diversify to reduce income risk, especially in the absence of economies of scale. Bodhlyera *et al.*, (2014) found a positive but non-significant effect of averting risk for Tanzania farmers concerning the adoption of grafted fruit trees and manure technology. Risks are mostly involved in joint technology being introduced then to be more uncertain with multiple technologies. Risk perception is an endogenous factor, so the implications of risk in terms of farmer decisions then to change if the attitude, perceptions, and influence of farmers change. Attitude and perceptions of risk related to multiple technologies diminish over time through the acquisition of interest, experience, and information.

There is a significant and positive relationship for a household headed by a man in adopting the joint technology TC4 faster than a household headed by a woman by 22%. In East Africa, the fundamental role for production and access to an improved variety and technological innovations are edged for a man. More so, technologies like biofortified maize variety and garden vegetables techniques preparation are not designed considering women's needs and conditions.

Crop cropping system is positively significant to the adoption of joint technology TC4 hence the change of cropping system by the household from the traditional to modern methods increase by 27% the chances adoption of joint TC4. Parks (2014) explains that improved crop change has been the basis for increasing agricultural productivity and promoting a new farming system by generating integrated grafted fruit trees technologies that are appropriate for farmer's circumstances.

Analyzing the results revealed that the frequency of contact with extension services increases the likelihood of technology bundle TC1 adoption. Household who receives the extension services is likely to increase the adoption of TC1 by 30%. This is explained by the fact that most household got the opportunity to practice improved beans variety, biofortified maize variety, and garden vegetable techniques in their home gardens hence more convenient.

4.3.2 Impact of Joint Multiple Agricultural Technology on Nutrition Outcome

Table 4.10 presents the result of the multinomial endogenous switching regression relationship between the nutrition outcome variables in terms of stunting (HAZ), underweight (WAZ), and wasting (WHZ) and the joint agricultural multiple technology adoption of TC1, TC2, TC3, and TC4 as a set of explanatory variables with IMRs as additional covariates in order to account for selection bias from time-varying unobserved heterogeneity.

The joint agricultural technologies TC1, TC2, TC3, and TC4 (improved beans variety, biofortified maize variety, grafted fruit trees and garden vegetables techniques) was found to have a negative significant relationship to stunting (HAZ), wasting (WHZ) and underweight (WAZ) Table 4.10.

With a one percent increase in the adoption of joint TC1, the prevalence of stunting reduces by 17.4%, wasting 15.4%, and underweight by 16.8%. The reduction of stunting, wasting, and underweight is a sign of better nutritional outcome. The utilization of dietary diversity due to the variety of the improved crop explained by Chang'al (2009) has a major implication for the reduction of stunting for rural households. Applying the biofortified maize variety on crop production had a greater impact on household wasting as per the studies of Behrman and Deolalikar (1988) supported by the findings of Hamshire *et al.*, (2009) that biofortified maize variety plays a very important role in reducing stunting through strengthening food value chains that aim to improve the availability of nutrients components.

Gottleib (2004) also pointed out that using garden vegetable techniques in crop production are sources of plant nutrients hence supply the basic food nutrients that improve underweight in the household through adequate dietary intake. According to

Gragnolati and Marini (2003), commercial fertilizers supply all the basic nutrients that crop need to thrive but Kim et al., (2011) reported that an increase in bean's nutrients yield is because of the use of garden vegetables techniques rather than commercial fertilizer. This was also enhanced by Krebs-Smith (1996) that the total fresh weight results from crop produced using garden vegetables techniques had a positive impact on household wasting and stunting status. Therefore, joint TC1 improved nutrition outcomes.

Table 4.10: Multinomial Endogenous Switching Regression results of technology combination adopted on Nutrition Outcome

VARIABLES	(1) HAZ	(2) WHZ	(3) WAZ
TC1	-0.174***	-0.154***	-0.168***
	(0.0564)	(0.0417)	(0.0404)
TC2	0.0920	-0.144**	-0.151***
	(0.0769)	(0.0569)	(0.0551)
TC4	-0.156***	-0.0807*	0.0625
	(0.0563)	(0.0417)	(0.0403)
TC3	-0.258***	-0.241***	-0.253***
	(0.0552)	(0.0408)	(0.0395)
Kenya (reference)			
Uganda	-0.1283***	- 0.1643***	- 0.1785***
	(0.28)	(0.18)	(0.16)
Tanzania	- 0.1555***	- 0.148***	- 0.1398***
	(0.18)	(0.84)	(0.11)
IMR	0.0278	0.0246	0.0315
	(0.0281)	(0.0208)	(0.0201)
Constant	0.373***	0.818***	0.633***
	(0.0768)	(0.0569)	(0.0550)
Observations	1,490	1,490	1,490
R-squared	0.424	0.412	0.433

Sources: Author’s own computation, 2021

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

The household that adopted the joint multiple agricultural technologies TC2 had a negative significant impact on wasting with the coefficient of 0.144 and underweight coefficient of 0.151. A one percent increase in the adoption of joint improved crop, biofortified maize variety, and integrated grafted fruit trees technology leads to a

14.4% percent reduction of wasting and a 15.1% reduction in the underweight prevalence.

Cooley and Prescott (1973) underline that grafted fruit trees is an ecosystem approach that combines different management strategies and practices to produce healthy crop and minimize the use of pesticides. Thus, EHNRI (2000) stated that with the joint agricultural technology these healthy crops are produced then to address the nutrients deficiency and household wasting. While Gragnolita and Marini (2003) explained that iron-bio fortified crop reduce the underweight as that the household health is so integral for their own wellbeing as well as their agricultural activities. Johnson *et al.,* (2015) explain that cover crops improve soil quality through increasing biomass by improving soil aggregates and stability. Similarly, green manuring increases the biomass returned to the soil thus enhancing improved crop production with high nutrient content to managed stunting.

Krebs-Smith *et al.,* (1995) noted that improved beans variety improves in complementary technology like biofortified maize variety thus decreases the burden of underweight. Malapi *et al.,* (2013) concluded in their findings that the high iron crop also known as Nyota variety grown in Kenya are a sustainable solution to tackling wasting. The combination of biofortified maize variety and integrated grafted fruit trees on the production of improved variety ensured the control of wasting and underweight (Nisbett *et al.,* 2014).

The households which adopted the joint multiple agricultural technology TC3 negatively affected stunting at coefficient 0.258, Wasting at 0.241, and underweight at 0.253. A one percent increase in the adoption of joint TC3 leads to a 25.8% decrease in the household stunting Z-scores. The use of grafted fruit trees utilizes biological control rather than chemical thus making it sustainable and resistant to disease control in crops without losing the nutrients value (Alderman, 1987). Therefore, being reach in nutrients value Bouis and Haddad (1990) explain how it improves house stunting in terms of diets, quality, and quantity through important vitamins and minerals linked to growth, development, and immune function. This is supported by Cuniana and Briggs (1984) emphasizing policies especially on biofortified maize variety which aimed at accelerating crops development which is generally effective at reducing underweight. With a 1% increase in the adoption of joint TC3 agricultural technology especially garden vegetables techniques, the household reduce the wasting Z-scores by 24.1% holding the other factors constant. Ehlers (2010) in his study concluded that there was an increase in foliar diseases after they stopped using composted manures and a decrease in the vegetable yield due to the less nitrogen and phosphorus nutrients which was filtered from compost. Poor access to good vegetable yields and particularly healthy foods contributes to wasting (EHNRI, 2000). WHO (2002) stated that vegetable field through garden vegetables techniques can both directly compromised diets and indirectly impacts on food production of a household which causes the household malnutrition on wasting Z-scores.

The joint agricultural multiple technology adoption TC4 was found to significantly affecting stunting and wasting negatively with coefficients of 0.156 and 0.807 respectively. TC4 was the joint combination of using garden vegetables techniques and integrated grafted fruit trees on improved beans variety. Increasing the adoption of joint TC4 by one percent the household stunting will reduce by 15.6% Z-scores holding the other factors constant. Adopting joint TC4 by 1% will improve nutrition outcomes by reducing wasting by 8.07% holding the other factors constant.

West (2000) explains that though it may appear to be a paradox, multiple agricultural productions through technology are often associated with underweight, stunting, and wasting. The higher cost of nutritious foods, the hardship of living with food insecurity, and the adoption of food scarcity in East Africa have a higher risk of nutrition deficiency.

Stanek and Koch (1985) confirm that one way of reducing stunting would be to improve the crops through the breeding of new varieties that have better yields and nutrient content. Crop bio-fortification of different varieties as explained by EHNRI (2000) offers sustainable and increased morbidity especially improved beans variety thus impaired development of underweight, wasting, and stunted household. Drichoutis *et al.,* (2006) proposed to deal with the issue through the promotion of improved biofortified maize variety practices which then enhance stunting.

Furthermore, the impact on nutrition outcome (i.e. WAZ, WHZ, and HAZ) was found to vary across East Africa. Countries included in the model are found to be highly statistically significant for both Uganda and Tanzania (the reference point is Kenya). The coefficient for Tanzania and Uganda for HAZ, WHZ, and WAZ has a negative sign and are statistically significant. These indicates that household in Tanzania and Uganda had significant mean difference in adopting the joint multiple agricultural technologies. It shows that households in Kenya had a significant higher propensity of adopting multiple agricultural technologies hence higher impact on nutrition outcome than Uganda by HAZ (12.83%), WHZ (16.43%), WAZ (17.85%) and Tanzania by HAZ (15.55%), WHZ (14.8%), WAZ (13.98%). At 1% increase in the adoption of joint multiple technology in Uganda and Tanzania the HAZ prevalence in Kenya will reduce by 12.8% and 15.55 % more than Uganda and Tanzania respectively. This indicates that there are ecological differences between the three countries and technology research and extension uptake in Kenya is high. This is supported by the report of World Bank (2016) that Kenya absorbs up to 60% of the digital technology in Agriculture than their East Africa counterparts.

4.3.3 Average Expected Treatment Effects

To investigate the overall (mean) impacts of adoption on child nutrition outcomes, the multi-endogenous treatment effects (METE) model as described in equation (6) was estimated for possible pathways that joint multiple agricultural technology adoption affects child nutrition in East Africa.

According to Beegle, *et al.*, 2012, the nutritional status of a child is usually measured with three indicators: weight-for-age z-score (WAZ), height-for-age z-score (HAZ), and weight-for-height z-score (WHZ). All of these indicators measure nutritional status in the form of z-scores derived by comparing a child's weight-for-age, height-for-age, and weight-for-height, respectively, with that of a reference population of well-nourished children. A child is considered underweight if his/her WAZ is below -2, stunted if his/her HAZ is below -2, and wasted if his/her WHZ is below -2 (Berhan, 1988).

Table 4.11 presents the expected nutrition outcome (i.e HAZ, WAZ, and WHZ) under actual and counterfactual conditions in East Africa. The predicted nutrition outcomes per household from endogenous switching regression model are used to examine the mean nutrition outcome gap between adopters and had they not adopted the joint multiple agricultural technology. Results represent the expected nutrition outcome per household observed in the sample. The expected nutritional outcome per household that adopted MATs is higher than the group of households that did not adopt. Based on this simple comparison it can be misleading to attribute the different level of observed nutrition outcome to adoption of joint multiple agricultural technologies.

The results from switching regression confirms that the adoption of joint multiple agricultural technologies has a positive and significant impact on log nutrition outcome. Treatment effect in this unit is presented as percentage difference. Actually, when the outcome variable is log-transformed, multiplying the ATT by 100 is an approximation and it's near enough only for difference < 0.05 (5%). The exact percentage difference is given by $100(e^{ATT} – 1)$, where e is the exponential e and ATT is the average treatment effect provided by the analysis of the log-transformed variable.

Table 4.11: Multinomial Endogenous Treatment Effects of Technology Adoption on Nutrition outcome.

	HAZ		WAZ		WHZ	
	Adopters	Non Adopters	Adopters	Non Adopters	Adopters	Non Adopters
TC1	-0.71***	0.28***	-0.63***	0.11***	-0.61***	0.26***
TC2	-0.62***	0.13***	-0.72***	0.21***	-0.74***	0.18***
TC3	-0.68***	0.25***	-0.67***	0.24***	-0.60***	0.14***
TC4	-0.73***	0.17***	-0.72***	0.26***	-0.78***	0.25***

Sources: Author's own computation, 2021

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

It is clearly shown that the treatment effect for HAZ, WAZ, and WHZ per households that adopted TC1 is log 0.71, 0.63, and 0.61 respectively. Household that adopted TC1 improved the HAZ by 103%, WAZ by 87%, and WHZ by 84%. When non-adopters had adopted TC1, their HAZ, WAZ, and WHZ would have been improved by 32%, 11%, and 29% respectively. The households that adopted the multiple agricultural technology practices improved their underweight status. Joint multiple agricultural technologies adoption shows a negative sign but significant impact since it lowers WAZ. For every technology combination adopted, the household status improved.

The treatment effects for nutrition outcome per joint multiple agricultural technologies TC2 adopters is 0.62, 0.72, and 0.74 respectively and for non-adopters is 0.13, 0.21, and 0.18 respectively for HAZ, WAZ, and WHZ. TC2 adoption reduced the number of stunted children by 85% improved the underweight by 105%, and reduce the wasting by 109%. When non-adopters had adopted TC2, the stunting status could have been improved by 14%, underweight by 23%, and wasting by 20%.

Results shown that the treatment effect for adopting TC3 for HAZ, WAZ, and WHZ is 0.68, 0.67, and 0.60 and for non-adopters is 0.25, 0.24, and 0.14 respectively. The adoption of TC3 reduced household stunting by 97%, wasting by 95%, and underweight by 82%. When non-adopters had adopted TC3, the stunting could have been improved by 28% while wasting and underweight would have been improved by 27% and 15% respectively.

The treatment effects for nutrition outcome per joint multiple agricultural technologies TC4 adopters is 0.73, 0.72, and 0.78 respectively. For non-adopters is 0.17, 0.26, and 0.25 respectively. TC4 adoption improved the household stunting status by 107%, underweight by 105%, and wasting by 118%. When non-adopters had adopted TC4, their nutrition status would have been improved by 18% for stunting, 30% for underweight, and 28% for wasting.

These results imply that adoption of joint multiple agricultural technologies improved the household nutrition outcome measured by HAZ, WAZ, and WHZ; that is the effect is bigger for the household that did adopt with respect to those that did not adopt. It shows that the households that adopted the joint multiple agricultural technologies improved their stunting, underweight, and wasting prevalence. Households which did not adopt the joint multiple agricultural technologies had an increase in stunting, underweight, and wasting prevalence.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the study findings, presents a conclusion, and makes policy recommendations. Section 5.2 gives all key findings, conclusions in section 5.3 and recommendations in 5.4

5.2 Summary of the Study Findings

This study uses panel data to model the factors that influence the East Africa household in adapting joint multiple agricultural technologies using the Multinomial Logit Model.

From the findings of objective one shows that only regional geographical location affected the farmers' decision to adopt the four joint technologies. In particular, the household from the region of Kenya, Uganda, and Tanzania had a significant effect on the joint technology thus agreeing with the study of Kaasie (2018) that there has been an increase in farm system reliance in East Africa through the wide adoption of smart agricultural practices than other regions in Africa. The combinations with less than three joint technologies were analyzed however the results were not presented because it detected the issue of collinearity thus omitting some technologies the findings which supports the work of Kassie (2018).

The empirical results have demonstrated that the factors that significantly affected the joint technology TC1 were: Regional diffusion of technology, a household member who did agricultural labor on the farm, the crop quantity planted at the given season, diseases that causes problems, the household hired labor, and the general participation in community meetings and barazas.

Just like the findings of the world bank (2005) the study also indicated a positive and significant influence of region, education level of household head, land ownership, quality of crop planted per season, control of diseases that caused problems to crop production, irrigation of crop crops, value addition and the processing of crop, household members who participate in general community meetings and workshops on joint technology TC2.

The significant influence to the adoption of joint technology TC3 was: regional diffusion of joint technology, education level of the household head, family members with permanent jobs, the disease that cause problems to the household products, the household which used irrigation, household who stored produce before selling in order to fetch higher prices and general participation in community meetings and the household members involved in group marketing. Therefore, it is important to focus on the policies that promote technology utilization on the farm.

The results further show that the adoption of joint technology TC4 is: Region typography, sex head of the household, household members that work on the farm on a part-time basis, household land size, the cropping system applied by the household in a particular season, membership to any savings/credit organization. These were found to be the key factors affecting the decision to adapt to TC4 joint technology.

Objective two shows that when the household utilized the joint multiple agricultural technology TC1, TC2, TC3, and TC4 the household nutrition outcome of underweight, stunting, and wasting reduces significantly. Thus, this joint multiple agricultural technology combination has helped improve the nutrition status of the East Africa households who adopted joint multiple agricultural technologies.

From objective three, it is found that the joint multiple agricultural technologies by households that adopted has a positive overall impact on child nutrition outcome, measured by HAZ, WAZ, and WHZ. Further, Multiple possible production of improved beans variety using joint agricultural technology adoption and child nutrition are explored through the technology combination of TC1, TC2, TC3, and TC4 adoption.

5.3 Conclusions

This study evaluates the potential impact of adoption of multiple agricultural technologies on nutrition outcomes in East Africa using a multinomial endogenous switching regression model. The study utilizes a unique primary household panel data of 2007-2017 in Kenya, Uganda, and Tanzania. The casual impact of technology adoption is estimated by utilizing multinomial endogenous switching regression. This helps estimate the true nutritional outcome effect of multiple agricultural technology adoption by controlling for selection bias and endogeneity originating from both observed and unabsorbed heterogeneity on both production and adoption decisions.

It can be concluded that the group of the household that did adopt has systematically different characteristics than the group of the households that did not adopt the joint multiple agricultural technologies. These differences represent the sources of variation between the two groups that the estimation of an OLS model cannot include a dummy variable for adopters or non-adopters. Also the switching endogenous results indicate that adopters of multiple agricultural technologies have significantly higher nutrition outcome than non-adopters even if controlling for all confounding factors. The results from the study generally confirm the potential indirect subsistence-oriented production link through the household's own consumption for the role of multiple agricultural technologies adoption on improving household nutrition status.

The analysis of the factors that affects adoption generated very interesting results. It's further concluded that the factors such as region, education level of household head, land ownership, quality of crop planted per season, control of diseases that caused problems to crop production, irrigation of crop crops, value addition and the processing of crop, household members who participate in general community meetings and workshops are identified as the key determinants to multiple agricultural technology adoption. When the household utilized the joint multiple agricultural technology TC1, TC2, TC3, and TC4 in objective two the household nutrition outcome of underweight, stunting, and wasting reduces significantly. Thus, this joint multiple agricultural technology combination has help improve the nutrition status of the East Africa households who adopted joint multiple agricultural technologies.

These findings provide the East Africa countries with a holistic picture of the gap in access to the driver of nutrition outcome that is critical for the formation of a more informed, evidence-based, and balanced multi agricultural strategy against malnutrition. This study also contributes to the literature as an empirical investigation on the casual linkage of the joint multiple agricultural technology adoption on the child nutrition outcomes using house panel data survey from East Africa countries of Uganda, Kenya, and Tanzania. It is concluded that households in East Africa rarely use a single agricultural technology but rather a combination of different joint technologies in order to improve their nutrition outcome.

The result leads to several policy implications that joint multiple agricultural adoption not only enhances farm household's economic wellbeing as stated in the literature but also reduce child malnutrition as found in this study. This study explores and confirms this relationship as the nutrition- enhancing impacts of adopting the joint multiple agricultural technologies which normally occurs among children with the poorest nutrition outcomes and is a practical value of policymakers and development agencies.

Multinomial endogenous switching regression model is evaluation tools aimed at generating knowledge to intensify the impact of agricultural technology programs, thus offers insight to policymakers, researchers, and extension workers regarding the advancement of factors suitable for joint multiple agricultural technology combination to be adopted by the East Africa households.

5.4 Recommendation

Since the geographical location plays to the advantage of the household for the four joint technologies of TC1, TC2, TC3, and TC4 within East Africa it's therefore recommended that more households be encouraged and influenced to adopt multiple agricultural technologies. The policy should be put in place to allow the household in East Africa to practice more than one technology application. Household members within East Arica are recommended to participate in the credit and savings organizations and also get involved in the group market strategies as it will encourage the maximum benefits of the joint multiple agricultural technologies. Households are recommended to encourage their members to increase their education level since it affects the uptake of joint technology. This will increase the chances of households making an informed decision on technology utilization. Local governments are advised to provide alternative methods, mechanisms, and support programs for controlling diseases. Pests and diseases pose a serious risk for production and technology adoption. It is also recommended that the household should follow the guide on the number of crop per space given so as to maximize the technology adoption.

The household is recommended to hire professional labor to oversee technology adoption. This then to ensure the right procedure are followed in the farm and can help in making the informed decision when calling upon. The agricultural extension officers are encouraged to organize frequent community meetings and barazas since the members learn from these meetings about the different methods of implementing joint technology. The government is recommended to provide title deeds and land ownership documents to the households. The household with land ownership then to make long term goals and plans thus affecting the joint technology adoption.

It is recommended that an irrigation system should be set up across the farms in East Africa. Policymakers and local leaders should mobilize for resource allocation to reach more farmers with irrigation kids and water supply. More processing industries and well-equipped storage facilities should be constructed to support the household in value addition. This will lead to higher adoption of multiple technologies as the household will be expecting better returns. It is recommended that the farmers should follow the right cropping system so as to utilize the multiple agricultural technologies in an appropriate way. Household members are encouraged to work on the farms on a full-time basis rather than part-time. The household members working on a part-time basis have a negative impact on multiple technology adoption.

It is recommended that an informed policy formulation that focuses on the joint multiple agricultural technology adoption efforts be strengthened and prioritize since it will improve household nutrition outcomes.

Child malnutrition can be reduced if the household’s nutrition outcomes are improved; adoption of improved beans variety needs to be promoted among the households. Policies that facilitate the adoption of improved beans variety using multiple agricultural technologies should be enhanced with a possible focus on joint biofortified maize variety, garden vegetable techniques, and garden vegetables techniques. Efforts should be put to foster home consumption of stable foods such as improved beans variety, since it can be of practical value, especially to those who are poor and food insecure.

REFERENCES

Abdulai A., Regmi P. P. (2000). 'Estimating Labor Supply of Farm Households under Non Separability: Empirical Evidence from Nepal', *Agricultural Economics, 22 (3): 309–20.*

Abonazel, M. R. (2009). Some Properties of Random Coefficients Regression Estimators. Institute of Statistical Studies and Research. Cairo University.

Abonazel, M. R. (2014). Some estimation methods for dynamic panel data models. Institute of Statistical Studies and Research. Agriculture Organization of the United Nations, Rome.

Alcacer, J., Chung, W., Hawk, A., Pacheco-de-Almeida, G. (2013). Applying random coefficient models to strategy research: testing for firm heterogeneity, predicting firm-specific coefficients, and estimating Strategy Trade-Offs. Working Paper, No. 14-022. Harvard Business School Unit.

Alderman H. (1987). Cooperative dairy development in Karnataka, India: An assessment. Research Report 64. IFPRI (International Food Policy Research Institute), Washington, DC, USA. 60 pp.

Alston JM, Marra MC, Pardey PG, Wyatt TJ. (1998). Research returns redux: a meta-analysis of the returns to agricultural R&D. Environment and Production Technology Division Discussion Paper No. 38. Washington, DC: International Food Policy Research Institute.

Anh, V. V., Chelliah, T. (1999). Estimated generalized least squares for random coefficient regression models. *Scandinavian journal of statistics 26(1):31-46.*

Anríquez G., Stamoulis K. (2007.) 'Rural Development and Poverty Reduction: Is Agriculture Still the Key?' ESA FAO Working Paper 07-02. Approach. *Food Security* 6 (2): 217-230.

AraarA., Duclos J.Y.(2007). DASP: Distributive Analysis Stata Package. PEP, World Bank,UNDP and Université Laval.

Avery, R.B. (1977). Error components and seemingly unrelated regressions. *Econometrica* 45(1): 199-209.

Ball, V. E. (1988). 'Modeling Supply Response in a Multiproduct Framework', *American Journal of Agricultural Economics, 70: 813–25.*

Baltagi, B. H. (2011). Econometrics. 5th ed. Berlin: Springer-Verlag Berlin Heidelberg.

Baltagi, B. H. (2013). Econometric Analysis of Panel Data. 5th ed. Chichester: John Wiley and Sons.

Beck, N., Katz, J. N. (2007). Random coefficient models for time-series–cross-section data: Monte Carlo experiments. *Political Analysis* 15(2):182-195.

Becker, G. (2002). The age of human capital. In E. P. Lazear (Ed.), Education (pp. 3-8).

Becker, G. S. (1965). "A theory of the allocation of time". *The Economic Journal, 75(299).*

Behrman J. and Deolalikar A. 1988. Health and nutrition. In: Chenery H. and Srinivasan T.N. (eds), Handbook of development economics. Volume 1. Elsevier, Amsterdam, USA.

Beran, R., Millar, P. W. (1994). Minimum distance estimation in random coefficient regression models. *The Annals of Statistics* 22(4):1976-1992.

Binkley, J.K. and Nelson, C.H. (2008). A note on the efficiency of seemingly unrelated regression. *The American Statistician* 42(2): 137-139.

Binswanger H.P. and von Braun J. 1991. Technological change and commercialisation in agriculture. The World Bank Research Observer 6(1):57–80.

Bodhlyera, O., Zewotir, T., Ramroop, S. (2014). Random coefficient model for changes in viscosity in dissolving pulp. *Wood Research* 59(4):571-582.

Boness, A. J., Frankfurter, G. M. (1977). Evidence of Non-Homogeneity of capital costs within "risk-classes". *The Journal of Finance 32(3):775-787.*

Boot, J. C., Frankfurter, G. M. (1972). The dynamics of corporate debt management, decision rules, and some empirical evidence. *Journal of Financial and Quantitative Analysis 7(04):1957-1965.*

Bos J. W. B., Koetter M. (2011). 'Handling Losses in Translog Profit Models', *Applied Economics*, 43 (3): 307–12.

Bouis H.E. and Haddad L.J. (1990). Agricultural commercialisation, nutrition and the rural poor: A study of Philippine farm households. Lynne Rienner Publishers, Boulder, Colorado, USA.

Carey, D., Jr. (2005). Engendering Mayan history: Kaqchikel women as agents and conduits of the past, 1875-1970. London, UK: Routledge. doi:10.4324/9780203954829

Chang'a, L. (2009). 'Seasonal Rainfall Forecasting in Tanzania'. Paper presented at the Workshop on High-Impact Weather Predictability and Information System for Africa and AMMA-THORPEX Forecastor's Handbook, ICTP, Trieste, Italy, 5–8 October.

Chary, A., Messmer, S., Sorenson, E., Henretty, N., Dasgupta, S., & Rohloff, P. (2013). The normalization of childhood disease: An ethnographic study of child malnutrition in rural Guatemala. *Human Organization*, 72(2), 87–97.

Chelliah, N. (1998). A new covariance estimator in random coefficient regression model. The Indian *Journal of Statistics, Series B 60(3):433-436.*

Cheng, J., Yue, R. X., Liu, X. (2013). Optimal Designs for Random Coefficient Regression Models with Heteroscedastic Errors. *Communications in Statistics-Theory and Methods* 42(15):2798-2809.

Conniffe, D. (1982a). A note on seemingly unrelated regressions. *Econometrica* 50(1): 229-233..

Conniffe, D. (1985). Estimating regression equations with common explanatory variables but unequal numbers of observations. *Journal of Econometrics 27: 179-196.*

Cooley, T. F., Prescott, E. C. (1973). Systematic (non-random) variation models: varying parameter regression: a theory and some applications. *Annals of Economic and Social Measurement* 2(4): 463-473.

Cunia, T. and Briggs, R.D. (1984). Forcing additivity of biomass tables: some empirical results. *Canadian Journal of Forest Research 14: 376-384.*

DeSerpa, A. (1971). "A theory of the economics of time". *The Economic Journal, 81(324).*

Dewey, K. G., & Begum, K. (2011). Long-term consequences of stunting in early life. Maternal & Child Nutrition, 7(Suppl. 3), 5–18. doi:10.1111/j.1740-8709.2011.00349.x

Dielman, T. E. (1983). Pooled cross-sectional and time series data: a survey of current statistical methodology. *The American Statistician* 37(2):111-122..

Dielman, T.E. (2008). Chapter 3: Seemingly unrelated regressions. Pooled cross-sectional and time series data analysis (pp. 29-47). New York: Marcel Dekker, Inc. *PCPFS Research Digest*, 2(1).

Drichoutis, A. C., Lazaridis, P., and Nayga, R. M., Jr. (2005). "Nutrition knowledge and consumer use of nutritional food labels". *European Review of Agricultural Economics*, 32(1): 93- 118.

Drichoutis, A. C., Lazaridis, P., and Nayga, R. M., Jr. (2006). "Who is looking for nutritional food labels?" *Eurochoices* , 4(1): 18- 23.

Dwivedi, T.D. and Srivastava, V.K. (1978). Optimality of least squares in the seemingly unrelated regression equation model. *Journal of Econometrics 7: 391-395.*

Dziechciarz, J. (1989). Changing and random coefficient models. Berlin: Springer Berlin Heidelberg. Econometrics 11:619-632.

Ehlers, T. (2010). Silent looms: Women and production in a Guatemalan town. Austin, TX: University of Texas Press.

EHNRI (Ethiopian Health and Nutrition Research Institute). (2000). Food composition tables for use in Ethiopia: Part III. EHNRI, Addis Ababa, Ethiopia.

Elhorst, J. P. (2014). Spatial Econometrics: From Cross-Sectional Data to Spatial Panels. Heidelberg, New York, Dordrecht, London: Springer.

Elías, S. (2013). Guatemala. In C. Mikkelsen (Ed.), The Indigenous world 2013 (pp. 78–87). Copenhagen, DK: The International Working Group for Indigenous Affairs.

Engle, P. L. (1993). Influences of mothers' and fathers' income on children's nutritional status in Guatemala. *Social Science & Medicine*, 37(11), 1303–12.

Evans, A. W. (1972). "On the theory of the valuation and allocation of time". *Scottish Journal of Political Economy, 19(1): 1- 17.*

FAO (2018). A systematic analysis for the global burden of disease study 2013. *The Lancet*, 384(9945), 766–781.

Fleming, T., Robinson, M., Thomson, B., Graetz, N., Margono, C., et al. (2014). Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013:

Fomby, T.B., Hill, R.C. and Johnson, S.R. (1984). Advanced econometric methods. New York: Springer-Verlag. (pages 155-169)

Food and Nutrition Technical Assistance II Project. (2013). Summary report: Development of evidence-based dietary recommendations for children, pregnant women, and lactating women living in the western highlands in Guatemala. Washington, DC: FHI 360/FANTA.

Forster, M. (2001). "The meaning of death: Some numerical simulations of a model of healthy and unhealthy consumption*". Journal of Health Economics, 20(4): 613638.*

Gallant, A.R. (1975). Seemingly unrelated nonlinear regressions. *Journal of Econometrics* 3: 35-50.

Ganster, D. C., and Schaubroeck, J. (1991). "Work stress and employee health". *Journal of Management, 17(2): 235- 271.*

Glei, D. A., & Goldman, N. (2000). Understanding ethnic variation in pregnancy-related care in rural Guatemala. *Ethnicity & Health*, 5(1), 5–22. doi:10.1080/13557850050007301

Gottlieb, A. (2004). The afterlife is where we come from: The culture of infancy in West Africa. Chicago, IL: University of Chicago Press.

Gragnolati, M., & Marini, A. (2003). Health and poverty in Guatemala (World Bank policy research working paper 2966). Washington, DC: The World Bank.

Grassley, J., & Eschiti, V. (2008). Grandmother breastfeeding support: What do mothers need and want? Birth, 35(4), 329–335. doi:10.1111/j.1523-536x.2008.00260.x

Gregoire, T.G. and Walters, D.K. (2008). Composite vector estimators derived by weighting inversely proportional to variance. *Canadian Journal of Forest Research 18: 282-284.*

Grossman, M. (1972). "On the concept of health capital and the demand for health". *Journal of Political Economy, 80(2): 223- 255.*

Gupta, A.K. and Rohatgi, V.K. (1982). Estimation of covariance from unbalanced data. Sankhya 44(B, 2): 143-153.

Guthrie, J. F., Fox, J. J., Cleveland, L. E., and Welsh, S. (1995). "Who uses nutrition labeling, and what effects does label use have on diet quality?" *Journal of Nutrition Education, 27(4): 163- 172.*

Hampshire, K., Casiday, R., Kilpatrick, K., & Panter-Brick, C. (2009). The social context of childcare practices and child malnutrition in Niger's recent food crisis. *Disasters*, 33(1), 132–151. doi:10.1111/j.1467-7717.2008.01066.x

Haskell, W. L. (1995). "Physical activity in the prevention and management of coronary heart. *Stata Journal* 4(3): 282-289.

Hausman J.A. (1978). Specification tests in econometrics. *Econometrica* 46:1251–1271.

Hazell P, Ramasamy C. (2010). The Green Revolution reconsidered: the impact of high yielding rice varieties in South India. Baltimore, Md, USA: Johns Hopkins University Press,.

Hendrickson, C. (1995). Weaving identities: Construction of dress and self in highland Guatemala, TX. *Journal of Econometrics 125(1-2): 305-353.*

IFPRI (2015). Individual Dietary Diversity. Nutrition and Consumer Protection Division. Economics *Letters* 45: 33-40.

Johnson, N., Guedenet, H., & Saltzman, A. (2015). What will it take for biofortification to have impact on the ground? Theories of change for three crop–country combinations. IFPRI discussion paper. Washington: International Food Policy Research Institute.

Judge, G.G., Griffiths, W.E, Hill, R.C. and Lütkepohl, H. (1985). Chapter 12: Disturbance-related sets of regression equations. The Theory and Practice of Econometrics (2nd ed., pp. 465-514). New York: Wiley.

Kadiyala, S., Harris, J., Headey, D., Yosef, S., & Gillespie, S. (2014). Agriculture and nutrition in India: mapping evidence to pathways. Annals of the New York Academy of Sciences, 1331.

Kaitibie, S., Omore, A., Rich,K., & Kristjanson, P.(2010). Kenyan dairy policy change: influence pathways and economic impacts. *World Development,* 38(10), 1494–1505.

Kakwani, N.C. (1967). The unbiasedness of Zellner's seemingly unrelated regression equations estimators. *Journal of the American Statistical Association 62(317): 141-142.*

Kariya, T. (1981). Bounds for the covariance matrices of Zellner's estimator in the SUR model and the 2SAE in a heteroscedastic model. *Journal of the American Statistical Association 76(376): 975-979.*

Kassie, M., M. Jaleta., and A. Mattei. (2014). Evaluating the Impact of Improved Maize evidence based on analysis of value chains linking smallholders and markets, Working Paper 6, International Livestock Research Institute (ILRI), Nairobi, Kenya.

Kennedy P. (1985). A guide to econometrics. 2nd ed. The MIT Press, Cambridge, UK.

Kennedy, G., Berardo, A., Papavero, C., Horjus, P., Ballard, T., Dop, M. C.,etal.(2010).Proxy measures of household food consumption for food security assessment and surveillance: comparison of the household dietary diversity and food consumption scores. *Public Health Nutrition*, 13(12), 2010–2018.

Kennedy, G., T. Ballard., and M.C. Dop. (2013). Guidelines for Measuring Household and functions and mechanisms. Proceedings of a workshop organized by the Standing Panel on Impact Assessment, CGIAR, 2001

Kerr J, Kolavalli S. (2009). Impact of agricultural research on poverty alleviation: conceptual framework with illustrations for the literature. Discussion Paper. Washington, DC: International Food Policy Research Institute.

Khoury, C. K., Bjorkman, A. D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., et al. (2014). Increasing homogeneity in global good supplies and the implications for food security.

KNBS (2015). Proceedings of the National Academy of Sciences of the East Africa, 111(11), 4001–4006.

Kim, S., Habicht, J.-P., Menon, P., & Stoltzfus, R. J. (2011). How do programs work to improve child nutrition? Program impact pathways of three nongovernmental organization intervention projects in the Peruvian highlands. IFPRI discussion paper. Washington: International Food Policy Research Institute.

Kim, S.-Y., Nayga, R. M., Jr., and Capps, O., Jr. (2001). “Food label use, self-selectivity, and diet quality”. *The Journal of Consumer Affairs , 35(2): 346-363.*

Kim, S.-Y., Nayga, R. M., Jr., and Capps, O., Jr. (2003). “Health knowledge and consumer use of nutritional labels: The issue revisited”. *Agricultural and Resource Economics Review*, 30(1): 10- 19.

Kluve, J., Schneider, H., Uhlendorff, A., and Zhao, Z. 2012. Evaluating Continuous Training Proceeding of the American Statistical Association (Business and Economics Section), pp. 423-426.

Kmenta, J. and Gilbert, R.F. (2010). Small sample properties of alternative estimators of seemingly unrelated regressions. *Journal of the American Statistical Association 63(324): 1180-1200.*

Koppmair, S., M. Kassie, and M. Qaim. 2017. Farm Production, Market Access and Dietary. *Economics Letter*s 45: 33-40.

Krebs-Smith "Fruit and Vegetable Intakes of Children and Adolescents in the United States." Archives of Pediatrics and Adolescent Medicine 150(January 1996):81-86. Lancaster, K.J. Consumer Demand: A New Approach. New York: Columbia University Press, 1971.

Krebs-Smith, S.M., A. Cook, A. Subar, L. Cleveland, and J. Friday. "U.S. Adults' Fruit and Vegetable Intakes, 1989-1991: A Revised Baseline for the Healthy People 2000 Objective." Amer. J. Public Health 85(December 1995):1623-29.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition, 137(10), 2311–2316.*

Lukmanji, Z., E. Hertzmark., N. Mlingi., V. Assey., G. Ndossi, and W. Fawzi, (2008). Efficiency of the two-step estimator for models with endogenous sample selection. *Journal of Econometrics 24: 181-196.*

Maeshiro, A. (2016). New evidence on the small properties of estimators of SUR models with autocorrelated disturbances. *Journal of Econometrics 12: 177-187.*

Magnus, J.R. (August 1982): "Multivariate Error Components Analysis ofLinear and Nonlinear Regression Models by Maximum Likelihood." J. *Econometrics* 19239-85.

Malapit, H. J. L., & Quisumbing, A. R. (2014). What dimensions of women's empowerment in agriculture matter for nutrition-related practices and outcomes in Ghana? IFPRI discussion paper. Washington: International Food Policy Research Institute.

Malapit, H. J. L., Kadiyala, S., Quisumbing, A. R., Cunningham, K., & Tyagi, P. (2013). Women's empowerment in agriculture, production diversity, and nutrition: Evidence from Nepal. IFPRI discussion paper. Washington: International Food Policy Research Institute.

Masset, E., Haddad, L., Cornelius, A., & Isaza-Castro, J. (2012). Effectiveness of agricultural interventions that aim to improve nutritional status of children: BMJ, 344, d8222.

Masset, E., L. Haddad, A. Cornelius., and J. Isaza-Castro. (2012). Effectiveness of Agricultural impact assessment at the International Institute of Tropical Agriculture: functions and mechanisms. Proceedings of a workshop organized by the Standing Panel on Impact Assessment, CGIAR, 2001

Mayne, J., & Stern, E. (2013). Impact evaluation of natural resource management research programs: A broader view. ACIAR impact assessment series report no. 84. Canberra: Australian Centre for International Agricultural Research.

McElroy, M.B. (1977). Goodness of fit for seemingly unrelated regressions. *Journal of Econometrics 6: 381-387.*

Mehta, J.S. and Swamy, P.A.V.B. (1976). Further evidence on the relative efficiencies of Zellner's seemingly unrelated regressions estimator. *Journal of the American Statistical Association 71(355): 634-639.*

Menon,P.,and Ruel,M.(2013).Bringing rig or to evaluations of large-scale programs to improve infant and young child feeding and nutrition: the evaluation designs for the Alive & Thrive initiative. Food and Nutrition Bulletin, 34(3), S195–S211. *Econometrica* 54 (3): 679-685.

Muriithi, B.W., and J.A. Matz. (2015). Welfare Effects of Vegetable Commercialization: The adoption potential of new groundnut varieties in Malawi. Working Paper 11, ICRISAT, Patancheru, India.

Muthayya, S., J.H. Rah., J.D. Sugimoto., F.F. Roos., K. Kraemer., and R.E. Black. (2013). The analysis of alternative estimators in models involving selectivity. *Journal of Business and Economic Statistics 9: 41-49.*

Nayga, R. M., Jr. (1996). "Determinants of consumers' use of nutritional information on food packages*". Journal of Agricultural and Applied Economics, 28(2): 303- 312.*

Nayga, R. M., Jr. (2000). "Nutrition knowledge, gender, and food label use". *The Journal of Consumer Affairs , 341: 97- 112.*

Neumann C., Bwibo N.O. and Sigman M. (1993). Diet quantity and quality: Functional effects on rural Kenyan families. Kenya Project Final Report, Phase II—1989–1992.

NBS (2016). Human Nutrition Collaborative Support Program Kenya Project, Office of Nutrition, USAID, Washington, DC, USA.

Nisbett, N., Gillespie, S., Haddad, L., & Harris, J. (2014). Why worry about the politics of childhood undernutrition? *World Development*, 64, 420 –433.

Olney, D. K., Talukder, A., Iannotti, L. L., Ruel, M. T., & Quinn, V. (2009). Assessing impact and impact pathways of a homestead food production program on household and child nutrition in Cambodia. *Food and Nutrition Bulletin*, 30(4), 355–369.

Olwande, J., M. Smale, M.K. Mathenge, F. Place, and D. Mithöfer. (2015). Agricultural International Livestock Research Institute, Towards priority actions for market development for African farmers. *Review of Livestock and Statistics* 67(2):212

Omore, A. & Baker, D.(2011). Integrating in formal actors into the formal dairy industry in Kenya through training and certification. *Journal of the Statistical Association 2(318): 500-509.*

Papke, L.E., and J.M. Wooldridge. (1996). Econometric Methods for Fractional Response central role of the propensity score in observational studies for causal effects. *Biometrika* 70(1): 41-55.

Parks, R.W. (2014). Efficient estimation of a system of regression equations when disturbances are both serially and contemporaneously correlated. *Journal of the American Statistical Association 62(318): 500-509.*

Pelletier D.L., Frongillo Jr. E.A. and Habicht J.P. (1995). The effect of malnutrition on child mortality in developing countries. *Bulletin of the World Health Organization* 73(4):443–448.

Pingali, P. (2015). Agricultural Policy and Nutrition Outcomes – Getting Beyond. Production and Dietary Diversity Link. *Land Economics* 81(2): 265-283.

Pitt M. and Rosenzweig M. (1985). Health and nutrient consumption across and within farm households. *Review of Economics and Statistics* 67(2):212–223. Policy 52: 22-32.

Pollak, R.A., and Wales, T.J. (1992). Demand System Specification andEstimation. New York: Oxford University Press.

Popkin, B.M., and L.S. Adair (2012). Global Nutrition Transition and the Pandemic Preoccupation with Staple Grains. *Food Security* 7 (3): 583–591. Production and Dietary Diversity Link

Prucha, I.R. (1984). On the asymptotic efficiency of feasible Aitken estimators for seemingly unrelated regression models with error components. *Econometrica* 52(1): 203-207.

Ramezani. "Aggregation, Flexible Forms, and Estimation of Food Consumption Parameters." *Amer. J. Agr. Econ. 77(August 1995):525-32.*

Rao, P. and Griliches, Z. (2000). Small-sample properties of several two-stage regression methods in the context of auto-correlated errors. *Journal of the American Statistical Association 64(325):*

Remans, R., DeClerck F.A.J.., Kennedy G., and Fanzo, J. (2015). Expanding the View. *Journal of science and nature 5: 365-377.*

Revankar, N.S. (1976). Use of restricted residuals in SUR systems: some finite sample results. *Journal of the American Statistical Association 71(353): 183-188.*

Rivers, D., and Q.H. Vuong. 1988. Limited Information Estimators and Exogeneity Tests. *Journal of Econometrics 5: 365-377.*

Rose, D., J.P. Habicht, and B. Devaney. (March 1997): "Household Participation in the Food Stamp and WIC Programs Increases the NutrientIntakes of Preschool Children." J. Nutr. 128548-5.

Sadoulet E. and Janvry A. (1995). Quantitative development policy analysis. John Hopkins University Press, Baltimore, USA.

Schmidt, P. (1977). Estimation of seemingly unrelated regressions with unequal numbers of observations. *Journal of Econometrics 5: 365-377.*

Schmidt, P. (1978). A note on the estimation of seemingly unrelated regression systems. *Journal of Econometrics 7: 259-261.*

Sehmi, J. K. (1993). National Food Composition Tables and the Planning of Satisfactory Diets. *Journal of Dietary 8: 259-261.*

Senauer ,B. and Garcia M. (1991). Determinants of nutrition and health status of preschool children: An analysis with longitudinal data. Economic Development and Cultural Change 39(1):371–389.

Senaue,r B., Garcia M. and Jacinto E. (1988). Determinants of the intra-household allocation of food in the rural Philippines. *American Journal of Agricultural Economics 70(1):170–180.*

Shapiro B.I., Haider J., Alemu Gebre Wold and Abebe Misgina. (2000). Crossbred cows and human nutrition and health in the highlands eco-region: Evidence from Ethiopia. ILRI (International Livestock Research Institute), Addis Ababa, Ethiopia. (Mimeo).

Sibhatu, K.T., Krishna., V.V., and Qaim, M. (2015). Production Diversity and Dietary Diversity Simultaneous Probit Models. *Journal of Econometrics 39 (3): 347-366.*

Singh I., Squire L. and Strauss J. (eds). (2016). Agricultural household models: Extensions, applications and policy. The John Hopkins University Press, Baltimore, USA.

Smith L, Haddad L. (2000). Explaining child malnutrition in developing countries: a cross-country analysis. Research Report 111. Washington, DC: International Food Policy Research Institute,

Smith, L.C., and L. Haddad (2015). Reducing Child Undernutrition: Past Drivers and Priorities

Smith, R.J., and R.W. Blundell. (1986). An Exogeneity Test for a Simultaneous Equation Tobit

Srivastava, V.K. and Giles, D.E.A. (2017). Seemingly unrelated regression equations models: estimation and inference. New York: Marcel Dekker.

Stanek, E.J., III and Koch, G.G. (1985). The equivalence of parameter estimates from growth curve models and seemingly unrelated regression models. The American Statistician 39(2): 149-152. Statistical Society: Series A (Statistics in Society) 175 (2): 587-617.

Stigler, G. J. (1961). “The economics of information”. Journal of Political Economy, 693: 213-225. Tanzania Food Composition Tables. MUHAS-TFNC, HSPH: Dar es Salaam-Tanzania.

Telser, L.G. (1964). Iterative estimation of a set of linear regression equations. *Journal of the American Statistical Association* 59(307): 845-862.

Tribe D. Feeding and greening the world: The role of international agricultural research. Oxon, United Kingdom: CAB

UBOS (2001). Discussion Paper, 70. International Food Policy Research Institute. *Journal of Business and Economic Statistics 9: 41-49.*

USAID (2017). International in association with the Crawford Fund for International Agricultural Research, 2014. USA (34): 10657-10662.

Vinod, H.D. and Ullah, A. (1981). Recent advances in regression methods. New York: Marcel Dekker. (pages 241-261)

Von Braum J. (1995). Agricultural commercialisation: Impacts on income and nutrition and implications for policy. *Food Policy* 20(3):187–202.

Von Braun, J., Johm, K. and Puetz, D. (1994). "Nutritional effects of commercialization of a women's crop: Irrigated rice in the Gambia." Johns Hopkins University Press. Baltimore. 343-364.

Walker T, Ryan J. (1991).Village and household economies in India’s semi-arid tropics. Baltimore, Md, USA: Johns Hopkins University Press.

Wang , J. and Ni, D. (1995). A comparative study of the ability of fish to catch mosquito larvae. In K.T.Mackey (ed.) 1995. Rice – Fish Culture in china. International development research centre (IDRC) Ottawa, Canada.

Wang, G.H.K. and Fuller, W.A. (1982). Estimators for a simultaneous equation model with lagged endogenous variables and autocorrelated error. *Communications in Statistics-Simulation and Computation* 11(2): 123-142.

Waterlow,J.C. and Payne, P.R.. (1975). "The protein gap." *Nature*. 258:113-117.

Weerahewa J. (2004). Impacts of Trade Liberalization and Market Reforms on the Paddy/Rice Sector in Sri Lanka. MTID Discussion Paper, 70. International Food Policy Research Institute, Washington DC

Wellenius, B. (1993). Telecommunications. World Bank Experience and Strategy. Washington, The World Bank.

West, C. (2000). Consequences of revised estimates of carotenoid bioefficacy for dietary control of vitamin A deficiency in developing countries. *Journal of Nutrition 32: 2926S*

West, K.P. (2002). "Extent of vitamin A deficiency among preschool children and women of reproductive age." *Journal of Nutrition. 132:2857S-2866S*.

WHO (2002). Food Safety and Food-Borne Illness. World Health Organization, Geneva WHO/FAO. 2003. Joint

WHO (2016). Expert Consultation on Diet, Nutrition and the Prevention of Chronic Diseases. World Health Organization. Geneva.

Wickramasinghe P.J., T. Abeysekera, and A. Herath. (2003). Agricultural Diversification in Sri Lanka. Paper presented at the International Workshop on ―Agricultural diversification and Vertical integration in South Asia,“ November 5-7, New Delhi, India jointly organized by ICRISAT, FICCI and IFPRI.

Wild,S., G.Roglic, Green A., Sicree,R. and H.King. (2004). "Global prevalence of diabetes: estimates for 2000 and projections for 2030." *Diabetes Care Repots*. 27:1047-1053.

Wilkins, K., and Beaudet, M. P. (1998). “Work stress and health”. Health Reports, 10(3): 47.

Williams, G.W., (1984). Development and future direction of the world soybean market. *Quarterly Journal of International Agriculture 23, 319–337*.

Wilson, B.K. (2015). Simultaneity and its impact on ecological regression applications. *Biometric*s 41: 435-445.

Winikoff, B. (1978). Program and policy: Some specific questions. In Nutrition and National Policy. Cambridge, MA, USA: MIT Press. 523-546.

World Bank (2004). Repositioning Nutrition as Central to Development: A Strategy for LargeScale Action. Washington DC:

World Bank (2005). From Competition at Home to Competing Abroad: The Case of Indian Horticulture, mimeo

World Bank (2006). Aquaculture: Changing the Face of the Waters. Meeting the Promise and Challenge of Sustainable Aquaculture. Report No. 36622.GLB

World Bank (2008). Agriculture and Achieving the Millennium Development Goals. World Bank. Washington DC.

World Bank. World Bank. (1986). The Hesitant Recovery and Prospects for Sustained Growth, Trade and Pricing Policies in World Agriculture. New York: Oxford University Press. World Bank. 2004. Saving Fish and Fishers. Report No 29090-GLB

World Health Organization. (2003). Obesity and overweight. Geneva: *Journal of the World Health Organization.*

Yach,D., Hawkes C., Gould,C.L. and Hofman K.J.. (2004). "The Global Burden of Chronic Diseases: Overcoming Impediments to Prevention and Control." *Journal of the American Medical Association.*

You, W., and Nayga, R. M., Jr. (2005). "Household fast expenditures and children's television viewing: Can they really significantly influence children's dietary quality?" *Journal of Agricultural and Resource Economics, 30(2): 302- 314.*

Zellner, A. (1962). An efficient method of estimating seemingly unrelated regressions and tests for aggregation bias. *Journal of the American Statistical Association* 57(298): 348-368.

Zellner, A. (1963). Estimators for seemingly unrelated regression equations: some exact finite sample results. *Journal of the American Statistical Association* 58(304): 977-992.

Zellner, A. and Huang, D.S. (1962). Further properties of efficient estimators for seemingly unrelated regression equations. *International Economic Review* 3(3): 300313.